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International Telephone and Telegraph Corporation
and Associate Companies

TACAN DATA LINK

Automatic Transmission of Information Between Aircraft and Surface

Volume 34 SEPTEMBER, 1957 Number 3

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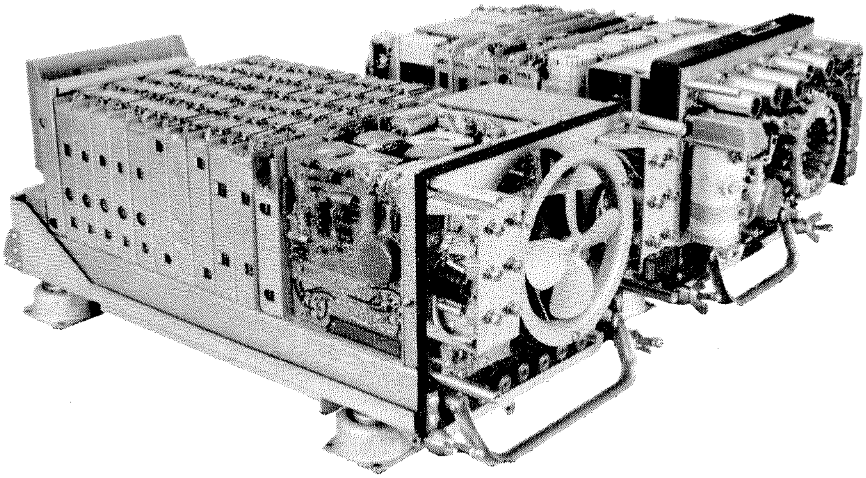
CONTENTS



Every 3 seconds, the taca data link calls the roll of u to 100 aircraft under control of the surface station and obtains full informatio on and delivers instruction to each aircraft individually Airborne and surface equipment are shown at left an below, respectively.

Tacan Data Link

IN JUNE 1946, *Electrical Communication* contained a paper on "Aerial Navigation and Traffic Control with Navaglobe, Navar, Navaglide, and Navascreen," describing a proposal for en-route avigation and traffic control.

The equipments proposed at the time were subsequently developed and tested on contracts with the United States Air Force, Civil Aeronautics Administration, and Navy. The work was also supported by large company-sponsored programs that produced the first practical crystal-controlled 1000-megacycle-per-second distance-measuring equipment.

Electrical Communication also published at the same time (more than ten years ago) the description of a system for exchanging avigational and flight data between air and ground with full identification of aircraft, which was considered indispensable for future air-traffic control. The daily press as well as the technical magazines show that the need for such a system is obviously clearer at this time.

As a result of a contract with the United States Navy, the tacan radio avigational system was developed and is now in production in the United States and in some countries that are members of the North Atlantic Treaty Organization. Tacan is now in use by the armed services of the United States and will also be used by those of the North Atlantic Treaty Organization.

A full history of tacan was published in a special issue of *Electrical Communication* for March 1956. Much experience and "know-how" applied by Federal Telecommunication Laboratories to the development of tacan resulted from its pioneering and early work on avigation as mentioned above and on its instrument landing system now accepted on a world-wide basis.

The need for an exchange of data between air and surface, which is not satisfied in practice as yet, was recognized for some time. Under sponsorship of the United States Navy, a tacan data link was developed, which in connection with tacan surface and airborne equipment permits the exchange of all data considered necessary without any additional radio equipment and therefore without requiring the use of more frequency spectrum. This project overlapped the last stages of developing the tacan system; a coordinated concept of a complete system of avigation and traffic control was always kept in mind during the tacan development.

The papers in this issue describe the tacan data link and its advantages; some of the salient features are as follows.

A. No modifications or additions need be made to the present crowded communication system, which remains available for nonroutine conditions.

B. No additional frequency spectrum is necessary and any country can plan its use and application without concern for national or international frequency allocation.

C. The civilian application to vortac as well as tacan can be effected in two successive stages.

1st stage—A simple airborne transistor-equipped attachment will transmit to the ground through vortac or tacan all avigational and flight data necessary for air-traffic control with complete identification and with exchange of messages coded to eliminate all language barriers.

2nd stage—Ground-to-air flight-command information can be added to complete the system.

D. At present pilots must wait for many minutes for the fundamentally important exchange of information. With the vortac or tacan data link, complete exchange of information including identification can be effected for all of 100 aircraft every 3 seconds most of the time and with a maximum waiting time of 6 seconds.

This is due to a *fundamental advantage* of the tacan data link. The airborne interrogators of all the airplanes equipped with vortac or tacan are on the *air simultaneously at all times* furnishing complete multiplexing of all data communication for up to 100 aircraft.

Other data-link systems are obviously feasible and some are in development and test. Many schemes can be conceived for the necessary exchange of information. No scheme is as simple and advantageous as the vortac and tacan data link for the reasons just mentioned.

A complete tacan and data-link system is under experimentation by the United States Navy. This experimentation is scheduled to continue for several months. There is no equipment in production at this time.

The International Telephone and Telegraph Corporation has a program to develop, demonstrate, and make available the first phase of a data link for tacan or vortac for air-to-ground identification and reporting satisfying the most urgent needs of civil aviation.

Henri Busignies
President, Federal
Telecommunication Laboratories

Electronic System in Air-Traffic Control

By PETER C. SANDRETTO

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THE URGENCY of the air-traffic-control problem in the United States is no news. This problem has been mentioned in the press of the United States since 1946. Unless it is solved, it appears that it will hamper the further growth of aviation in the United States. President Eisenhower has appointed General Edward Curtis as his advisor on the subject, which appointment gives evidence of the seriousness of the problem.

The problem is not simple, for it involves such matters as the basic laws relating to property rights and governmental regulations. For example, one group advocates the control of all air traffic while another argues that since 90-percent of flying is done in good weather, air traffic should be controlled only when flying is on airways and in bad weather. Another problem involves the use of airways. One group advocates an airway system, while another believes that all space should be employed without the necessity for defining paths. Still another problem involves the airports and their dispositions about an area, et cetera.

Whatever the air-traffic-control solution, however, it is certain that it will include an electronic system. This fact is evident because there must be coordination among movable objects and electronics provides the only practical solution to

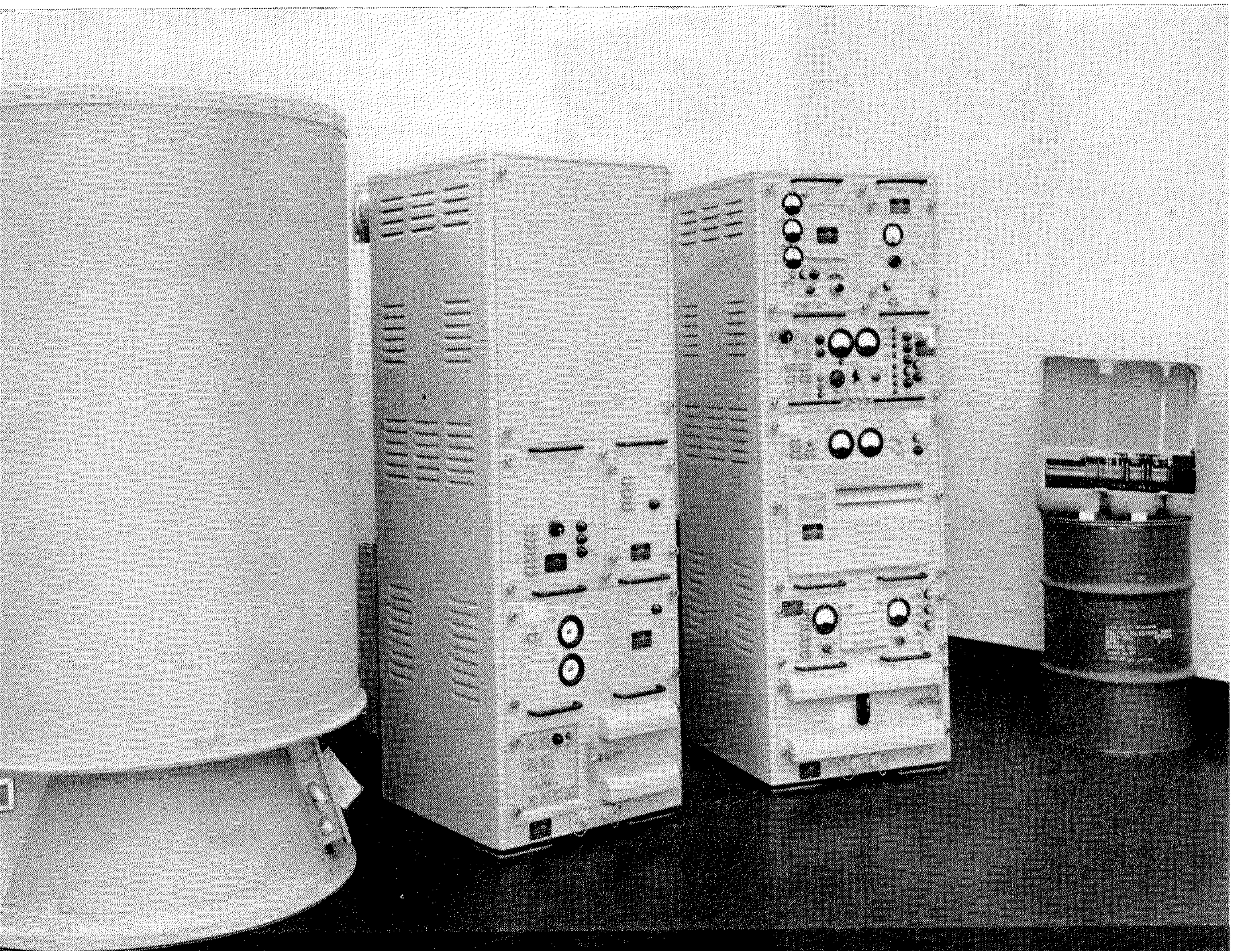

Figure 1—Ground equipment for tacan. From left to right, are the antenna, power supply and the test equipment, receiver and transmitter, and one of the transmitting klystrons placed on top of its shipping container.

this problem. However, let us look broadly at what must be performed by any electronic air-traffic-control system. It is evident that the following is required.

A. Means whereby a pilot may know his position in three dimensions and means whereby he may proceed along any arbitrarily chosen path to his destination, the loading dock.

B. Means whereby a decision-making authority may know at all times the position of all aircraft.

C. Means for determining nonconflicting flight paths instantaneously.

D. Means for issuing unambiguous clearances or safe-procedure instructions to all pilots instantaneously.

E. Means for coordinating flight plans and instructions among decision-making entities.

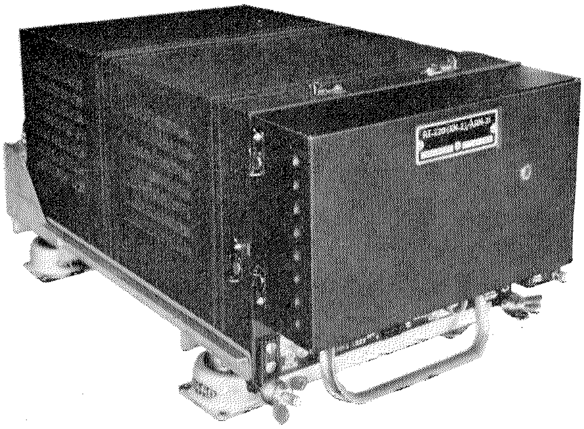

Figure 2—Airborne equipment package for tacan.

The above requirements of a system apply without much modification to any type of traffic. As an example, consider the case of pedestrians. The pedestrian going down a crowded street uses the street and the sign post as his means of knowing his position and his means of proceeding to a destination. By visual observation, he knows the position of all the other pedestrians and will make the necessary decisions as to how he shall avoid his fellow pedestrians. He decides to move to the right or left on the street by using his brain as the decision-making device. He conveys his intentions of a movement to the other pedestrians by a slight feint to the right or left and the other pedestrians recognize this intent and move in a manner to avoid collision. The requirements but slightly modified can be applied to marine traffic.

In the Civil Aeronautics Administration system as it was implemented in 1936, the means by which the pilot was to know his position was the 4-course *radio range*, the 75-megacycle *marker*, and the barometric *altimeter*. These devices were also the means by which he made his approach to his destination. He used a high-frequency *radiotelephone system* provided by his company to inform the central traffic-control agency of his position. All other aircraft under control did likewise. A *controller* used a slide rule to compute the probable future positions of all the aircraft in his area to reach decisions as to whether the aircraft should be held or allowed to proceed. The controller passed this information to the pilot of the aircraft again using the company radio stations. Coordination between control centers was maintained through *teleprinter* circuits.

In the system now being implemented, the pilot determines his position by means of the very-high-frequency omnidirectional range (VOR), which indicates the direction to the selected beacon station, and a distance-measuring equipment (vortac DME), which indicates the distance to that beacon. He is to descend to his terminal by the use of a fixed-beam low-approach system (ILS), and the operation is to be monitored by a radar low-approach system (GCA). Airport surface detection radar (ASDR) is to be used to help direct the aircraft to the loading dock. These equipments fill the first requirement for the electronic means of air-traffic control that was discussed above.

Let us see how the second requirement is to be fulfilled. That is, how is the *decision-making agency to know the position of all aircraft?* This is done by the pilot communicating his position to the ground using voice over a very-high-frequency radio link. This procedure is slow and has been shown to be the limitation to the amount of air traffic that can be handled in some areas of the United States. In addition, if a pilot

Figure 3—Airborne indicators for a tacan installation.

is busy and the ground agency *wants to know his position,* he may be "lost" temporarily while the ground calls and calls attempting to contact him. To improve this position-reporting system, radar is being installed. Radar is no cure-all. It produces a spot on a cathode-ray scope indicating that an aircraft is located in that position; it gives neither the height of the aircraft nor its identity. The radars scan relatively slowly, some as slow as 6 turns per minute. Therefore the controller often has to wait for an appreciable length of time for the spot representing the aircraft in which he is interested to appear. Radar returns are often obscured by clouds. Recently there has been publicized a new technique for radar called circular polarization. Circular polarization is a technique discovered during the war and while it helps in some cases, it produces certain losses so it is no panacea.

To help the radar situation, there has been talk for years about installing a radar beacon. The beacon is employed in this manner. The ground entity communicates by radiotelephone with a pilot and determines that the aircraft is for example, United Air Lines Flight *343.* The pilot is instructed to use code *3* in his beacon and to turn it on. The controller then sees 3 spots on the scope and is able to associate the spots with the position of United *343.* There are many technical problems in the radar beacon that will not be enumerated, but it can be seen that the radar beacon does not avoid the necessity for voice communication and the attending delay.

Incidently, the group of airborne equipments requires the use of radio frequencies from 75 to 1215 megacycles in 6 different bands and is anything but simple. A total of 3 transmitters and 7 receivers must be carried in the aircraft.

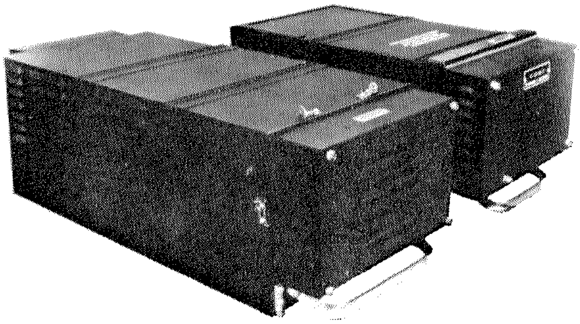

Figure 4—In the foreground is an airborne data box to provide data-link service to the aircraft.

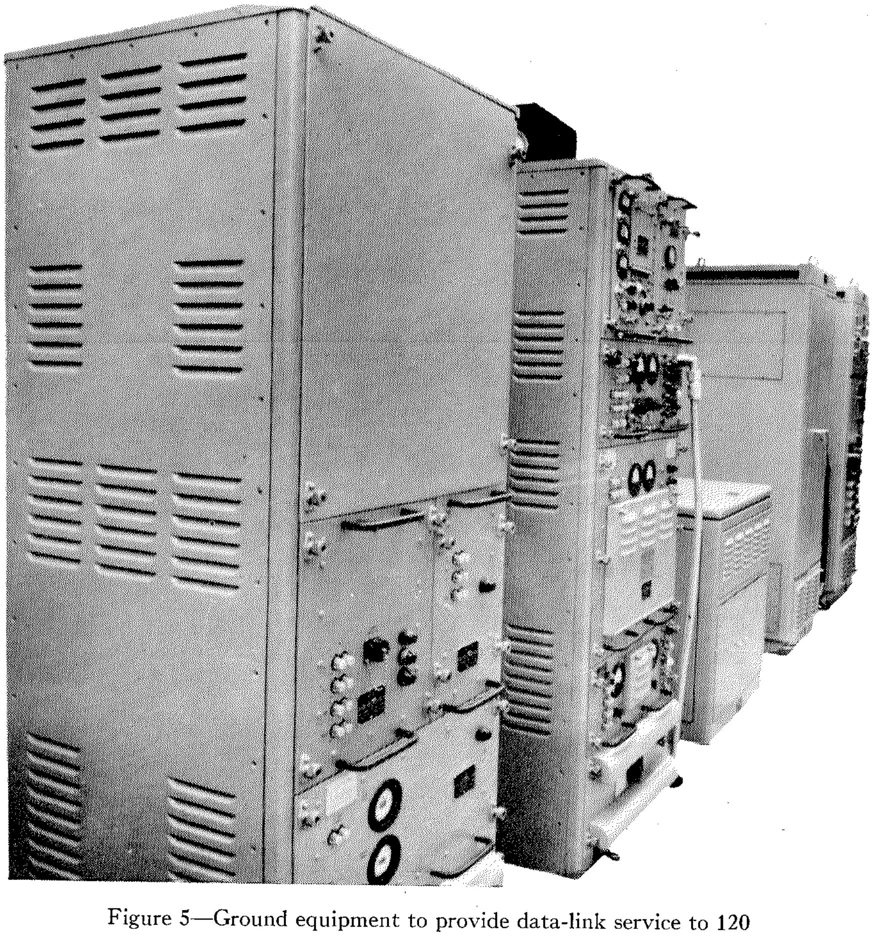

Figure 5—Ground equipment to provide data-link service to 120 aircraft simultaneously.

When the information on the position of the aircraft reaches the ground entity, that is, what is now called the traffic control center, the *controller uses a slide rule* and slips of paper to determine safe procedures. This is the equipment that meets the third listed requirement. He then relays permission to proceed or instructions to hold over the same radiotelephone link, thus fulfilling the fourth requirement listed. When it is remembered that this voice communication is the means for contacting all pilots, it is easy to understand why this communication system is the bottleneck in our traffic control. It is very similar in operation to a multiple-party rural telephone line with all pilots trying to use it at the same time.

A manual teleprinter installation meets the fifth requirement. To summarize, it can be concluded that of the five requirements of the electronic system in traffic control, the plan presently in implementation fulfills one requirement rather well. It meets two other requirements in a passable manner, while the mechanisms for the other two constitute intolerable bottlenecks.

Tacan, however, was planned as a complete coordinated system from the start. The ground-station beacon employs the apparatus shown in Figure 1. This equipment transmits both bearing and distance data as a tacan beacon or distance only as part of a vortac installation. In either case, it will serve 120 aircraft simultaneously. The aircraft equipment is shown in Figure 2. Measuring approximately 7 by 10 by 15 inches (18 by 25 by 38 centimeters) and weighing 55 pounds (25 kilograms), it provides bearing and distance from the ground beacon that is chosen. A unit half this size gives distance only as part of a vortac installation. Bearing and distance information is indicated on the airborne instruments of Figure 3. An arbitrary-course computer can be added and with the existing barometric altimeter will fulfill the pilot's requirement for a means of knowing his position in three coordinates and of providing guidance over any arbitrary course to his destination.

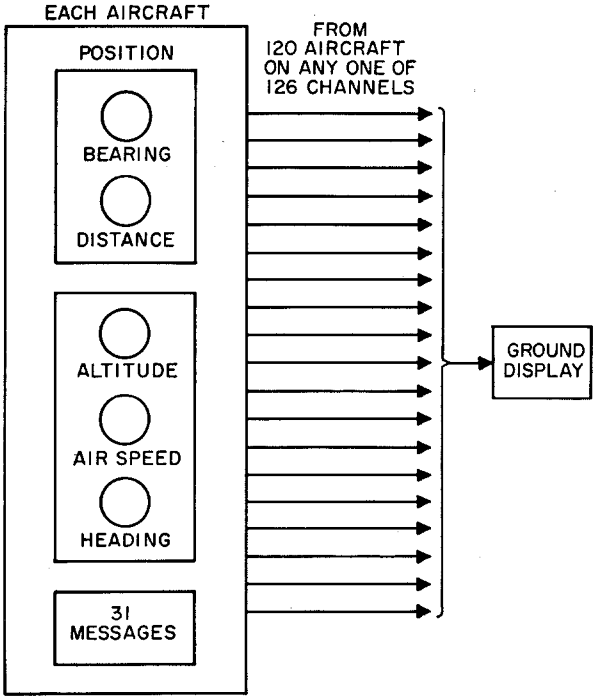

Figure 6—Each of 120 aircraft will report to the ground display once every 3 seconds giving the data shown and any of 31 procedural messages, which may be changed from time to time as needed.

A data box may be added to the airborne equipment. It may be seen in Figure 4. On the ground, a corresponding equipment shown in Figure 5 is also added to the beacon. As soon as this is done, the aircraft's location in terms of bearing and distance plus heading, altitude, air speed, and identity are relayed to the ground. Reports of position from 120 aircraft can be accepted by this equipment in a period not to exceed 3 seconds as is illustrated in Figure 6. It is possible to vary the rates, so that reports from nearby aircraft that are in dense traffic can be received oftener. In addition, the pilot can send 31 procedural messages such as REQUEST LANDING INSTRUCTION, LEAVING 1000 FEET, et cetera. The sender unit is shown in Figure 7.

The information received on the ground may be inserted into a computer, which can be the decision-making means, or it can be put on the screen of what is called a charactron. The charactron as shown in Figure 8 is very much like a television picture tube in that it gives a brighter presentation than a radar scope. Instead of a blip appearing indicating an aircraft, however, the display appears in a position corresponding to the position of the aircraft but is made up of characters indicating the identity of the aircraft, its altitude, and its air speed. An arrow passing through the blip will indicate the heading on which the aircraft is flying. It is possible therefore for controllers operating from the charactron to make a decision regarding the permission of aircraft to proceed. This automatic reporting feature, without adding radio-frequency channels, does the same work as the radiotelephone link but in just 3 seconds, and revises the information every 3 seconds.

As soon as the decision is made, the controller

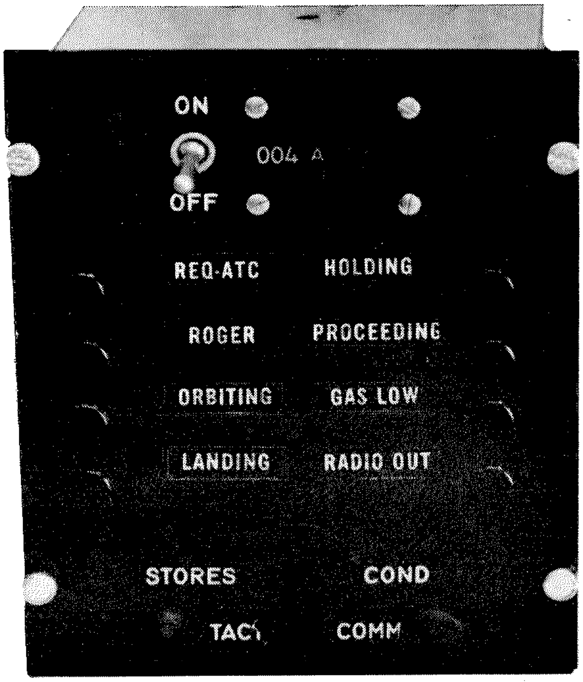

Figure 7—Airborne sending unit for the procedural messages that may be transmitted to the ground station.

can pass the clearance to the aircraft. Figure 9 shows a console for controlling an aircraft. When a clearance is transmitted, it appears on the aircraft instruments shown in Figure 10. These instruments are the standard instruments with "bugs" added to indicate the clearance in terms of direction, distance, altitude, air speed, and heading. When there is trouble, a button on the instrument shows red. When a new instruction is received, the symbol changes to a speckled yellow. The pilot acknowledges the receipt of the new instruction by pressing the button, and this action indicates on the ground that the message has been received and plainly understood. At this action, the button shows green. In addition, 31 instructions can be sent and appear on a tape before the pilot. What do these distances and directions mean? They can mean the setting of an offset-course computer or can constitute deviation for a course that the pilot is to fly. This is a matter of operational procedure and no attempt is made to indicate how it should be employed by traffic-control personnel. One of the interesting characteristics of this communication is not only speed, because the controller can in 3 seconds send information to 120 aircraft, but also that it can appear in terms that each pilot can understand regardless of his nationality. When the button is pressed on the ground corresponding to HOLD in the aircraft, the writing on the plaque in the aircraft can appear in Spanish, French, or any language desired. It will be remembered that language difficulties seemed to play an important part in the collision involving a Bolivian pilot and a domestic air liner over Washington airport some years ago.

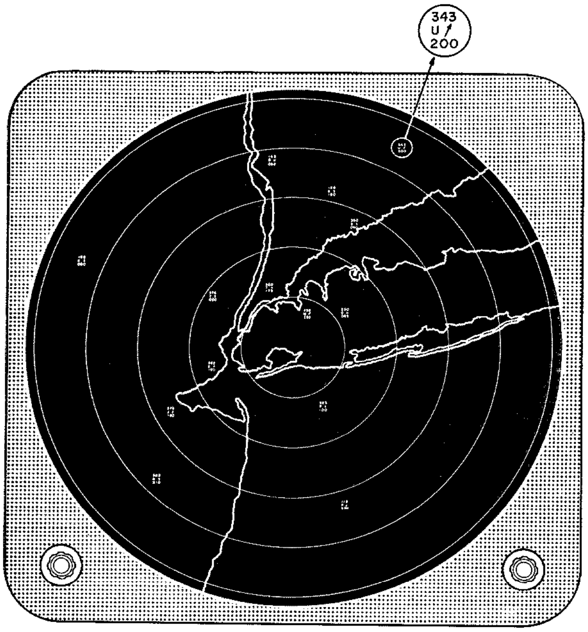

Figure 8—Charactron-tube display at the ground station.

Thus, this coordinated system includes all of the elements required for modern air-traffic control except the computer and the coordination between centers. There are many computer developments that could be adapted to this use. The communications between centers should preferably be of an automatic type.

The coordinated system has the following advantages.

A. It is economical of tubes. Since it employs only a few radar-frequency elements, it can consist largely of reliable transistor circuits.

B. It is economical of radio frequencies and uses only one antenna system.

C. It is compatible with the present program. The distance-measuring part of vortac is the only element now common to civil and military operations. Incidentally, the distance-measuring equipment is the only transmitter that is sending out omnidirectional signals continuously.

D. The system offers the speed required for modern air-traffic control. It is inconceivable that reports can today be received by radiotelephone from 120 aircraft in less than one hour. Contrast this speed with the 3 seconds offered by the system described.

E. The system makes use of techniques compatible with modern computers.

To summarize, while it is not to be implied that the system described constitutes a solution to the air-traffic-control problem in the United States, it is believed that the coordinated system has the capability of furnishing in an economical

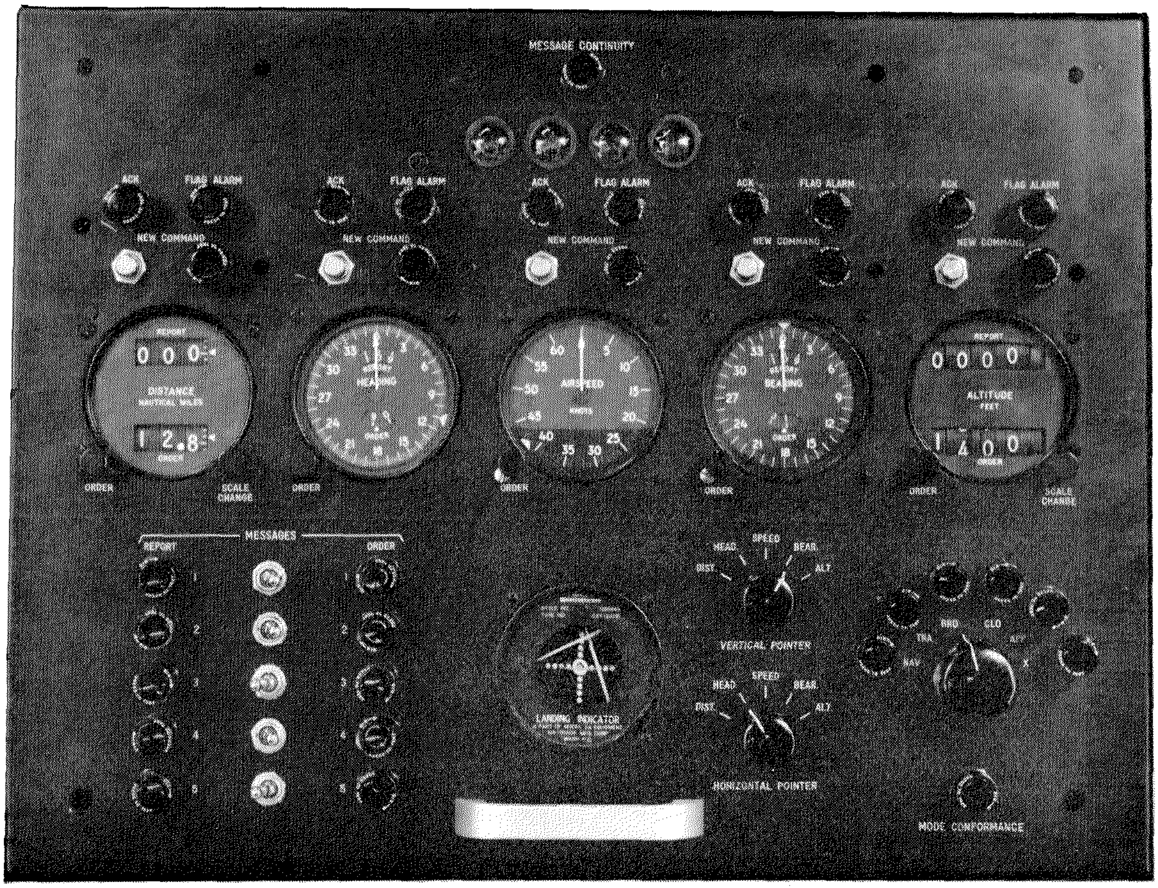

Figure 9—Console on ground for indicating information being received continually from a given aircraft. It includes the sending unit for transmitting standardized messages to the aircraft.

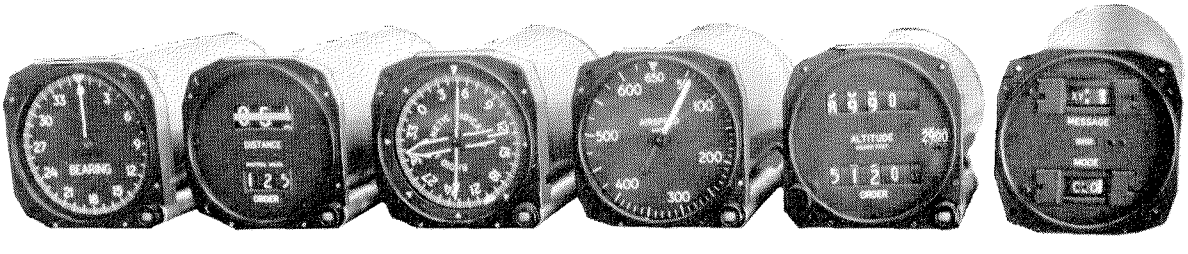

Figure 10—Airborne instruments.

manner a solution to the most-serious bottlenecks in the present program. That such a solution is imperative is attested to by General Edward Curtis, who has stated, "We must, at least, augment our overburdened voice communications with some form of rapid simplified data link to pass essential information back and forth between controller and pilot."

Background and Principles of Tacan Data Link

By BEN ALEXANDER and ROBERT C. RENICK

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A MAJOR ADVANCE was made toward the solution of the air-traffic problem last year when the United States government announced its decision for the integration of civil and military short-range avigational systems into a common system. The tacan avigational system[1] was combined with the existing very-high-frequency omnidirectional radio range and standardized as vortac to provide a common civil and military avigational aid. Either tacan or vortac will supply avigational information to enable a pilot to travel accurately to any destination. The vortac program is now being broadly implemented by the Civil Aeronautics Administration and the Department of Defense.

The tacan equipment has been brought to a high state of readiness. The surface equipment has been ordered in large quantity. Over 5000 airborne sets have been delivered and 23 000 additional are on order. Figure 1 shows a tacan airborne installation of the type *AN/ARN-21* now in quantity production. In parallel with this production program, development has been continued on vortac equipment for the commercial operator. Figure 2 shows the recently developed vortac equipment, which is designed in modular form so that a vortac distance-measuring equipment can be used with existing very-high-frequency omnidirectional bearing equipment.

Figure 1—Airborne tacan equipment.

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[1] *Electrical Communication* for March, 1956, volume 33, number 1, was devoted entirely to the tacan system.

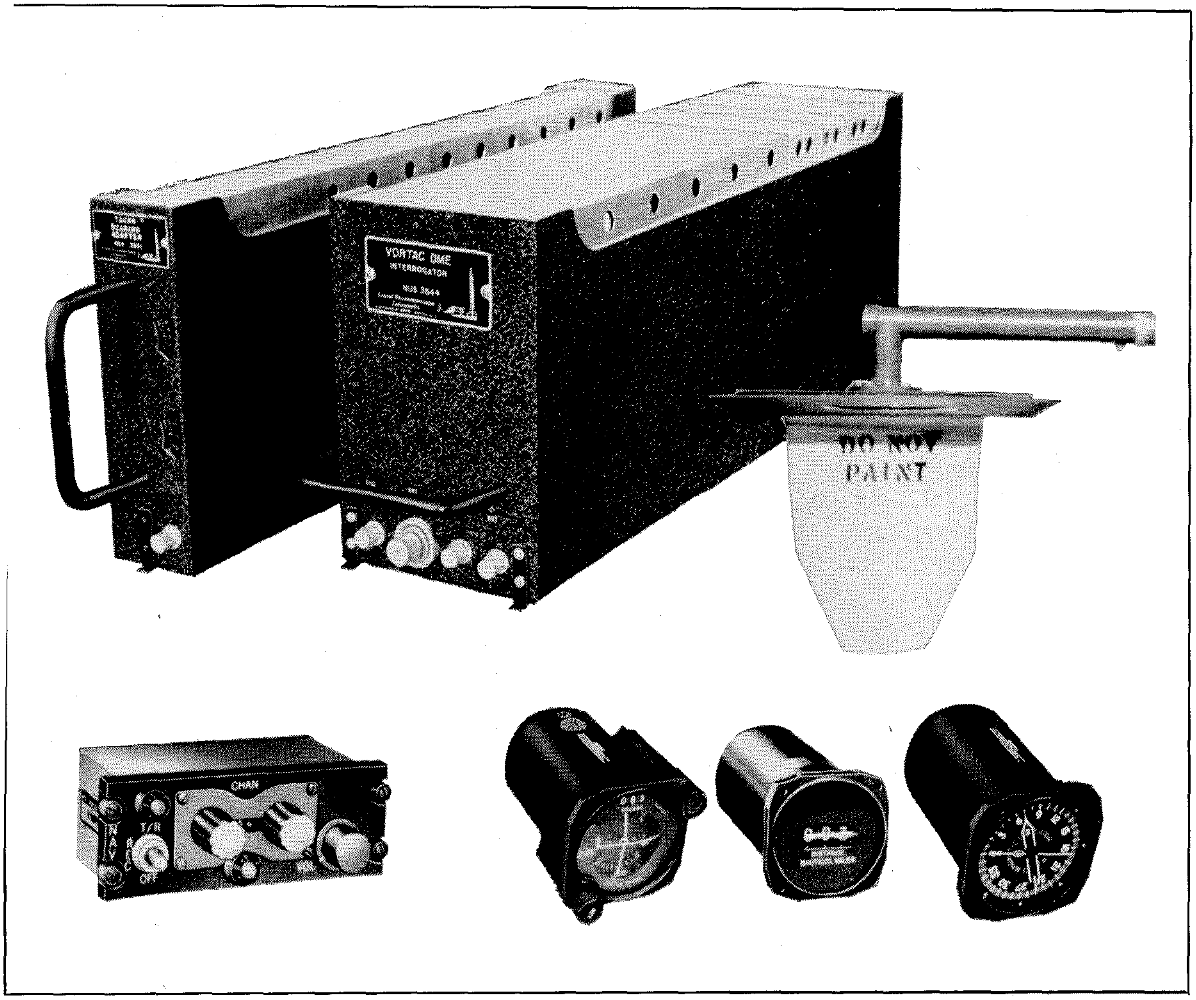


Figure 2—Airborne vortac equipment.

In this picture is also shown the small vortac bearing adapter that can be added as a replacement for the present omnidirectional range apparatus.

1. *Common System*

Both the tacan and vortac avigational aids were designed with the common-system philosophy in mind. Rather than using a multiplicity of radio-frequency channels and a corresponding multiplicity of antennas, transmitters, and receivers on each aircraft, the common-system philosophy envisions use of a single band of radio-frequency channels to provide all the necessary services for routine aviation operations. Substantial technical success has resulted from the program of integrating other essential services with tacan. An instrument landing system consisting of both glide-slope and localizer services is under development. A data link is now under technical evaluation.

The research program for integrating the instrument landing system with tacan was undertaken before the development of tacan was complete. Research on the localizer was sponsored by the Air Force; an experimental model was delivered in 1955. The glide-slope research has been conducted under sponsorship of the International Telephone and Telegraph Corporation.

This program has resulted in equipment for a 1000-megacycle localizer that can be used by any tacan-equipped aircraft with no additional equipment whatsoever and a glide slope that will require a minimum of additional airborne equipment. Figures 3 and 4 show the ground antenna installation for a tacan localizer and two versions of the glide-slope antenna. These antennas are substantially smaller than the corresponding equipment for the conventional instrument landing system and offer the great advantages of enhanced accuracy and site freedom. It is clear that with this type of equipment, airport runways may be easily provided with both instrument landing facilities so that aircraft equipped with tacan can derive the benefits of this service without disrupting present instrument landing practices.

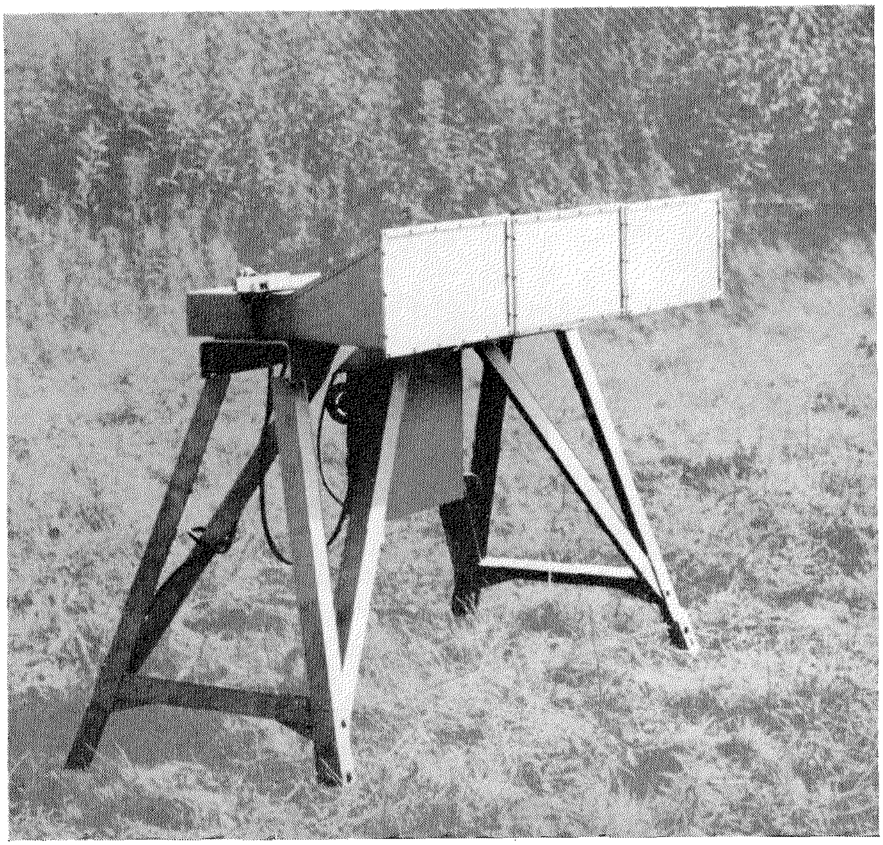


Figure 3—Tacan 1000-megacycle localizer antenna.

The addition of tacan instrument landing is the first step in applying the common-system point of view and the data link is the second.

Tacan or vortac would permit a pilot to fly safely to his destination were there only one aircraft in the air. By itself, however, it helps very little in avoiding collisions or maintaining orderly traffic in the vicinity of crowded terminals. To accomplish these ends, air-traffic-control centers must have accurate information on the identity, position, altitude, and direction of travel of all aircraft in the controlled air space.

Under sponsorship of the United States Navy, a method of automatic air–surface communication has been developed that makes use of the tacan/vortac channels without deteriorating the avigational service provided by this system and that can be added as adjunct equipment to the tacan or vortac sets already produced. This new communication service, designated the tacan data link, has gone through both experimental and service-test engineering phases and is now undergoing evaluation for military use.

Tacan was initially developed for the avigation of carrier-based aircraft. Its use as a general-purpose aid was soon recognized, and incorporation in the common system resulted. Similarly, tacan data link was initially developed for automatic two-way transmission of control data for naval air operations. This development was predicated on the full use of the tacan system and made fully compatible with tacan. Thus, now that tacan is incorporated in the common system, it is possible to provide integrated data-link service, as originally conceived in the common-system master plan.

2. *Data Link*

An aircraft, with a data-link unit added to its tacan or vortac set, automatically reports position, altitude, course, and speed to the tacan data-link terminal to which it is tuned. Thus, tacan data link offers to the air-traffic controller an indispensable tool for performing his duties. Reports from the instruments in the aircraft are transmitted automatically at regular intervals and at a high rate. Consequently, the position of the aircraft and other information made available to the controller is up to date and accurate.

By providing these services to the controller, the pilot is freed of the responsibility for making position reports by voice radio. It also frees the overcrowded radiotelephone channels from the heavy load of routine reporting, leaving them free for emergency traffic.

In addition to furnishing automatic reports, the data link may be used for transmitting clearances or commands from the air-traffic-control center to individually addressed aircraft. These messages have the same accuracy and up-to-date character as the automatic position reports. By using this feature, a controller can automatically transmit and have displayed to the pilot a full set of avigational orders, including ordered position, altitude, course, and speed. Moreover, routine traffic-control procedural messages such as LET DOWN 1000, HOLD, et cetera, can be transmitted and displayed to the pilot in his own language.

Thus, without the use of radiotelephone channels, without more crowding of the radio spectrum, and without the language problems encountered in international flight, substantially all the communications necessary for orderly traffic control can be accomplished.

The services provided by the data link are illustrated in Figure 5. In less than 3 seconds, on any of the 126 tacan channels, 120 aircraft can

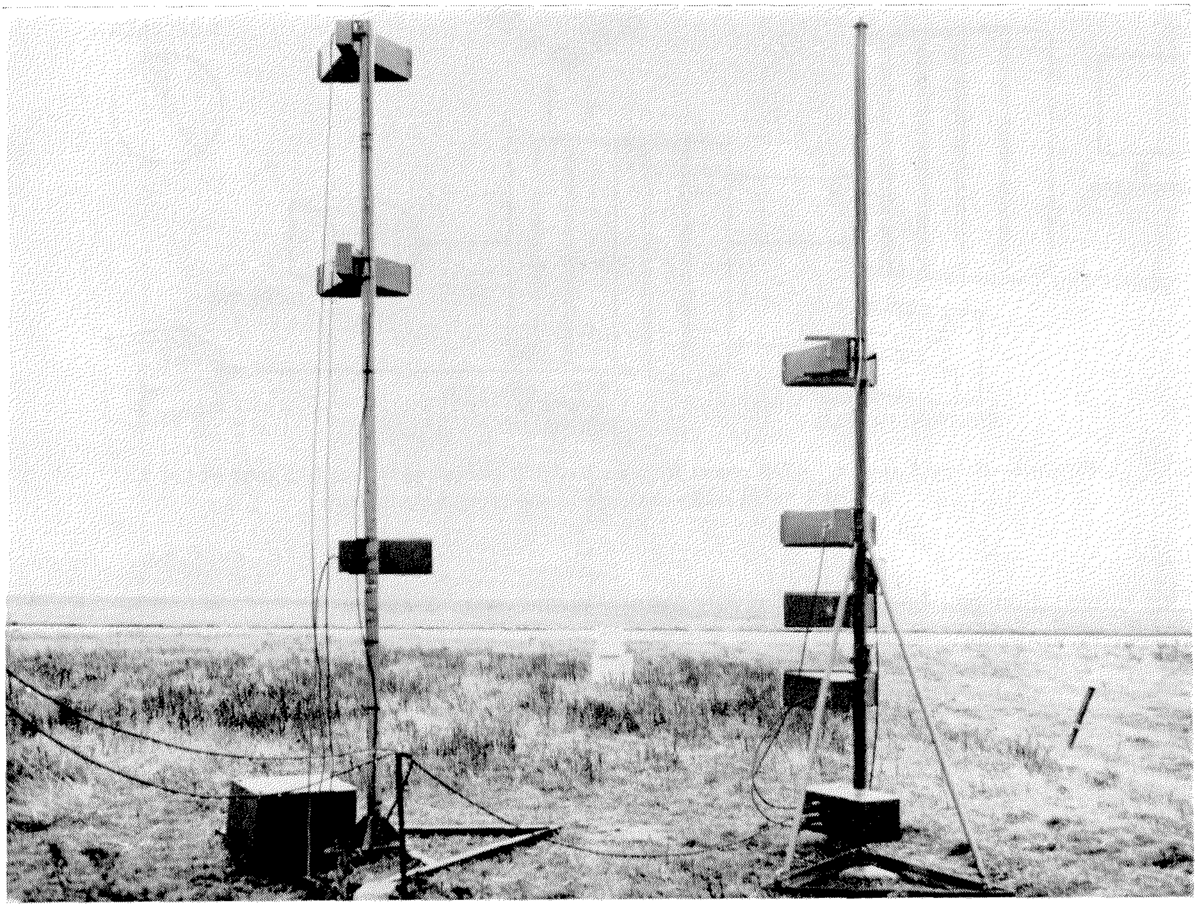


Figure 4—Tacan 1000-megacycle glide-slope antenna. The antenna at the left produces a 2-degree glide-slope angle and the other provides for a 5-degree slope.

be serviced. To each aircraft, individual orders of bearing, distance, heading, altitude, and speed can be transmitted, in addition to 31 ready-made messages such as HOLD, PROCEED, et cetera. This information can be generated either automatically, by computers, or manually via suitable control positions. At the same time, each of the 120 aircraft automatically encodes a full report including its bearing and distance from the vortac beacon, its heading, altitude, and speed, and any of 31 predetermined pilot-originated messages. These data are passed to computers for automatic processing and to displays for monitoring and/or manual control.

Table 1 shows in detail the message content of the data link as presently instrumented. Only minor equipment modifications would be required to change the data transmitted. For example, if for some reason a speed report was not required but a fuel-reserve message was, the encoding pick-off device for generating reports would have to be put in the fuel-gage unit rather than in the air-speed instrument as at present.

The accuracy with which data is transmitted is commensurate with the accuracy of the basic data itself. The discrete orders and discrete reports are transmitted with protective coding features so that errors are practically impossible. The control orders and status reports have tapered accuracy depending on the significance of the data. Thus, bearing signals are precise to within 0.5 degree and heading messages to

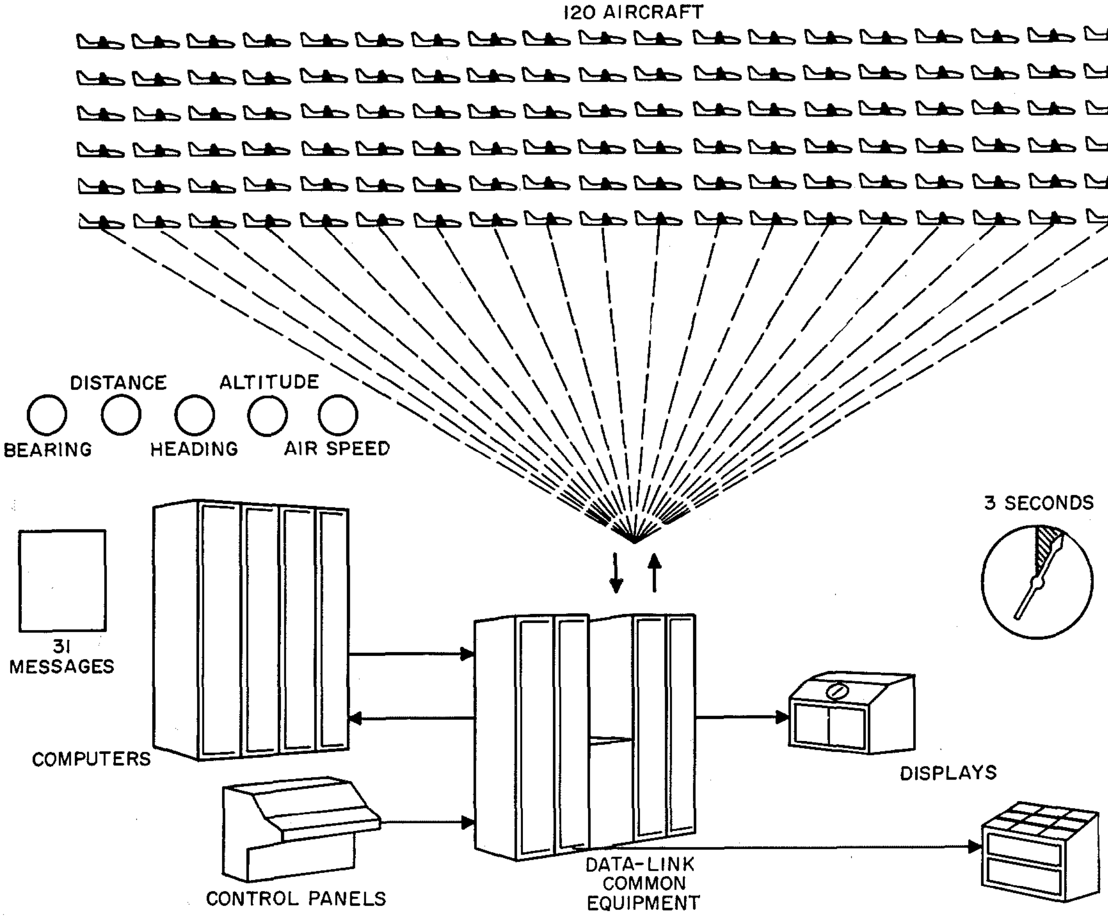


Figure 5—Every 3 seconds, a full report from each of 120 aircraft is transmitted over one of 126 available tacan radio channels to the ground equipment.

within 2 degrees. Comparable accuracies are employed for the other orders and reports.

To guarantee thoroughly up-to-date information, service rates have been established for data-link transmissions that are sufficient to have negligible effect on traffic-control dynamics. The data-link equipment located at each vortac site is capable of handling 90 messages per second (45 surface-to-air orders and 45 air-to-surface automatic reports). Since each vortac site is capable of servicing 120 aircraft simultaneously, each 2.67 seconds every aircraft can receive an individually addressed order and transmit back its automatic report. It has been estimated that voice transmission of these data for the 120 aircraft would require one hour. Flexibility has been provided to permit some aircraft to be addressed even more often. It should be noted that this capacity is far more than sufficient for the foreseeable future. Based on the modest assumption that a maximum of only 100 aircraft will ever simultaneously use a single vortac beacon, the 126 tacan/vortac channels are estimated to be more than adequate for future air operations.

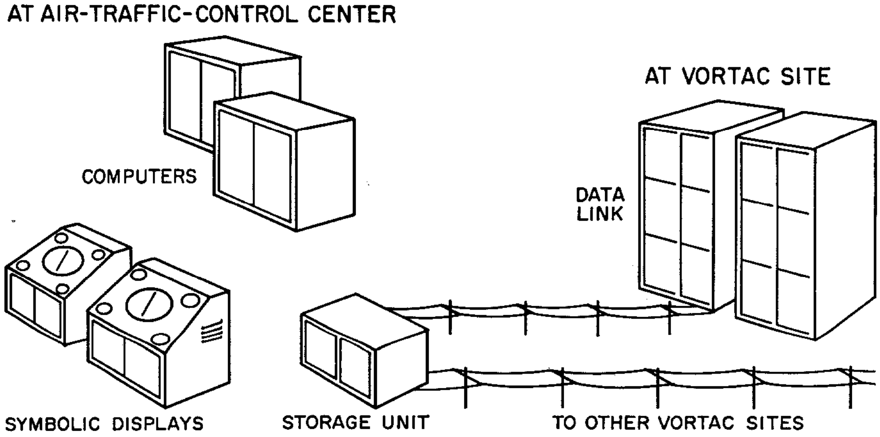


Figure 6—Data link for air-traffic control.

TABLE 1

Tacan Data-Link Message Contents

Aircraft to Surface	Surface to Aircraft
GENERAL	GENERAL
Identity—automatic by time separation	Address—any of 1008 identities
Mode—automatic feedback feature	Mode—such as traffic control, automatic approach, et cetera
31 Ready-made messages—pilot initiated, such as HOLDING, LANDING, et cetera	31 Ready-made messages—such as HOLD, PROCEED, WHEELS DOWN, et cetera
5 Acknowledgments—pilot initiated reply to new orders from surface	5 Commands—indication of major change in control orders
STATUS REPORTS	CONTROL ORDERS
Distance—automatically encoded from tacan distance equipment using 20- or 200-nautical-mile (37- or 370-kilometer) scales	Distance—on 20- or 200-nautical-mile (37- or 370-kilometer) scales
Bearing—automatically encoded from tacan bearing equipment, 0–360 degrees	Bearing—on 0–360-degree scale
Altitude—automatically encoded from barometric or radio altimeter using 5000- or 50 000-foot (1520- or 15 200-meter) scales	Altitude—on 5000- or 50 000-foot (1520- or 15 200-meter) scales
Heading—automatically encoded from radio-magnetic indicator, 0–360 degrees	Heading—on 0–360-degree scale
Air speed—automatically encoded, 0–650 knots (0–1200 kilometers per hour)	Air speed—on 0–650-knot (0–1200-kilometer) scale

Considerable attention has been paid to the problems of integrating the data link with an air-traffic-control system. Figure 6 illustrates how this might be done.

Only the tacan data-link common equipment need be added at each vortac site. This is substantially less than the vortac equipment presently located at each site. Communication between the vortac-site data-link terminals and the computers and displays at air-traffic-control centers requires merely conventional telephone lines as illustrated in Figure 6.

3. *Principles of Tacan*

From the earliest days of tacan, the integration of a compatible data link was envisioned. The selection of the tacan frequencies, bandwidth, and modulation, was guided by the objective of ultimately adding data-link service. Therefore an explanation of tacan must precede a description of the data link.

Tacan is a polar-coordinate avigational system by means of which each aircraft measures its bearing and distance with respect to a surface beacon to which it is tuned. Transmission to the beacon and from the beacon are on separate channels, each 1 megacycle wide, in the band from 962 through 1213 megacycles, thereby providing 126 clear 2-way channels.

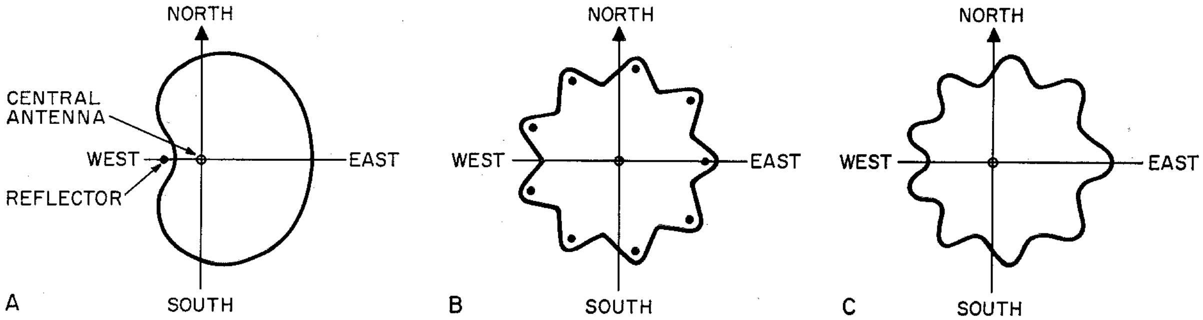


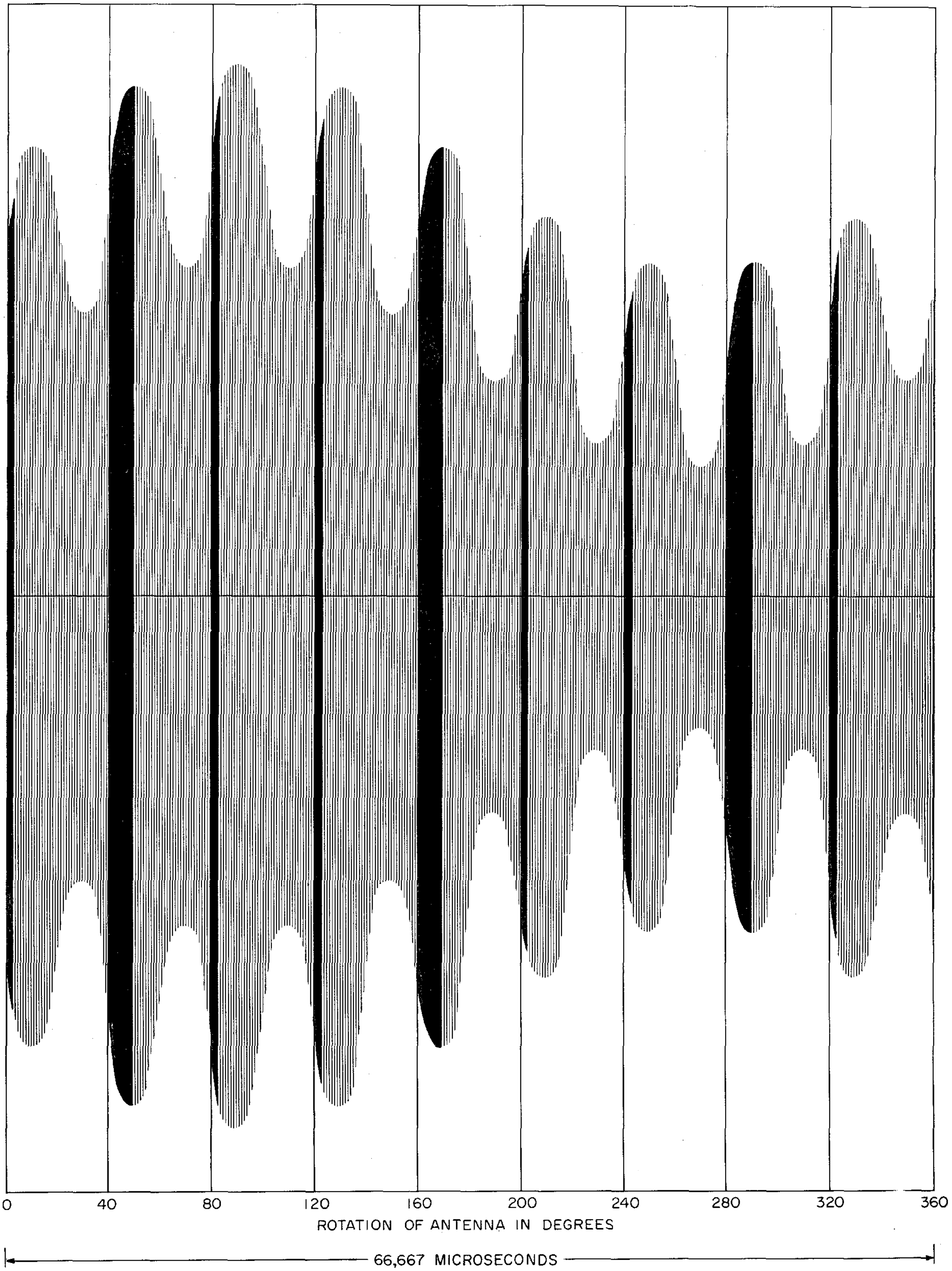
Figure 7—Tacan beacon-antenna radiation pattern in the horizontal plane.

The bearing portion is something like that of a conventional very-high-frequency omnidirectional radio range. The surface beacon transmits a directive pattern that is rotated at a high rate. Each time a characteristic portion of this pattern passes through north, an omnidirectional north signal is sent to all aircraft tuned to the frequency of the beacon. By measuring the time between receipt of the north signal and receipt of the characteristic north portion of the pattern, the relative bearing between the station and the aircraft can be determined. To reduce the effect of obstacles in the vicinity of the surface-beacon antenna, a somewhat-complex rotating antenna pattern is actually employed. The actual pattern is the sum of patterns *A* and *B* of Figure 7. Pattern *A* is a conventional cardioid of the type used in omnidirectional and many other beacons. Pattern *B* has a 9-lobed cogwheel shape. The combination of *A* and *B* produces the complex eccentric shape shown as *C* in Figure 7. In addition to an omnidirectional pulse being transmitted each time the cardioid component rotates through north, a different, characteristic reference pulse is transmitted each time a cog of the nine-toothed wheel passes through north. In the airborne equipment, the north pulse and the cardioid component are used to determine which of the 9 cogs carries the significant bearing information for any particular aircraft, and the position of the cogs with respect to the reference pulses yields the precise bearing information. Theory indicates that this "coarse–fine" beacon system should yield great advantages in accuracy and site freedom over a simple cardioid shape. Exhaustive experimentation has confirmed the theoretical predictions.

The physical rotation of the antenna is at 15 revolutions per second. Thus, to an observer in the air, the antenna pattern gives the appearance of a fundamental component due to the cardioid at 15 cycles per second and a 9th-harmonic component due to the cogwheel effect that is at 135 cycles per second. In each antenna revolution, 1 north pulse and 8 reference pulses are generated. The time between successive reference pulses is 1/135th second.

The rotating directional pattern of the surface-beacon antenna modulates constant-amplitude signals presented to it from the transmitter. The fine-grain structure of the signal is composed of pulses transmitted at an average rate of 5400 per second. The exact positions of the pulses are used to carry distance and data-link information. As regards bearing, however, these pulses are

Figure 8—Transmission is by pulse pairs with 12-microsecond spacing to reduce the effects of interference from single extraneous pulses. The pattern of pulses received due south of a surface beacon is shown. The 15- and 135-cycle modulations for bearing indication are evident as are the reference bursts at 40-degree intervals. By limiting, the unmodulated central section is extracted for distance measurement. The additional bursts starting at 40, 160, and 280 degrees are data-link transmissions.


0
40
80
120
160
200
240
280
320
360
ROTATION OF ANTENNA IN DEGREES
66,667 MICROSECONDS

sufficiently closely spaced so that the envelope can be extracted. Figure 8 shows typical pulses and the amplitude modulation caused by the rotating antenna. It is apparent that the pulses act as a carrier frequency for the envelope.

For distance measurement, each aircraft transmits interrogating pulses as shown in Figure 9.

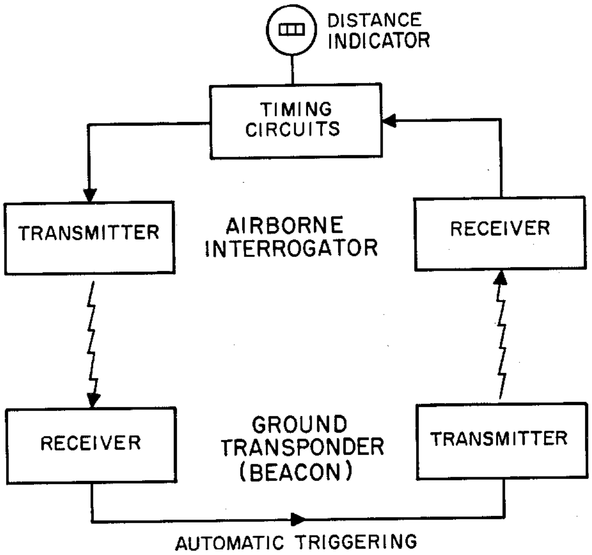


Figure 9—Principles of distance measurement.

The surface beacon receives these pulses and transmits replies automatically over the ground-to-air channel. The airborne receiver is tuned to this channel and by measuring the time elapsed between its transmitted pulse and the received reply, it computes the radio travel time and hence the line-of-sight distance between itself and the surface equipment.

4. Principles of Data Link

The precise location in time of roughly 50 percent of the pulses transmitted from the surface beacon does not affect bearing and distance measurement. Thus, a small percentage of the surface-beacon pulses may be arranged into code groups to provide additional information.

Techniques for arranging pulses into code groups were carefully chosen so that the tacan equipment, both air and surface, could be adapted to data-link service without significant modification. Furthermore, the airborne equipment that must be added to a basic tacan or vortac installation to provide full data-link service is surprisingly modest.

As shown in Figure 8, the basic tacan system contains a synchronizing signal or reference burst that occurs at a 135-cycle rate. The data-link service utilizes this same synchronizing signal for the coding and decoding of its information. The surface equipment interrupts the transmission of its standard pulses 45 times a second and inserts a burst of pulses with a special configuration that conveys the entire surface-to-air transmission to a single aircraft. This transmission includes the identity of the aircraft, discrete data being transmitted to that aircraft, and all telemetered command information for that aircraft. The duration of this pulse-burst transmission is approximately 3 milliseconds, a relatively short period of time compared with the standard tacan waveform patterns. Immediately following the receipt of a message, the particular aircraft addressed transmits back to the surface a similar pulse-burst transmission that conveys its entire reply, consisting of both discrete data and telemetered report data concerning its status.

All data-link and tacan transmissions employ rounded pulse pairs that are tailored to the 1-megacycle tacan channels. Pulse pairs are employed because of their proved freedom from noise and pulse-type interference. The basic coding techniques are matched to the type of data being transmitted. Analog data, such as for instrument-dial indicating, use analog codes suited to pulse-position modulation, as shown in Figure 10. When a dial indication of 0 degrees is to be sent, the pulse pair is transmitted at the beginning of its assigned time interval. As the dial indication increases in value, the pulses are transmitted at a correspondingly later time. Due to the basic simplicity of this code, no bulky analog-to-digital or digital-to-analog converters are required in the aircraft. Digital-type data such as identities of aircraft, ready-made messages, and other on–off type of information, make use of digital codes.

The complete message structure is shown in Figure 11. Each pulse pair is represented by a single vertical line. The basic tacan north-reference bursts, which are used for synchronizing both bearing information and data-link transmission, are followed by various combinations of 135 pulses. These pulses convey the identity of the aircraft, ready-made messages, designation of mode of operation, and various procedural information. Following the transmission of these discrete orders, 5 position-modulated pulses are transmitted to convey the telemetered control orders to the particular aircraft.

The entire pulse train in surface-to-air transmission is modulated by the rotating antenna array. There is no deterioration whatsoever of bearing information.

Since the total duration of all data-link surface-to-air transmissions occupies less than 10 percent of the total transmission time of the surface beacon, even when the system is used at maximum capacity, there is insignificant deterioration of distance service with the addition of data link. When data link is added to an existing tacan or vortac installation, unequipped aircraft can continue to receive tacan or vortac avigational information and equipped aircraft receive full avigational service plus data-link service, all simultaneously.

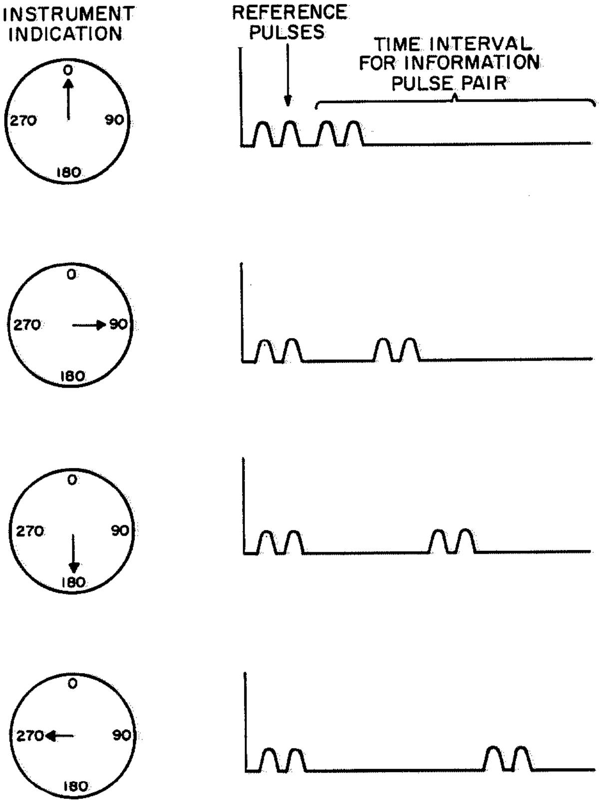


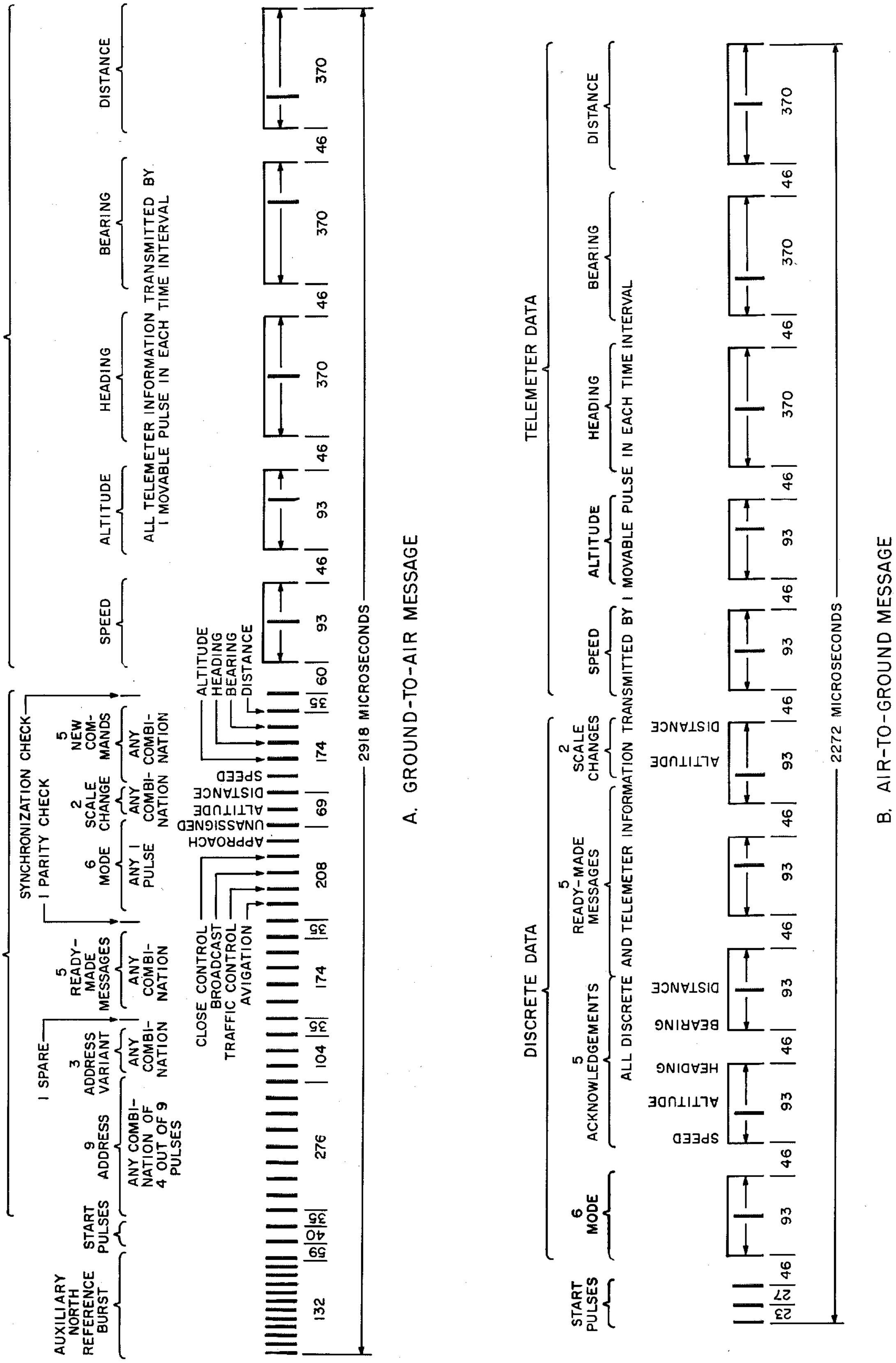
Figure 10—Pulse-position modulation for transmission of analog information.

5. *Data-Link Aircraft Installations*

Any aircraft equipped for tacan distance and bearing or vortac distance measurement can be provided with data-link service by the addition of a data unit. This unit, consisting entirely of pulse and video circuits, provides simultaneous data-link service to the existing tacan or vortac avigational aids on the same radio-frequency channels and without additional transmitters or receivers. Figure 12 shows a military-type airborne installation consisting of tacan navigational equipment and an *AN/ARN-26* tacan data-link coding and decoding equipment. Figure 13 shows a vortac aircraft installation and a smaller data unit that adds data link for air-traffic-control purposes to a vortac installation. In both cases, it should be noted that avigational information is unimpaired and little additional instrumentation is added to the overcrowded instrument panel of the aircraft.

An idea of the equipment provided in the aircraft can be obtained from Figure 14, which shows the military *AN/ARN-26* set. This unit adds complete 2-way data-link service to a tacan distance and bearing installation. It uses vacuum tubes and is housed in an *ATR* rack. It weighs 50 pounds (22.7) kilograms and occupies a volume of 1 cubic foot (0.03 cubic meter). It employs interchangeable plug-in units of the types shown in Figure 15. The equipment is readily adaptable to transistor operation.

The flow of signals through the airborne equipment is outlined in Figure 16. All signals arriving at the antenna are amplified in the receiver and passed through a pulse-pair decoder. The decoder filters out interference and its output starts the master time base and the address decoder. The master time base synchronizes an oscillator with the reference-pulse burst, thereby generating a timing reference for the encoding and decoding functions of the equipment. The address decoder scans the output of the pulse-pair decoder unit to find a group of pulses that corresponds to the address configuration set into the airborne equipment. On receipt of such a code group, the address decoder permits the immediately following series of pulses to pass through the various message decoders. These message decoders actuate the information display. Immediately after the information display



A. GROUND-TO-AIR MESSAGE

B. AIR-TO-GROUND MESSAGE

Figure 11—Code structure. Rounded figures are given for the time intervals.

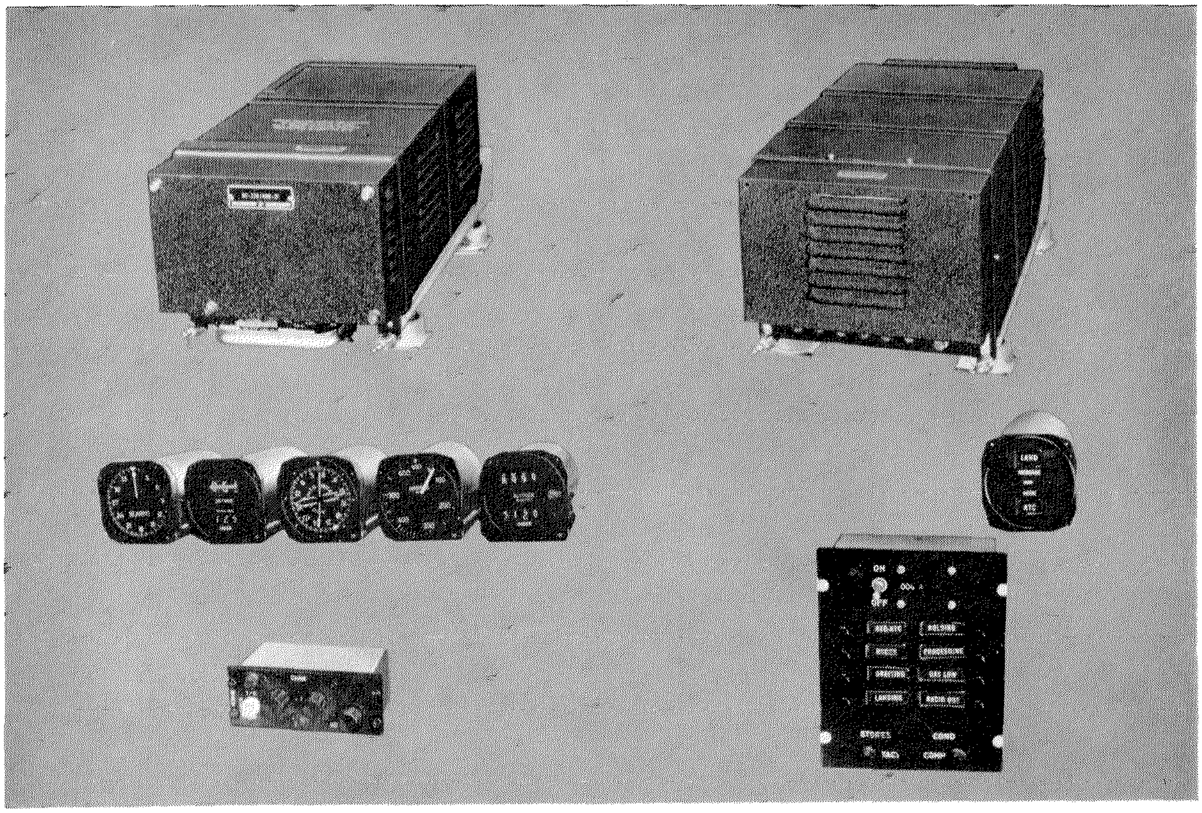


Figure 12—Equipment for airborne use. At the left are the tacan avigational units and at the right are the data-link equipments.

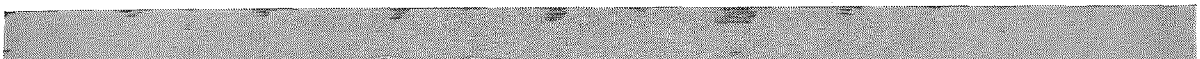


Figure 13—Simplified airborne apparatus with vortac equipment at the left and data-link units at the right.

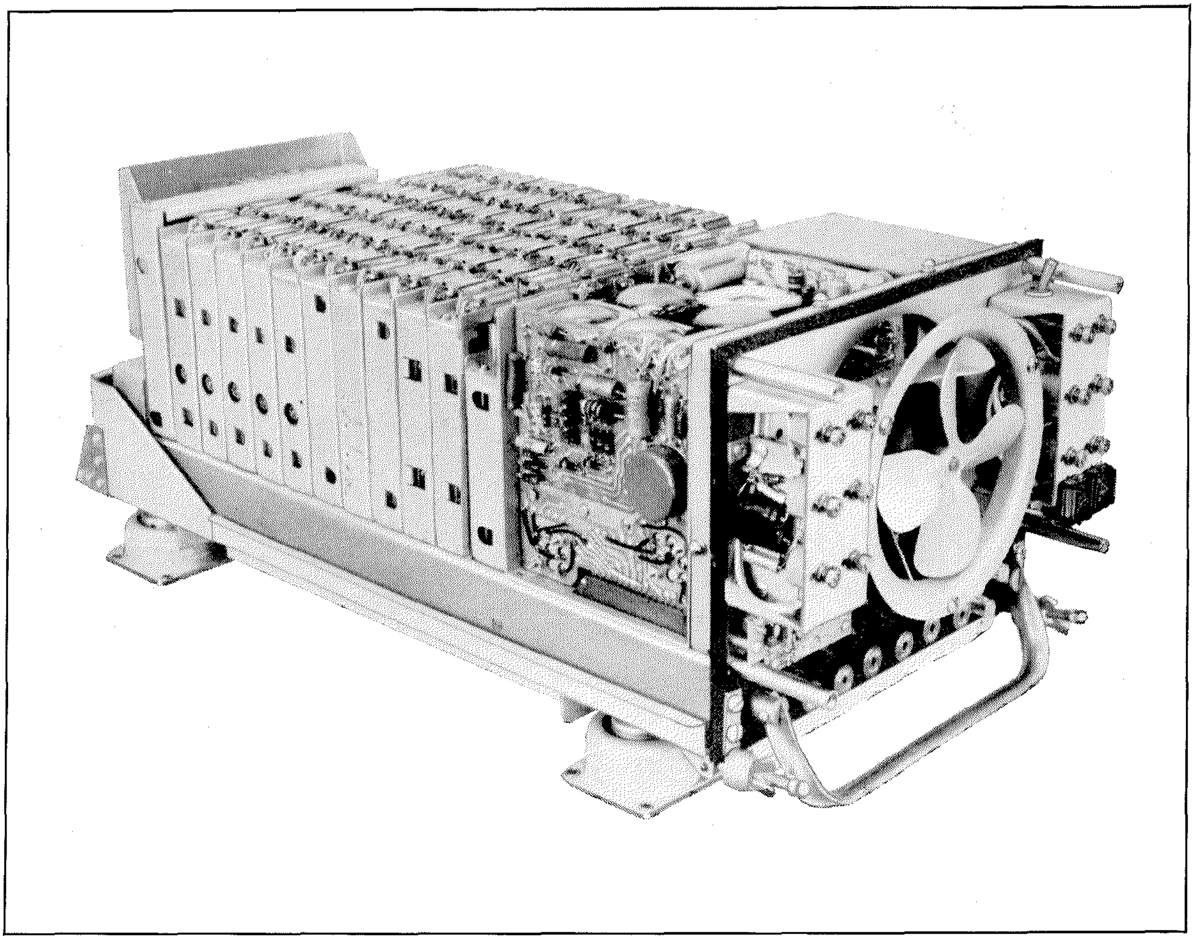


Figure 14—Military *AN/ARN-26* set with dust cover removed.

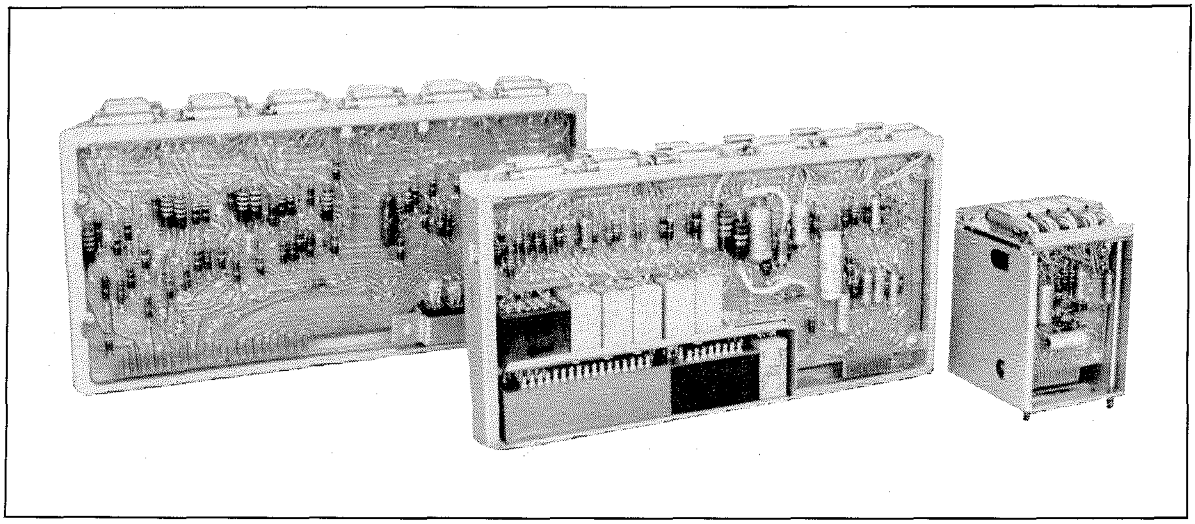


Figure 15—Plug-in units of the type used in the *AN/ARN-26* set.

receives signals from the decoder, it is permitted to energize the message encoders, which translate the various measured quantities in the aircraft into data-link signals. These signals pass to the modulator where they are mixed with the normal distance interrogations of tacan. This combined wave train then actuates the tacan transmitter, generating radio-frequency signals that energize the antenna.

One feature of the data link is the 2-way transmission of ready-made (canned) procedural messages, which make up a large percentage of the present air-to-ground voice communication. The selector shown in Figure 17 displays some of the more common of these routine messages. These are grouped into categories from which individual messages are then selected by the pilot for transmission to the ground by pressing the corresponding button. This arrangement is similar to the selector on a public automatic phonograph (juke box), in which tunes are listed in categories, such as classical, jazz, and hillbilly, and an individual piece is selected by pressing the corresponding button.

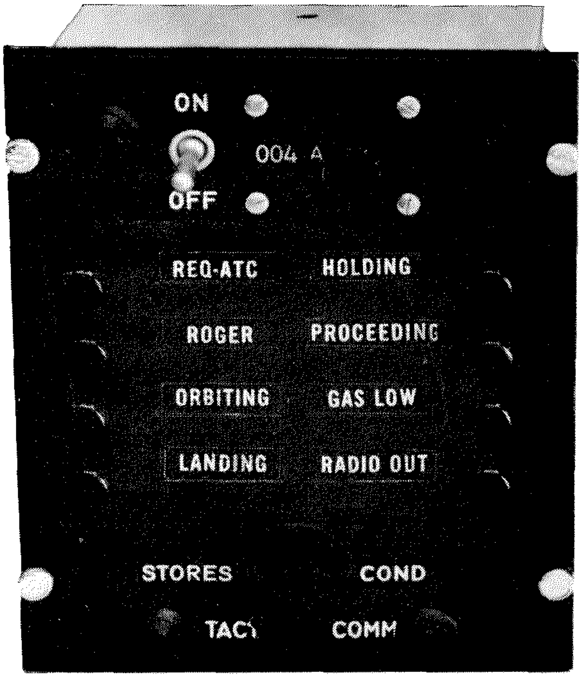


Figure 17—Selector for ready-made messages.

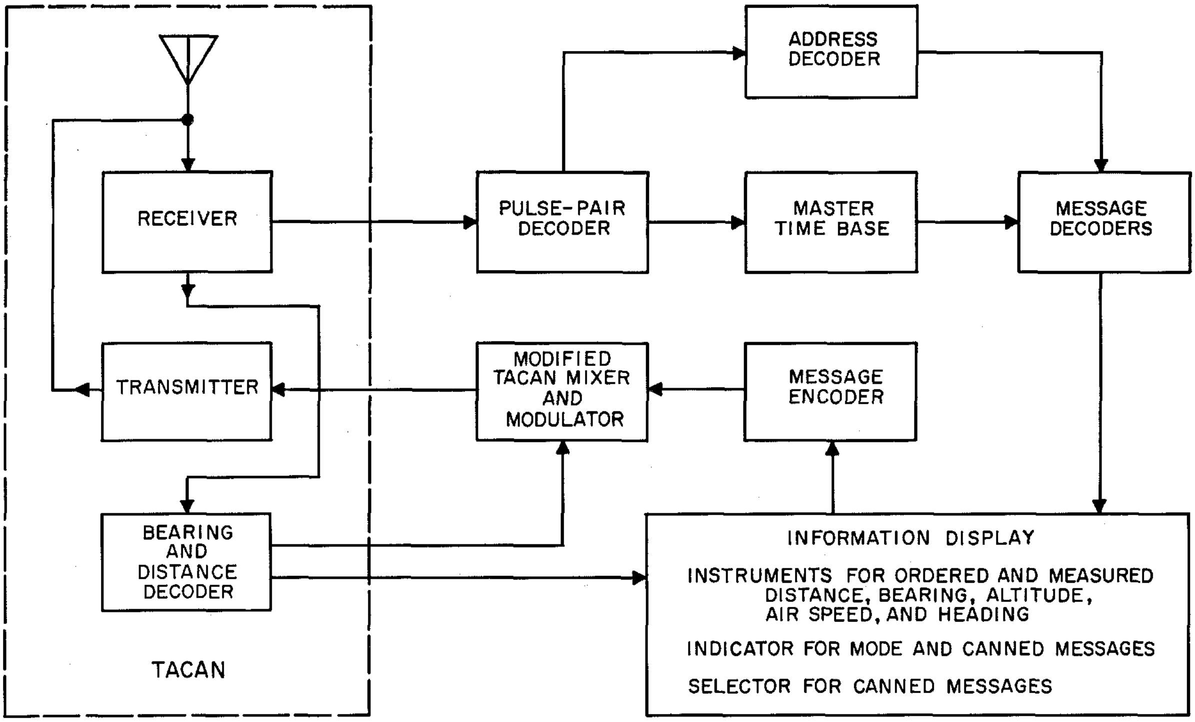


Figure 16—Functional diagram of data-link system.

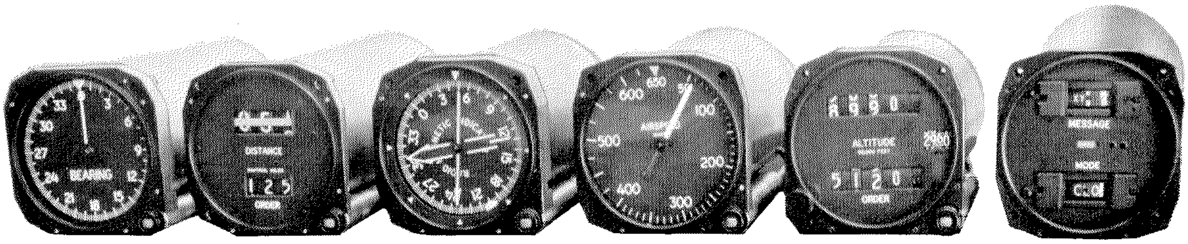


Figure 18—Aircraft instruments modified for data-link service are but slightly larger than the regulation units.

The tacan data link is a communication system; as such, it can handle any information that is supplied to it in suitable form. One particular instrumentation is shown in Figure 18. The primary emphasis has been to provide displays of all information, both commands and reports, without the necessity of adding instruments to the already overcrowded control panel. Accordingly, distance, bearing, radio-magnetic indication, air speed, and altitude instruments were modified to indicate ordered values and to encode the corresponding information for transmission to the surface. These hermetically sealed replacement instruments are but slightly larger than standard instruments. The only additional instrument is the message and mode-of-operation unit that displays any one of 31 ready-made messages being sent from the surface and any one of 6 modes of operation, which are types of ground control. Each instrument also contains a color indicator in the lower right-hand corner: red indicates off or malfunction; green is for proper operation; and yellow calls attention to a new command. By pressing the color indicator, an acknowledgment of this new command is sent back to the surface.

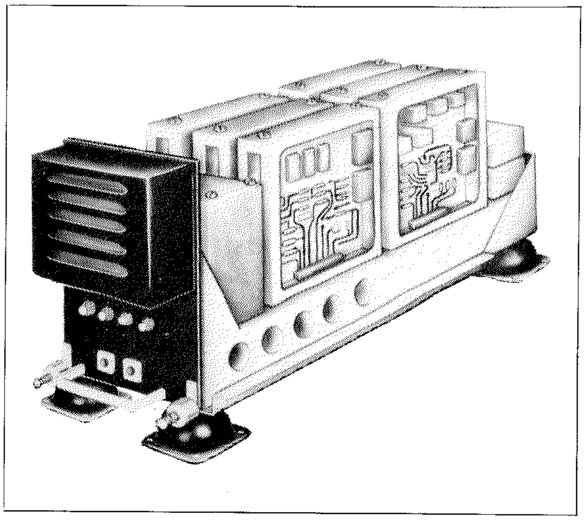


Figure 19—Airborne unit only for reporting to surface.

Tacan data links used primarily for air-traffic control could be less complex than the full 2-way military system. The number of maneuvers that must be performed by these aircraft and the precision with which they have to be accomplished are much lower than some of the military tactical requirements. Hence, the amount of surface-to-air control information to be transmitted is greatly reduced. In fact, the major use of data link in the air-traffic control picture may be for automatic air-to-ground reporting of the status of the aircraft. As has been discussed, a major service of data link is that of automatic aircraft reporting: it relieves the pilot of having to read his instruments and relay the readings over voice radio; it relieves the surface operator of properly translating these voice reports into symbolic form for displays and machine processing. Development work is under way on vastly simplified versions of the data link. A drawing of one such a unit is shown in Figure 19. This unit provides for automatic reporting from air to ground. It weighs approximately 15 pounds (6.8 kilograms) and occupies a volume of approximately 500 cubic inches (8200 cubic centimeters). It uses transistors completely and was designed for modern high-speed aircraft.

6. Surface Equipment

The tacan data-link surface equipment consists of two cabinets at the vortac site and a smaller digital-storage cabinet, which may be located at the air-traffic-control center and is connected to the vortac-site equipment by telephone lines.

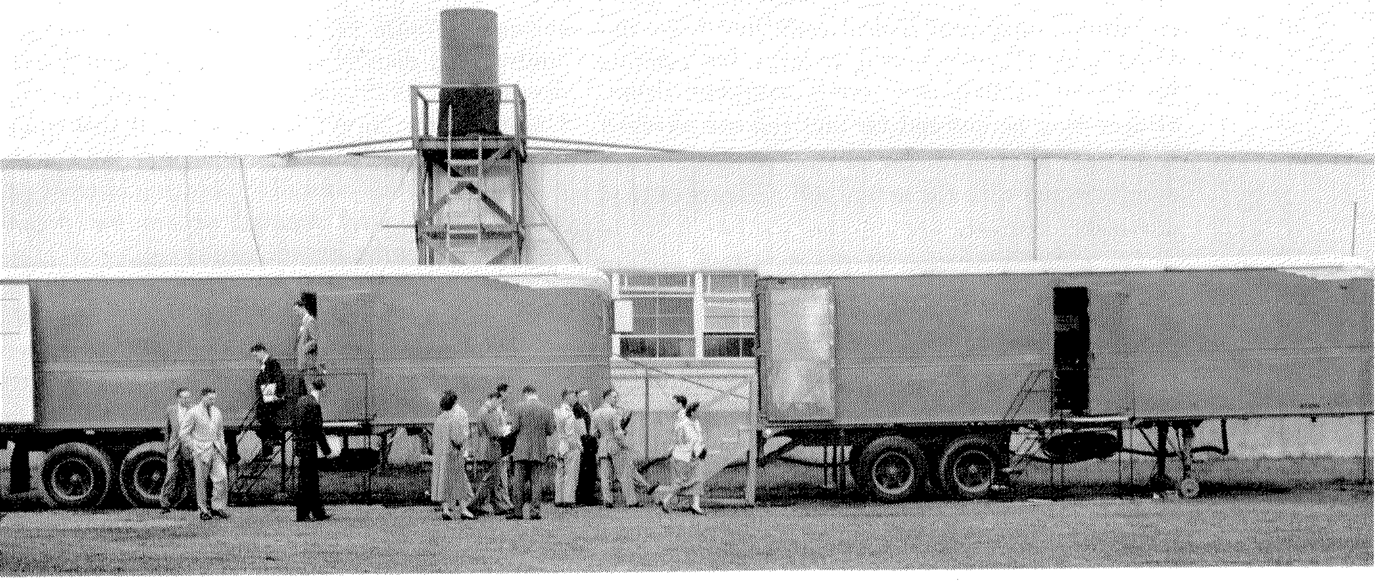


Figure 21—*AN/URN-6* trailers.

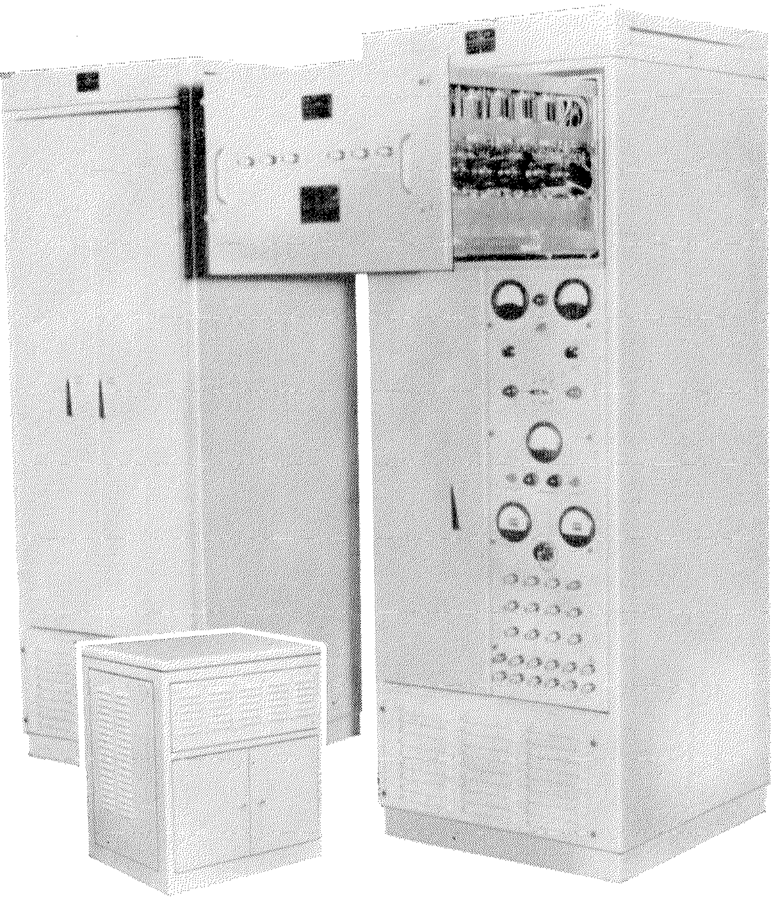


Figure 20—The two upper cabinets house coding and control circuits and are installed at the vortac station. The lower unit provides for digital storage and may be at the traffic-control center.

These equipments are shown in Figure 20. The vortac site equipment consists of a coding unit and a control unit. The control unit houses the various timing circuits, power supplies, and a margin-testing and circuit-malfunction feature to facilitate servicing and to provide an output to automatic switch-over equipment. The coding unit accepts data from the storage unit. It automatically encodes and transmits all orders, while also decoding all reports into a form suitable for storage. The coding and sequencing is performed by digital circuits employing 6 different types of interchangeable plug-in circuits that are interconnected through germanium-diode logic networks.

The data link has been designed for maximum versatility in handling messages from nonsynchronous users of the equipment, such as, computers, manual traffic-controller positions, et cetera.

A common-language digital code has been devised and all orders and reports for aircraft are stored in that code on a magnetic drum. Orders may be entered for and reports received from any aircraft under control at a time not synchronized with the actual roll-call rate of that particular aircraft.

The military version of the data-link surface equipment, designated the *AN/URN-6*, is housed in two trailers as shown in Figure 21. The tacan antenna can be seen in the background. One trailer houses a standard tacan surface installation and the data-link storage, coding, and control units. These equipments are shown in Figure 22. The second trailer contains control and display equipment designed for the operational evaluation of the system by the United States Navy. The interior of this trailer can be seen in Figure 23. At each of the control positions, the behavior of a reporting aircraft can be monitored and manual orders for precise maneuvers can be issued.

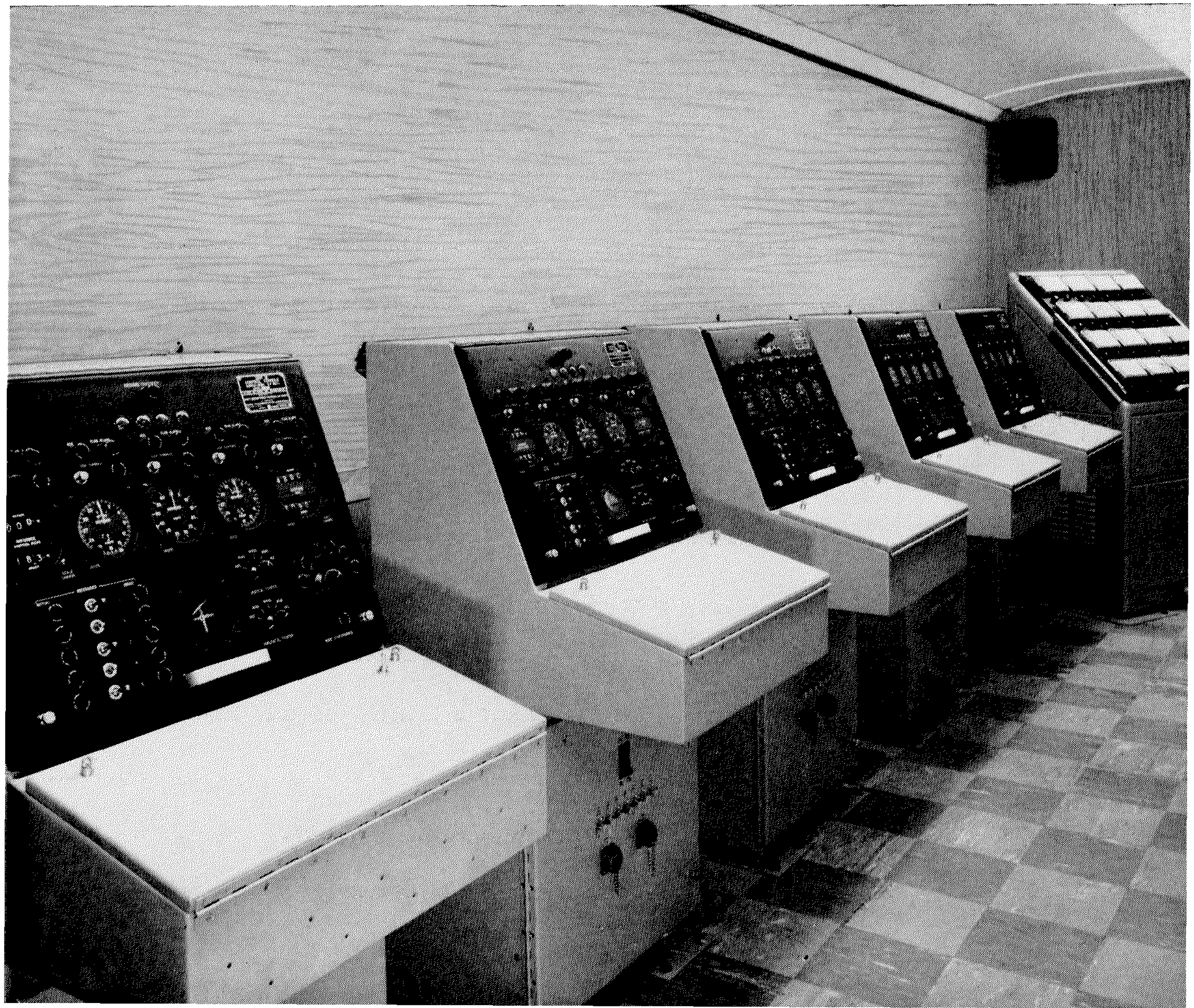
The operation of the equipment can be understood with reference to Figure 24. Either the manual control console or associated computers are identified with individual aircraft via the assignment panel, which can be seen in the far right of Figure 22. Through drum-access circuits messages intended for individual aircraft are stored in a common-language digital code in the magnetic drum of the storage unit. Along with the message details, a requested service rate is

Figure 22—One of the trailers houses a standard tacan beacon in the two cabinets at the left and digital storage, coding, and control units for the data link.

stored. Line-finder equipment, very similar to units used in automatic telephone exchanges, provide a connection between orders stored on the magnetic drum and the coding unit. A crystal oscillator with associated count-down service constitutes the master clock that controls the precise timing of the various phases of operation. Signals from the clock are also used for the precise control of antenna rotation. When used with the data link, field modifications must be made in the antenna drive and speed-control equipment of the standard *AN/URN-3* tacan set. Having received an order from storage for a single aircraft, the coding unit under control of the clock generates a surface-to-air message as described in section 3. This message, coded as voltage pulses, is mixed with the normal tacan video signal and passed to the transmitter.

The airborne reports, which immediately follow the surface-to-air message, are received from the tacan receiver, subjected to filtering by pulse-pair detection, and passed to the coding unit. Under the control of the clock, this message is put into the common-language code and stored on the proper magnetic-drum track under the influence of the line finder. As soon as the reply message has been properly stored, the line finder moves on to handle the next surface-to-air message. Since the reports are stored in the common-language code, they are available almost continuously to the users, which may be manual control consoles, other displays, or computers.

Figure 23—The other trailer accommodates 5 control consoles and the assignment panel.



One of the displays adapted to the tacan data link that is of particular interest for air-traffic control is illustrated in Figure 25. The outputs of the storage unit are assembled on a symbolic display where each aircraft is represented by a group of letters and numbers. In Figure 25, a number of aircraft reports are displayed. The one circled represents United Airlines flight *343*, located over Connecticut, heading northeast at an altitude of 20 000 feet. A spare character is provided for display of speed if desired. By means of this type of display, a convenient and easily filtered over-all situation can be presented showing all aircraft in an area of a given type, in a given altitude layer, or in some other significant category.

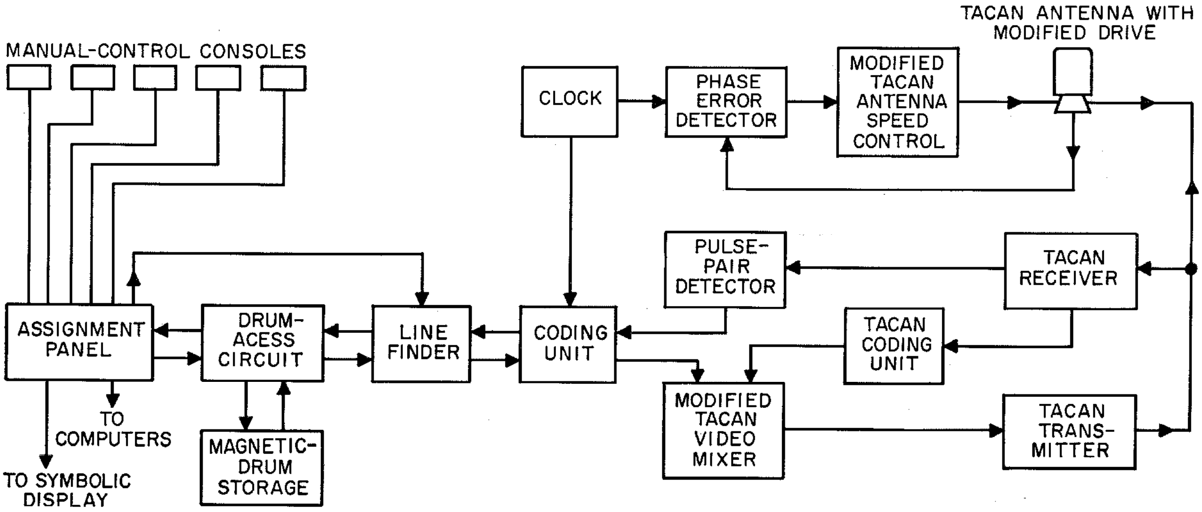


Figure 24—*AN/URN-6* functional block diagram.

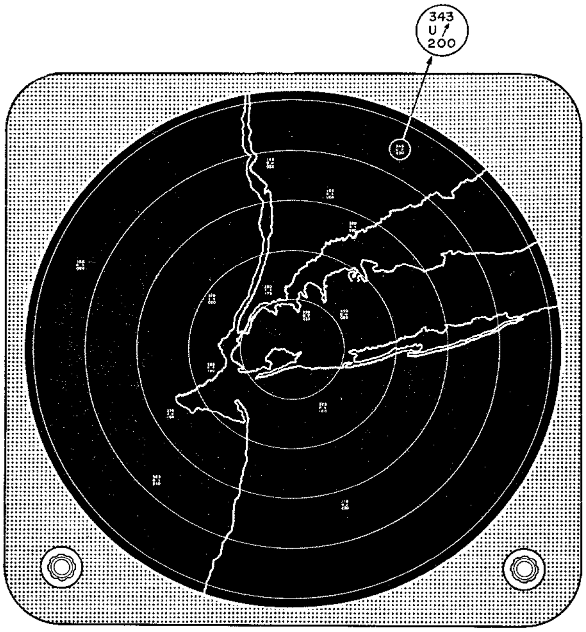


Figure 25—Symbolic display.

History of Tacan Data Link

By ROBERT I. COLIN

Federal Telecommunication Laboratories, a division of International Telephone and Telegraph Corporation; Nutley, New Jersey

DATA LINK is a term that refers to some sort of rapid, automatic, and selective communication system, not using voice radio, for exchanging messages between aircraft and ground stations as an aid to air-traffic control. Other terms for these systems include private line, impulse-signaling system, air-traffic-control signaling system, and discrete-address system. The tacan data link is an air-traffic-control signaling and automatic reporting system that operates over the same radio-frequency channels and equipment that provide the tacan air navigational services of bearing and distance indication[1] and operates simultaneously with these navigational services.

The tacan data link has been developed under sponsorship of the Department of the Navy by Federal Telecommunication Laboratories. The military nomenclature for the airborne equipment is *AN/ARN-26* and for the ground or shipborne equipment, *AN/URN-6*. Work began on the data link at Federal in 1951; but it is instructive to trace the earlier background of the project, which may be regarded as an outgrowth of certain needs and trends that began to be displayed shortly after the start of the modern era of air transportation some 25 to 30 years ago.

1. General Background of Data-Link Concept

Actually, in August 1917, shortly after the entry of the United States into the first world war, the first two-way aviation radiotelephone was successfully tested by the United States Army. The apparatus[2] was developed by the Bell Telephone Laboratories in cooperation with the Signal Corps. No accurate records of this historical date have been preserved, but later the official date of August 11, 1917 was adopted by consent of all the participants.

However, in the period following the first world war, voice air-to-ground communication was dormant; it was not revived until air mail was transported by private firms under contract with the Post Office, which began on February 15, 1926. In those days "normal" air-transport operations often included the landing of aircraft at emergency airstrips having no means of communication. The Post Office was anxious to have news of where the aircraft had landed with the mail. To encourage aircraft to install two-way radio, a bonus feature was appended to air-mail contracts. Since commercial air operations in the United States were then conducted largely in single-engine aircraft, the desirability of pilot-operated voice radio was evident. Largely through the initiative and leadership of Thorpe Hiscock of United Air Lines, crystal-controlled voice radio[3] became a requirement and a possibility. The equipment was supplied by Western Electric Company as designed by Bell Telephone Laboratories, with work commencing as early[4] as 1927. By 1929, United Air Lines (then Boeing Air Transport) had a chain of voice-communication stations in successful operation. Other air lines followed suit.

By 1936, it became apparent that the growing air traffic required a unified system of guidance and at that date air-traffic control was taken over by the Bureau of Air Commerce of the United States Department of Commerce. The air-traffic-control system was put in operation by assignment of personnel to the then-established airway-traffic-control centers. The operational computation of the future positions of all aircraft was based on reports of position determined by pilots flying the four-course radio ranges and transmitted by the pilots via their own airline air-to-ground voice radio circuits. Over these same circuits, the traffic controllers then issued their clearances to pilots; that is, instructions to hold, proceed, descend, et cetera.

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[1] R. I. Colin and S. H. Dodington, "Principles of Tacan," *Electrical Communication*, volume 33, pages 11–25; March, 1956.

[2] H. W. Roberts, "Aviation Radio," W. Morrow and Co., New York; 1945: pages 7–9.

[3] *IRE Transactions on Aeronautical and Navigational Electronics*, volume ANE-3, pages 49–50; June, 1956. (Citation of Pioneer Award to Thorpe Hiscock.)

[4] D. K. Martin, "Laying a Foundation for Aircraft Communication," *Bell Laboratories Record*, pages 315–318; April, 1929.

Voice radio communication was an almost indispensable accessory for the development of systematic air transport; but with that development the needs began to show signs of outgrowing the capabilities of the communication system. The need for an automatic air-to-ground communication system was first recognized by the Royal Air Force during the second world war. Under contracts between the Royal Air Force and Standard Telephones and Cables, Limited, a London associate of the International Telephone and Telegraph Corporation, there was developed[5] a system known under the wartime code name of Beechnut. In Beechnut, certain fixed types of messages associated recurrently with various air-traffic operations could be sent from ground to air and be suitably acknowledged by the pilot. The messages were displayed in the aircraft on a special annunciator-type indicator composed of drums with a number of markings consisting of figures, letters, and symbols. During the war, a similar development was carried out by the Radio Corporation of America for the United States Air Force; this system[6] was known as Voflag.

An early presentation of the requirements for automatic communication in air-traffic control was made by the Advisory Group on Air Navigation in its well-known compendium[6] issued by Wright Field (now Wright Air Development Center) in 1946. Early recognition of the requirements for an "indicator signaling system" by a purely civil group appears in a report[7] on "Recommended United States Air Policy" issued in 1946 by the Radio Technical Commission for Aeronautics. This report recommended that experimental work on the system start by 1948.

The requirements for a private-line system were studied and set forth systematically in 1947–1948 by Special Committee *31* of the Radio Technical Commission for Aeronautics as part of its common-system plan[8] for air navigation and traffic control. This plan was accepted by all groups, military and civil, concerned with aviation electronics and by official endorsement is considered to be the blueprint of United States policy. On page 15 of the *SC-31* report, the functions of the airborne portion of the traffic-control equipment are described as follows:

"(3) Provides the ground periodically with information as to the aircraft's position as determined by the airborne navigational equipment for ground check.

"(4) Provides private line communication over which:

(a) The pilot may transmit requests for information from the ground.

(b) The ground may issue traffic clearances to the aircraft.

(c) Either source will be provided automatic acknowledgement of message reception.

(d) The above information will be displayed by indicator signals."

In a footnote, the report defines a private-line system as ". . . a communication channel with its terminal equipment which uniquely connects each aircraft with the Traffic Control Agency."

On page 16 of the *SC-31* report cited, the functions of the ground portion of the air-traffic-control equipment are described as follows:

"(2) The private line transmitter–receiver comprises the ground portion of the private line air–ground link. This equipment transmits traffic control clearances and information, safety separation signals, and acknowledgement of and answers to pilot's requests. From aircraft, this equipment receives pilot's requests and confirmation of traffic control clearances. It also receives, at regular intervals, the air-derived navigation data and repeats it to the Automatic Air Traffic Control Equipment."

According to the time schedule in Figure 2B of the *SC-31* common-system report, the development of the target private-line equipment was to be undertaken so as to permit operational service by 1960, with trials of the equipment to commence in 1954. This portion of the common-system development program has not been

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[5] Third Commonwealth and Empire Conference on Radio for Civil Aviation (CERCA); Summer, 1945: page 152.

[6] Report of Electronic Subdivision Advisory Group on Air Navigation, Report *TS ELC-SP2*, Wright Field, Dayton, Ohio, pages 844–847; February, 1946.

[7] "Recommended United States Policy, Air Navigation—Communication—Traffic Control," Radio Technical Commission for Aeronautics, Washington, D. C.; August 28, 1946: page 9.

[8] "Air Traffic Control," Radio Technical Commission for Aeronautics, Paper *27-48/DO-12* prepared by *SC-31*; May 12, 1948.

carried out, although in the intervening years several types of private-line systems have been proposed and some military types experimentally constructed. There have been very-many subsequent reports and discussions on the subject of air-traffic-control signaling systems.

In January, 1948, special committee *41* of the Radio Technical Commission for Aeronautics was set up for the specific purpose of studying and reporting in more detail on the "performance characteristics for a private-line/transpondor element of the air traffic control system and the transition period transpondor." The report[9] of *SC-41* was issued in October, 1948. In June, 1949, another special committee, *SC-52*, was set up to make a study of the ". . . operational and economic values of a transition period private-line system." The report[10] of *SC-52*, prepared jointly with *SC-41* was issued in December, 1949. This report is one of the fullest expositions on the requirements of a common-system private line and it is therefore interesting to note here some of its recommendations, with which the present-day services and capabilities of the tacan data link can be compared. The report is prefaced with the following statement.

> "The efficiency of air traffic control is primarily dependent upon the adequacy of the communication system employed to exchange information between the control agency and the pilot. Within the United States, the air–ground communication medium most widely used today is radiotelephone. Its utilization in air traffic control is a limiting factor in the expeditious movement of aircraft in high traffic density areas because of its relative slowness, because it is subject to misunderstanding by both the pilot and the controller, and because of interruptions and delays caused by mutual interference between aircraft transmissions. RTCA Special Committee *31* took cognizance of this problem and, in its report 'Air Traffic Control' (Paper *27-48/DO-12*), specified the requirements for a Private-Line communication system for both the Ultimate and Transition Periods which would provide a means for the rapid exchange of messages between a ground station and each aircraft on an individual communication link. The messages (of a pre-established nature) are visually displayed both to the controller and to the pilot either pictorially or symbolically."

The *SC-52* report then goes on in detail to describe the services to be performed by the transition-period private-line system. Quoting from page 4 of the report:

> "It is recommended that for the Transition Period, equipments be obtained which will satisfy the following requirements:
>
> 1. Provide for ground-to-air transmission and automatic symbolic display in the cockpit the following clearance information:
>   (a) HOLD
>   (b) PROCEED
>   (c) LAND
>   (d) EXECUTE MISSED APPROACH
>   (e) BEGIN APPROACH
>   (f) LENGTHEN PATH
>   (g) SHORTEN PATH
>   (h) DEPART GATE
>   (i) DESCEND
>   (j) CLIMB
>   (k) MAINTAIN
>   (l) RUNWAY NUMBER
>   (m) FIX NUMBER
>   (n) HEADING
>   (o) TIME."

The report mentions additional services that should be provided by the private line. These include (page 4), ". . . ground-to-air transmission and symbolic display of assigned altitude information"; and (page 6), a ". . . cockpit warning signal, both aural and visual, to call attention to revised information being displayed in the aircraft. This signal shall be arranged to turn off when the manual acknowledgement signal is activated."

As regards the air-to-ground transmissions, the *SC-52* report (page 5) calls for means that will ". . . enable the pilot by a manual method to acknowledge the receipt of ground-to-air messages received in his aircraft"; and a ". . .

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[9] "Performance Characteristics, Private Line/Transpondor Element of the Common Air Traffic Control System and the Transition Period Transpondor," Radio Technical Commission for Aeronautics, Paper *96-48/DO-22* prepared by *SC-41*; October 6, 1948.

[10] "The Operational and Technical Characteristics of a Transition Period Air Traffic Control Communication System and a Study of its Operational and Economic Values," Radio Technical Commission for Aeronautics, Paper *116-49/DO-30*, prepared by *SC-41* and *SC-52*; December 15, 1949.

manual method whereby the pilot may indicate to the control agency when clearance instructions are being acted upon."

On page 7, the *SC-52* report calls for an additional air-to-ground service, namely ". . . means for automatic reporting of aircraft altitude." In this connection, it should be noted that the requirements indicated in the preceding quotations are for the *transition-period* private line. On page I, the *SC-52* report mentions that the *ultimate* private line requires means of air-to-ground reporting of ". . . three dimensional position information," that is, bearing and distance as well as altitude (a service that, like the transition-period services quoted above, are provided by the tacan data link). Thus in 1949 because of considerations of urgency and expediency, it was deemed that a less-complete and less-elaborate *transition-period* private line should be developed and installed first, to be followed by a more-refined *ultimate* private line. As stated on page IV of the *SC-52* report:

> "The schedule contemplated for the implementation of the Common System provides that the Transition Period Private-Line be in use about 1955 and that the Ultimate Period Private-Line be placed in service about 1963."

As remarked previously in this paper, the private-line portion of the common-system time schedule has not been followed. Meanwhile, air traffic has been expanding in a spectacular manner, in point of size and speed of aircraft, in the number of aircraft and airports in service, in miles flown, et cetera, and in all ways that render the problem of air-traffic control more difficult and make greater demands on the accessories required for safe and expeditious flight. Figure 1 indicates graphically some highlights of the aviation expansion since 1925, as contained in published[11,12] statistics. The data shown in the figure cover only *domestic scheduled air-transport service*, omitting consideration of military, business, and general flying. One result of the expansion in air traffic has been bottleneck situations in air-traffic flow caused by inherent limitations of the accompanying voice-communication facilities. The following appraisal of the situation was made in a study[13] prepared in 1955 for the Air Navigation Development Board.

> "Saturation of the air space is not a factor, but capacity of the present voice communication system imposes an appreciable delay in limiting aircraft to 16 to 20 flights per hour in a traffic control sector."

It is no wonder that voice radio communication limits air-traffic control, for it was designed some thirty years ago when there were fewer than 200 transport aircraft in service in the country, flying at speeds under 100 miles per hour, while today[11,12] there are some 1400 transport aircraft in scheduled service with cruising speeds ranging up to 400 miles per hour. More-recent remarks on the inadequacy of voice communication for handling modern traffic are here quoted. From a report[14] of Special Working Group *13* of the Air Coordinating Committee:

> "In areas where a high volume of aircraft operations must be accommodated, the use of voice only for air–ground communications will eventually be the limiting factor in the use of the airspace and a serious problem for the pilot and the controller."

The President's special assistant for aviation facilities planning, E. P. Curtis, has stated:[14]

> "We must, at least, augment our present overburdened voice communications with some form of rapid simplified data link to pass essential information back and forth between controller and pilot, and between controllers themselves."

In addition to the importance of a data link as an aid for reducing communication congestion and expediting traffic flow, there is mounting interest in it as a practical means of reducing the danger of collisions and near misses, a problem of vital concern to the air-transport industry. The possibility of solving this problem by airborne radar alone, in the near future or ever, appears dim. A data link would help immeasurably by providing automatic and continuous position reports of aircraft for digestion by the ground control agency utilizing either human or machine computers; the ground control agency

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[11] W. Littlewood "Technical Trends in Air Transport," *Journal of the Aeronautical Sciences*, volume 20, page 247; April, 1953.

[12] "CAA Statistical Handbook of Civil Aviation," Civil Aeronautics Administration; 1955: page 62.

[13] K. G. VanWynen and C. I. Stanton "Distribution and Movement of Aircraft," Institute of The Aeronautical Sciences; January 26, 1956.

[14] *Aviation Week*, February 25, 1957: page 256.

in turn would transmit safe procedural instructions to the aircraft.

2. Tacan Data-Link Development

Turning now specifically to the tacan data link, this system was developed for the United States Navy; its services and capabilities quite closely fit the function of a private-line system as described in the Radio Technical Commission for Aeronautics reports[7–10] and the requirements[13,14] enunciated in more-recent times. In view of this, together with the official decision of the Air Coordinating Committee in 1956 to incorporate the tacan navigational system into the nation's common system of air navigation, designated[15] vortac, the possibilities of the tacan data link as a common-system private line assume considerable interest and importance.

The tacan data link has been a parallel development of the tacan navigational system, the history[16] of which has already been related in detail. The original Federal proposal on the navigational aspect was issued in May 1948 and the initial contract for what proved to be the forerunner of the tacan system was awarded to Federal in June 1948 (Contract *NObsr-42422*). As work on this project during the next two years demonstrated the feasibility and usefulness of the tacan *air navigational* system, the Navy and Federal began to develop an interest in the possibilities for some suitable accompanying air-traffic-control signaling system or *data link*. Exploratory discussions on this subject took place throughout the year 1949 among J. Loeb of the Bureau of Ships, Department of the Navy, who has been the prime mover in the tacan development program for the United States Navy; P. R. Adams, then head of the Aerial Navigation Department of Federal, under whose general direction the initial stages of the tacan project were started at Federal; and the author of this paper, then an engineer in the same department at Federal.

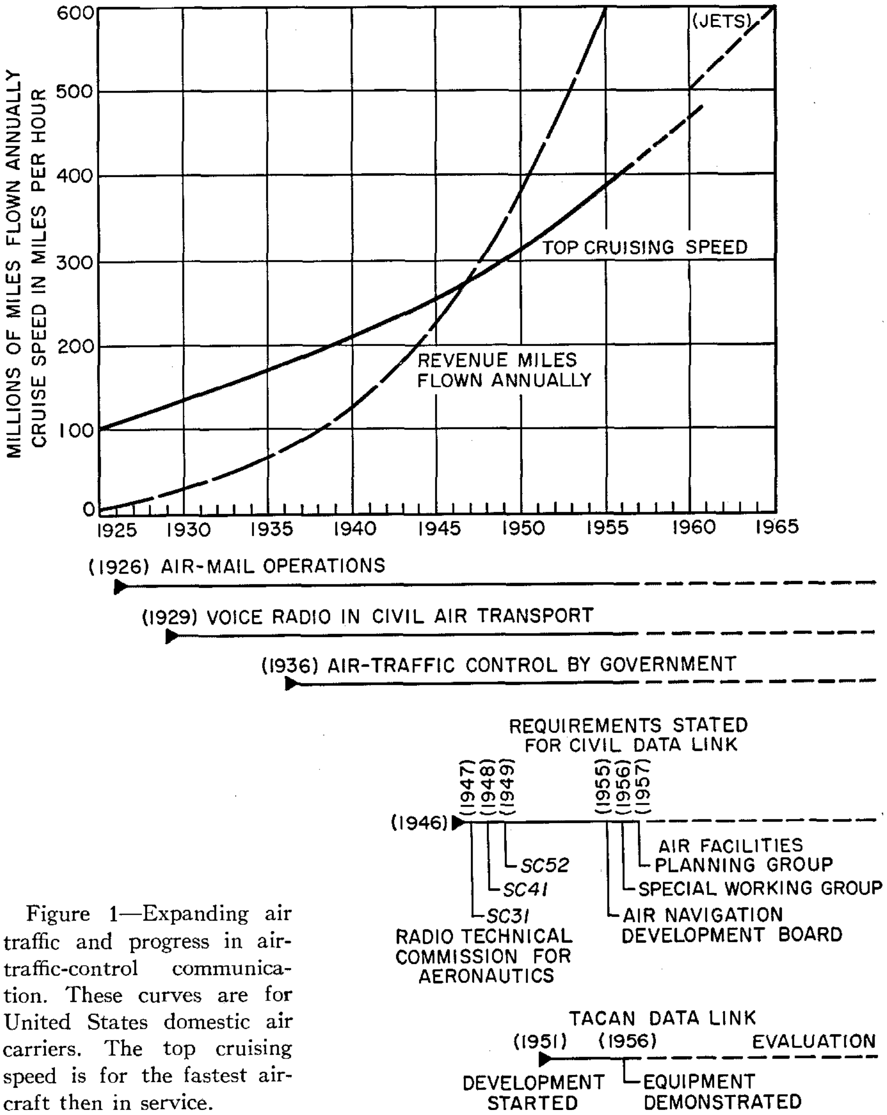

Figure 1—Expanding air traffic and progress in air-traffic-control communication. These curves are for United States domestic air carriers. The top cruising speed is for the fastest aircraft then in service.

Three general types of questions had to be explored. First, what types of services and

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[15] *American Aviation Daily*, August 31, 1956: page 460.

[16] P. C. Sandretto, "Development of Tacan at Federal Telecommunication Laboratories," *Electrical Communication*, volume 33, pages 4–10; March, 1956.

facilities should the data link provide to satisfy the particular operational needs—such as, what types of information and messages need to be exchanged between aircraft and ground, what speeds of transmission are required for the various messages, what number of aircraft must be accommodated? Second, what general techniques would be most suitable for these transmissions—what kind of codes, multiplexing, time sharing, roll call. . .? Third, and basic in consideration of any new radio system, what portion of the radio-frequency spectrum should be used for the new service? Consideration must, of course, be given to what channels were actually available.

The third question is always a particularly troublesome one in planning new radio services since finding suitable and available radio-frequency space is a great practical problem. It was clear that it would be highly desirable if the data link could be made to operate over the same radio channels, transmitters, and receivers used for the navigational functions. This would solve the channel allocation problem and save on equipment, space, and weight, an especially important consideration for airborne installations.

Radio channel and equipment coordination was in fact one of the basic features of tacan itself, in which bearing- and distance-indication services are multiplexed together[17] to obtain a number of advantages. Also, there is a close operational association between a navigational service and a data-link facility. The ground station to which an aircraft is tuned for bearing and distance is the one it should be in contact with for traffic-control purposes; in fact, part of the information to be transmitted between air and ground over the data link is the actual, and possibly also the desired or "ordered," indications of the airborne navigational instruments.

Multiplexing a data link on a radio navigational facility was not generally feasible with previous radio navigational systems. The characteristics of tacan, however, appeared to offer this possibility. Tacan provides[1] both bearing and distance by means of pulse transmissions of low duty cycle. This means[18] that there is room for additional pulses for other purposes. The tacan service operates on clear radio-frequency channels, hence different pulse codings can be used for the several functions without disturbing the channeling features. The nature of the distance-measuring service is such that occasional missed pulses or occasional extra, nonsynchronous, pulses will not disturb the distance operation.[1] The nature of the bearing service is such that any additional pulses radiated from the surface station actually reinforce the pulse envelope created by the directional antenna pattern without disturbing the phase of the envelope that carries the essential bearing information.[1] And finally, the bearing reference signals transmitted periodically during rotation of the tacan ground antenna provide a perfect source of accurately timed signals for synchronizing and timing the various stages necessary for the operation of a sequential-type data-link system.[1]

Around the middle of 1949, it was decided that it was not too early to plan at least some preliminary development work on the data link to test experimentally the feasibility of a multiplexed navigational and data-link system. By doing this work at an early stage, useful information for long-term planning could be gained; that is, the tacan navigational system could be designed from the beginning to permit the addition of data-link services without requiring later changes in the basic navigational equipments already in service.

Around the autumn of 1949, work started at Federal on the preparation of a formal technical proposal incorporating the discussed objectives and sketching out specific designs and techniques to put the exploratory ideas into practice. In January 1950, Technical Proposal *806*, entitled "Carrier Aircraft Homing and Interception Aids" was issued. After submission of this proposal and protracted study by the Navy, contract *NObsr-52128* was awarded to Federal by the Bureau of Ships in December 1950. This contract

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[17] P. C. Sandretto, "Coordinated System Concept of Air Navigation," *Electrical Communication*, volume 33, pages 74–79; March, 1956. This paper discusses the advantages of coordination in detail, especially from the point of view of reliability. However, at the time of publication of the paper, the tacan data link was still classified; the paper therefore could not allude to the additional coordination of data-link services with bearing–distance and other navigational services. Such additional coordination had been under consideration practically from the beginning of the tacan project in 1948 and was actually in process experimentally at the time the paper was written.

[18] S. H. Dodington, "Quartz Crystal Control at 1000 Megacycles," *Electrical Communication*, volume 33, pages 80–84; March, 1956: page 84.

was the initial one in the series of four tacan data-link contracts issued to date.

Work started at Federal on the initial contract early in 1951. The purpose of the original contract was essentially to develop experimental equipment to demonstrate the feasibility of the system. The system was later assigned the nomenclature *AN/URN-6* for the ground or shipborne portion, and *AN/ARN-26* for the airborne portion. (More properly, these designations refer to the combined navigational and data-link system, comprising the basic tacan navigational equipment *AN/URN-3* and *AN/ARN-21*, plus the accessory data-link equipment.) As is common in new technical developments, the exact techniques and details of operation described in the original proposal were not followed in the equipment actually constructed. However, the basic features, that is, the types of functions performed and general principles of operation, described in the original proposal have been followed in all the data-link equipment built to date.

To give an idea of the time scale in relation to other events, it may be recalled that by the middle of 1951, when work on the first tacan data-link contract had barely started, this was the situation with respect to tacan[16]: Federal had already built and successfully demonstrated tacan bearing and distance equipments; the Department of the Air Force had joined in the program and added its own requirements to the specifications; and later in 1951 and early in 1952, the first production contracts for tacan equipment were awarded to Federal Telephone and Radio Company, manufacturing affiliate of Federal. With this progress and acceptance of tacan, it was natural that the work on the associated data link began to assume increased importance.

The experimental equipment constructed under contract *NObsr-52128* was completed to the point where flight tests could be made around the autumn of 1953. A large amount of useful information was gained from the extensive program of flight testing that took place in 1954, some 400 hours of test data having been recorded and analyzed. The details are described in another paper in this issue of *Electrical Communication.*

As a result of the demonstrations of the feasibility and promise of the tacan data link, as performed with the initial experimental equipment, the second stage of the data-link program was initiated with the award of two further contracts to Federal by the Department of the Navy. These contracts called for the design and construction of more-refined "service test models," to permit evaluation tests to be made of the system by the Navy. Contract *NObsr-64140*, dated March 1954, covered the shipborne *AN/URN-6* equipment and contract *NObsr-64645*, dated March 1955, was for the *AN/ARN-26* airborne equipment. By this time, quantity production of specification-type tacan navigational equipment had progressed so far that the data-link developments, tests, and demonstrations were carried out in conjunction with regulation factory models of tacan navigational equipment as used in the field.

The service test models of tacan data-link equipment were completed sufficiently to permit flight testing around the beginning of 1956. On May 3 and on May 10 of 1956, formal flight demonstrations of operation of this equipment were held at Federal in Nutley, New Jersey. The Federal *DC-3* aircraft was used in these demonstrations. The demonstrations and exhibits were witnessed by nearly 200 representatives, many of high rank, from various United States and foreign aviation and electronics agencies, both civil and military, under invitation from the United States Department of the Navy. Descriptions of the equipment and the test results are given in the other papers in this issue of *Electrical Communication.* The equipment was delivered to the Navy around August 1956.

Under date of August 1956, contract *NObsr-71537* was awarded to Federal for engineering and field service to assist the Navy in its program of evaluation testing of the tacan data-link equipment. This project is now is progress at the Naval Air Test Center, Patuxent River, Maryland.

To conclude the record to date, part of the tacan data-link system was officially declassified on March 12, 1957. On March 13, 1957, the first exhibition of equipment and release of information to the press took place[19] in New York City. Discussions of future possibilities and programs involving the tacan data link are included in the other papers in this issue of *Electrical Communication.*

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[19] *New York Times*, March 14, 1957: page 31.

Tacan Data Link for Common-System Air-Traffic Control

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TACAN DATA LINK is a system that offers a world-wide solution to present and foreseeable air-traffic-control problems. Originally it was designed to meet certain high-speed information-exchange requirements of the United States Department of the Navy. Its evaluation in this connection is currently being carried out by the Navy. While its ultimate military application is not known, recent declassification of the equipment makes possible a consideration of its application in other fields; the most promising appears to be in air-traffic control. The system is ideally suited for this purpose because it is capable of automatically deriving and exchanging information vital to the pilot of the plane and the controller at air-traffic-control (ATC) facilities. In addition, it is integrated with the distance-measuring facility of tacan, which is now destined for use in the navigational system known as vortac, recently adopted for common civil–military use in the United States. Through this integration, the joint goals of traffic control and navigation are achieved with resultant economy in equipment and frequency spectrum and with no degradation in the service provided.

It has been apparent for some time in the United States and elsewhere that air traffic would eventually increase to a point where manual control procedures, despite refinements and marginal improvements, could no longer satisfy traffic-control needs. The necessity for automation has thus been recognized. The tacan data link, which offers a high degree of automation, together with some of the problems that it could assist in relieving will be discussed in this article from an operational viewpoint. Technical descriptions of units of the system will be found elsewhere in this issue of *Electrical Communication.*

1. *Air-Traffic-Control Problems*

Recognizing that much has been written about the inadequacies of the air-traffic-control system, the following is a brief summary, in controllers' language, of those problem areas that illustrate the shortcomings of the present manual system.

1.1 AIR SPACE

Air space is a fixed commodity that, when used efficiently, should meet the requirements of the foreseeable future. Under the present manual traffic-control system, the increasing speeds of aircraft are dissipating this commodity at an alarming rate. For example, the United States' federal airways manual of operations, "Air-Force–Navy–Civil (ANC) Procedures for the Control of Air Traffic," establishes a minimum of 10 minutes longitudinal separation between aircraft with similar speed characteristics following the same flight path. Previously, when aircraft made good a ground speed of 180 knots (334 kilometers per hour), this time represented 30 nautical miles (55.6 kilometers) of air space. Aircraft making good a ground speed of 420 knots (780 kilometers per hour), which is not uncommon today, have 70 nautical miles (130 kilometers) of air space reserved. Using the present separation standards based on units of time, availability of air space decreases in direct proportion to increase in aircraft speed. It is readily apparent that unless something is done to change the separation standards, considerably fewer aircraft will be able to use the air space at a given time.

The 10-minute separation standard was established because both controller and pilot lacked knowledge of the exact position of the aircraft, because of the airway route structure giving a radio fix every 60 to 70 nautical miles (110 to 130 kilometers), the types of communications employed, and the present manual traffic-control techniques. Controllers frequently extend this minimum standard when the navigational aids and/or communications are inadequate.

In present operation, as an airway becomes fully occupied, the control center responsible will initiate "flow-control" procedures and will restrict the number of aircraft entering the area. As this backup of traffic occurs, the control problems become more acute and extremely complicated, requiring extensive intercenter and intracenter coordination. In scope, a backup of traffic in the New York metropolitan area, for example, affects air traffic throughout the United States. Controllers have often stated that the secret to good operation is to keep the traffic flow commensurate with the acceptance rate of an airport.

Although this paper is primarily concerned with air-traffic-control matters, mention must be made of the effect of air-traffic slowdowns on economy in airline personnel, efficiency of military operations, and the disturbance to the flying public.

1.2 Display

The prime purpose of an air-traffic-control display is to depict the existing and significant future air situations. The displays shown in Figure 1, known as flight progress boards, form the basis of the manual en-route air-traffic-control system. The flight-progress strips on the desk show the time that each aircraft was over its last fix and the projected times for succeeding fixes. The translation of this information into the current and forecast air-traffic pattern is the most-difficult job of the controller. He must take the written route, ground-speed, and altitude information on his flight-progress strips and mentally visualize it in three-dimensional geographic form. Even in the days when the system served aircraft with similar speed characteristics (*DC-3*) and the instrument-flight-rules (IFR) landing rate at most airports was 6 per hour or less, this manual system was recognized as being inadequate.

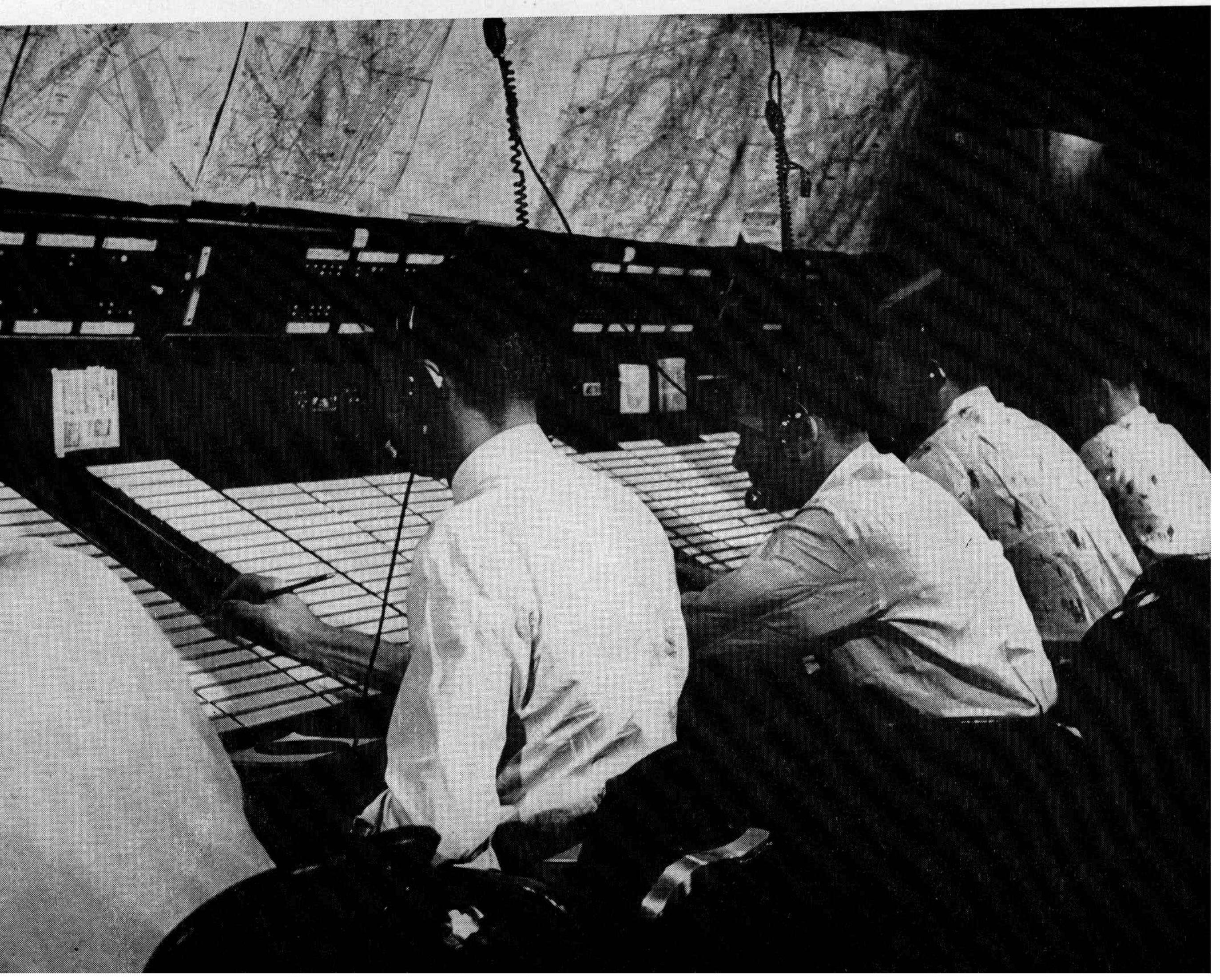

Figure 1—Row of flight progress boards as used in air-traffic manual-control center.

Present aircraft have widely divergent speed characteristics and the instrument-flight-rule landing rate at major airports exceeds 20 aircraft per hour. However, the basic traffic-control system is still the manual flight-progress board. An increase in system capacity has been realized through advances such as radar, direct voice communication between pilot and controller, and improved controller techniques. However, the present system capacity is not meeting the existing requirements and most assuredly will not keep pace with the demands of the future. In parallel industries, such as railroading, manual systems are fast being replaced by semiautomatic and automatic systems that are considerably more efficient and not as liable to human error.

1.3 COMMUNICATIONS

1.3.1 Air–Ground–Air

Significant progress has been made during the past decade in improving vocal traffic-control communications. The use of very-high frequencies for civil and ultra-high frequencies for military communication to clarify reception and the implementation of the peripheral radio method to provide direct speech between the pilot and controller has improved the aircraft handling rate. Narrowing the very-high-frequency channel bandwidth from 200 to 50 kilocycles per second and for ultra-high-frequencies from 100 to 20 kilocycles will probably relieve the present spectrum congestion. However, air-to-ground communication would still be by slow vocal means and many more controllers will be needed to guard the additional frequencies. This will require breaking the controller's job down to smaller areas; increasing coordination, which also requires more people; and, while the system capacity will be increased, it will be accomplished neither efficiently nor in proportion to the cost and it will not meet the future requirements.

1.3.2 Point-to-Point

The exchange of information between controllers, centers, and allied agencies (military and civil operations, weather, communication stations, et cetera) is accomplished vocally by telephone or manually by teletype. These means of communication are time consuming, diverting the controller from his prime task of controlling air traffic, and are subject to human error. Controllers at busy control sectors immediately adjacent to the area of another center have estimated that they spend 50-percent of their time coordinating, forwarding, and receiving flight-plan information. In some cases, this has been alleviated by assignment of an assistant controller for this function. The author has had considerable experience with near misses that have occurred because of errors in the transmission of information.

1.4 COORDINATION

Among the more-severe bottlenecks in controlling air traffic is the coordination required between controllers, centers, and other operating agencies. At the present time, most of this coordination is accomplished via human means using the communications described in section 1.3. Simple semiautomatic devices have been used successfully in some instances, such as altitude interlocks between center and tower and a system of "go–no–go" lights between sectors in the Boston air-route traffic-control center.

2. Tacan Data Link for Semiautomatic System

The major requirements of any air-traffic-control system are acceptably accurate knowledge of aircraft position by both pilot and controller and ability to communicate at an acceptable rate. These factors determine the separation between aircraft and when combined with the airport acceptance rate establish the over-all system capacity.

The tacan data link is a rapid two-way system of automatic communication. The aircraft forwards to the tacan beacon its distance and bearing from the beacon and its altitude, heading, and air speed with a high order of accuracy. On each tacan channel, 31 data-link messages such as LET DOWN 1000, HOLD, REQUEST LANDING INSTRUCTIONS, et cetera may be handled at the rate of 90 messages per second (45 ground-to-air orders and 45 air-to-ground reports) without interfering with the tacan navigational service otherwise provided on this channel. Consequently, 120 or more aircraft can easily get data-link service on each channel. Standard telephone lines can be used to transmit data-link information between the equipment at the transmitter site and a storage unit at the air-traffic-control center.

The system postulated herein (Figure 2) would then use this information as the basis for a semiautomatic air-traffic-control system. Continuous aircraft positional information would be supplied to the traffic-control system via data-link connection to a magnetic storage drum. A computer would extract the pertinent information (identification, altitude, computed ground speed, and route), which in turn would control a dynamic, pictorial, three-dimensional display. The computer would also keep current a totalizator-type board containing pertinent information (including, if a three-dimensional display is not feasible, altitude information). The system would be fail-safe. To provide service for partially or unequipped aircraft, means would be provided for manually inserting necessary information into the computer; vocal communication would be the link with such aircraft. In a highly refined computer, a phantom standard separation block of air space could be maintained around each aircraft and projected for possible future conflict with other aircraft in or desirous of entering the system and at intersections of routes. A warning device would bring impending conflict to the attention of the controller. This device, in conjunction with a scheduling device, would ultimately form the basis for an automatic system.

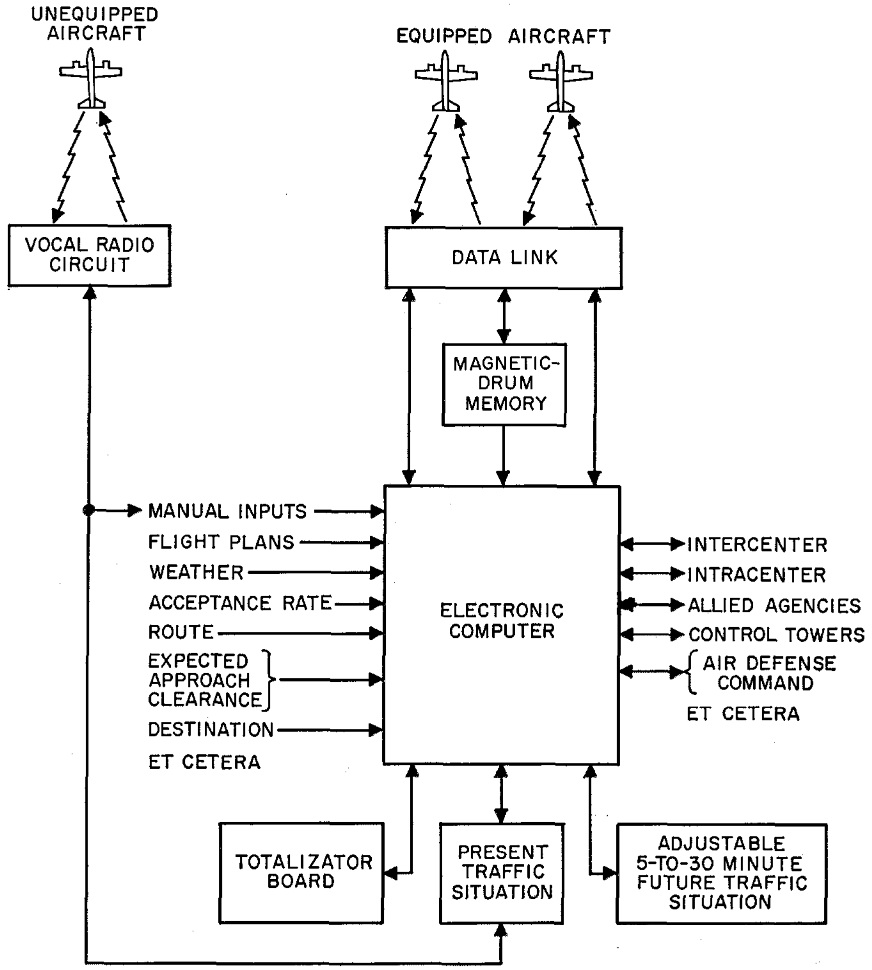

Figure 2—Semiautomatic air-traffic control using tacan data link in conjunction with a magnetic-storage-drum memory and an electronic computer.

The system outlined above would alleviate many existing problem areas in the following fashion.

2.1 Air Space

The availability of continuous precise positional information and a more-rapid means of communication would permit a considerable reduction of the separation standards. For example, when using radar, which affords continuous positional information, the standards now call for 3 nautical miles (5.6 kilometers) within a 40-mile (74-kilometer) radius of the radar and 5 miles (9.3 kilometers) beyond that distance. Consequently, the unit of measurement in the proposed system would be distance rather than time, with the distance determined by the accuracy of the equipment.

Considerably more aircraft could then be fitted into a fixed amount of air space. To meet the requirements of the future, the remaining problem would primarily be that of increasing the acceptance rate of the airports.

2.2 Display

Without making mental calculations, the en-route controller would have before him the existing traffic situation. To determine the projected traffic situation, he would turn to the adjustable display and select the future time in which he is interested. The information would be relatively free of human error. Supervisory personnel would be aware of the situation at a glance and would be in a position to provide any necessary assistance. In present operation, unnecessary slowing down and in some cases complete denial of entry to a route and holding of air traffic in an area must be done until an air-traffic picture is understood. In high-density areas, as previously stated, this has a snowballing effect.

2.3 Communications

2.3.1 Air–Ground–Air

By adding an automatic identification feature or automatic storage-drum access to the tacan data-link system, the controllers would not be required to guard a number of frequencies constantly. The controllers would select their messages and direct them to the computer, which would electronically determine the beacon the aircraft was in contact with and would relay the message to that beacon. Conversely, messages from a pilot would appear electronically on the totalizator board and would be called to the attention of the controller by a warning signal. Using this system, there would be no waiting for availability of the frequency, no chance of misunderstanding messages on the part of controller or pilot; and the rapid means of communication required for supersonic flight would be realized.

2.3.2 Point-to-Point

Flight information would be relayed electronically 30 minutes before the computer estimated that an aircraft would enter the area of the adjacent sector or center. The pertinent information, identification, altitude, route, and estimated entry time, would initially be indicated on the totalizator board for advance planning. Control towers would receive flight information in a similar fashion. Interested agencies would have access to the appropriate computers for current and forecast traffic situations.

2.4 Coordination

Most of the coordination in this system would be by semiautomatic means as outlined above. The coordination required between controllers would be lessened considerably as the individual displays in the system would encompass a greater area than that served by the present sector system. Controllers would work side-by-side using one dynamic pictorial display and, being relieved of the present functions of manual coordination, communication, and constant checking of flight-strip information for accuracy, they could devote more time to actual traffic planning.

To illustrate the proposed system briefly, a hypothetical flight from New York to Washington will be followed. The operations office of the airline would submit the proposed flight plan, including estimated departure time, via teletype to the computer handling the area. The computer would automatically relay the flight plan to the totalizator boards in the tower and in the center for advance planning.

The center controller, will have a choice of two actions: In the case of a highly refined computer and accurate departure (chock) time, he may query the instrument for available routes and altitudes and a suitable time of departure would then be reserved for the aircraft. Using a less-capable computer and less-accurate departure time, he could, by scanning his display, determine an available route and altitude in his area and request via semiautomatic means an altitude reservation in the adjacent areas.

When the aircraft departs, the data link would provide tracking information on the controller's display similar to that provided by radar in the manual system employed today. On the basis of the flight information it is continually receiving, the computer would make any changes necessary to depict the existing and forecast traffic situations. The totalizator boards in the concerned area and adjacent areas would be automatically changed by the computer to reflect the flight plan of the aircraft. Providing that the acceptance rate of the airport concerned is adequate, a safe, expeditious flight from departure to touchdown would be assured. In the event the capacity of the airport was saturated, this semiautomatic traffic-control system would terminate at the holding fixes serving the airport area. At this time, manual approach-control techniques or perhaps semiautomatic techniques using the scheduling and tracking capability of a volscan air-terminal approach-control system would be employed to ensure the highest landing rate.

3. Compatibility of Tacan Data Link

The tacan data link is multiplexed on the transponder distance-measuring function of tacan with no degradation of the navigational signal and only a minor effect on the aircraft-handling capacity of the transponder. Propagational studies by the United States National Bureau of Standards have indicated that the available tacan frequencies will meet the short-range navigational-aid requirements of the future. It is anticipated that the operational advantages of distance-measuring service, particularly during instrument-flight conditions, will lead the majority of air-space users, civil and military, to add this equipment to their aircraft. The transmitter of the airborne interrogator is the only device on an aircraft that is continuously sending out signals in all directions. Consequently, use of tacan data link would permit implementation of semiautomatic air-traffic control at minimum expense to the government for ground equipment and to aircraft users for airborne equipment. Any other type of link that might use the civil and military voice-frequency-communication channels would add complexity and expense to the ground and airborne equipment. An additional problem of very- and ultra-high-frequency data links would be the availability of frequencies during the transitional period when the need for both voice and data-link frequencies will be high.

4. Comparison with Radar

The high initial cost, as well as the installation, maintenance, and operational costs of a single radar are well known. Adequate coverage for traffic-control purposes would, in certain terminal areas, require many radars with attendant large outlays in money, materials, and manpower.

The problem of tracking individual airplanes by radar in dense-traffic areas is most difficult. At present, a controller is limited to handling about 6 aircraft by this method.

While it might be argued that there would be no requirement for airborne equipment in a traffic-control system based on radar alone, this is not borne out by operational experience in the field, where there is strong opinion that each aircraft should be equipped with a radar beacon.

It would appear, therefore, that any air-traffic-control system based on radar would eventually have to be supplemented by auxiliary ground and airborne equipment, thus adding greatly to the basic radar costs.

The operational capabilities of the tacan data link for air-traffic control have already been described. While a direct comparison of costs with a radar system is not possible at this time, the joint use of tacan and tacan data-link equipment to provide simultaneous navigational and traffic-control services should result in a more-economical solution. For example, there should be fewer items of complex equipment; less space and weight use in aircraft; there would be less frequency-spectrum congestion; and lower manpower requirements.

Radar will be required, for the foreseeable future at least, for military purposes and for interim use in certain cases at commercial airports. Its wartime military significance and value, however, should not be allowed to influence unduly a logical, efficient, and economical solution to the commercial air-traffic-control problem; a solution that, it is believed, the tacan data link can provide.

Vortac Data Link

By ROBERT C. RENICK

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RECENT PUBLICITY on the inadequacies of the present air-traffic-control system draws attention to a condition that has existed and has steadily grown worse for a period of years. The anticipated traffic loads during the next few years, radically different flight characteristics of aircraft that will have to be accommodated, and the economics of delays in air transportation require immediate action to establish an integrated air-traffic-control system that includes avigation, traffic control, communication, and positive identification.

Such an integrated system must provide safe separation and expeditious avigation for all aircraft for taxiing, approaching, landing on and departing from all air bases, and avigating from point to point. It must report on the instantaneous position, direction of travel, altitude, speed, and destination of every aircraft in its area of control and provide all these aircraft with the necessary information to maintain safe separation under all weather conditions. The system must accept aircraft with varying flight characteristics and be capable of expansion to accommodate anticipated traffic requirements for many years to come.

1. Inadequacies of Present System

One has only to attempt to fly from New York to Washington on a bad-weather day to realize the inadequacy of the present air-traffic-control system. On such a day, thousands of passengers will be forced to cancel travel plans. Every flight on the entire system of an airline may be delayed to such an extent that it may take two or three days to regroup its entire flight equipment and resume normal scheduling. The traffic jams do not result from air space or airports being saturated, but rather from the obsolescent control system now in use.

Poor knowledge of the position of an aircraft and inadequate communication to notify it of changes in clearance require extremely large separations to be maintained to prevent collision. The air-traffic controller, handling aircraft passing a given check point in chronological order and trying to maintain altitude separation of aircraft within 10 minutes of each other, is unable to visualize the over-all air-space utilization. He sees only a narrow portion of the complete picture. To minimize the possibility of dangerous errors on his part, the traffic is channeled along a single airway, thereby using only a small fraction of available air space. In addition, this controller has no information on other aircraft in his area flying on visual-flight rules. He may be presented with an aircraft suddenly appearing in his area and asking for instrument-flight-rule clearance. He then has to reshuffle the aircraft under control to make room for this new aircraft. The limited facilities available and the chance of possible further delay often tempt pilots to risk unsafe conditions to get a better clearance or be cleared for a quicker landing. A single lost plane in an area can result in delaying all traffic for many miles out and a piling-up that takes hours to clear. Perhaps worst of all, the present system, already overcrowded, has no facilities ready for the introduction of jet aircraft into the pattern, since these aircraft must cruise at high altitude and then finally descend rapidly for landing because of their high rate of fuel consumption at low altitude.

2. Inadequacies of Radar

One of the primary requirements of the air-traffic-control system is accurate identification and positional information on every aircraft within the control area. Under the present state of the art, it appears impossible to acquire sufficient data about all aircraft even from extensive radar installations. While aircraft equipped with radar beacons are a partial answer to the identification problem, the predicted traffic densities seem to rule out this solution in the areas of highest traffic density.

To provide adequate radar coverage under all weather conditions, it would be necessary to saturate an area with many unmanned radar stations and transmit the radar information to the control center, such as is being done in the sage system. While this technique may be a partial solution in the continental United States, its use on a world-wide basis is impracticable. The communication net alone that is required to bring this information to the control center invalidates this solution. All this is not to say that radar will not be used in the future air-traffic-control system; indeed, it will undoubtedly remain a very valuable control tool. However, it should not be used as the primary means of gathering positional information. Aircraft are now being equipped with adequate automatic avigational systems that give the pilot his position to the required degree of accuracy. A simple automatic signaling system to encode these reports and transmit them to the ground is the obvious answer to the position-reporting problem.

3. New System

The most-important feature of the air-traffic-control system will be the use of area rather than airways traffic control. Area-type control will give a two-fold gain. First, aircraft will be able normally to travel in direct lines to the destination. Second, the whole air-space volume will be used to separate the aircraft. For maximum effectiveness, instantaneous information must be available to the control center on the identity, position, altitude, and heading of every aircraft in its area. The control center, which then will generate the necessary control information, must have completely reliable communication with each aircraft to issue instructions to it. In addition, it is necessary to have special means for handling emergencies without disrupting normal traffic flow.

The air-traffic-control system must be capable of directing aircraft into any airport in its area at the maximum rate that that airport can accept landing and departing aircraft. The control center must contain sufficient automatic computational ability to handle the maximum density of aircraft in its area, but at the same time must present over-all visual displays to controllers for continuous monitoring of the existing situation in that area. The operators must be provided with manual controls that will permit them to intervene in the case of equipment failure or other emergencies.

4. Choice of Transmission Facilities

In a system designed for world-wide use, the first obvious answer to a position-reporting system would seem to be a communication channel that can operate over the longest required distance; namely, when the plane is over the middle of the ocean. However, such a system requires either large amounts of power or the use of very-low-frequency transmission, which calls for impossibly large airborne antennas. The choice of these techniques would place an undue burden of weight and complexity on aircraft that are operating only over land. Therefore, it seems logical to employ a line-of-sight system for position reporting over land areas. There are two practical choices—either the ultra-high-frequency voice channels from 225 to 400 megacycles per second or the vortac ultra-high-frequency avigational channels. The distance-measuring portion of the vortac system has been provided with the necessary bandwidth for simultaneous multiplexing of the positional information along with full avigational data. Since the vortac system will be used by both civil and military aircraft, the development of a position-reporting data link to operate in conjunction with it is the obvious choice.

5. Requirements of Vortac Data Link

5.1 MINIMUM SIZE AND WEIGHT

To achieve minimum size and weight, it is convenient to multiplex the data-link system with some other communication or avigational equipment in the aircraft. Minimum size and complexity of the aircraft equipment will result if it is designed to the rule, so often overlooked by equipment designers, of keeping system complexity on the ground wherever possible.

5.2 INDIVIDUAL ADDRESSES

The signaling system must provide for individual identities for every aircraft expected to operate in a given control area. The maximum address capacity of the system should take care of predicted numbers of aircraft for the foreseeable future. The address structure should be arranged so that there is no possibility of sending the wrong clearance to an aircraft or of receiving back false identification for an aircraft.

5.3 SYSTEM CAPACITY

The data link has to be able to accommodate maximum traffic densities to be encountered in a control area within the foreseeable future. It should have adequate data-handling capacity to provide all required report information on every aircraft at data rates substantially higher than those required for adequate dynamic control and should have capacity for sending all necessary control information plus certain other simple procedural information.

5.4 ACCURACY

The data link should be able to transmit commands and report back any data required for air-traffic control without appreciable loss of accuracy in these data. Adequate redundancy or error checking should be provided to assure the rejection of completely incorrect information.

6. Proposed Vortac Data Link

6.1 SYSTEM DESIGN PARAMETERS

6.1.1 Information Content and Rates

The information content and information rates required for the control of traffic for all phases of operation of a polyglot air population should be determined from considerations of the operations, aircraft performance, control center network, and time and space separations. A well-designed data link will not limit this determination, but requires that the design of the computer to utilize reported data and to generate command signals and the signaling system should be coordinated at an early phase to obtain an optimum over-all system.

6.1.2 Identity of Aircraft

The amount of information theoretically required to identify positively each aircraft within the cognizance of a traffic-control center is limited to the maximum number of aircraft in the area simultaneously at a rate of once per entrance into the area. This minimum requirement assumes that each aircraft that passes through the area is assigned an identity on entrance to the area and this identity is associated with the aircraft track at the ground computer.

While this system is feasible, operational problems are considerably simplified by providing enough identities in the system to allow for any equipped aircraft to pass from area to area without change of identity. This method also allows for considerable information concerning the particular aircraft (such as type, performance characteristics, ownership, et cetera) to be filed at the computer.

If the rate of identity information is the same as that of messages to aircraft, association of the information with track of the aircraft is greatly facilitated. This is especially important in the case of tracks merging or crossing at narrow angles.

6.1.3 Report Information

6.1.3.1 Surface Position of Aircraft

Positional information may be available in different aircraft in a variety of forms; that is, latitude and longitude from a dead-reckoning or inertial computer or distance and bearing from a tacan or vortac station. The most-convenient form from the point of view of simplifying aircraft equipment is that in which it is already displayed to the pilot. The conversion to a common reference form could take place on the ground, but a detailed analysis of the most-efficient point for conversion should be undertaken.

6.1.3.2 Altitude of Aircraft

Information on altitude is most-universally derived from barometric pressure-sensing devices, although radio altimeters are available for more-accurate information at lower levels. A decision to utilize this more-accurate information, if available, requires an analysis in terms of what improvement in over-all system performance could be obtained.

6.1.3.3 Rate Information

Information as to heading, air speed, and rate of climb are also available in the aircraft. While accurate averages of this information can be obtained on the ground, the time lags inherent in such averages may be inconsistent with tight control. Such information may be valuable and economically feasible if sent in a much-abbreviated form such as the transmission in an on–off code showing whether the aircraft is exceeding rates consistent with program traffic separations.

6.1.3.4 Other

In addition, there are available certain other parameters such as amount of fuel, oxygen supply, et cetera, that affect the control of an aircraft. This type of information is only occasionally of importance, however, and it may be sufficient to present it as a single emergency button for transmission via automatic data link or even by voice with facilities at the control center for entering it into the computer.

The previously mentioned information is available in the aircraft. Decision on the provision for its inclusion in an automatic data link and the required rates of transmission of such information depend on a detailed study of operational requirements and existing and projected airborne measuring devices.

6.1.4 Control Information

Since any control system involves the transmission of some command information individually addressed to each aircraft, facilities must be included for this. Prefiled or reported flight plans provide a valuable standard with which to compare actual measured conditions. However, it is worse than useless merely to observe such deviations without provisions for closing the loop and correcting them.

The amount and rate of information required for such ground-to-air correcting orders are inherently lower than those required for measuring parameters in well-behaved air traffic. It may well consist of simple on–off commands to fly up or down, left or right, speed up or slow down; or perhaps an incremental change by the number of transmissions containing such an incremental order. It may be convenient to utilize, in addition to the control information, certain routing and discrete commands such as REPORT DESTINATION EN ROUTE OR TERMINAL. Transmission of a new command to call the attention of the pilot to a change in orders and requiring an acknowledgment provides a valuable operational feature that should be included. Again, the form and rates of such transmissions should be determined from a careful analysis of the requirements.

6.2 Ground Netting

The ground installation of an air-traffic-control system will probably be composed of a control center that will display and evaluate data from a network of information-gathering facilities. Information on all aircraft within the jurisdiction of the control center will be available from one or more of these sources. In addition, provisions for exchange of pertinent data among various control centers will be provided. A pictorial diagram of such a system appears in Figure 1. As presently envisioned, primary data inputs to the control center will be from a vortac network providing aircraft control and report service for the control center, search radar, air-defense systems, civilian and military prefiled flight plans, and other control centers. These data will be presented in a quasi-three-dimensional situation display to facilitate evaluation by control-center personnel. These data inputs will also be available to the traffic-control computer at the control center, which will evaluate routine situations and afford partial solutions to nonroutine problems. It will then be the responsibility of the control-center personnel to complete the partial solutions and dispatch correcting data to the aircraft concerned, as well as to monitor and manually override the automatic equipment in any potentially dangerous situation.

7. Vortac Site Equipment

By 1960, the civil airways will be fully equipped with tacan at all en-route vortac sites as well as at many instrument-landing and terminal installations. Such an equipment will receive over land lines digital transmissions that consist of identities and control information destined for one aircraft at a time. It will then automatically encode each message and transmit it via the tacan beacon transmitter. If the particular aircraft is tuned to this vortac station,

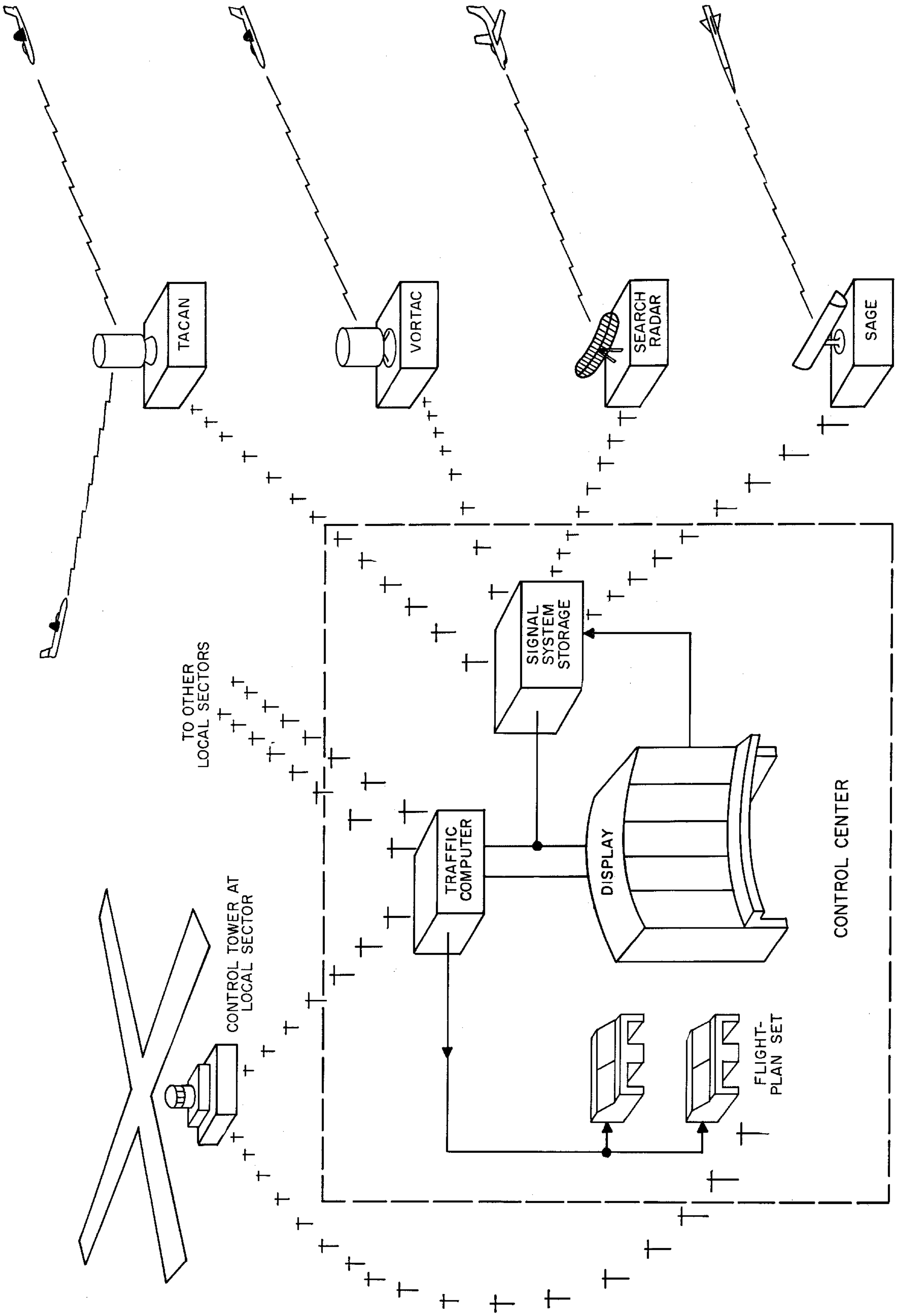

Figure 1—Pictorial diagram of traffic-control system.

the beacon receiver will get a report from that aircraft. This report will be decoded by data-link equipment and automatically transmitted in digital code over the land lines to the air-traffic-control center. The encoding and decoding techniques used in this ground equipment will be almost identical with those used in the *AN/URN-6* tacan data link. However, the over-all equipment will be much simpler due to the fact that storage is required for information on only one aircraft at a time; there is no requirement for a line finder or sequencing system to multiplex data to many aircraft or for a service-rate generating equipment since these services are accomplished at the air-traffic-control center.

Such remote coding equipment will probably be duplicated with automatic monitoring devices to switch over automatically when necessary and then indicate to the center the need for maintenance of the equipment.

8. Aircraft Equipment

Since most aircraft flying the civil airways under air-traffic-control conditions will soon be equipped with vortac, conversion to a vortac data link will be relatively simple. The amount of equipment that has to be added to the vortac receiver–transmitter is exceptionally small. Figure 2 shows an artist's conception of this unit, which will probably weigh 15 pounds (6.8 kilograms) and have a volume of approximately 500 cubic inches (8200 cubic centimeters).

This coding unit will "listen" to the tacan receiver, and when it hears its identity transmitted by the control beacon will decode the ready-made procedural data and display it to the pilot. Then it will automatically encode the report on the conditions in the aircraft for transmission to the ground. While the exact parameters to be reported can be selected only after a very-thorough operational study, it may be assumed that they will consist of tacan distance and bearing as well as barometric altitude. The only encoding equipment external to the coding box that will then be required is the addition of a small low-torque resolver to each of the three corresponding instruments in the aircraft. Special instruments are already available that contain these or similar pick-off devices.

At the present time, such a unit is being developed at Federal Telecommunication Laboratories. Several agencies concerned with the air-traffic-control problems have shown interest in this development.

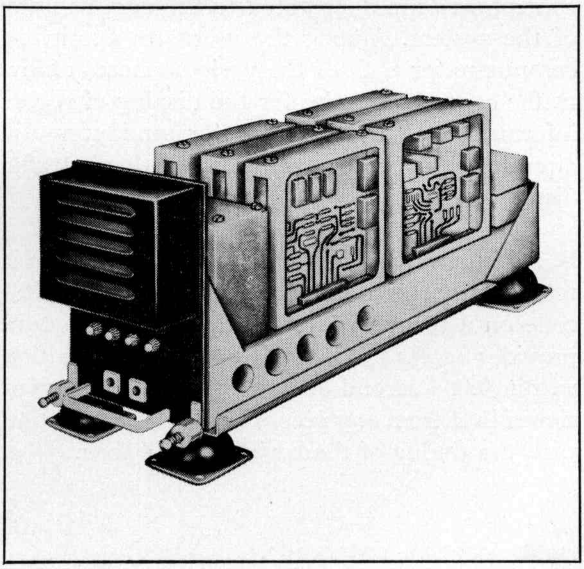

Figure 2—Artist's conception of airborne converter for vortac data link.

Operation of AN/URN-6 Data-Link Surface Equipment

By JOHN F. SULLIVAN

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FUNDAMENTALLY, the tacan data-link surface equipment is a system complementary to the basic tacan surface beacon providing computer-type data transmission, switching, and storage facilities as an adjunct to the basic avigation service. The data-link equipment functions as follows.

A. Commands transmitted to and reports received from up to 120 aircraft in the beacon control area are distributed to the various users of the system. Among the users are automatic computers for each of the various phases of air-traffic control, consoles for the display of report information to the operator for semiautomatic aircraft command generation, and air-traffic displays.

B. All information flowing through the system is temporarily stored in a common-language digital code on a magnetic storage drum. This feature provides access to all aircraft-report information within 0.004 second and relieves the users mentioned in *A* from any necessity of synchronization with the timing of the basic tacan beacon.

C. The commands transmitted to aircraft in a beacon system and messages received from them are translated between this common-language digital code and the data-link radio-frequency pulse code used for efficient multiplexing of information on the tacan channels.

D. Commands are multiplexed with the standard tacan signals and transmitted via one of the 126 *AN/URN-3* transmitting channels. In addition to commands, data-synchronizing signals are also multiplexed and transmitted, the tacan antenna rotation being controlled in precise phase relation with these synchronizing signals. The radio-frequency pulses containing the reports transmitted by the aircraft are demultiplexed from the associated tacan receiving channel.

1. Assignment Panel

Some details of how these functions are performed can be understood by reference to Figure 1, the functional block diagram of the surface system. At the left of this diagram is a box marked assignment panel, which is the point of

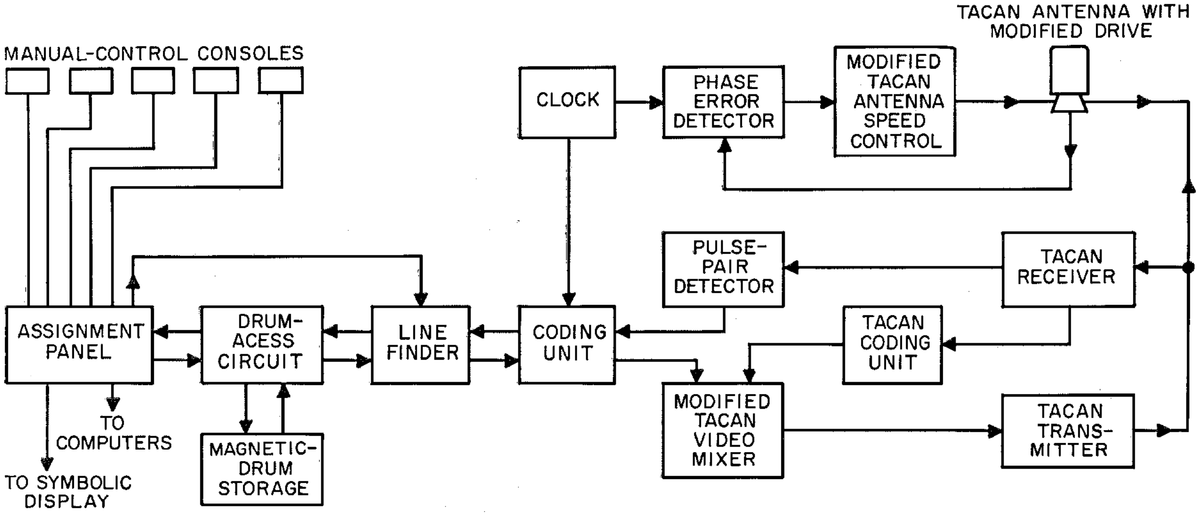


Figure 1—Functional block diagram of *AN/URN-6* surface equipment.

system access by the various users. Reports received from aircraft in the system and orders transmitted to these aircraft are routed through this unit. Figure 2 is a photograph of an assignment panel. On its sloping front are 16 sockets and 16 switches. In the rear of the unit is a junction box for the numerous connections and inside are the vacuum tubes, germanium diodes, and other components necessary for the indexing and routing of signals and the regeneration of program waveforms.

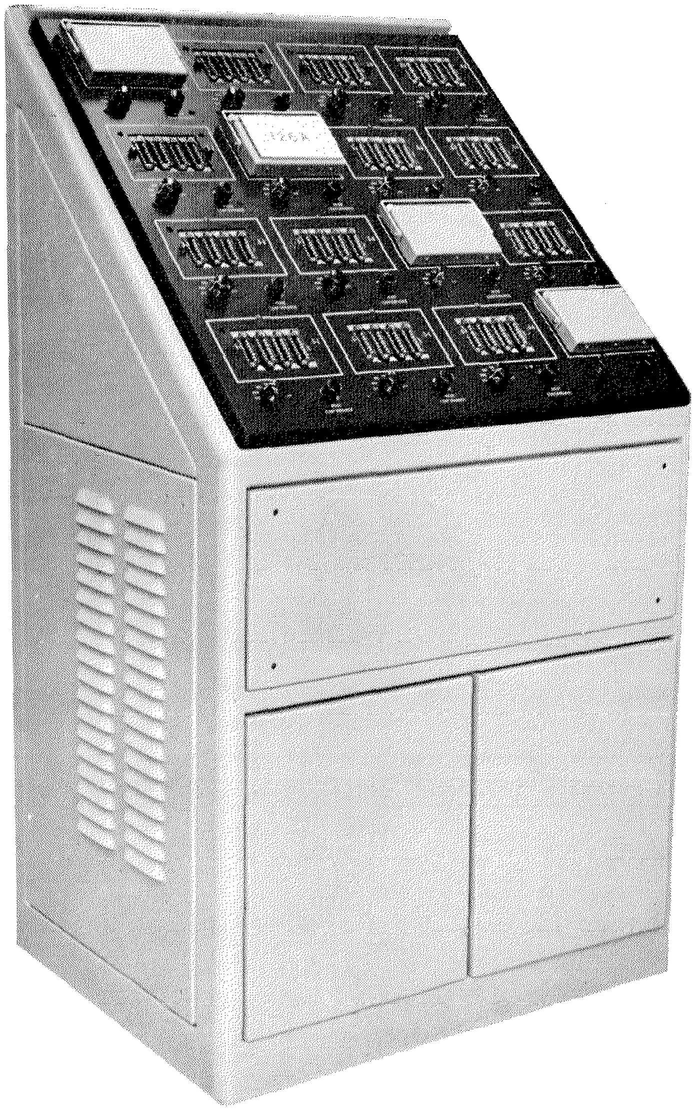


Figure 2—Assignment panel, the focal point of information flow in the surface equipment.

When it is desired to enter an aircraft into the data-link beacon system, a plug marked with the code address of the aircraft is inserted in one of the 16 sockets. By a switch next to the plug, the aircraft is assigned either to a computer appropriate to the mode of operation desired or to one of the manual control consoles represented by five boxes in Figure 1. These consoles are the mechanism for manually entering orders and for displaying reports from individual aircraft to an operator.

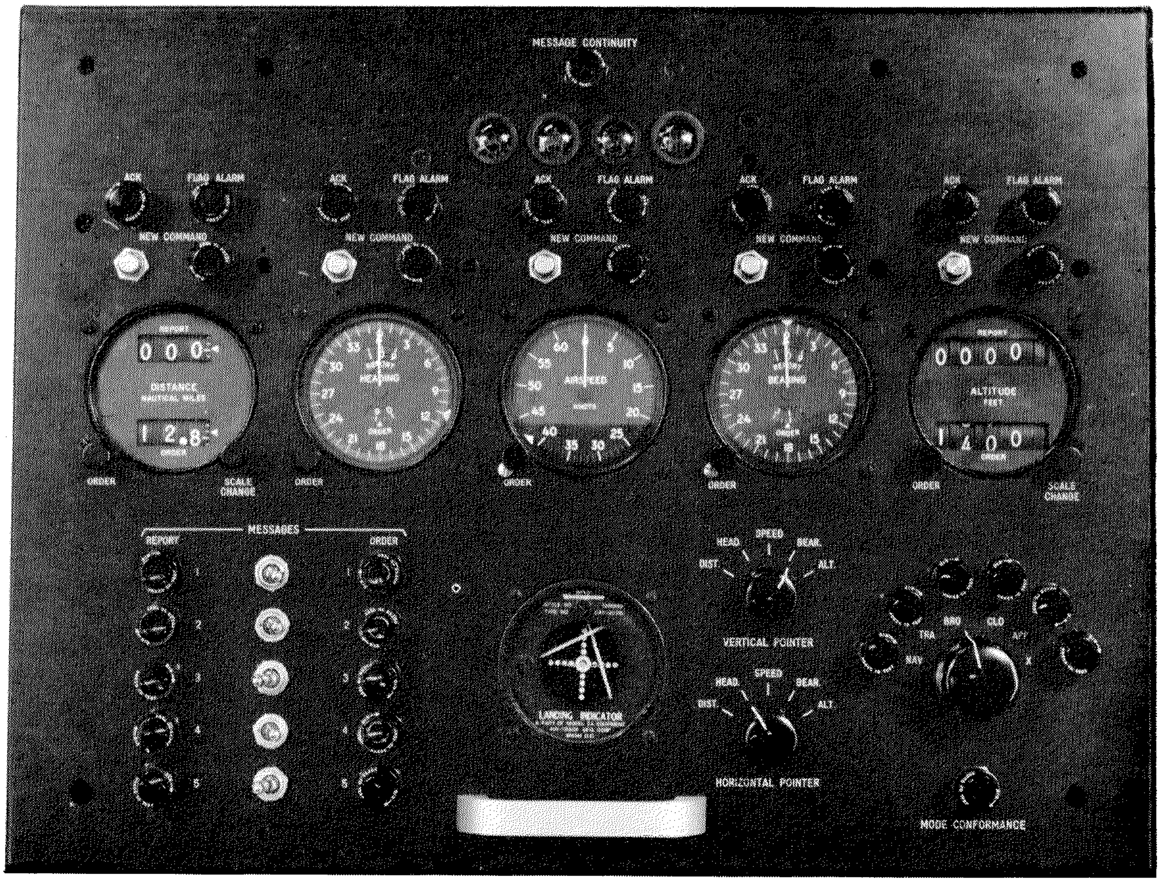
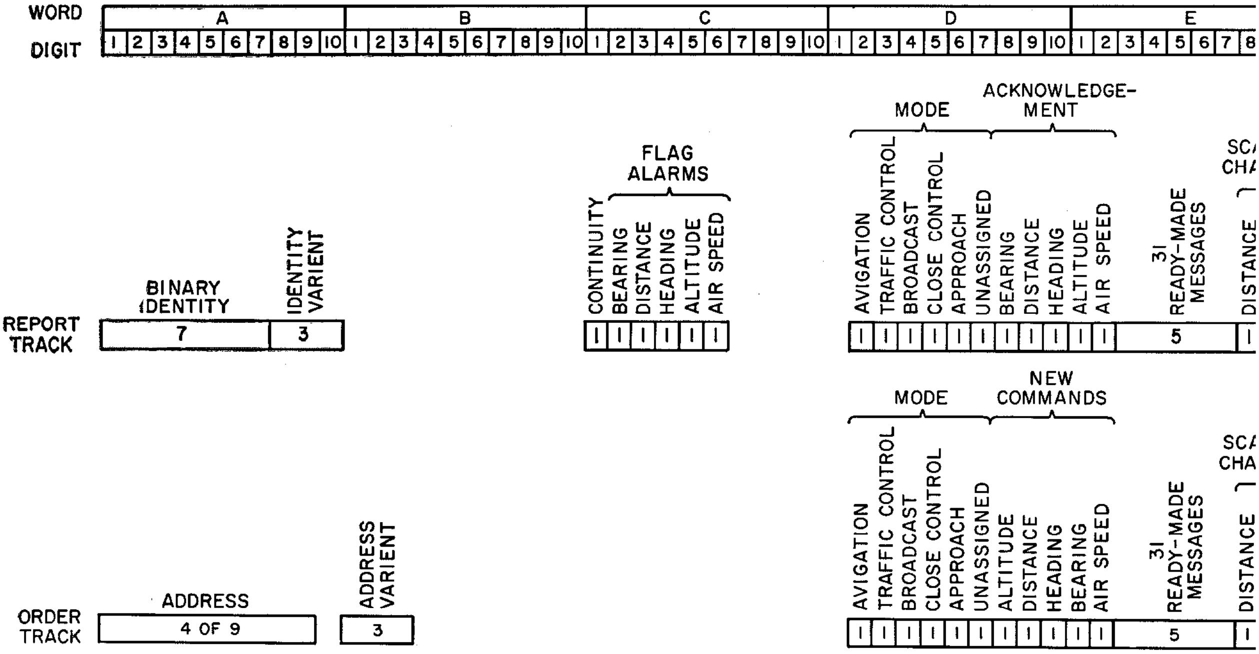


Figure 3—Control console for manual ordering of aircraft and display of aircraft reports.



2. Control Console

One of the control-console panels is shown in Figure 3. There is a MESSAGE CONTINUITY signal lamp at the top of the panel that indicates that the panel is in service, that data-link contact has been established with an aircraft, and that the displayed data are current. Immediately below this lamp are four numerical indicators that display the address of an aircraft under control.

There are five round instruments across the panel center, each of which serves a dual function. Number wheels on the DISTANCE and ALTITUDE instruments and peripheral pointers on the BEARING, AIR SPEED, and HEADING instruments indicate to the operator the orders being transmitted to the aircraft under control. A small ORDER knob on the left of each instrument is provided for changing these commands. On the DISTANCE and ALTITUDE instruments, an additional knob is provided for SCALE CHANGE by a factor of 10.

A set of number wheels on the DISTANCE and ALTITUDE instruments and the main pointers on the BEARING, HEADING, and AIR SPEED instruments indicate those values as measured in the aircraft and transmitted via the data link. A FLAG ALARM lamp above each instrument indicates that the report displayed by that instrument is current. Should the aircraft bank sharply, fly in the region near line-of-sight, or go through a deep null in the radio-frequency pattern, causing loss of the pulse carrying the information for this instrument, or if noise or interference cause ambiguous data, the instrument will continue to display the last valid data received. The FLAG ALARM indicator lamp would then show that this information was not current.

Above each instrument is also a small pushbutton that serves the following purposes. Should the operator desire to give a radical change in command to the pilot, he would enter this new command into the appropriate instrument and push the NEW COMMAND button. This information would then be instantaneously transmitted and displayed to the pilot by an indicator on his corresponding instrument. The rate of message transmission is automatically speeded up to once per second for 9 seconds and the NEW COMMAND information is transmitted until data-link acknowledgment is received from the pilot that the change order was received and understood. The two lamps adjacent to the button indicate to the operator when the new command is being transmitted and when the acknowledgment (ACK) of this new command is received.

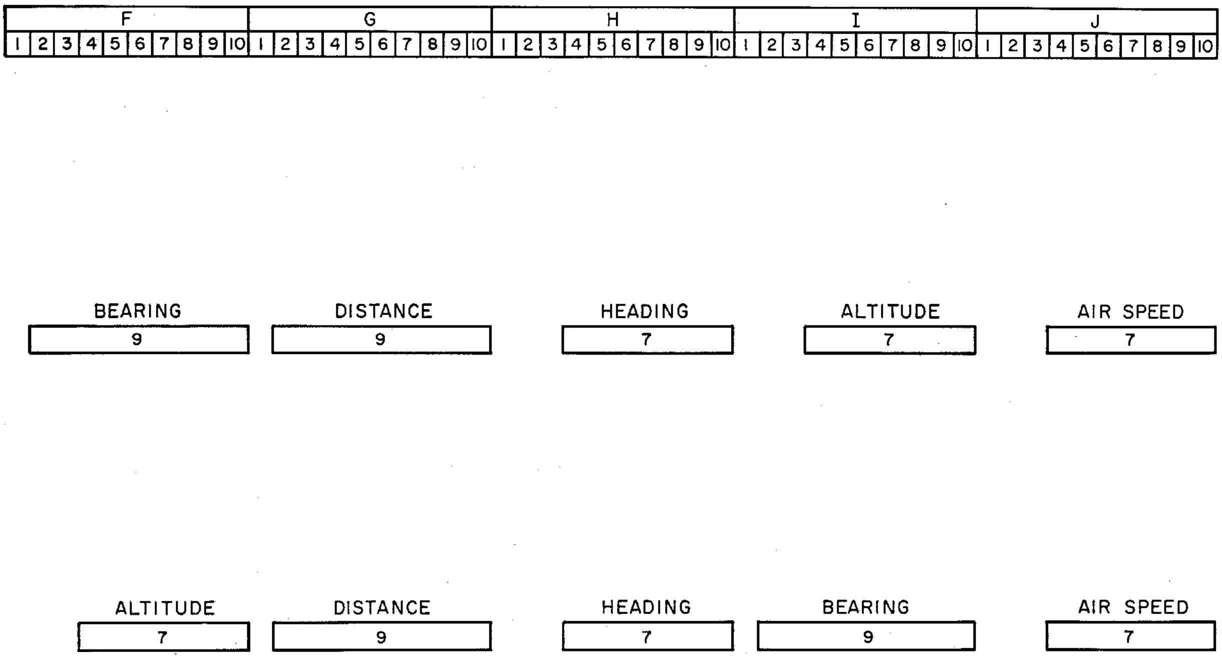


Figure 4—Binary code used in the magnetic storage drum.

The five REPORT lamps in line on the lower left corner of the console indicate the five binary bits designating any one of the 31 ready-made messages that may be sent from the aircraft. Immediately to the right are five switches that in various combinations convey the 31 surface-to-air ready-made messages and five ORDER lamps to indicate the message being transmitted.

A cross pointer instrument is provided to display to the operator on each needle the difference between the order and the report function of any of the five central instruments by means of the two switches just to the right of the cross pointer.

On the lower right corner of the panel is a switch that selects the message transmission rate together with the mode of operation. Round-trip message continuity is indicated by the MODE CONFORMANCE lamp immediately below this switch. This indicates to the operator that the mode selected by him is being displayed to the pilot.

3. Magnetic Storage Drum

Code wheels mounted on the control-console meters and contacts on the appropriate switches convert the information of these mechanical motions into a series of electric pulses by electronic switching of the programing waveforms. These pulses are routed to the assignment board where they are multiplexed with similar pulse trains from the other consoles and computers and stored in the order section of the magnetic storage drum.

Similarly, the sequence of pulses containing reports from an aircraft is stored in the report section of the magnetic drum by the coding equipment and is routed to the appropriate console by the assignment panel. From the configuration of these pulses and programing waveforms, the meaning is displayed on the lamps and meters.

Figure 4 shows a timing diagram of these pulse trains and the meanings assigned to the presence or absence of pulses during specific intervals. That portion of the data conveying the command and the reported distance, bearing, air speed, heading, and altitude (the telemetered data) are converted into binary code as a percentage of full scale. As shown in Figure 4, the storage time required for an order to one aircraft or a report from it is 800 microseconds. This time is divided into 100 intervals of 8 microseconds each. To manipulate and sort these data, the following programing waveforms are available: Clock pulses at the start (shift pulses) and at the center (digit pulses) of each of the intervals; 10 sequential voltage waveforms one interval in width (bit gates); waveforms encompassing 10 groups of 10 consecutive intervals (word gates); the full 100 intervals (aircraft gates); and special programing trains to select portions of the data.

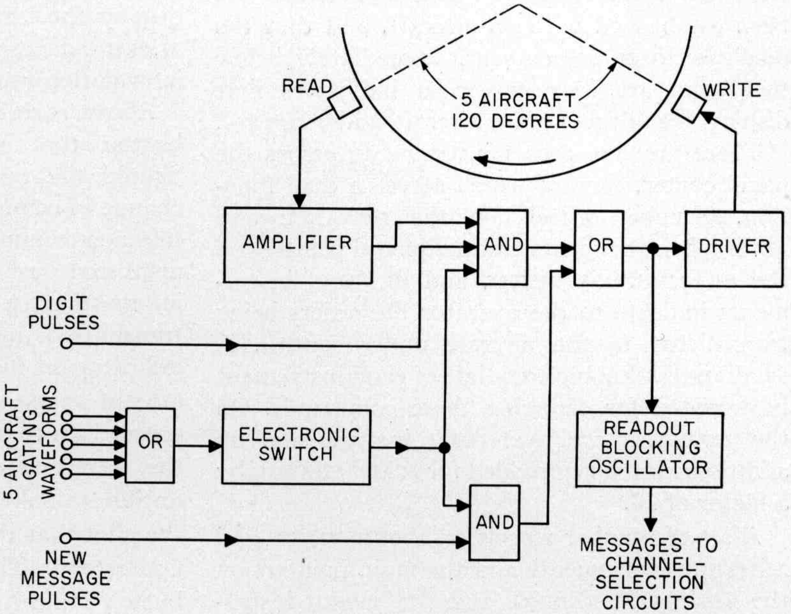


Figure 5—Recirculating drum loop.

The data are stored in groups of five aircraft channels in recirculating loops on the magnetic storage drum in the following manner: The series of pulses conveying the information is entered into the aircraft-gating-waveform input line of Figure 5, the electronic switch being in the position to pass these pulses to the write (input) head on the drum. Through the write head, the electric pulse changes the magnetic flux density on the coating of the drum from negative saturation, caused by passing the erase magnet, to positive saturation. When the last pulse of information in this aircraft channel is written, the electronic switch operates either to connect the next of the five aircraft channels or, if no new information for that channel is to be written on the drum, the information already on the drum for that channel is rewritten. This rewriting continues until such time as the electronic switch is thrown and new information inserted. The timing is such that immediately following the last of the five channels the magnetic disturbance from the first pulse of the first channel passing under the read (output) head produces a voltage that is gated by the clock to rewrite this first pulse. The stored information on any aircraft is available at the output within a maximum of 4000 microseconds, this being the time required for a cycle of information on five aircraft. Since the clock and programing waveforms are derived from a series of magnetic disturbances on the drum surface, the synchronism necessary for proper recirculation is not affected by minor variations of drum rotational speed. A detailed analysis of this input–output section of the *AN/URN-6* is available in a companion[1] paper.

4. *Information Flow*

The various users of the system have access to the drum inputs and outputs through the assignment panel at times indicated by the drum code. An entirely distinct and nonsynchronous timing system is required for multiplexing on the data-link channels.

Figure 6 shows the output of an *AN/ARN-21* airborne receiver tuned to a tacan channel providing data-link service. This pattern occurs 15 times per second due to the rotation of the tacan antenna. The lines dividing the pattern into 9 parts mark the transmission of reference bursts utilized for the vernier asimuth measurement. The high energy density in these pulse bursts is used in the data service as a noise protection for the synchronizing start pulses that are transmitted immediately following these bursts. Very-high harmonics of this basic 15-cycle-per-second timing pattern are required to generate the sequencing patterns required for construction of the data-link message. Since these are next to impossible to generate with known phase by multiplication of the rotational frequency of the antenna, a 15-cycle pulse is derived by dividing the output of a 1.35-megacycle oscillator by 90 000; the rotation of the antenna is so controlled that the 15-cycle "north" pulse generated by a magnetic slug on the antenna passing through a fixed pulser coil is locked in phase with the pulse derived from the clock. This function is indicated in Figure 1 by the coupling between the clock and the antenna and requires some modification of the antenna drive for speed control and phase locking. The basic justification for the antenna modification is the simplicity accruing from the decoding of telemetered data in the airborne equipment by utilizing as a time reference a continuous-wave 20th-harmonic oscillator phase-locked with the synchronizing start bursts.

Referring again to the airborne-receiver output of Figure 6, darkened areas following every third reference burst (45 times per second) will be noted. These indicate the times when the surface-to-air data-link messages of Figure 7 are transmitted. (When the system is operated at less then full capacity, a message will not follow every third reference burst.)

The information in the transmitted message is carried in one of two ways. The first part (discrete data) is conveyed by the presence or absence of pulses in 33 fixed time intervals after the start pulses. Those parts of the message having an on–off character (the address, ready-made messages, new commands, and scale changes) are conveyed in this manner. Those parts that change in a continuous manner (the telemetered data) are transmitted in a pulse-time code using the position of only one pulse in a time slot for each of the telemetered functions (bearing, distance, air speed, altitude, and heading). This code selection permits the design of simple and compact decoding and noise-protection devices in the airborne gear.

Since the data-link pulses are modulated by

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[1] G. W. Reich, Jr. and H. J. Mills, "Input and Output Facilities of Data-Link Surface Equipment," *Electrical Communication*, volume 34, pages 209–218; September, 1957.

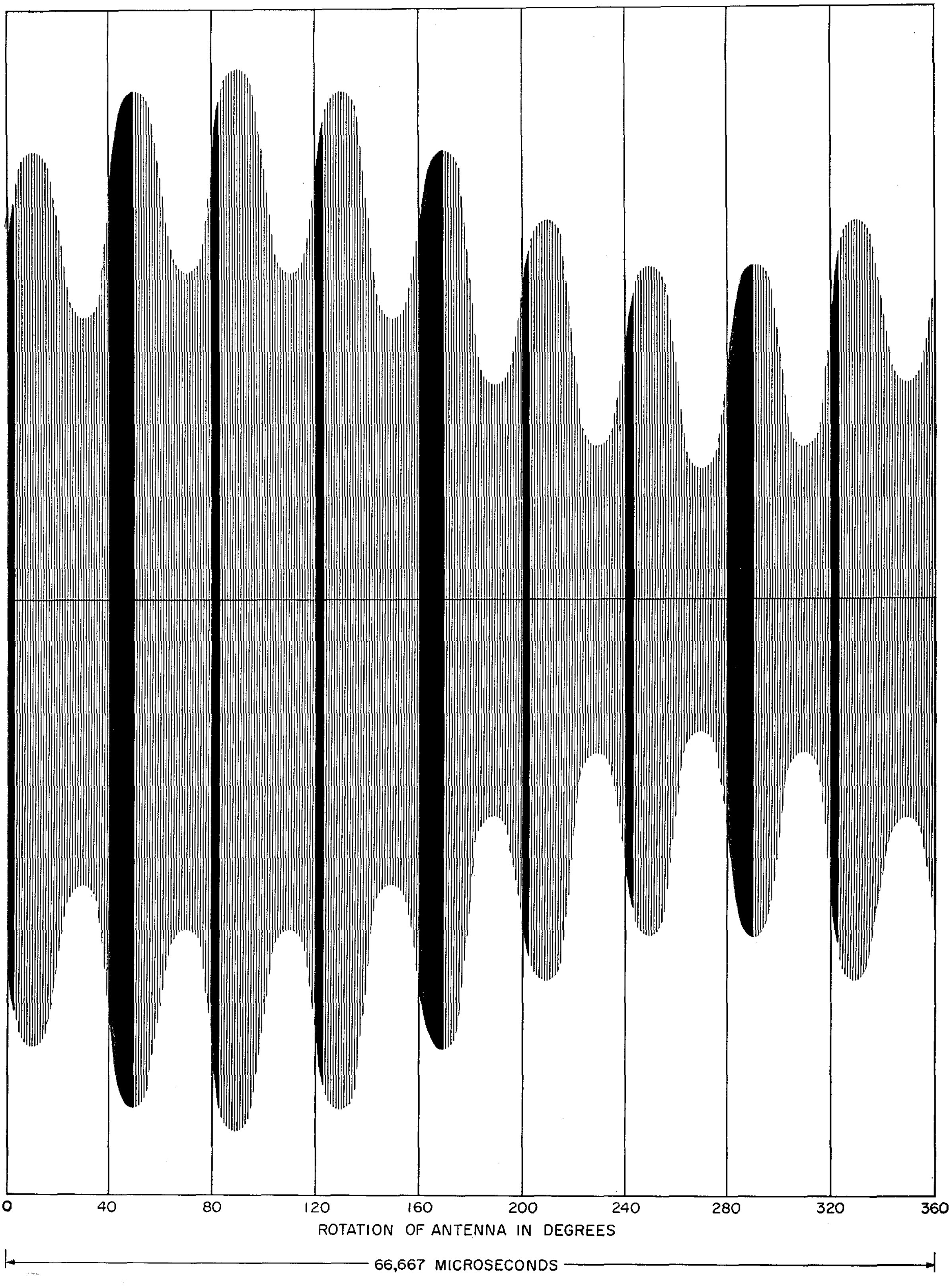

Figure 6—Modulation pattern received by a data-link airborne set during one rotation of the tacan antenna.

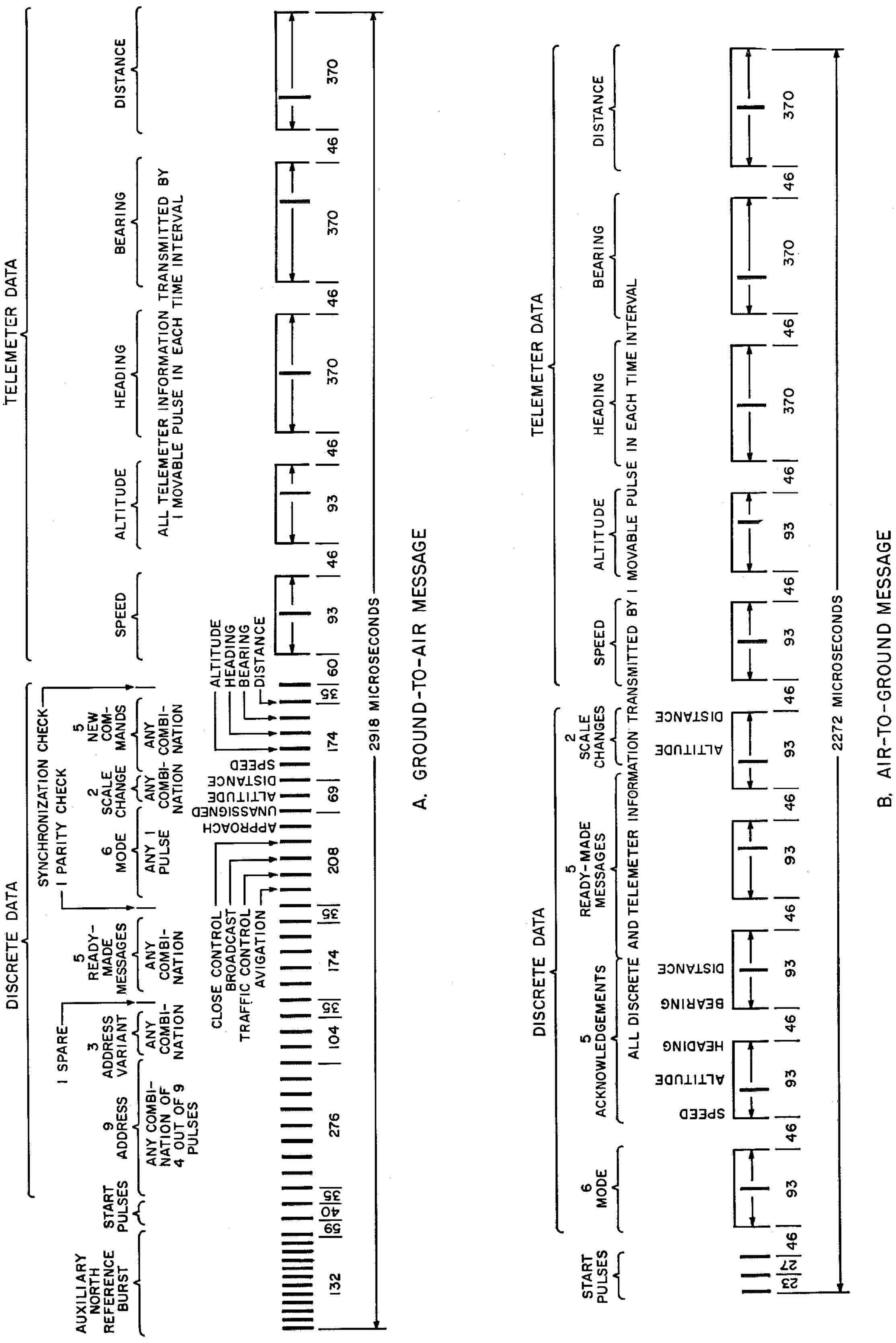

Figure 7—Data-link radio-frequency codes. Rounded figures are given for the time intervals.

the parasitic elements on the tacan antenna in exactly the same way as the normal surface-transmitter pulse replies to distance-measuring interrogations and filler pulses, no deterioration of tacan bearing service is involved. Since the transmitted data pulses occupy only 13 percent of the time normally allocated to distance-measuring replies, only a slight reduction in beacon ranging service is involved.

The basic programing cycles of the surface coding equipment are determined by the following transmission cycle. During the period between reference burst transmissions, the particular aircraft to which the next data-link message is to be transmitted is determined by an automatic electronic line finder with a random access. Location of the information in the drum storage by drum track and aircraft-channel position in that track is determined and this information is entered in the appropriate registers by the drum-code programing waveforms and germanium-diode gating techniques.

The information stored in the registers is next put in the radio-frequency code and the resulting pulse train is applied to the *AN/URN-3* pulse modulator, being transmitted immediately following the reference burst. A blanking signal interrupts ranging replies and filler pulses during the 2918 microseconds required for the command data transmission.

The transmission of command data requires approximately one-third of the period between two reference bursts.

At the end of the transmission, the registers are cleared and after a variable delay *dependent on the round-trip transmission* time corresponding to the distance from the beacon to the addressed aircraft, the reply from the aircraft is received. The data-link reply is distinguished from the 12-microsecond-spaced pulse-pair ranging interrogations by use of an 18-microsecond pulse-pair spacing for the message. The information in each part of the reply is conveyed by the position of a single pair in a predetermined time interval following a start-pulse group.

The report data are decoded from pulse pairs to single pulses and routed to the appropriate registers by timing waveforms generated by a start–stop clock gated by the receipt of the air-to-ground start pulse. The registers translate the information from the data-link radio-frequency code to the common-language digital drum code.

During the next period (the write period) the data are transferred from the decoding registers to the magnetic storage drum, becoming available to the users of the system.

This completes the cycle for the message to and reply from an aircraft. The rate at which new messages are transmitted to an individual aircraft and fresh reports are available is at the discretion of the controller handling that particular aircraft.

5. *Automatic Monitor*

Some features that have proved useful in the maintenance of the equipment have been the provision of an automatic monitor, indicating lamps mounted on the bistable circuits, and means for manually raising and lowering the supply voltages to facilitate preventive maintainance.

The automatic monitor operates as follows. During normal operation, the line finder is automatically stopped every 6 seconds in a position for monitoring. A prearranged message recorded in the drum is then routed through the encoding equipment and translated from the drum code to the radio-frequency code. The resulting pulse train is then compared with a nominally identical pulse train generated from the clock. If every pulse is present and no spurious pulses are introduced, a green lamp marked GROUND TO AIR lights. Immediately thereafter, a simulated radio-frequency reply is generated from the clock and applied to the decoding circuits. The results of this decoding are compared with a known message stored in the drum code. Again, if all pulses are present and there are no spurious pulses, a green lamp marked AIR TO GROUND lights. From the aspect of these lights, the operator can detect the majority of equipment malfunctions.

Should malfunction occur, a manually operated switch stops the line finder in the monitor position, thereby circulating the prearranged message through the equipment. This lights the indicator lamps throughout the circuits in a known configuration depending on the fault. Examination of these lamps and the waveforms at various testing points aids maintenance personnel in locating the faulty component.

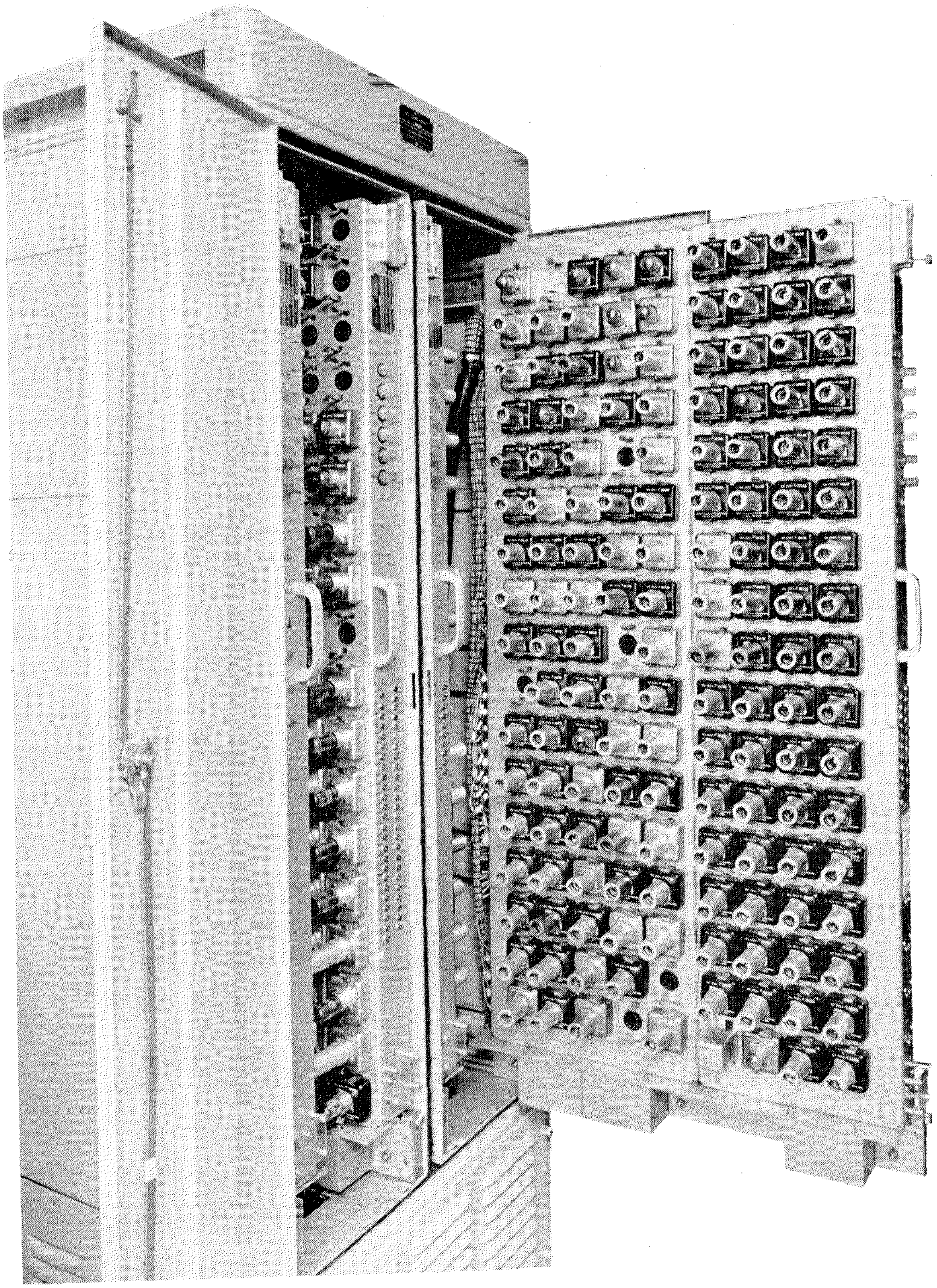

Figure 8—Cabinet showing plug-in units.

6. Constructional Features

The circuits required for the coding of the data are contained in two large cabinets. A smaller cabinet contains the magnetic drum. These units have been termed the common equipment since the data for all aircraft flow through them.

Figure 8 illustrates some of the constructional features of this common equipment. The circuits employed are digital in nature, using vacuum tubes as the active elements and germanium diodes for switching. The vacuum tubes are used largely in connection with six circuits (high- and medium-speed bistable multivibrators, high- and medium-speed blocking oscillators, and high- and medium-power cathode-followers). The components of these units together with a tube socket and shield base are assembled into packages that plug into sockets on vertical sliding panels as shown in the illustration. Access to the connections between the basic packages is from the back of the panel. When the panels are pushed in, the tubes on two adjacent panels are interleaved in a chimney provided with a blower at the bottom and a vent at the top of the cabinet. This results in an efficient transfer of heat to the cooling air and, together with the use of blackened tube shields and inserts, results in a relatively cool equipment with a minimum of hot-spots.

Some of the pertinent data on the equipment are shown in Table 1. This relatively large and complex machine (1149 tubes and 4818 diodes) has been packaged in a form suitable for military applications; ease of maintainance was a prime design criterion. The system is now undergoing evaluation at the Naval Air Station at Patuxent, Maryland. The preliminary results of these tests indicate that this equipment, together with its companion *AN/ARN-26* airborne unit, will provide a very-useful tool for coded aircraft-to-surface intercommunication at a time when the need for such a tool is urgent due to our ever-increasing air traffic and the frequent overloading of vocal-link systems. It can be used with automatic computers handling vast amounts of data in coded form at high rates.

TABLE 1

SURFACE EQUIPMENT CHARACTERISTICS

Name of Unit	Volume in Cubic Feet	Weight in Pounds	Power Dissipation in Kilowatts	Number of Tubes	Number of Semiconductor Diodes
Modified Tacan Surface Equipment					
Receiver–Transmitter Group	34	1173	5.4	95	5
Power-Supply, Test-Set Group	34	1051	2.9	41	—
Antenna Group	266	752	7.0	—	—
Antenna Control System	16	733	1.5	—	—
Subtotal	350	3709	16.8	136	5
Data-Link Equipment					
Data-Coding Group	34	830	3.3	452	2029
Data-Control Group	34	1085	4.6	220	396
Data-Storage Cabinet	21	310	0.25	66	28
Assignment Panel	19	565	1.0	95	480
Control Consoles	70	1465	4.0	180	1880
Subtotal	178	4255	13.15	1013	4813
Total	528	7964	29.95	1149	4818

Input and Output Facilities of Data-Link Surface Equipment

By GEORGE W. REICH, JR. and HAROLD J. MILLS

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FACILITIES for input to and output from the tacan data-link surface equipment are designed to provide simultaneous data-link service to a group of special-purpose computers. An air-traffic-control center using the data link with computers handling such functions as marshaling, approach, and landing of aircraft is typical of the integrated system made possible by the extremely flexible data-link input and output systems.

Since each computer using the data-link service will have a specific function, the computer code structures will inherently be incompatible. The data link must, therefore, provide a common input–output code structure that can be made compatible with the computer codes. A study of this problem initiated at the beginning of the data-link program resulted in the selection of a digital binary code structure to provide this required flexibility. This code, with translation and sequencing, makes any computer compatible with the data link.

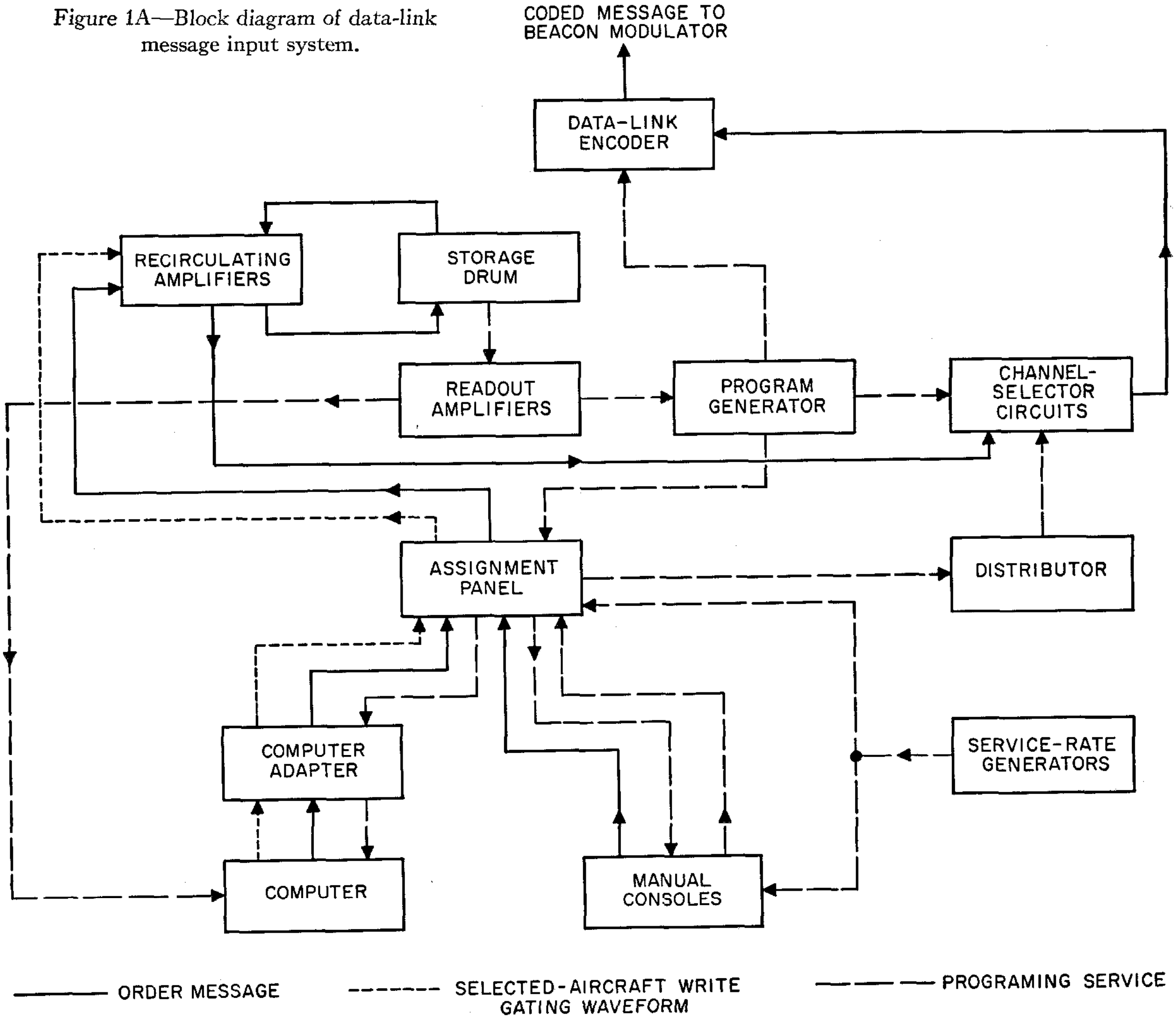
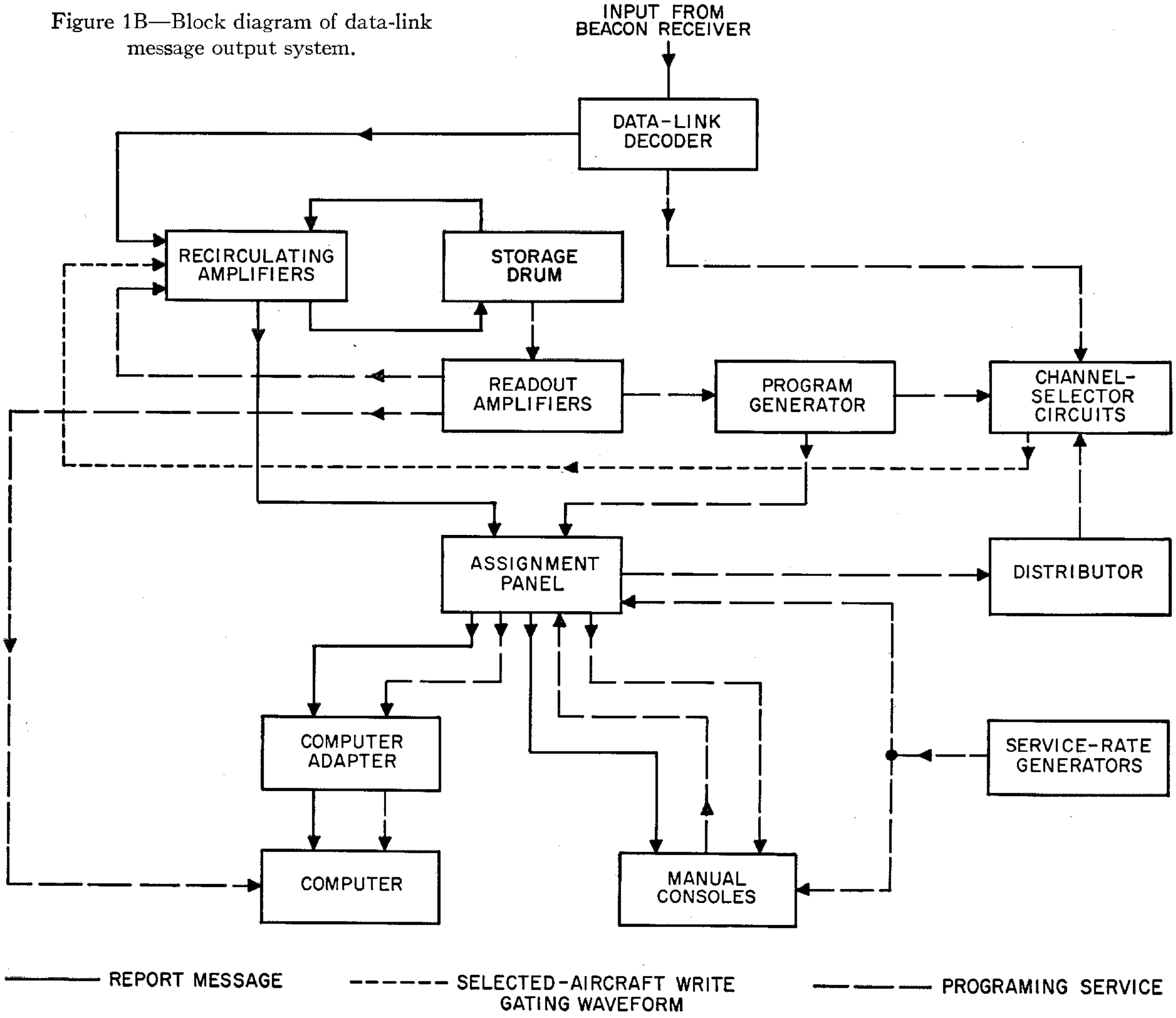


Figure 1A—Block diagram of data-link message input system.

1. General

A block diagram of the data-link input and output systems appears in Figure 1. A digital code structure is used in this portion of the surface equipment; translation between the analog radio-frequency code and this digital code is accomplished by the data-link encoder and decoder. The input–output system consists of a conventional magnetic storage drum system, a distributor, channel-selection circuits, and an adapter unit that provides any operations necessary for computer compatability. System control is centralized in the assignment panel where provisions are made for manually entering the addresses of aircraft to be controlled by an operator. In the present equipment, the assignment panel and storage drum can handle 15 aircraft simultaneously. The program generator, distributor, and channel-selection circuits are open-ended so that additional capacity can be added; provisions have been made for addition to these units when a full 120-aircraft system is desired. Besides entering the address of an aircraft, the assignment panel permits selection of either manual or computer control for an aircraft, establishes its service rate on automatic control, and enters the address of the aircraft into the distributor for service. Once so entered into the system, orders to an aircraft are continually dispatched either from the manual consoles or the computers. The orders are stored in recirculating memory loops in the storage-drum unit. The service rate for each aircraft entered in the distributor is determined by the channel-selection circuits that are described in

Figure 1B—Block diagram of data-link message output system.



detail below. As each aircraft is designated for service in the roll call of the channel selector, its orders are extracted from the drum, sent to the encoders, and then to the beacon for transmission to the aircraft. Replies to this transmission are received shortly thereafter, decoded, and entered into the report section of the storage drum. The complete two-way transmission takes place during each service period allotted to an aircraft by the channel selector. The report sections of the storage drum are continually read and channeled by the assignment unit to the proper console display or computer input.

2. *Storage System*

The magnetic storage drum is a Kollsman Instrument Corporation digital recording drum, type *1996*. The drum is 9.5 inches (24 centimeters) in diameter, has a speed of 3600 revolutions per minute, and a storage capacity of 60 000 bits. The magnetic recording heads used with the drum are Kollsman type *1996-91023*. With a spacing between head and drum of 0.001 inch (0.025 millimeter), the writing or input heads require a 280-milliampere 1-microsecond pulse for optimum writing. The read or output head produces 60 millivolts across 180 ohms. A diagram of the drum showing the positioning of the heads appears in Figure 2. The two lower tracks contain order and report storage loops; both tracks being evenly divided into three loops, each loop containing reading, erasing, and writing heads. All remaining tracks are for permanently recorded monitor messages and service pulses. The clock track consists of 2100 evenly spaced pulses recorded on the drum surface. At the surface speed used, this track provides two 126-kilocycle-per-second clocks; one shift clock generating program gating waveforms and a digit clock, phased 180 degrees from the shift clock. A chart showing the outputs of these permanently recorded tracks together with the program derived from the shift clock appears in Figure 3.

It is necessary to lock the program generator outputs to the mechanical position of the drum for coherent readout of the permanent drum messages: A particular word and a bit gating

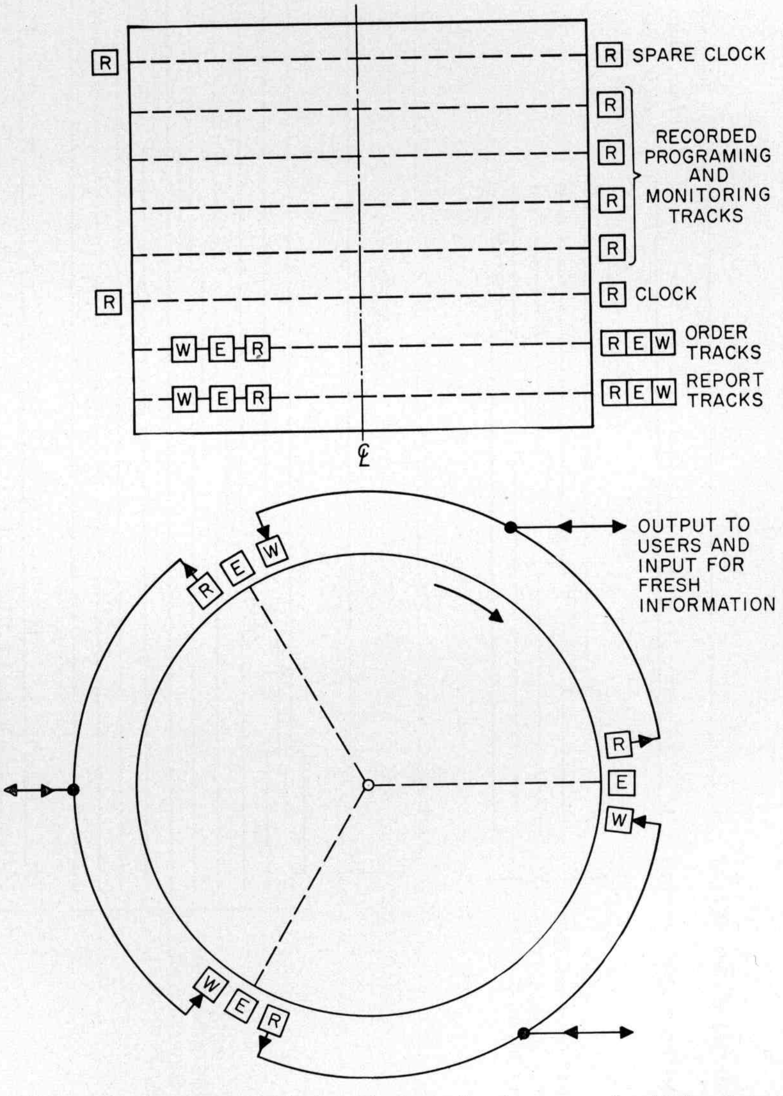


Figure 2—Arrangement of magnetic drum. Read, erase, and write heads are shown as *R*, *E*, and *W*, respectively. The recorded tracks for programing and monitoring are written continuously around the drum, being read by one head for each track. The clock tracks are read by one head for shift pulses and a 180-degree head for digit pulses. The order and report tracks are recirculated in 3 loops of 5 aircraft each, or 15 aircraft per track, by means of 9 heads arranged as at the bottom.

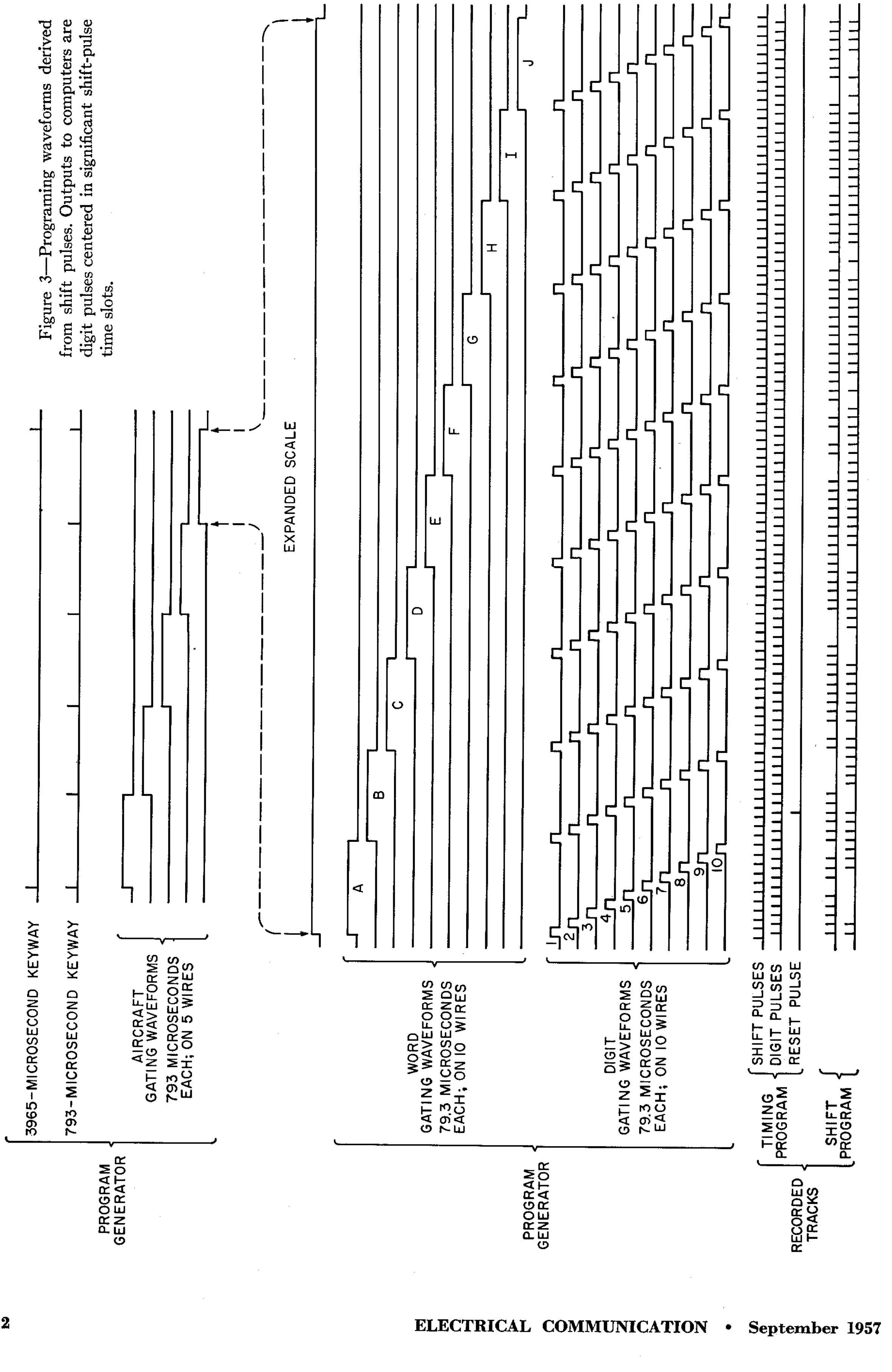


Figure 3—Programing waveforms derived from shift pulses. Outputs to computers are digit pulses centered in significant shift-pulse time slots.

waveform in the program is locked to the mechanical position of the reset pulse on the drum.

The programing gates are established by three ring counters. The first ring counts by 10 directly from the shift clock and yields the bit gating program. The second ring counts by 10 from the first to generate the word waveforms, and the third ring counts by 5 from the word ring to generate the aircraft gates. Low-impedance outputs of both polarities are available from the aircraft ring. The specifications for standard positive-going outputs and a discussion of the circuits are given in a companion[1] paper.

Two sets of keyway pulses are available from the program generator, the first being a 793-microsecond keyway indicating the beginning of each aircraft gate and the second a 3965-microsecond keyway indicating a complete cycle of the program generator. These outputs, together with the digit and shift clocks, are available to computers for entering and extracting data-link information. In addition, all programing waveforms can be regenerated in the computer adapter for the sequencing and code-translating functions of the adapter and to give the computers access to the entire program. Where a shift-register type of intermediate storage is used in the computer as a buffer between computer synchronization and that of the data-link storage system, the appropriate shift program is recorded in the storage drum and readouts are provided from this track directly to the computers. A typical shift program recorded on the drum is shown in Figure 3.

The standard drum storage code is shown in Figure 4. The meaning of the discrete-data bits and the telemetered portions of the code are flexible and can be changed where appropriate transducers are provided in the aircraft equipment. The standard code structures for orders and reports are as follows.

The first word of an aircraft report contains identity and identity-variant information. Bits *1–7* are for a binary identity code and bits *8–10* for a binary identity-variant code. The least-significant digit is first in both codes. In word *C*, bit *1* contains message-continuity information to indicate whether or not the message following is stale. In word *C*, bits *2–6* contain flag-alarm information pertaining to the telemetered bearing, distance, heading, altitude, and speed data. In word *D*, bits *2–7* contain information regarding the reported mode of operation for the particular aircraft. In word *D*, bits *8–10* and word *E*, bits *1–2* contain acknowledgment information. In word *E*, bits *3–7* are a 5-digit binary code containing 31 ready-made messages while bits *8–9* contain scale-change information for distance and altitude, respectively. All bits in words *A* to *E* not included above are always zeros. Word *F* contains 9-bit telemetered bearing information. Bit *1* is always a zero. Bit *2* is the least-significant digit, bit *10* the most-significant digit. Word *G* contains telemeter distance data in the same arrangement as word *F*. Word *H* contains 7-bit telemeter heading information. Bits *1* to *3* are always zero. Bit *4* is the least-significant digit, bit *10* the most-significant digit. Word *I* contains 7-bit telemeter altitude information in the same arrangement as word *H*. Word *J* contains 7-bit telemeter air-speed information in the same arrangement as word *H*.

The order message from a computer is timed to coincide with words and bits as follows: In word *A*, bits *1–9* contain an identity code consisting of 4 pulses positioned in 9 slots. Bit *10* is not used. In word *B*, bits *1–3* are the binary-code address variant. In word *B*, bits *4–10* and all bits in word *C* are zeros. Bits *2–7* in word *D* are mode information. Bits *8–10* and bits *1* and *2* in word *E* contain new-command information for altitude, distance, heading, bearing, and speed. In word *E*, bits *3–7* contain ready-made messages. Bits *8* and *9* contain distance and altitude scale-change information, respectively. In word *F*, bits *1–3* are always zero. Bit *4* is the least-significant digit and bit *10* the most-significant digit of 7-bit telemeter altitude information. Word *G* contains 9-bit distance information with bit *2* the least-significant digit. In word *H*, bits *1–3* are always zero; bit *4* is the least-significant digit and bit *10* the most-significant digit of 7-bit telemeter heading data. Word *I* contains bearing information in the same form as word *G*. Word *J* contains speed information in the same form as word *H*.

For telemeter data, the binary numbers stored in the drum express the measured datum as a fraction of the full-scale value. A full-scale range

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[1] H. J. Mills and F. L. Van Steen, "Standardization of Circuits for Data-Link Surface Equipment," *Electrical Communication*, volume 34, pages 219–227; September, 1957.

of 512 levels is used for distance and bearing and a full-scale range of 128 levels is available for heading, altitude, and speed. For bearing, 9 bits are used, and 180 degrees will be represented by a binary count of 256. For altitude, 7 bits are used for both scales: On a 0–5000-foot (1525-meter) scale, 2500 feet (763 meters) would be represented by a binary count of 64; on the 0–50 000-foot (15 250-meter) scale, a binary count of 64 would indicate 25 000 feet (7630 meters).

3. Entering and Extracting Storage Data

Fresh order information for all aircraft under manual control in a data-link beacon system is sent to the storage drum on each complete cycle of the aircraft-gating-waveform ring in the program generator. When its address plug is placed in the assignment panel, each aircraft in the system is automatically assigned one of the 5 program-generator aircraft gates and its orders and messages are channeled to one of the 3 storage loops on the drum. Therefore, as each aircraft gate is sequentially generated in the program generator, order information is simultaneously applied to each of the 3 order-track storage loops. A block diagram of the circuits involved in entering the data on the drum is shown in Figure 5. The new-message pulses are multiplexed from the consoles through the assignment panel to the new-message inputs of the proper recirculating amplifier. To break the recirculation loop and replace the old message on the drum, the proper aircraft gate must simultaneously be applied from the assignment unit to the electronic-switch input. This switch then breaks the storage loop and allows the new message to enter the drum in place of the old information. The length of the drum path between the write and read heads is exactly one complete cycle of the program generator. Thus, as each message recorded on the drum reaches the read head, its associated aircraft gate is supplied by the program generator and a new message enters the loop at the writing head. It follows that the access time of data for the encoders is 5 aircraft gates or 3965 microseconds and the messages are available from either the drum readout or directly from the consoles at this rate. Thus, under manual control, the order-storage section serves no useful purpose. This is not the case where the aircraft is under automatic control by a computer and the message rate to the drum may be much lower than that from the

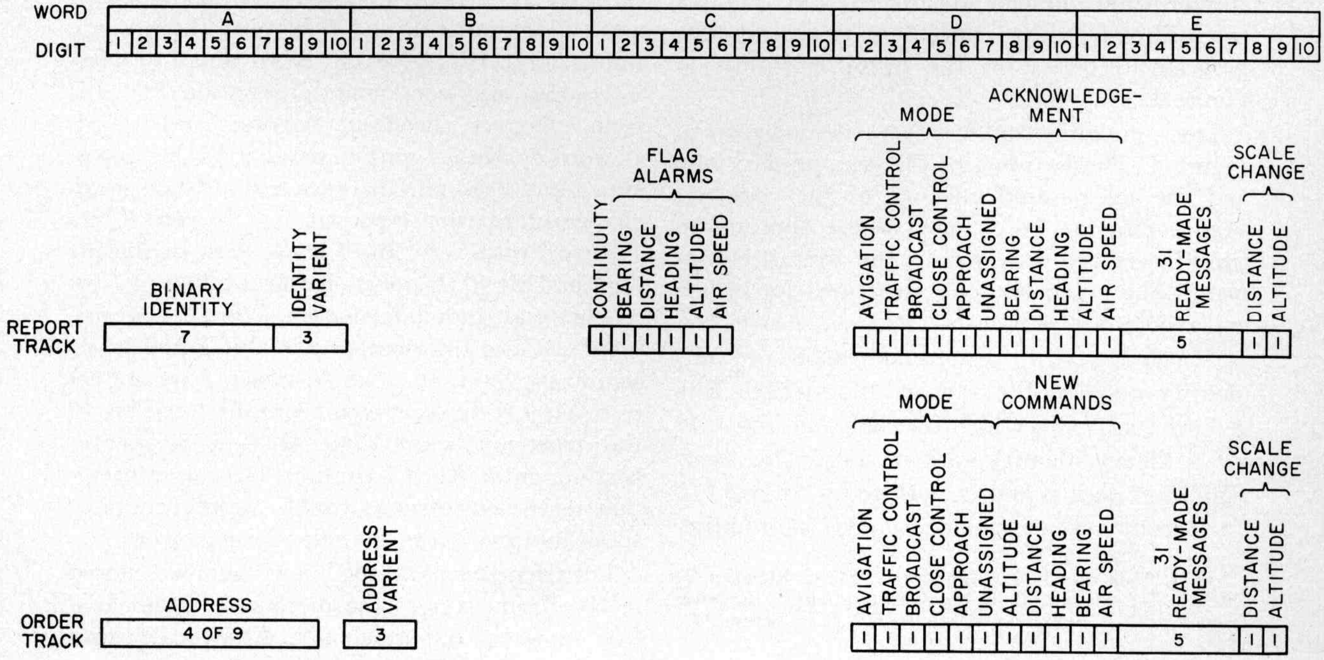

Figure 4—Code structure for drum storage. In words *A* and *F–J*, the least-significant digit is recorded first. The numbers in the boxes indicate the number of bits required for storage of the particular information.

consoles. The order-storage section of the drum then serves as a high-capacity permanent storage for computer outputs. It should be noted that in this case, the aircraft-gate line associated with each aircraft under computer control is made available to the computers so that they can select and channel to the proper recirculating loop only those gating waveforms that occur simultaneously with the new-message outputs from the computer.

The report-storage loops of the drum are essentially the same as the order loops, the only difference being that report messages from the decoders are in the form of gates and must be gated against the digit clock to re-establish their timing before use as new-message inputs to the recirculating amplifiers. When the report message is racked up in the decoder and is ready for transfer to the drum, a circuit is activated by the decoder to regenerate the first complete aircraft gate following this rack-up pulse. This single waveform is then routed by the channel-selection circuits to the proper report-recirculating amplifier where it activates the electronic switch, allowing the new message being sequenced from the decoder to enter the storage system. The report message once entered in the storage

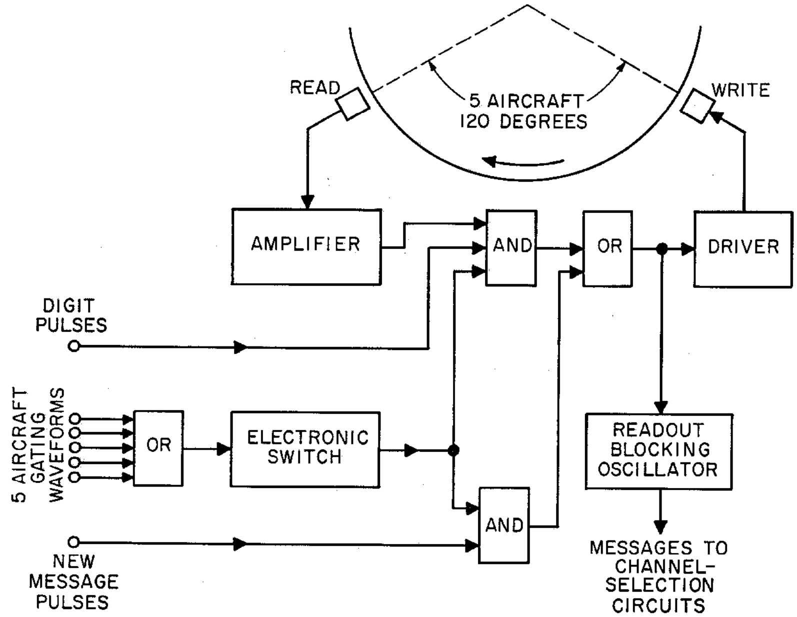

Figure 5—Storage drum recirculating loop and method of entering new information.

F										G																				I										J									
1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10

BEARING	DISTANCE	HEADING	ALTITUDE	AIR SPEED
9	9	7	7	7

ALTITUDE	DISTANCE	HEADING	BEARING	AIR SPEED
7	9	7	9	7

system is continually available to the manual consoles or the computers once each cycle of the program generator (3965 microseconds). The readouts from the three report-recirculating loops in the storage system are sent to the assignment board where they are separated and channeled to the proper computer or manual control console.

The reliability of these report messages to the computers is indicated by the flag-alarm bits in the word *C* of the drum-code structure. When any portion of a report message is unreliable as determined by the decoder, it is omitted and the previous information is allowed to remain on the drum; a flag-alarm bit is inserted in the code by the decoder indicating that the datum is stale. This stale information is available to the computers and consoles or it may be gated out of the report message, if desired.

4. Distribution

Provision is made internally by the service-rate generators of Figure 1 for 6 service rates to enable a computer or display console to send orders and receive reports from aircraft under their control. The rates are generated by 6 free-running multivibrators and are available on 6 lines. Provision can be made for any other service rate that may be desired. With the proper control relay, service can be switched between two or more service rates as required by any outside computer.

The 6 service-rate lines go to the assignment panel where they are paralleled to 15 mode-selector switches, each of which can select any of the 6 modes for its associated aircraft and channel the selected rate back to the position of that aircraft in the distributer storage. There are 15 storage elements in the distributer, each assigned to an aircraft. As the service-rate requests arrive in accordance with the selected service rate, they are stored in the distributer. The distributer storage is continually scanned in sequence by a linear-counter matrix or line finder in the channel-selecting circuits. The line finder scans until it finds a stored request for service in the distributer, when it stops and initiates complete order-and-report service for the particular aircraft before advancing to the next position. In one second, the line finder can provide a maximum of 45 complete stops or service periods. If the rate-of-service requests entering the distributer storage are higher than 45 per second, all aircraft will continue to be serviced; however, a proportionate lowering in the average service rates will result.

Service rates are chosen at the assignment board in all mode-selector positions except under manual operation, when selection of the service rate is determined by the control console operator. When computers are connected to the system, they may also have control over the service rate if so desired.

The detailed operation of the distributer and line finder is as follows: Referring to Figure 6, the *S* elements are binary counters used as distributer storage elements. There are 16 in the present system, one for each of the aircraft positions on the assignment board plus a pre-empt position for any aircraft. The input binary counter is set into the *one* state by a pulse that occurs about 7.4 microseconds before the actual transmission of any message. This allows 34.7-kilocycle pulses to proceed through the *and* gate into the ring of 6 linear counters (*LC1* to *LC6*). Each time *LC6* switches to the low state, a ring of 4 linear counters (*LC7* to *LC10*) advances one step. It would take a total of 24 input pulses to return the aspect of the counters to the starting state. The two rings are arranged in matrix form to point up the fact that the *and*-gate input to each storage element, shown in the detailed drawing on the bottom, has one input from the counter at the top of its column and the other input from the counter at the end of its row. A service request will set the storage element to its *one* state and the coincidence of a row and column counter will reset the storage element to the *zero* condition. However, when this occurs, a signal is immediately sent to the halt-count blocking oscillator, which resets the input binary counter to its zero state. This prevents further pulses from advancing the line finder and both rings remain quiescent. The line finder is now locked on one combination of a column and a row of linear counters. The column output is the gate for the particular aircraft to be serviced, and the row output determines the recirculating loop on the drum that contains the message for this aircraft. This uniquely determines the location of the information to be taken out of the drum storage and to be transmitted to the aircraft and also the location of the reported information after the reply is received from the aircraft and decoded.

The line finder will resume scanning and locate the next aircraft to be serviced 7.4 microseconds before the next service period. Since the counters advance systematically and the order of searching is fixed, all requests will be serviced as their turn comes up. In the event that there are no service requests, the counters stop on *LC6*, which corresponds to no aircraft messages in the storage system.

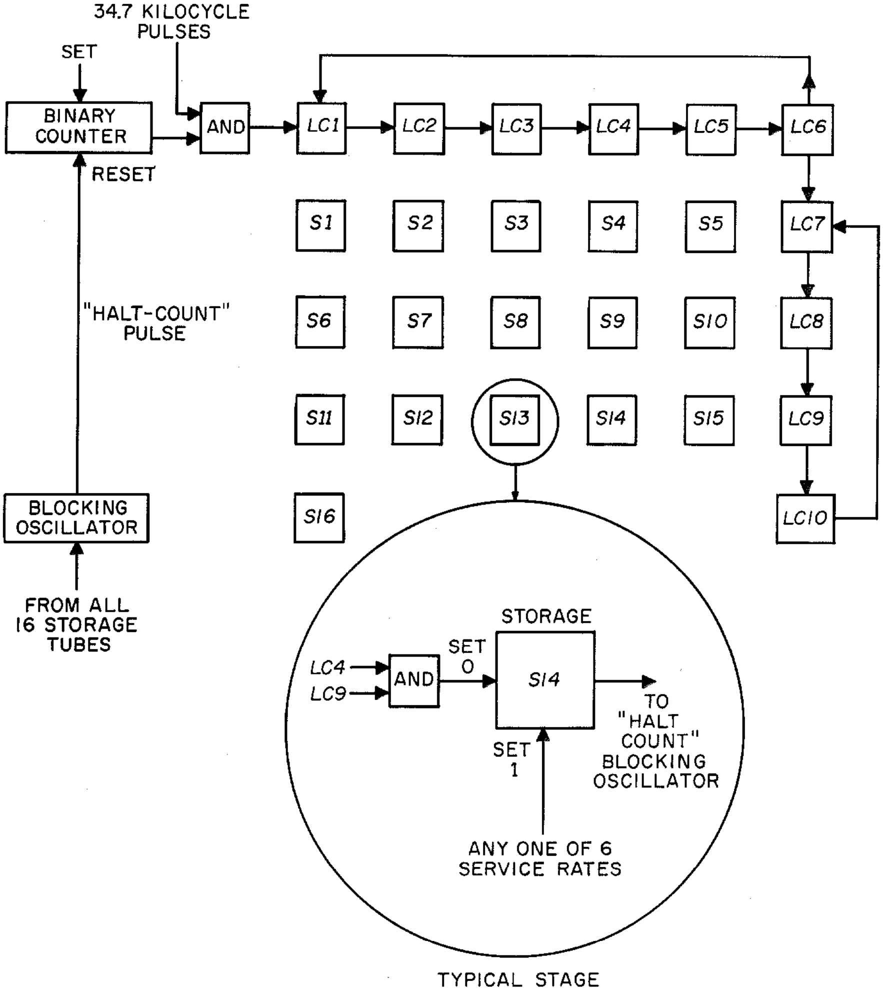

Figure 6—Distributer and line-finder block diagram. *LC* = linear counter. *S* = binary counter used as storage element.

5. *Assignment Panel*

The assignment panel serves as the central control board that determines where information shall go for order and report. It also provides regeneration for basic timing gates, pulses, and drum messages for consoles.

The assignment panel (Figure 1) has 16 assignment units on the front of the cabinet. The first 5 are allotted to the possible control of an aircraft by a manual control console. This takes place when the mode-selector switch on an assignment unit is turned to MAN (manual). In the other positions—BRO (broadcast), TRA (traffic control), APP (approach), NAV (navigation), and X (unassigned)—the control of the aircraft is by the computers. The position of the same switch also determines the rate that the aircraft associated with that assignment panel will request and receive service as previously described. The next 10 assignment panels have no manual control consoles connected to them and may only be used for switching control to external computers. The 16th unit is designed for use in the touchdown phase of a landing operation and provides for pre-empt service.

Since many aircraft can be handled by the system at the same time, it is necessary to provide means for identifying them. In the order message, an aircraft is called with a special 4-out-of-10-pulse code address. In the report message, the aircraft has an identity denoted by a prearranged number suitable for computer insertion. The address and identity are marked in the assignment panel by a metal card that is plugged into the panel. In addition, the assignment panel puts into the order message a pulse indicating the mode of operation assigned to the aircraft.

Reports and orders are funneled through the assignment panel when an aircraft is under control by a computer; on the manual position, information is sent to and from the control console.

The manual control consoles were designed to provide interim control and display facilities and are essentially for evaluation purposes only. It is not expected that any practical system would have one console for each of the aircraft under control since this would be too cumbersome. The consoles initiate orders and display the reports from the aircraft under control. Telemeter data are displayed on dials, while discrete data are displayed by means of single lights—one for each bit or part of a bit. Future possibilities envision a large integrated display with all the information on the aircraft in the system simultaneously presented.

Since each computer associated with the data link will not have the same requirements and the voltage levels and code structures for each are different, it is necessary to adjust the information arriving from the various computers to data-link levels before they can be used. This is one of the functions of an input–output computer adapter cabinet. This unit provides all special services required by a computer to operate with the tacan data link. The unit is relatively free of circuit complexity and is easily expanded to handle any number of computers in any future integrated system.

Standardization of Circuits for Data-Link Surface Equipment

By HAROLD J. MILLS and FRED L. VAN STEEN

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DURING initial design of the tacan data-link ground equipment, all pulses and enables (gating waveforms) were standardized; the specifications are listed in Table 1. Analysis of the system made it evident that three types of circuit would be widely used in the system. These were the blocking oscillator, the Eccles–Jordan multivibrator, and the cathode-follower, all operating in conformity with the pulse and gating-waveform specifications. A decision was made to develop several basic package units; this paper outlines the design, construction, and the versatility of these units.

TABLE 1

PULSE AND GATING-WAVEFORM SPECIFICATIONS

	Pulse	Gating Waveform
Amplitude in Volts Ones Zeros	 40±10 0	 43±10 −2 to +5
Line Impedance in Ohms	92 (Terminated cable)	10 000 (Maximum)
Width in Microseconds at 50-Percent Amplitude	0.4±0.1	Varies
Rise Time in Microseconds from 10-to-90-Percent Amplitude	0.05	2 (Maximum) 1 (Minimum)
Decay Time in Microseconds from 90-to-10-Percent Amplitude	0.05	2 (Maximum) 1 (Minimum)

The requirement that maintenance time be minimized suggests the use of standardized units. Both the ease and the speed of maintenance is facilitated when plug-in units make possible the substitution of known-quality packages for those suspected of faults.

Design time is also reduced with the use of a versatile selection of units. The units can be considered building blocks that require the designer to develop only the special coupling circuits enabling the assembly of individual blocks to function as one complete system.

It is necessary that the order of reliability of the individual parts be many times that of the system. The over-all equipment reliability P is

$$P = P_1 \times P_2 \times P_3 \ldots P_N,$$

where $P_1, P_2 \ldots P_N$ are the reliabilities of each of the units making up the complete system. From this relation, it becomes evident that the package reliability must be of high order if the equipment reliability figure is to be acceptable. For this reason, considerable effort was spent in the development of the basic package designs, both electrically and mechanically, to reduce significantly the probability of failure of the complete system.

1. Package Design—General

The *AN/URN-6* surface equipment makes use of 7 standard plug-in units. As much of each circuit as can be packaged without seriously sacrificing flexibility has been placed in a standard package. Coupling, clamping, and logical circuits are not packaged.

Since the base plugs of these packages (with the exception of the high-speed blocking oscillator) all fit a 12-pin socket of a design comparable to the octal socket, the color code shown in Table 2 has been adopted to distinguish among

TABLE 2

STANDARD PACKAGES

Package	Color	Tube Type	Pins
Medium-Speed Blocking Oscillator	Blue	*5670*	12
High-Speed Blocking Oscillator	Green	*6197*	8
Medium-Speed Binary Counter	Black	*5670*	12
High-Speed Binary Counter	Gold	*6197*	12
General-Purpose Cathode-Follower	Brown	*6201*	12
High-Power Cathode-Follower	Red	*5687*	12
High-Speed Trigger	Green	*6201*	12

them. All the components are encased in Araldite after assembly and each package weighs about 0.25 pound (113 grams). Unit dimensions are $1\frac{31}{32}$ by $1\frac{31}{32}$ by 1 inch high (5 by 5 by 2.5 centimeters) without the tube and tube shield. Printed-circuit techniques are used for the internal wiring of all packages.

All components of the packages were carefully selected for maximum reliability in service. The *5670* is the military version of the standard *2C51* and was found to have high plate-dissipation rating and rugged design. The peak cathode current of the *5670* was also found satisfactory for use of the tube as a blocking oscillator. For higher transconductance and plate dissipation, the *6197* pentode was selected for the high-speed binary and the high-speed blocking-oscillator packages. For general-purpose cathode-follower use and as a trigger for the high-speed binary and high-speed blocking oscillator, the *6201*, military version of the *12AT7*, was found satisfactory. It should be noticed that each of the tubes mentioned above is used in at least two different packages. One tube that was found useful as a high-power cathode-follower was the *5687WA*. Its power capabilities more than offset its requirement for high grid bias for cathode-follower and phase-splitter operations. All tubes used in the packages are military-recommended types.

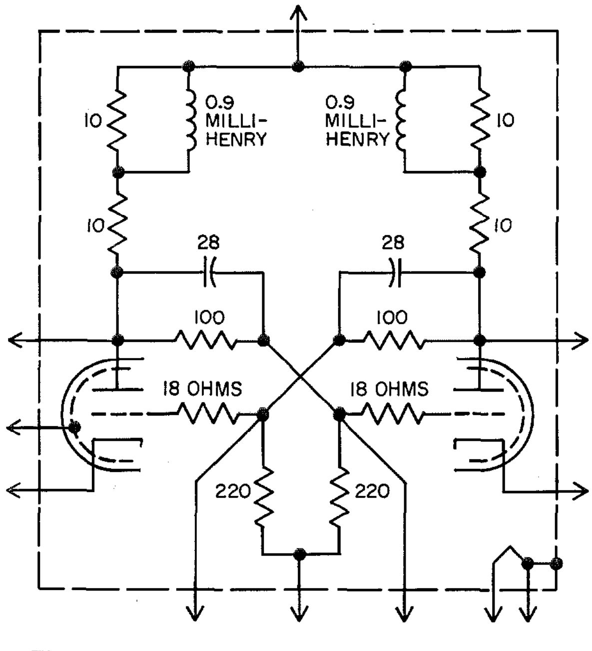


Figure 1—Medium-speed binary counter using *5670* dual triode. Except for the tube, all components shown are included in the package, connection to external circuits being made through the base-plug pins indicated on the sides of the circuit box. Resistances are in kilohms and capacitances in picofarads except where noted.

The blocking-oscillator packages required the use of specially designed pulse transformers. In the construction of the packages, the transformer was mounted underneath the tube socket. Since the packages were encased in Araldite as the final step in production, it was not necessary to make the transformers mechanically rugged in themselves; the completed package is able to withstand the shock of dropping on a concrete floor from a height of 6 feet (1.8 meters) with no detectable impairment of its operation.

The resistive voltage dividers in the cathode-follower packages are composed of matched resistors. Since there is a relation between the ohmic value of a resistor and the amount the resistor will drift with temperature, resistors of roughly equal values were designed into the packages. Therefore, all resistors will drift roughly the same amount with temperature, and the resulting change in voltage-divider output will be minimized.

The circuit for each of the packages is on printed wiring cards, approximately 2-inches (5-centimeters) square. The resistors, capacitors, and tube sockets are wired directly to these cards and then are tested. If the test indicates that the wiring is correct, an anodized aluminum can, color-coded for the particular type of package, is placed over the circuit and the entire assembly is filled with Araldite and cured.

Vacuum tubes and all other package components are operated well within their ratings to ensure that the reliability specifications for the packages will be met.

2. *Medium-Speed Binary Counter*

The binary-counter package is basically an Eccles–Jordan bistable multivibrator (Figure 1) and is used principally as a static storage device or as a counting unit. In this latter application, it can be used either as part of a binary counter or in a linear counting ring.

Triodes are used in each half of the multivibrator. The only external supply voltages required are +200 volts, −250 volts, and a 6.3-volt heater supply. Series compensating inductors

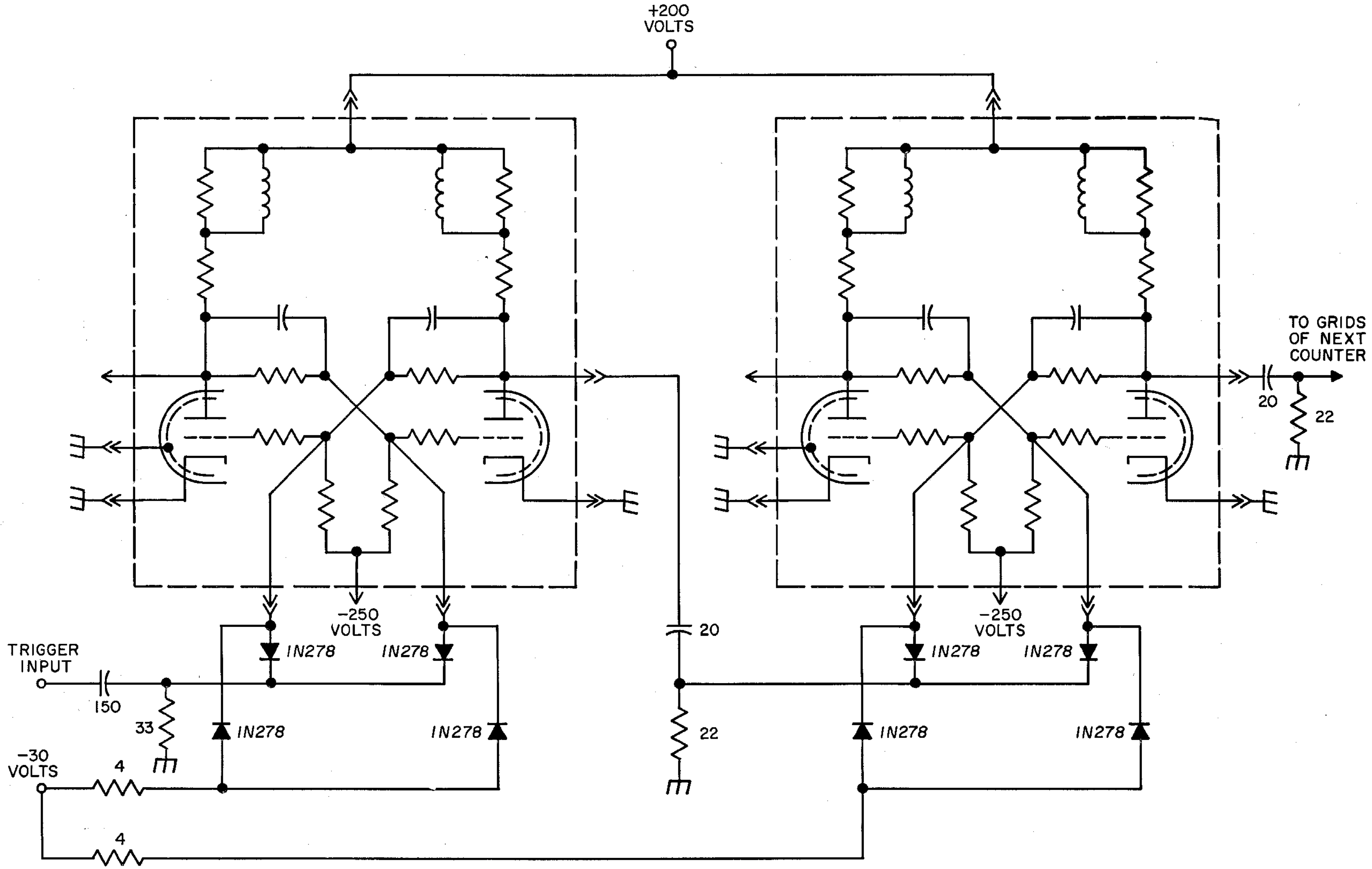


Figure 2—Use of counter packages of Figure 1 as a binary counter, showing coupling and clamping circuits. Resistances are in kilohms and capacitances in picofarads.

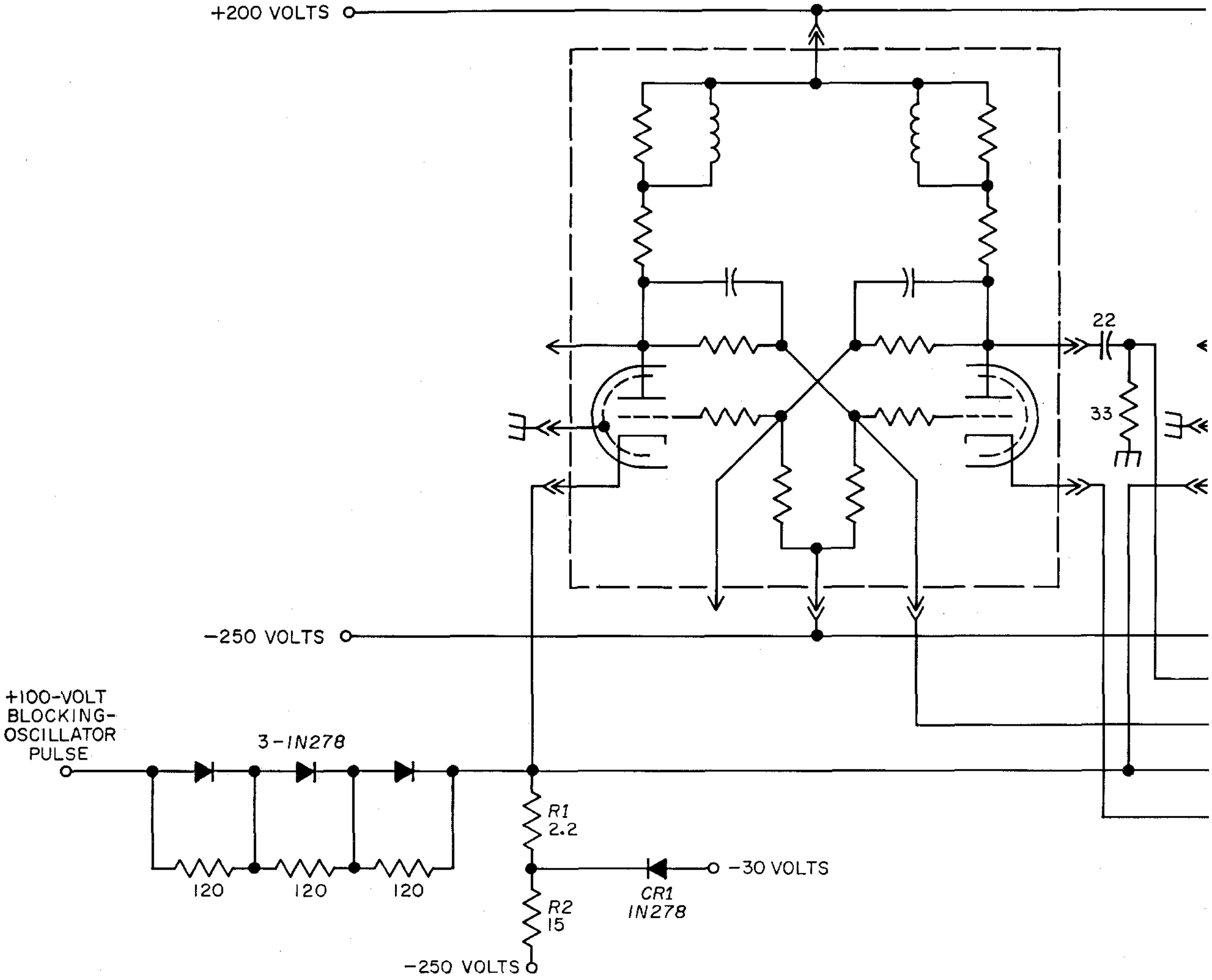
are provided in the tube plate circuits to increase the high-frequency response of the amplifier without harmful overshoot. This decreases the plate-voltage rise time, thereby reducing the time delay of the counter.

The tube is operated under very-conservative conditions. With an open-circuited output, under 10-percent supply voltage fluctuations, output is 185 ± 15 volts for ones and 65 ± 3 volts for zeros. For a 50-kilohm load and 10-percent voltage variations, the values are 155 ± 15 and 62 ± 5. Rise time is 0.8 and decay time is 0.25 microsecond. Time delay is 0.2 microsecond. Maximum frequency is 0.2 megacycle or 1 megacycle with external grid-circuit clamps. The minimum required trigger is −10 volts.

One plate of each unit is coupled through an external differentiating circuit to both grids of the following counter. Figure 2 shows the circuit. Diodes isolate the two grids and prevent positive pulses from triggering the counter. Negative pulses are used in transferring the count to successive stages because of delays inherent to positive pulses due to slow plate-voltage rise times.

To extend the high-frequency range of the counter, a grid clamping circuit can be added. This clamping circuit consists of a diode from each grid returned to −30 volts through a resistor with a value $R_c = 4000/N$, with N = number of counters.

The clamping diode removes the large negative overshoot normally present on the grid. This greatly decreases the counter recovery time and allows higher-frequency operation without requiring excessive triggering voltage. With this addition, the useful range of operation can be extended to 800 kilocycles.



When connected as a linear ring, the count is one per package. The circuit is shown in Figure 3. All the left-side cathodes are interconnected and placed at 0 volts through *R1* and a clamping circuit. Resistor *R2* and diode *CR1* clamp their common junction at −30 volts. With one tube conducting, the resulting 12.6-milliampere plate current causes a 30-volt drop across *R1* that places the left-side-cathodes bus at 0 potential. Should more than one tube try to conduct at any one time, the total cathode current will increase, raising this *off* cathode bus above ground potential and biasing all tubes *off*. One tube will therefore preferentially conduct, keeping the remaining tubes in a nonconducting state. The ring is triggered by 100-volt positive pulses having no negative undershoot. Coupling to the common *off* cathode bus is through 3 diodes, each paralleled by a voltage-equalizing resistor. The right-hand cathodes are all connected to a common *on* bus. This bus, which carries the plate current of all but one tube, is returned to −30 volts through a resistor *R3* = 2200/(*N* − 1) ohms, where *N* is the number of packages.

With this value, the *on* cathode bus will be at ground potential. Coupling between successive stages consists of a differentiating circuit diode-coupled to the *on* grid of the following package. The diode allows only the differentiated negative pulses to pass the count.

3. High-Speed Binary Counter

Each high-speed binary-counter package (Figure 4) contains half of the circuit needed to form a 2-megacycle counter. The circuit is a conventional pentode bistable multivibrator with series compensating inductances. External grid clamps

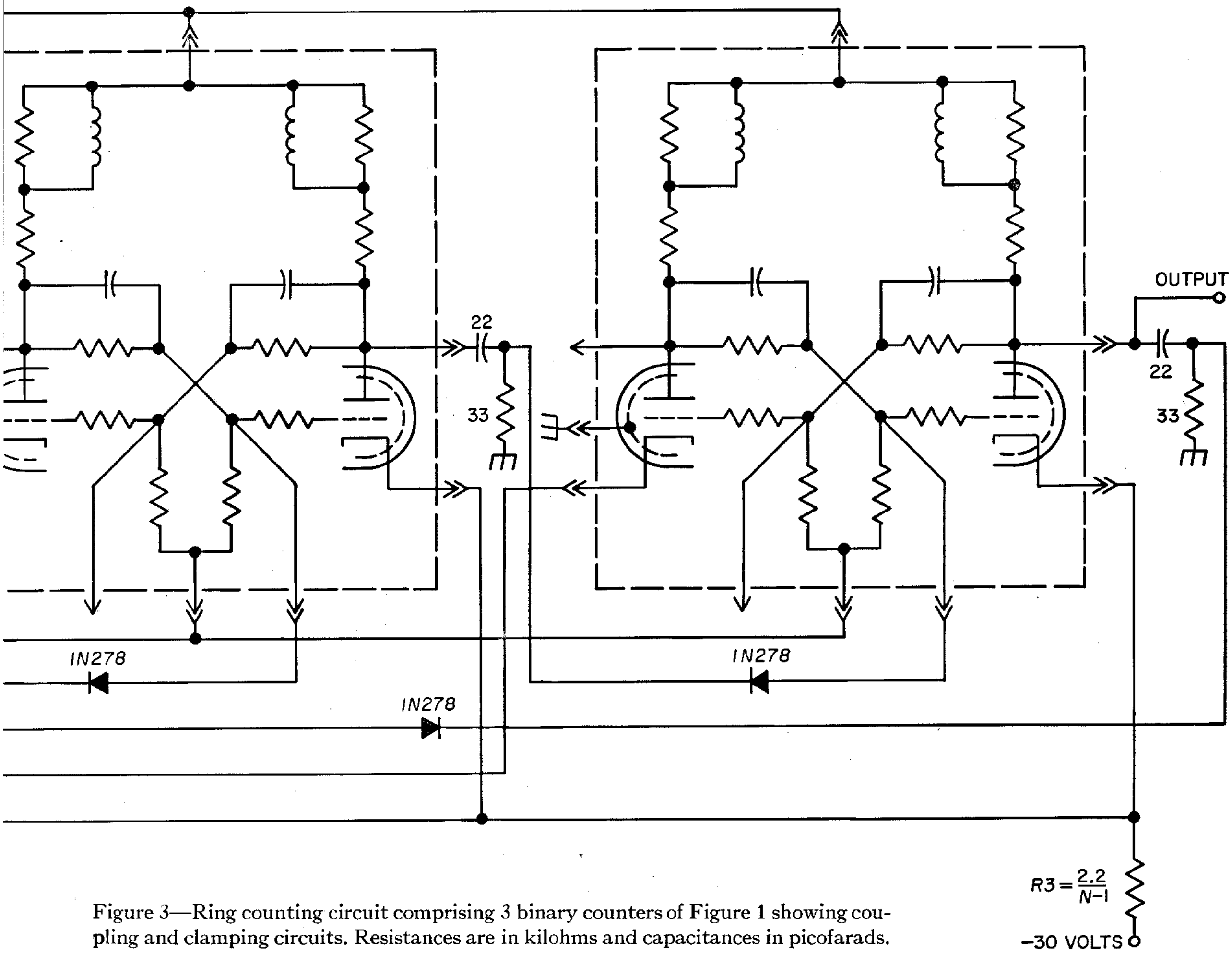


Figure 3—Ring counting circuit comprising 3 binary counters of Figure 1 showing coupling and clamping circuits. Resistances are in kilohms and capacitances in picofarads.

increase the high-frequency response. With these refinements, delay time through the counter is about 0.1 microsecond. Shunt triggering using an external *6201* triode tube is required to trigger reliably the first of a chain of binary counters. As in the medium-speed counters, these are reliably triggered by the fall of a preceding counter's plate voltage.

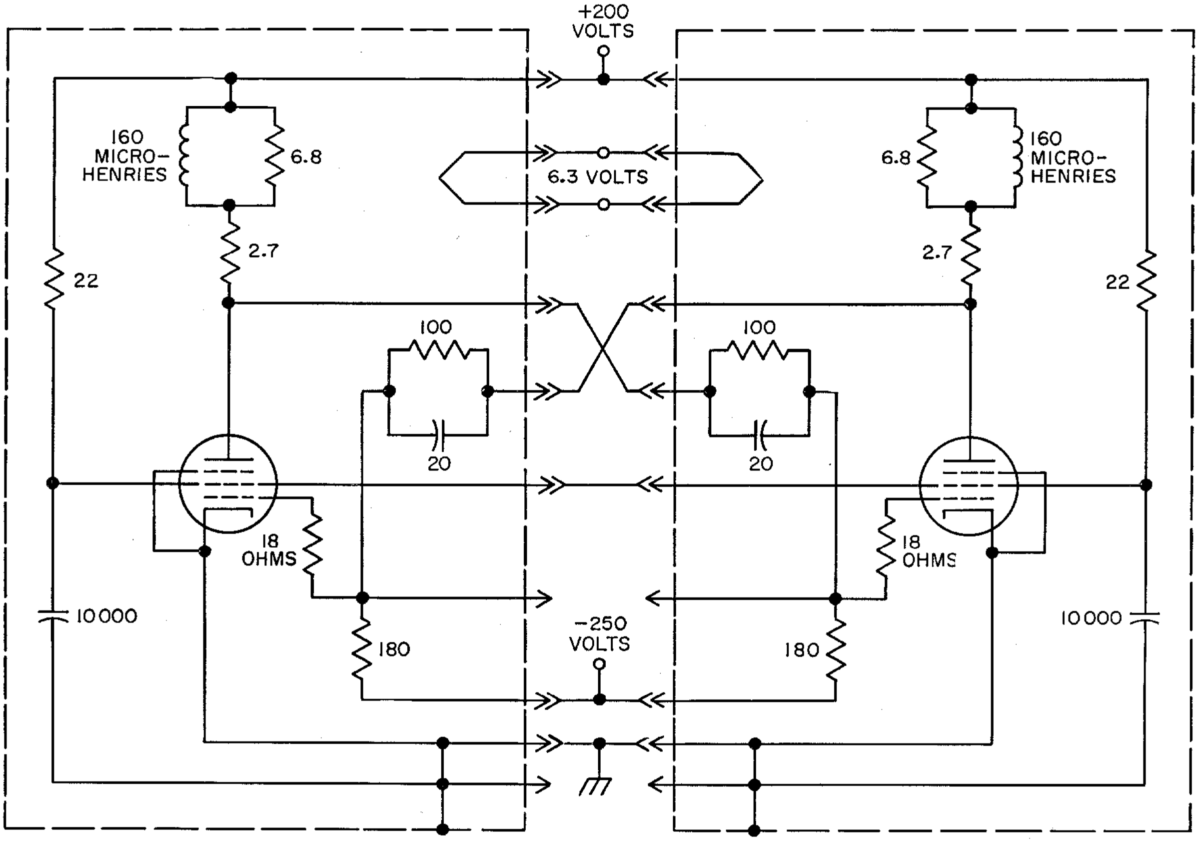


Figure 4—The high-speed binary counter consists of two interconnected packages each with a *6197* tube. Capacitances are in picofarads and resistances in kilohms except where noted.

With open-circuited output and 10-percent supply voltage variations, output for ones is 194 ± 20 volts and for zeros, 95 ± 10 volts. For a 50-kilohm load and 10-percent fluctuations, the figures are 165 ± 14 and 70 ± 5 volts. Rise time is 0.24 and decay time 0.09 microsecond. Time delay without external clamps is 0.08 microsecond and maximum frequency is above 2.5 megacycles.

4. Medium-Speed Blocking Oscillator

The medium-speed blocking oscillator is capable of driving a 100-ohm line at frequencies up to 110 kilocycles with nominally 0.5-microsecond pulses. The schematic diagram of the package appears in Figure 5. The input is coupled through a series-trigger triode that is in the same envelope as the blocking-oscillator triode. A low-impedance path is provided for the pulse of grid current by an external diode shunted across the trigger-tube cathode resistor. This diode, as well as a transformer-primary shunt damping diode also shown in Figure 5, is mounted on an external terminal board.

This unit is provided with a −22-volt bias supply that keeps the unit quiescent until triggered. If the bias disappears, the unit will run free with a consequent large increase in average plate current. To protect against damage from this condition, all blocking-oscillator plate-voltage lines are fused separately.

Open-circuit output voltages with supply variations of 10-percent are 60 ± 6 volts and 40 ± 4 volts, the latter dropping to 35 ± 4 volts

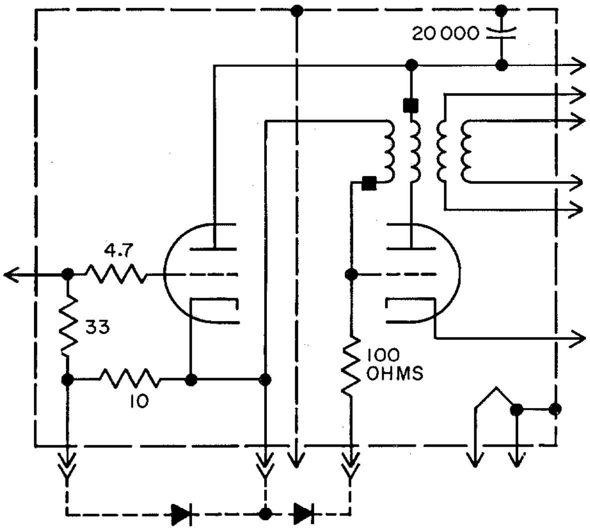


Figure 5—The medium-speed blocking oscillator using a *5670* tube. Two windings on the transformer give alternative outputs of ± 40, ± 60, or ± 100 volts. Values are in kilohms and picofarads except where noted.

with a 12-watt load. Rise and decay times are 0.04 microsecond; pulse width is 0.4 ± 0.02 microsecond with no load and between 0.4 and 0.2 microsecond with full load. A 12-volt trigger is required.

Since the outputs are from transformer windings, pulses of either polarity are obtainable. Furthermore, by connecting the windings in series, 100-volt pulses are available.

To increase the versatility of this package further, the cathode of the blocking-oscillator section is brought out to a terminal of the package. Normally this pin is grounded, but if a slowly rising input trigger must be used, an external parallel resistance–capacitance combination is placed between the cathode and ground to increase the recovery time of the oscillator and thus prevent multiple triggering. If the rise time of the trigger is extremely long, the stability of the pulse will be considerably reduced; tests have shown that a trigger with a rise time of 25 microseconds and an amplitude of 40 volts produces a jitter of one microsecond. In this case, a 0.01-microfarad differentiating capacitor is used at the package input and a 10-kilohm resistor in parallel with a 0.03 microfarad capacitor is placed in the oscillator cathode circuit. This cathode biasing arrangement blocks the circuit after one pulse and thus prevents multi-triggering.

When the trigger has a rise time faster than 1 microsecond, a small package-input capacitor of about 20 picofarads is used to prevent multi-triggering.

5. High-Speed Blocking Oscillator

The high-speed blocking oscillator consists of two packages capable of driving a 200-ohm line with a 0.1-microsecond pulse at a maximum frequency of 1.5 megacycles.

The schematic diagram of the unit is shown in Figure 6.

Series triggering is used to allow the unit to operate with low values of trigger voltage and with triggers having relatively poor rise times. Two external diodes are used. One diode is

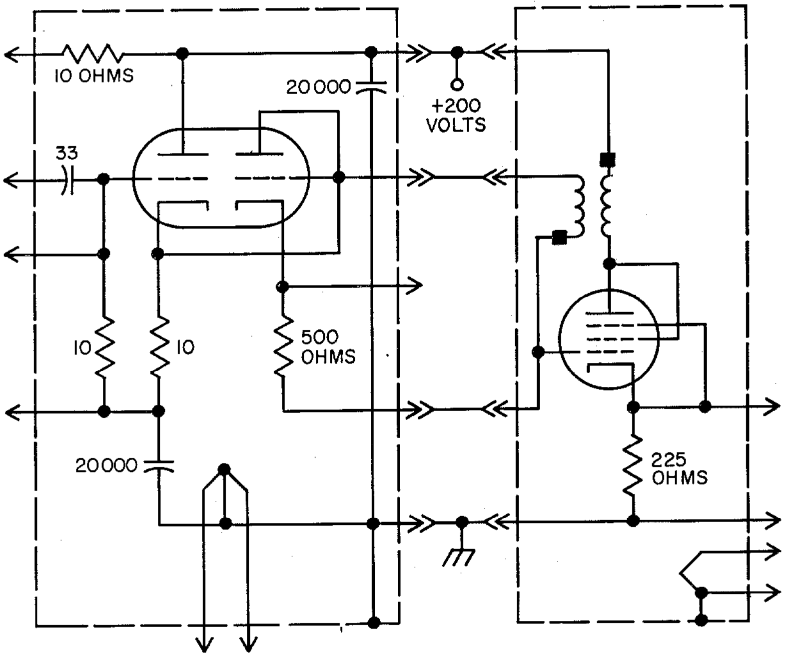


Figure 6—The high-speed blocking oscillator is comprised of a trigger package using a *12AT7* tube and an oscillator package with a *6197*. Capacitances are in picofarads and resistances in kilohms except where noted.

connected across the trigger-tube grid return to speed the recovery of the input differentiating network. The other diode, across the cathode resistor of the trigger tube, is used to clamp the grid-return end of the transformer at −22 volts. The second half of the trigger-tube envelope is diode-connected to damp the pulse transformer.

Output voltages with 10-percent supply voltage variations are 50 ± 5 volts, open circuit, and 62 ± 6 volts with a 50-picofarad load. Rise and decay times are 0.05 and 0.07 microsecond, respectively, and pulse width is 0.1 ± 0.02 microseconds with full load. A 20-volt trigger is required.

Unlike the medium-speed blocking oscillator, this unit has only a single positive output. When a negative high-frequency pulse is required, an inverting transformer, external to the package, must be used.

6. General-Purpose Cathode-Follower

A schematic diagram of the cathode-follower appears in Figure 7. The compensated voltage dividers in the grid circuits are designed for a flat output response when the divider input is direct-current coupled to the plate of a medium-speed binary counter. An external shunting circuit is necessary when the input is from the plate of a high-speed binary counter. Signals can also be introduced directly into the grid or cathode.

The output voltage of the general-purpose cathode-follower is −35 (+15, −10) volts for ones and 0(+0, −1) volts for zeros. In keeping with its use as a coupling circuit and waveform regenerator, the design is such that the specifications for gating waveforms, Table 1, are exceeded; depending on the driving circuit, rise time varies between 0.2 and 0.8 microsecond; decay time, 0.3 to 0.5 microsecond; and time delay, 0.7 to 0.8 microsecond.

This package is commonly used to provide isolation and to act as a low-impedance source for logical circuits. As such, it provides coupling between the binary counter and the gate to be controlled. Since *and* gates require low-impedance drivers that are not present in binary counters, the cathode-followers are widely used. Similarly, binary counters are sensitive to plate loads; the cathode-follower provides the needed isolation.

The next-most-common connection of the package is the noninverting amplifier or waveform regenerator with a low-impedance output. The conventional regenerator circuit is shown in Figure 8.

The circuit is basically a grounded-grid amplifier followed by a direct-current-coupled cathode-follower. Proper biasing is obtained by placing the amplifier grid at a small positive voltage. The plate resistor is such that the plate-voltage swing is nearly identical to that of the binary-counter package. This makes possible the use of the existing coupling circuit within the package to provide an output with voltage levels identical to those of the standardized gating-waveform specification.

The input grid is placed at about +7 volts and the signal is applied to the cathode. When the input signal is high (+30 volts or higher) the first half of the tube cuts off, the plate voltage rises to about 180 volts, and the rise is directly coupled to the grid of the conventional cathode-follower. Thus, the output of the cathode-follower rises as the input rises. When the input falls to 0 volts, the first half of the tube conducts very heavily and the plate voltage becomes low, of the order of 60 or 70 volts. This voltage is divided to about −25 volts at the grid of the cathode-follower, which drives it below cutoff, since the cathode is clamped to ground.

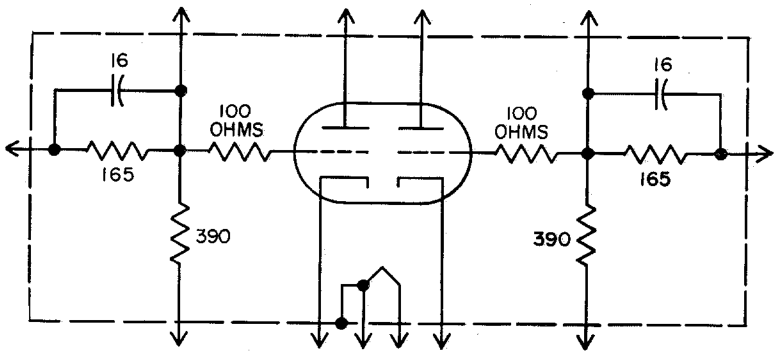


Figure 7—The general-purpose cathode-follower uses a *6201* tube. Capacitances are in picofarads and resistances in kilohms except where noted.

The cathode-follower package can also be adapted by external wiring for use as a phase splitter providing a low-impedence output and 180-degree phase reversal of the driving signal. Since the plate signal of the phase splitter is referred to the plate-voltage supply circuit, this circuit is principally used in conjunction with negative-going *and* gates.

7. *High-Power Cathode-Follower*

This unit is similar to the general-purpose cathode-follower, Figure 7, but uses a *5687* in place of the *6201* tube.

With the exception that a slightly higher output voltage for ones is available, other waveform output specifications are as in section 6 above.

Its main uses are as a cathode-follower or phase splitter. It allows the use of negative-going as well as positive-going *and* gates. The *5687* tube can drive a heavier load of gates, or can drive long signal leads. Units are frequently paralleled for higher output.

When used as a phase splitter, the high-power cathode-follower package is connected as a conventional cathode-follower circuit, except that a resistor is placed in series with the plate. Its use with positive and negative *and* gates is described in the preceding section.

8. *Test Data*

A total of 697 packages of the 7 basic types are used in the data-link coders and associated equipment. A record has been kept of the packages that have failed to provide stable continuous service for approximately 3100 operating hours; a tabulation is shown in Table 3.

Because of the small number of high-speed blocking-oscillator packages, their high failure rate (4.96 percent) is statistically inconclusive. It might be noticed, however, that all the high-speed or high-power packages had higher failure rates than the average. In many cases when packages were removed from service, the tube was found to be faulty, but the package itself was operative. This was nevertheless considered a total package failure, since the unit as a whole had a detrimental effect on the operation of the data link.

Temperature tests were made on the body of each of the packages under operating conditions in still air and in no case did any of the packages exceed 52 degrees centigrade in a 30-degree ambient. Tube bulb temperatures without a tube shield varied from about 73 degrees centigrade for the *6197* high-speed blocking-oscillator to about 198 degrees for the *5687* high-power cathode-follower.

TABLE 3
PACKAGE RELIABILITY DATA

Package	Total Used	Failures in 3100 Hours	Percentage of Failures per 1000 Hours
Medium-Speed Binary Counter	241	4	0.54
General-Purpose Cathode-Follower	141	1	0.23
High-Power Cathode-Follower	109	7	2.07
Medium-Speed Blocking Oscillator	98	5	1.65
High-Speed Binary Counter	64	2	1.01
High-Speed Trigger	13	0	0.00
High-Speed Blocking Oscillator	13	2	4.96
Over-All	679	21	1.00

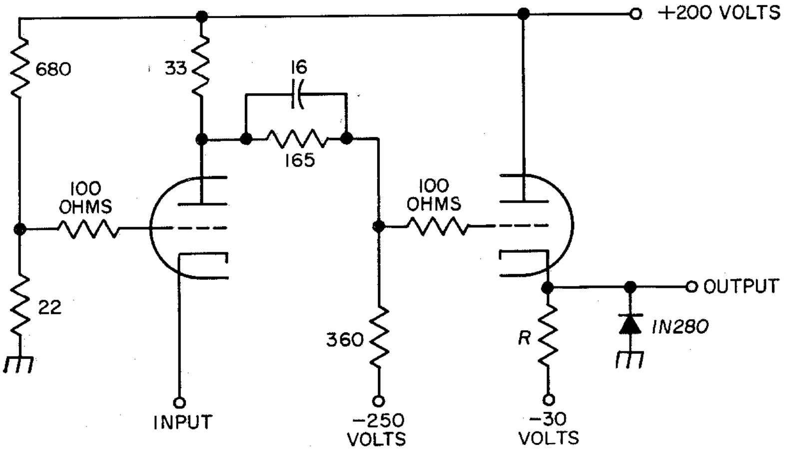


Figure 8—Regenerator circuit using the general-purpose cathode-follower package of Figure 7. Values are in picofarads and kilohms except where noted.

Airborne Tacan Data-Link Equipment AN/ARN-26

By EDMUND R. ALTONJI

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FROM INCEPTION, the tacan system was envisioned as an eventual integral part of an ultimate common system of air-traffic control and avigation. The combination of bearing service and distance measuring in a single facility, together with pulse transmissions on 126 clear radio-frequency channels, provides one of the basic building blocks for a common system.

Since pulse coding is not used to separate the transmissions from different surface beacons, freedom to use pulse coding for telemetering is obtained. The use of a pulse code to add a two-way data link to the system was part of the original concept. Development of the link was initiated early in 1951 when tacan was in its final development.

The *AN/ARN-26* data-link airborne equipment is a logical extension of the *AN/ARN-21* tacan airborne equipment in the development of a complete airborne system. Basic requirements of the system were integrated instrumentation and common radio-frequency circuits. The first requirement marked the beginning of an extensive redesign of existing cockpit avigational instruments so that no extra panel space would be required for the incorporation of the telemetering functions of the data link, the philosophy being to transfer any resultant complexity from the instruments to the radio compartment of the aircraft.

The second requirement made efficient time multiplexing of the tacan channel, without deteriorating its performance as an avigational facility, an absolute necessity. The signal from the *AN/URN-3* surface beacon lends itself quite readily to time-division multiplexing techniques as can be seen in Figure 1A. The auxiliary reference pulses that occur at a 135-cycle rate lend themselves particularly well to providing a basic synchronizing signal for the airborne equipment without utilizing a large portion of the available information capacity of the channel. While these pulses are not used directly, they are used to provide protection for the actual synchronizing signal, which consists of two 12-microsecond pulse pairs, uniquely spaced.

To multiplex the data-link transmission on the *AN/URN-3* signal, a basic change in the method of timing the signal is necessary during data-link operation. The tacan surface equipment uses a speed-controlled rotating antenna as its time base to trigger its north and auxiliary reference bursts. This is accomplished[1] by a pulser slug rotating past magnetic pickups, which are located so that the north-reference pulse coil is oriented due east of the beacon. In contrast, a crystal clock provides the system with a time base when the data link is added. To retain bearing information, the rotating antenna must be phase-locked to a 15-pulse-per-second signal derived from the clock. This is done in the *AN/URN-6* data-link surface equipment by a precise speed control, combined with a pulse phase-sensing circuit that compares the time position of the pulse generated by the rotating antenna with one derived from the *AN/URN-6* clock and uses the resulting error for correction. Once antenna phase-lock is achieved, insertion of the code structure into the radiation pattern presents no problem since the timing of the data-link message and the time position of the north and auxiliary reference bursts are determined by a common time base. No deterioration in bearing service and a reduction in distance-measuring capacity of approximately 12 percent results from the multiplexing. The composite tacan data-link signal is shown in Figure 1B.

This slight reduction in distance-measuring capacity is more than repaid by the enormous increase in service to both the aircraft and the surface environment. A total of 45 complete surface-to-air messages consisting of 74 bits each (including code protection) can be transmitted each second and a corresponding number of 56-bit replies received. As will be explained later,

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[1] R. I. Colin and S. H. Dodington, "Principles of Tacan," *Electrical Communication*, volume 33, pages 11–25; March, 1956.

this information is sent both in digital form as pulse-code modulation and in analog form as wide-deviation pulse-time modulation. These totals do not include the surface-to-air synchronizing pulses nor the start pulse triplet preceding each air-to-surface reply. The message pattern is shown in Figure 2.

The surface environment is provided with complete avigational data including bearing, distance, heading, altitude, and air speed on each aircraft in the system as well as 15 bits of on–off discrete data including 31 ready-made messages.

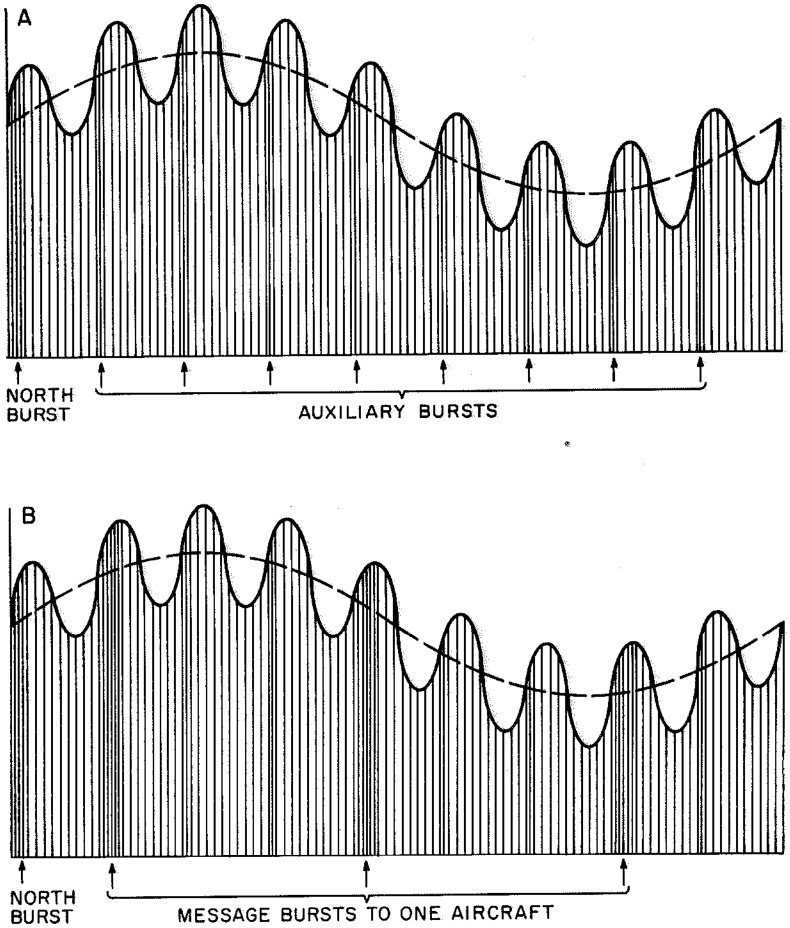

Figure 1—Standard tacan signal has 8 equally spaced uniform reference bursts (8 pulses) between adjacent north reference bursts as shown at *A*. The data-link pattern adds a message burst (of pulses) immediately after every third reference burst starting with that burst immediately following the north signal as shown in *B*.

The information provided to the aircraft includes telemetered orders on each of the 5 instruments mentioned above as well as 33 bits of on–off or discrete information including an address peculiar to the aircraft, 31 ready-made messages, mode of operation, et cetera. These services are described in detail below.

The air-to-surface report from each aircraft follows immediately after a surface-to-air message addressed to that aircraft. The roll-call method of address that is used provides three distinct advantages, not the least of which is flexibility. Aircraft requiring high service rates (for example, aircraft on landing approach) can be addressed more often than others without any deterioration in the service to any of the aircraft.[2]

The use of a surface-initiated roll-call-type address assures freedom from interference or clash that would occur if the address were aircraft initiated. If such were the case, the system would be at the mercy of statistical probabilities as far as overlapping of different aircraft communications was concerned.

The third and perhaps the most-important advantage of roll-call addressing is that it relieves the aircraft of the necessity of carrying address-coding equipment. A positive identity of each aircraft is made on the surface by scanning the period immediately after a surface-to-air message for a reply. Since the surface-to-air messages are spaced far enough apart in time, it is impossible for any aircraft other than the one addressed to reply to a message regardless of the required transit time.

Beside the unique address for each aircraft,

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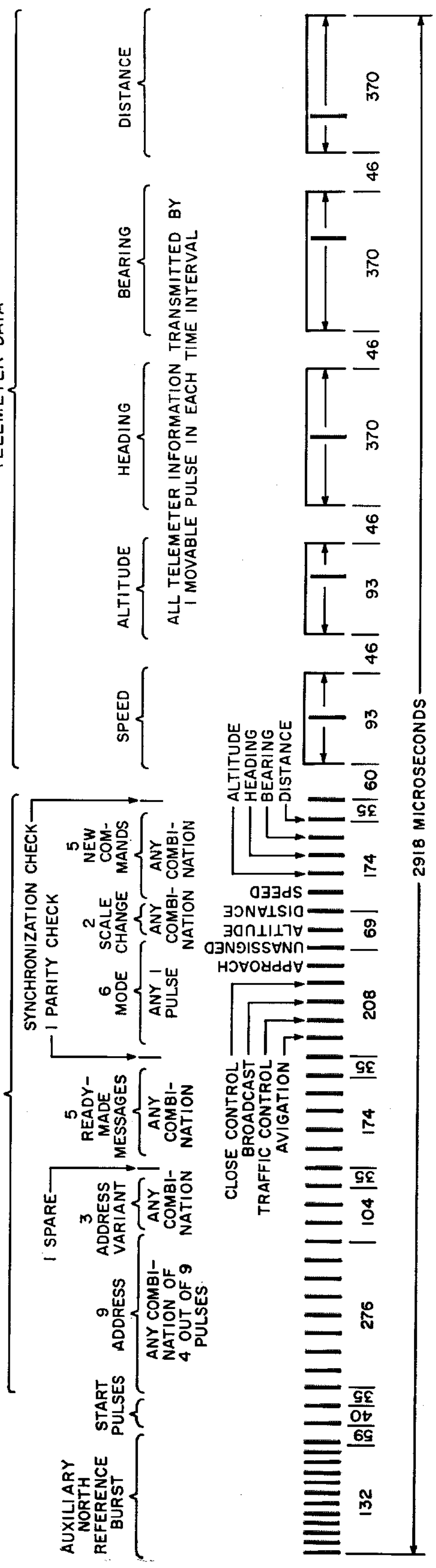
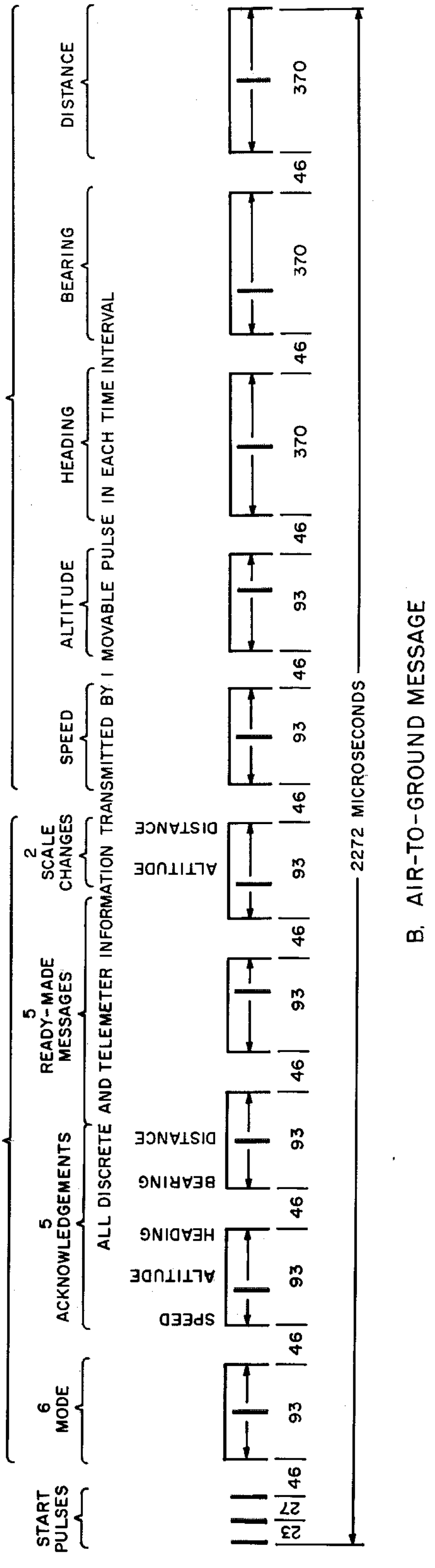
[2] G. W. Reich, Jr. and H. J. Mills, "Input and Output Facilities of Data-Link Surface Equipment," *Electrical Communication*, volume 34, pages 209–218; September, 1957.



A. GROUND-TO-AIR MESSAGE



B. AIR-TO-GROUND MESSAGE

Figure 2—Data-link message pattern. Rounded figures are given for the time intervals.

the surface also provides avigational control orders on 5 different instruments—distance, bearing, altitude, heading, and air speed. These are automatically displayed to the pilot directly on the *AN/ARN-26* instruments. The message preamble, which includes the address, also contains 31 ready-made messages, 5 new-command signals that indicate a change of control orders on each of the instruments, and signals that indicate the mode of control applicable to that particular aircraft.

Essentially, these various modes of operation indicate to the pilot the interpretation that is to be placed on each of the instruments. In addition, there is a corresponding message rate for each mode that is tailored to the requirements for aircraft response when in that mode. This rate varies from 10 messages per minute in the avigation mode to 10 messages per second in the landing-approach mode. In some cases as, for example, in the landing-approach mode, not only is the interpretation of the instruments changed, but the data from one or more of the instruments may be switched to some other indicating device as, for example, to the cross-pointer unit. Thus, when the landing-approach mode is displayed to the pilot, the bearing and distance time intervals are then used to transmit left–right and up–down information that is automatically switched to the cross-pointer indicator in the aircraft by the *AN/ARN-26* equipment. Table 1 shows the message content of the standard code structure. The meaning of all portions is flexible and may be changed to suit various applications.

As was indicated previously, the designs of the *AN/ARN-26* indicating instruments were undertaken with a view toward minimizing the amount of space required in the aircraft cockpit and transferring the resultant complexity, if any, to the radio compartment of the aircraft.

While cockpit space is at a premium, space in the radio compartment of an aircraft is by no means cheap; and the next logical stop was to transfer as much complexity as possible from the aircraft equipment to the surface. The code structure, shown in Figure 2, was carefully tailored with this aim foremost in mind. In addition, care was taken to design the code so as to minimize jamming and to be sure that as low as possible a duty cycle would be imposed on the *AN/URN-3* transmitter. That these three major requirements are interrelated will be seen later.

Since the 5 telemeter-data time intervals carry the greatest portion of the information contained in the surface-to-air message, attention was first directed to the design of this portion of the code. The transmission of this essentially analog data in digital form would have required storage plus digital-to-analog conversion in the aircraft. The use of this storage and conversion for each of 5 time intervals would require as much equipment as is now contained in the whole *AN/ARN-26* signal-data converter. In addition, it would have greatly increased the duty cycle of the surface transmitter since a maximum of 41 telemeter-data pulse pairs

TABLE 1

TACAN DATA-LINK MESSAGE CONTENTS

Aircraft to Surface	Surface to Aircraft
GENERAL	GENERAL
Identity—automatic by time separation	Address—any of 1008 identities
Mode—automatic feedback feature	Mode—such as traffic control, automatic approach, et cetera
31 Ready-made messages—pilot initiated, such as HOLDING, LANDING, et cetera	31 Ready-made messages—such as HOLD, PROCEED, WHEELS DOWN, et cetera
5 Acknowledgments—pilot-initiated reply to new orders from surface	5 Commands—indication of major change in control orders
STATUS REPORTS	CONTROL ORDERS
Distance—automatically encoded from tacan distance equipment using 20- or 200-nautical-mile (37- or 370-kilometer) scales	Distance—on 20- or 200-mile (37- or 370-kilometer) scales
Bearing—automatically encoded from tacan bearing equipment, 0–360 degrees	Bearing—on 0–360-degree scale
Altitude—automatically encoded from barometric or radio altimeter using 5000- or 50 000-foot (1520- or 15 200-meter) scales	Altitude—on 5000- or 50 000-foot (1520- or 15 200-meter) scale
Heading—automatically encoded from radio-magnetic indicator, 0–360 degrees	Heading—on 0–360-degree scale
Air speed—automatically encoded, 0–650 knots (0–1200 kilometers per hour)	Air speed—on 0–650-knot (0–1200-kilometer) scale

would have to be transmitted instead of the 5 required when wide-deviation pulse-time modulation is used. Furthermore, the transmission of these telemeter-data commands in digital form would have made the transmission much more susceptible to jamming and noise since the probability of a telemeter datum being knocked out would have been increased by a factor of 8. Therefore, from all points of view, the use of wide-deviation pulse-time modulation offers the best solution to the transmission of analog data.

On the other hand, the message preamble composed of the address and on–off-type information lends itself to digital techniques of decoding. The information contained therein is displayed to the pilot in what is essentially digital form. Therefore, the use of analog techniques to decode and display this information would only complicate the equipment unnecessarily. To protect the information contained in the preamble, various means are used for the different parts of the discrete orders. These will be discussed in the order in which they occur in the message.

The address is of the constant-length type and is transmitted in the first 13 time intervals. The first 9 intervals are devoted to the numerical part of an address of the aircraft. Any combination of 4 out of the 9 time intervals are used to encode the address. The remaining 5, however, are scanned as a protective measure. The 10th interval contains a spare pulse position that is not at present being used but can be used for any purpose whatsoever; perhaps to work with one-way data links transmitting telemeter data of a different nature from that being used in the present link. The last 3 intervals are used for variations on the numerical address of the aircraft. These variants would be necessary if several aircraft with the same address wished to operate from a single beacon. In this event, by simply turning a knob on this control panel, a pilot could change his address from *122A* to *122B* or to any other letter through *H*. Variants allow up to 8 aircraft of the same numerical address to operate from one surface station.

The next portion of the preamble is used to transmit the 31 ready-made messages by using a 5-bit binary number with a parity check designed so that the number of pulses transmitted for any ready-made message is always odd. The messages decoded in the aircraft are displayed on a suitable indicator in the form of clear-text messages.

Immediately following the parity check, there are 6 time intervals that are used for the transmission of the mode. Only one pulse at a time is sent in one of the 6 time intervals. The absence of a pulse or the presence of more than one pulse in the mode time intervals operates a flag alarm in the mode indicator.

Scale-change pulses for altitude and distance are sent in the two time intervals immediately following the mode, while new commands to any combination of the 5 instruments are sent in the 5 time intervals following the scale change.

The last message bit in the preamble is a synchronization check pulse that is used to check the synchronization of the airborne time base with the surface. If the airborne time base is found to be synchronous within a specified tolerance, then telemeter data are decoded. If not, the last complete message remains displayed on the instruments and the remainder of the message is disregarded.

The above sequence perhaps typifies the type of operation achieved in the airborne equipment. It is almost impossible for the aircraft to receive wrong information from the surface. The philosophy followed has been to give the aircraft no information rather than wrong information on any particular message in the event of excessive noise or interference. For example, if the aircraft time base is not synchronized with that of the ground, no address will be decoded. All data received up to that time will remain stored on the indicators. If the time base is synchronized but an improper address is sent or is knocked out by interference or noise, then no further decoding takes place. All data that had been received up to that time remain stored on the instruments but a flag alarm will be displayed on each instrument. The remainder of the preamble, however, will indicate that a false bit of data has been transmitted by immediately showing a flag alarm on the appropriate display.

Finally, there is the common-sense check on the new command and telemeter-data orders received by the aircraft. For example, if a new command is received without a radical change in the corresponding telemeter-data order, this will indicate to the pilot that something is amiss and he will disregard the new command unless it is sent repeatedly.

The spacing between the pulses in the code has been chosen with two requirements in mind, the first being a transmission requirement and the second being a decoding requirement.

Pulse transmissions between a beacon and a mobile station create an echo problem that effectively lengthens the duration of pulses to between 8 and 10 microseconds. Since the *AN/URN-3* surface equipment transmits 12-microsecond pulse pairs for added protection, these pulse pairs cannot follow each other more closely than 16 to 20 microseconds. Therefore, the lower-limit spacing between successive 12-microsecond pulse pairs is set at 20 microseconds. The 12-microsecond spacing between pulses in a pair was chosen to solve the single-pulse echo problem.

The decision to use delay-line decoding in the aircraft, however, dictated a wider spacing of pulse pairs than is required by echo considerations alone. Since delay-line decoding offers the advantage of passive circuits, reliability, and small volume, it was important to make certain that the code spacing was such that it could easily be accommodated by delay-line decoding circuits. The requirement that the delay lines be of reasonable size indicated that a lumped-constant line would have to be used that could handle a minimum pulse spacing of the order of 20 to 25 microseconds at half amplitude. The actual pulse spacing then had to be made appreciably wider than this minimum requirement. The pulse spacing shown in the code diagram was finally selected as being the best compromise between requirements for decoding and the timing requirements of the system including tacan.

The length of the telemeter-data time intervals with their associated guard bands were chosen from a different point of view. Their length was designed to coincide with the length of one period of the airborne time base, which operates at a frequency of 2700 cycles per second. Several considerations, outlined below, determined the frequency finally chosen.

Since the time position of a received pulse can be determined with an accuracy of approximately ±0.5 microsecond, an upper limit to system resolution was set. Consequently, the system quantizing error had to be smaller than this amount. The remaining determining factor is the accuracy obtainable from the resolvers used in the coding operation. An accuracy of ±0.5 degree is obtainable in the field from resolver synchros whose published accuracy is ±7 minutes of angle. Therefore, a time-shaft position relation of approximately 1 microsecond per degree was indicated, corresponding to a frequency of 2780 cycles. However, as will be seen later, it is essential for decoding telemeter data that the length of a telemeter-data time interval be equal to or some fraction of the period of the airborne time base. Therefore the frequency of the time base must be an integral multiple of 135 cycles, which is the frequency of the auxiliary reference and start pulses, and consequently a frequency of 2700 cycles was chosen.

Another very-important consideration in determining the length of the telemeter-data portions of the message was the practical length of delay line that could be used to sequence the decoding operation on the telemeter data in the surface-to-air message and the encoding of the air-to-surface message.

The pulse triplet initiating the air-to-surface message identifies the aircraft reply to the surface and also provides a time reference for the decoding operation in the surface equipment. The air-to-surface message consisting of mode reporting by the aircraft as a continuity check, 31 ready-made messages, acknowledgments to new commands, and 2 scale-change pulses are encoded by suitably phase-shifting the 2700 cycles in the aircraft and passing the phase-shifted waveforms to pulse formers to generate the reply. This technique was used to eliminate the necessity of carrying any complex counting and logic circuits in the aircraft. The spacing of the telemeter-data portions of the air-to-surface message were made for the reasons outlined above. While no attempt was made to add code protection at the aircraft for the air-to-surface reply because of duty-cycle limitations on the equipment as well as the increased complexity involved, a check is made in the surface equipment for the presence of one and only one pulse in each of the epochs of the reply.

1. System Description

A block diagram for a complete airborne system including the *AN/ARN-21* with its ancillary equipment is shown in Figure 3. While some of the components function as part of both the *AN/ARN-21* and *AN/ARN-26*, in most cases functions are peculiar to one or the other and the block diagram is arranged accordingly with the *AN/ARN-21* functions on the left. The junction box is necessary to fit the system to existing aircraft. All interconnections and transfers are made within the junction box except for the *AN/ARN-21* control panel, which goes directly to that equipment, and for three radio-frequency cables between the *AN/ARN-21* and *AN/ARN-26.*

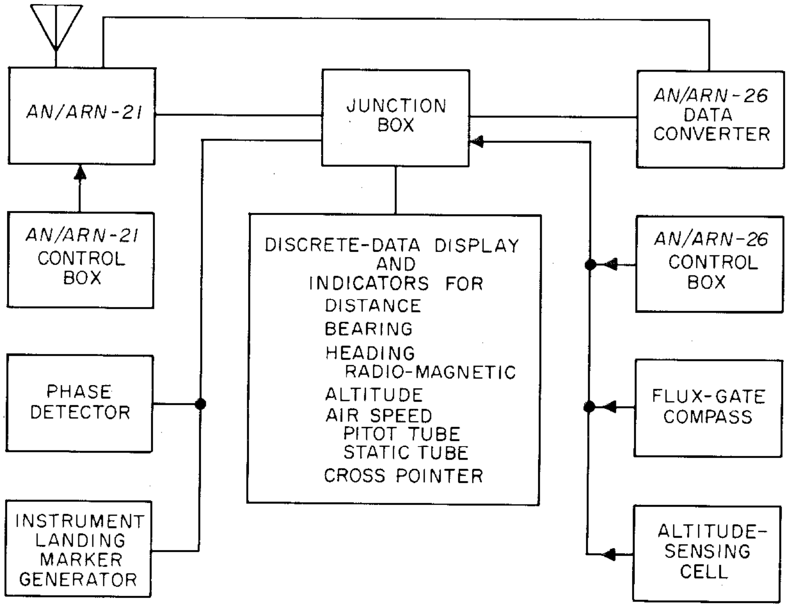


Figure 3—Complete airborne system.

The distance and bearing indicators, of course, have the dual function of providing both distance and bearing information from the beacon and also for displaying the ordered distance and ordered bearing, which are transmitted over the data link. All other instruments are independent of the *AN/ARN-21.* However, each of the other instruments, namely; heading, altitude, and air speed, not only display these ordered parameters, which are transmitted over data link to the aircraft, but also display the actual heading, altitude, and air speed of the aircraft to the pilot. In addition, both the aircraft bearing and the ordered bearing are displayed on the heading instrument by means of broad and narrow pointers, respectively. This was done on the *AN/ARN-26* heading instrument to provide the pilot with a composite situation picture on one instrument. It shows in addition to the actual and ordered headings, the relative bearing of the carrier or ground station as well as the relative bearing of the destination.

Altitude information, both actual and ordered, is displayed on two number wheels in the altitude indicator. The aircraft altitude is derived from an altitude-sensing cell whose synchrotel output goes to a servomechanism amplifier in the converter. The amplifier drives the number wheel of the altitude indicator through a motor and gear train.

A Bourdon gage moves the air-speed pointer on the indicator. In addition, a synchrotel directly coupled to the Bourdon gage output drives a servomechanism amplifier that is used to turn a resolver to encode the air speed of the aircraft for transmission to the surface.

The cross pointer is connected to perform the dual functions of an instrument low-approach or a ground-controlled-approach indicator using the data link. The 31 ready-made messages previously mentioned are displayed directly as clear-language messages on a movable tape incorporated in the ready-made-data-display unit. The messages are centered in a small window in the upper half of the instrument face. The lower half of the instrument face contains an identical decoding unit that is used to display the modes. Between these two windows is housed the system flag alarm, which will drop when an address has not been received for a period longer than 15 seconds. While the encoding of the air-to-surface telemeter data is done automatically by resolvers in the various instruments, the acknowledgments of new commands and the 31 air-to-surface ready-made messages are initiated by the pilot. New commands are acknowledged when the pilot depresses the timer button on the particular instrument involved, while the ready-made messages are sent by pushing the appropriate button on the *AN/ARN-26* control panel. Adjacent to each button is displayed the clear-text message that is sent to the ground. There are four categories of messages, which can be changed by a knob at the bottom of the panel. The control panels for the *AN/ARN-26* and *AN/ARN-21* are shown in Figure 4 together with the *AN/ARN-26* instrument group.

Figure 4—Controls panels for *AN/ARN-26* and *AN/ARN-21* and instrument group for the *AN/ARN-26*.

A detailed description will be given of the *AN/ARN-26* system proper. Figure 5 is a functional block diagram of the equipment. The desired information in the video signal from the *AN/ARN-21* is in the form of pulse pairs that are separated from the other information in a specially designed pulse-pair decoder in the *AN/ARN-26*, Figure 5A. The pulse-pair decoder is biased to discriminate against black noise to minimize interference from noise and jamming. The philosophy is that the probability of a pulse being knocked out is much smaller than that of a pulse being added somewhere in the message. In decoding, the pulse pairs are converted into single pulses that are regenerated into 5-microsecond 100-volt pulses and distributed to various parts of the equipment for decoding. The pulse-pair decoding process is described in detail[3] in another paper.

The two start pulses occurring immediately after the auxiliary reference burst are decoded by a 40.5-microsecond delay line in the start-pulse decoder that locks the phase of a high-stability oscillator. The output of the time base drives a pair of power amplifiers, one generating

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[3] E. R. Altonji, E. A. Kunkel, H. G. Whitehead, and R. Mead, "Techniques Developed for Airborne Tacan Data Link," *Electrical Communication*, volume 34, pages 243–263; September, 1957.

a sine function and the other a cosine function. These outputs time the airborne system. When the start pulses have been properly decoded and the time base is phase-locked to the synchronizing signal from the surface station, a negative drive consisting of a 125-volt 20-microsecond pulse is applied to the 700-microsecond delay line from the start-pulse decoder. This negative pulse is used to form address-decoding gating waveforms that are mixed in negative *or* gates and an address-encoding card. The resulting gating waveforms are then grouped by the address card to correspond to the address, including its variants, for that particular aircraft. The remaining gating waveforms are grouped in the no-go intervals, which are those time intervals that are not supposed to contain address pulses. The actual decoding is then done in the address decoder. The operation of the address decoder will be described in more detail later on.

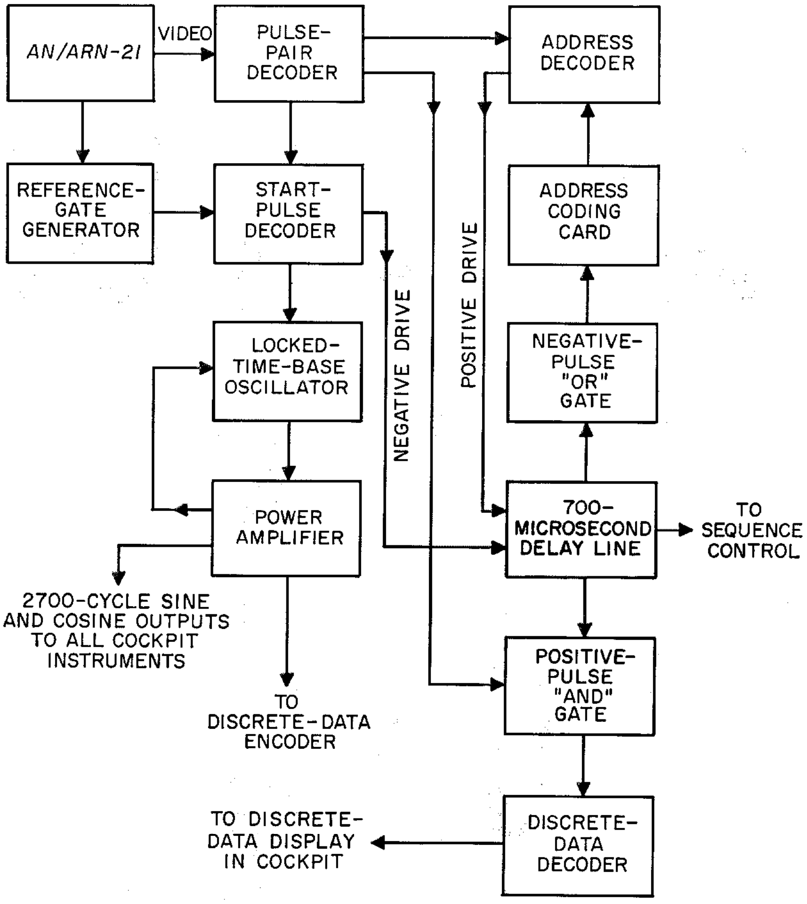

Figure 5A—Address and discrete-data decoder.

The proper receipt of an address applies a positive 125-volt 20-microsecond pulse to the same delay line from the address decoder for use in decoding the discrete data, which includes the 31 ready-made messages. The positive pulse traveling down the line successively actuates a series of *and* gates. The video signal from the pulse-pair decoder is applied to the other input of the diode *and* gates. When coincidence is obtained, the pulse output is stored in a register in either the ready-made-message decoder or the discrete-data decoder. These are shown under the latter name lumped together in one functional box on the block diagram. All discrete data with the exception of the 31 ready-made messages together with their parity check are stored in thyratrons that operate relays. The 31 ready-made messages are stored in vacuum-tube flip-flops with relays operating through buffers. This arrangement allows sufficient time for resetting the thyratrons in the discrete-data decoder when an address is received. The discrete-data display instrument in the cockpit is operated by the relays in the discrete-data decoding circuits.

Immediately following the decoding of the last discrete datum, which is the distance new command, the time-base synchronization check pulse is compared with a pulse formed from the output of the power amplifier. If the pulse formed from the power amplifier and the pulse sent from the ground coincide within a certain tolerance, the telemeter-data decoding is begun by driving the 1500-microsecond delay line from the power amplifier through the sequence control with a 225-volt 135-microsecond pulse. This is shown in Figure 5B.

This pulse is positive and is tapped off at appropriate times on the line successively to gate each of the telemeter-data decoders. Each of the telemeter-data decoders then searches for a pulse during the period when the gating waveform is applied to it. The pulse is extracted during this time and applied in the decoder to a pulse phase detector where the position of the

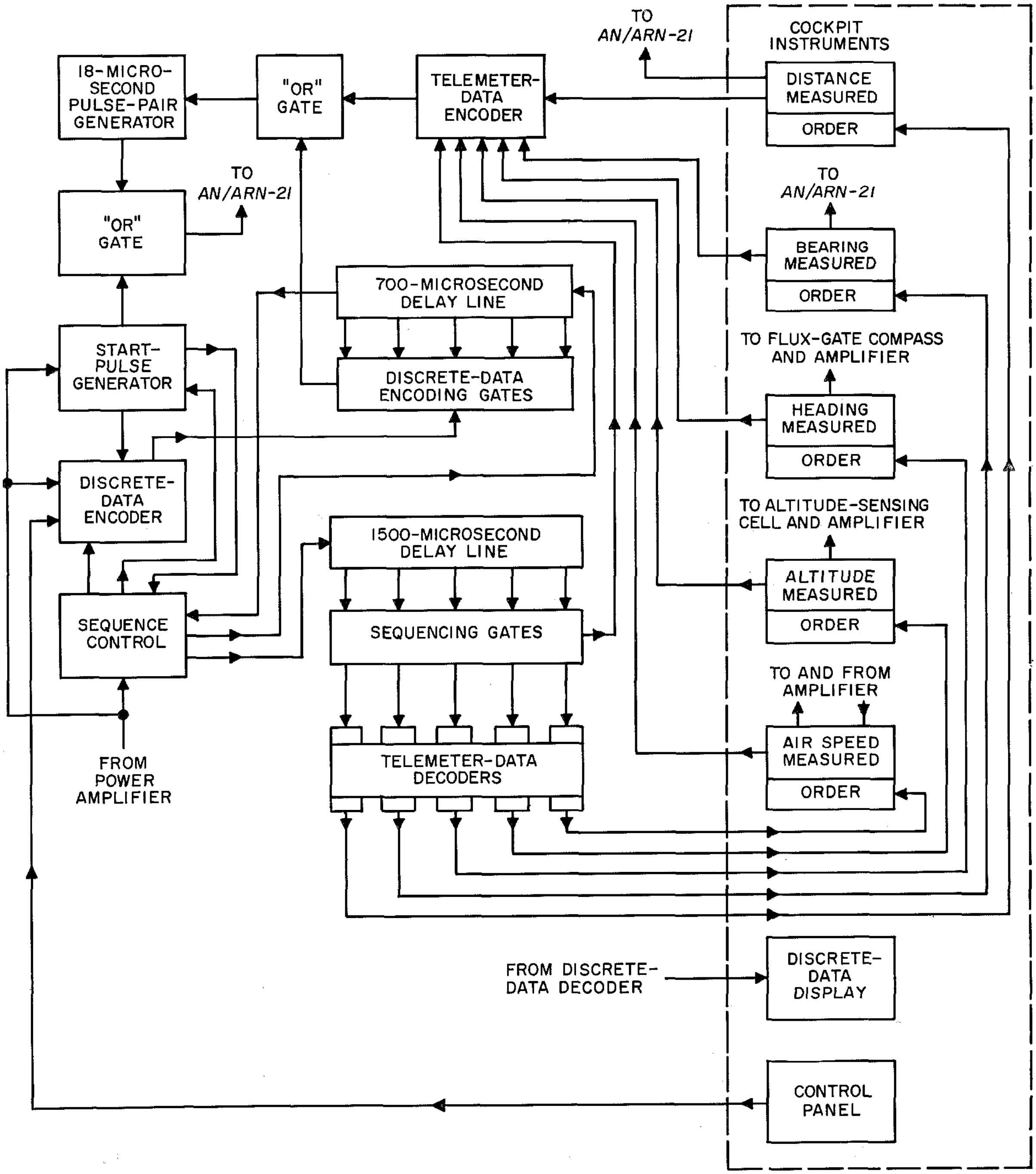

Figure 5B—Airborne equipment pulse-pair decoder.

pulse is compared with the positive zero crossing of the sine-wave output from a resolver on the order shaft of the instrument. If the zero crossing and the pulse do not coincide, as will normally be the case when orders are being changed from message to message, the phase-detector output will be proportional to the time displacement between the zero crossing and the pulse, and a corrective voltage will be applied to correct its position until the zero crossing and the pulse coincide. When coincidence is within ±5 degrees, a fine gate is put around the expected position of the telemeter-data pulse to give added protection against noise. Telemeter-data decoding is described in detail in another paper.[3]

The sequencing and encoding of the air-to-surface reply begins immediately after the decoding of the last telemeter datum. This is done by gating the positive output of the 1500-microsecond delay line against a pulse formed from the output of the power amplifier in a pentode coincidence gate not shown in Figure 5. The output of this gate will then fire a blocking oscillator thereby sending a 135-microsecond positive pulse down the 700-microsecond sequencing delay line to actuate the discrete-data encoding gates. The other input to these encoding coincidence gates is the output of the discrete-data encoder, which consists of a series of phase-shifting networks and pulse formers. Varying amounts of pulse shifts are used in the discrete-data encoder to position the pulses in the discrete-data portion of the air-to-surface reply. The resultant phase-shifted pulses are released by the gating waveforms from the 700-microsecond delay line and pass through an *or* gate to a generator producing pulse pairs having 18-microsecond spacing.

The telemeter-data encoding process is essentially the same, except that instead of using discrete phase shifts, the sine-wave output from a resolver geared to the measured condition of the aircraft is used to form the pulses for the telemeter-data portion of the reply. These pulses are gated against the sequencing gates from the 1500-microsecond line and then combined in an *or* gate with the discrete data. The output of this *or* gate actuates a pulse-pair generator that forms an 18-microsecond-spaced pulse pair from each of the single pulses.

The start-pulse triplet is formed by suitable phase shifting of the output of the power amplifier and transmission of the phase-shifted output to three separate pulse formers. The position of these pulses is made adjustable, so that their spacing with respect to each other and with respect to the remainder of the message can be varied. The start pulses are gated against the output of the 700-microsecond delay-line-drive blocking oscillator and then regenerated by a blocking oscillator whose output is combined with the pulse-pair-generator output in an *or* gate. The output of this *or* gate is then regenerated and sent over a cable to the *AN/ARN-21* modulator.

The *AN/ARN-21* modulator has been modified so that it can handle the higher short-term duty cycle imposed by the *AN/ARN-26* air-to-surface message. The physical size of the modulator has remained the same, however, despite numerous circuit modifications. The capacity of the modulator after conversion is a maximum rate of 10 air-to-ground messages per second in addition to the normal distance-measurement interrogations. The only other modifications necessary in the *AN/ARN-21* were the addition of a cathode-follower to extract the video signal from the receiver before pulse-pair decoding. The remaining addition to the *AN/ARN-21* was a lead from the rear plug to the modulator that carries the address-receipt pulse used to blank the distance-measuring pulses during the transmissions of the air-to-surface message.

A block diagram of a start-pulse decoder is shown in Figure 6. As was mentioned previously, the auxiliary reference burst from the *AN/ARN-21*, while not used directly to synchronize the airborne time base, is used to protect the actual start pair that provides for synchronization. The reference pulse, which is derived from the *AN/ARN-21* auxiliary reference burst, goes to a reference-gate generator in the *AN/ARN-26*. The reference gate straddles the start pulse pair, which follows the reference burst, and provides one gating waveform to a three-way diode coincidence gate. The delayed start pulse pair forms another input to this coincidence gate along with an inhibiting pulse that is derived from a tap 12 microseconds from the end of the 40.5-microsecond line. This inhibiting signal is inverted in polarity by a transformer and consists of the reference burst and start pulse pairs; it prevents accidental locking to every fourth reference pulse. The output of this diode *and* gate consists of only the first delayed start pulse since the reference gate closes immediately after the second start pulse and before passing through the delay line. The gate output goes to a pentode coincidence gate located in the master time base, where it is gated against the undelayed received pulse as well as a direct-voltage bias applied to the control grid of the pentode. Coincidence then occurs between the second undelayed start pulse and the first delayed start pulse, resulting in a negative output from the pentode that is inverted and impressed on a diode coincidence gate. The pentode output also goes to a pulse phase detector, which compares the position of the decoded start pulse with the positive zero crossing of the sine waveform from the power amplifier, thus generating an error signal proportional to the time displacement between the pulse position and the zero crossing.

When the time base has been locked to the surface reference pulses to within ±3 microseconds, coincidence occurs in a diode *and* gate between the pentode inverted output and the narrow gate derived from the time base. The output of this diode *and* gate actuates a blocking oscillator in the address decoder to form a start-receipt pulse. The integrated start-receipt pulses operate a relay that removes the direct-voltage bias from the pentode grid and substitutes the narrow gate in its stead as an additional noise protection.

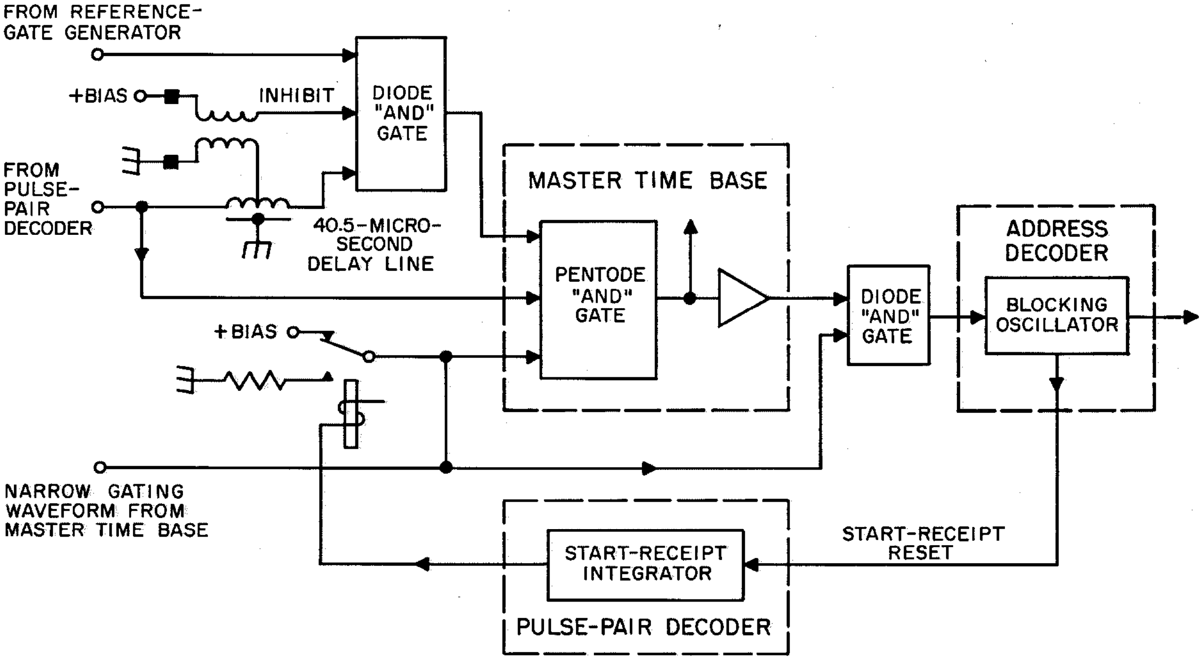

Figure 6—Block diagram of start-pulse decoder, the relative position of which may be seen in Figure 5A. The start-receipt integrator, on receipt of two pulses, will operate the relay to remove the bias from the pentode gate and apply the narrow gate waveform from the master time base. If three pulses are missed, the relay is released for the search condition.

In Figure 7, the decoded start pulse is applied to the 700-microsecond line to decode the address. A negative *or* gate consisting of 12 diodes is connected to the line and picks off the gating waveform at suitable time intervals as it travels along the delay line. The last three taps (for the variants) are connected through contacts on relays that are energized from the variant selector on the control panel.

An address-coding card peculiar to each aircraft sorts the gating waveforms between a *go* line and a *no-go* line. The gating waveforms on both the *go* and *no-go* lines are inverted and applied to their respective coincidence gates where they are gated against the received signal. Thus, a gating waveform on the *go* line at the time interval in which a pulse appears in the received signal sends that pulse to the address counters.

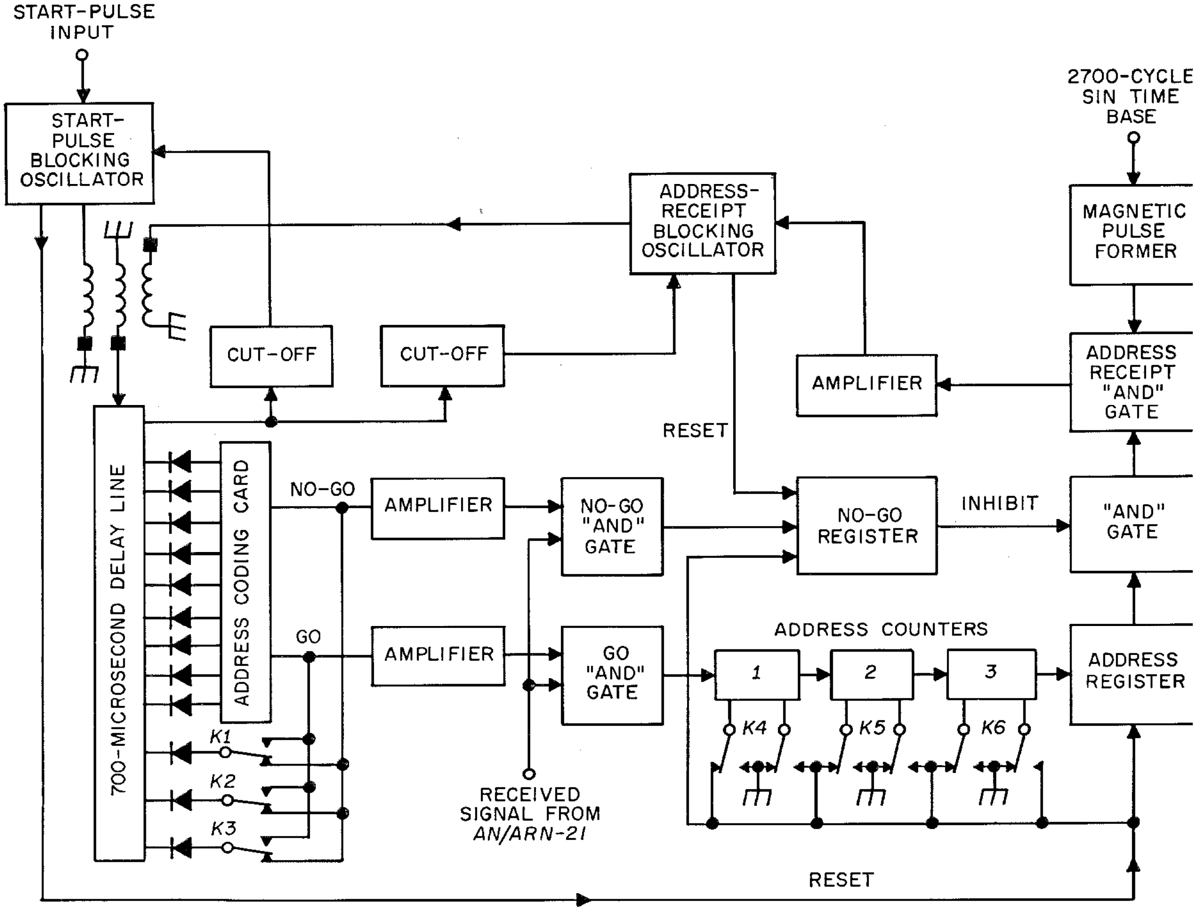

Figure 7—Address decoding circuit.

If a pulse is received at the time when the gating waveform is on the *no-go* line, when no pulses are to appear for that particular address, the pulse actuates the *no-go* register to inhibit further response to that coded address.

At the output of the *go*-line coincidence gate is a 3-bit binary counter, which has been previously reset by the start pulse. This counter can be reset to count any number from 4 through 7 depending on what variant the particular address contains, the number to which they are set being determined by the setting of the three relays, *K4*, *K5*, and *K6*, which are operated by the address-variant selector on the control panel. This system is used to make certain that none of the proper address pulses, including variants, have been lost. If such is the case, then the count will not progress far enough to set the address registers; and no gating waveform will be applied to the *and* gate actuated by the address register. If all the proper pulses are present, the address register is set and a gating waveform is applied to the following gate.

The *no-go* gate scans all the time intervals that should not contain pulses for the particular address. If a pulse appears in any of these time intervals, a *no-go* register consisting of a simple flip-flop circuit is set by the pulse and will inhibit the address-register pulse from passing through the gate common to these two circuits. However, if no pulses occur in the *no-go* intervals, the *no-go* register will continue to supply a

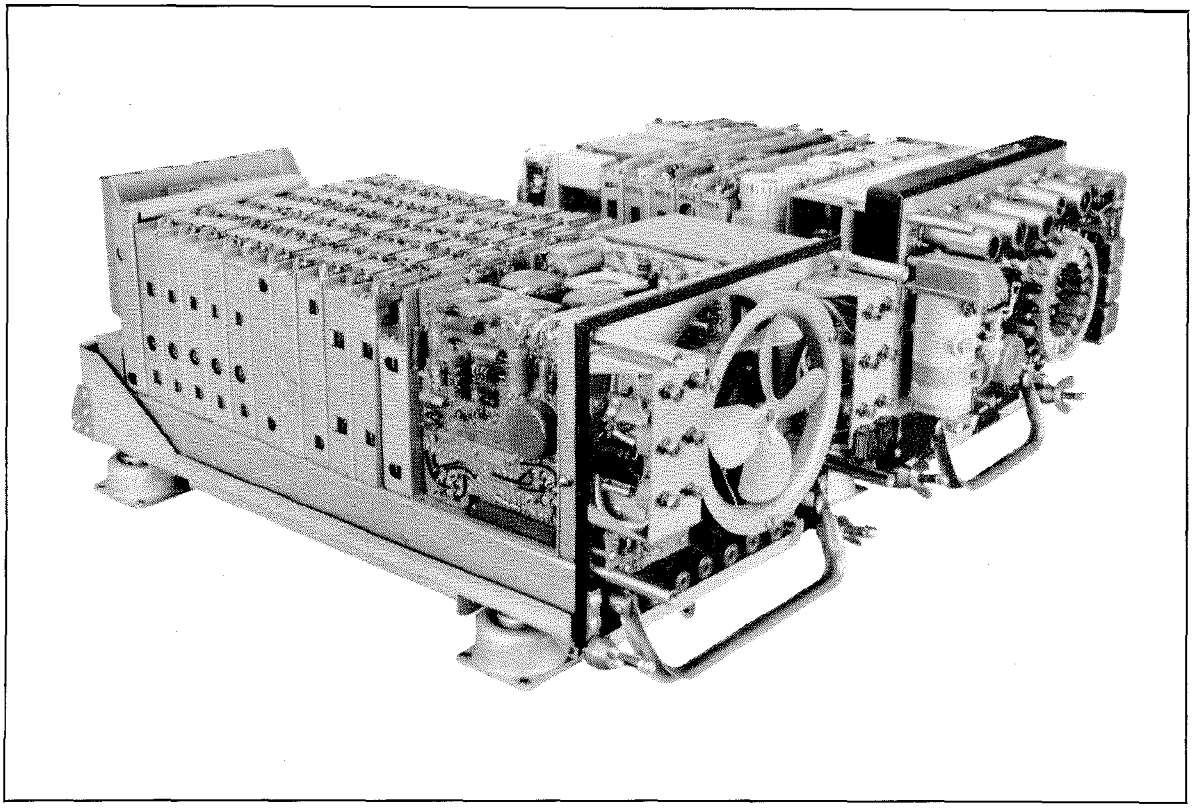

Figure 8—Data-signal converter at left and *AN/ARN-21* tacan set.

gating waveform and the address-register pulse passing through the gate can fire the address-receipt blocking oscillator when it coincides with a pulse derived from the 2700-cycle locked time base. As soon as this is done and a proper address had been decoded, the address-receipt pulse starts down the delay line to encode the discrete-data message. At the same time, the *no-go* register is reset by the address-receipt pulse. Failure to reset the *no-go* register will result in the address-receipt blocking oscillator being fired every 370 microseconds, the period of the 2700-cycle sine wave.

Since the data link is multiplexed on the normal tacan signal, no additional radio-frequency equipment is required. The complete signal-data converter is housed in a full *ATR* chassis, which is in the foreground of Figure 8. In the background is a standard *AN/ARN-21* tacan equipment. The weight of the complete signal-data converter, together with the covers and shock mount, is approximately 50 pounds (23 kilograms), while the total weight of the airborne equipment including the modified instruments and the *AN/ARN-21* is approximately 160 pounds (75 kilograms). The signal-data converter uses 159 vacuum tubes and occupies 1790 cubic inches (0.03 cubic meter) of space. To facilitate maintenance, modular construction has been used. Thus, by substitution of individual modules in the event of failure, it is possible to keep any particular equipment operating almost continuously.

In the signal-data converter, the power supply is mounted directly behind the front panel with the power-amplifier chassis adjacent to it. All tubes in the various subunits are mounted on top with a $\frac{5}{8}$-inch (16-millimeter) clearance between the top of the tubes and the dust cover so that a layer of air is forced over the tubes by the fan when the dust cover is on and is exhausted at the rear through dripproof vents. A temperature rise of 30 degrees centigrade above ambient was noted in the exhaust air. However, it is expected by improved venting in the rear to reduce this rise to 20 degrees. The controls on

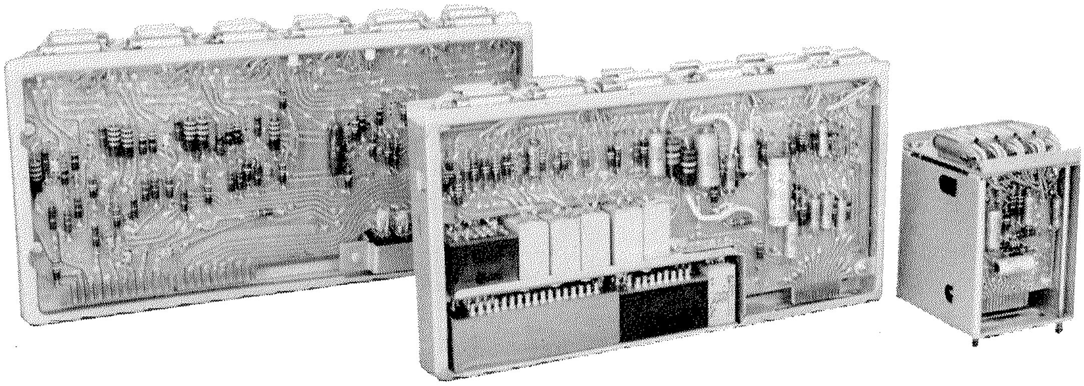

Figure 9—Typical subunits.

the two brackets mounted next to the fan provide for fine zero adjustment of the instruments. The magnetic amplifiers that drive the motors in the order section of each instrument are housed in the shock-mount tray. These circuits are completely passive and require almost no maintenance.

Typical subunits are shown in Figure 9. From left to right are the ready-made-message decoder, the pulse-pair decoder, and the servoamplifier chassis for the heading and air-speed servomechanisms. Printed circuits have been used throughout the unit except for the interchassis wiring in the base chassis. Printed circuits are incorporated in the preproduction prototypes designed since these evaluation equipments were built.

The control panel for the *AN/ARN-26*, shown in Figure 4, employs a set of sliding metallic panels operated by a cam to display four different sets of messages. A bank of four microswitches mounted behind each push button changes the inputs to a logic network mounted in the panel so that the 31 ready-made messages are properly encoded.

Address variants (*A* through *H*) are selected by the knob mounted on top of the message panels, while the *AN/ARN-21* panel permits the selection of any one of 126 radio-frequency channels assigned to the ground beacons.

Techniques Developed for Airborne Tacan Data Link

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EARLY in the development of the tacan data link, it became obvious that new techniques would have to be developed and existing techniques refined if the airborne equipment was to perform its functions and yet be of reasonable size, weight, accuracy, and complexity. In addition, it was necessary that the airborne equipment operate under conditions of noise and interference. Information had to be stored without deterioration from message to message and without the use of complicated circuits. It was desired that the complete coding equipment fit into a full *ATR* chassis.

It was realized that meeting these conditions was not entirely a matter of developing suitable techniques but that the code played a highly significant part and it was imperative that the techniques utilize the code to maximum advantage. For example, the advantage of coding the message into 12-microsecond pulse pairs could easily be lost by improper detection of these pulse pairs.

Since the data link is only as good as its time base, a great deal of attention was given to the problem of synchronizing the airborne time base with the surface time base. Extreme care has been taken to achieve both high accuracy in the phase lock of the time base and to protect the synchronizing signals against noise.

The problem of decoding, displaying, and storing analog information received from the surface afforded perhaps the greatest area for achieving economy in the airborne equipment. This economy and simplicity has been achieved by using the surface-to-air signals to correct the difference between stored information and new information rather than using new information to set the absolute position of each instrument shaft. Therefore, the information displayed is accurate as of the last received message.

Since the data link was designed for two-way operation, it was imperative that economical methods be found to decode the surface-to-air message and to sequence and encode the air-to-surface message without making the airborne equipment so bulky and heavy that it would destroy the feasibility of the system. Transistors were still in a very-early stage of development at the time many of the circuits were devised so the use of vacuum-tube techniques was an absolute necessity. This precluded the use of shift-register techniques for decoding and sequencing.

It was therefore decided that delay lines offered the most feasible, reliable, and best solution from the viewpoint of size, weight, and power consumption. Therefore, a very-intensive program of delay-line development using lumped-constant techniques was initiated. This has resulted in the development of an extremely compact high-performance type of lumped-constant line.

The necessity of generating narrow rapidly rising time pulses from sine waves throughout the airborne equipment would have created a tremendous problem in the number of vacuum tubes and diodes required if conventional clipping and differentiating techniques were used. It was decided that magnetic pulse formers offered the most-feasible solution to this problem. Existing magnetic pulse-forming techniques were unsatisfactory as regards pulse width, amplitude, and rise time. Therefore, a study was made of the general problem. The development of regenerative pulse formers resulted and they are incorporated throughout the airborne equipment. This article is devoted to a discussion of the designs and applications of some of the unique techniques utilized in the *AN/ARN-26* equipment.

1. Pulse-Pair Decoder

The *AN/ARN-26* airborne data-link equipment operates from information from the video-signal decoder of the *AN/ARN-21* airborne tacan receiver. This signal is in the form of pulse pairs that are amplitude modulated in accordance with the tacan bearing information.[1,2] Before any information is supplied to the data-decoding circuits of the *AN/ARN-26*, the pulse pairs must be separated from the noise and converted into single pulses.

Although this function of pulse-pair conversion is performed in the video decoder of the *AN/ARN-21*, the requirements of an avigational device and of a data link are considerably different. Since the distance-measurement replies are handled on a statistical basis, missing a desired pulse may be just as serious as accepting a noise pulse.

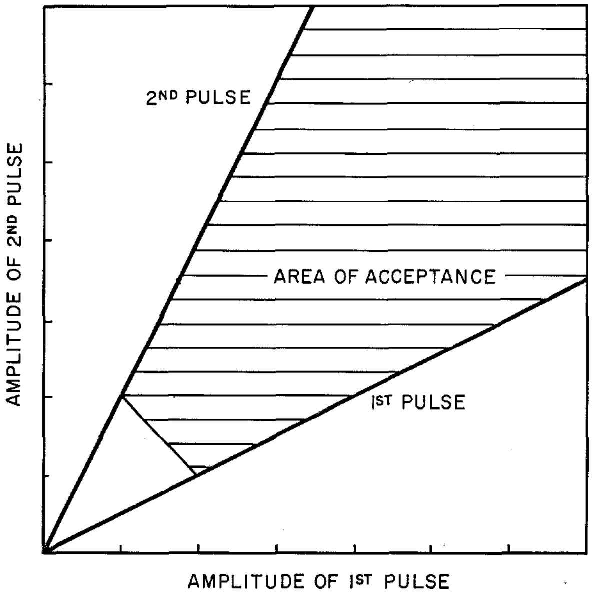

Figure 1—Idealized graphical representation of the amplitude ratio of the two pulses in a pair to be decoded. The limit of acceptance at small pulse amplitudes is set by the average signal level.

The data link must be capable of operating at service rates as slow as one message in 15 seconds, so the input signal must be carefully guarded against unwanted signals, interference, and noise. If a message or part of a message is missed, the old information will be retained. It is, therefore, more important to reject unwanted signals than to accept all desired signals. The pulse pairs to be decoded are approximately 3.5 microseconds wide and are spaced 12 microseconds apart. The pulse-pair decoder must be capable of accepting only those pulses that meet the following requirements.

A. The pulses must be spaced 12 microseconds apart.

B. The amplitudes of the two pulses of a pair must be within a ratio of 2:1 to preclude the possibility of decoding a single pulse and a noise burst as a pulse pair.

C. The sum of the amplitudes of the two pulses of a pair must exceed one-half the sum of the amplitudes of the accepted pulse pairs averaged over a sufficient time to prevent decoding low-amplitude pulse pairs. This level discriminator must be capable of following the modulation envelope.

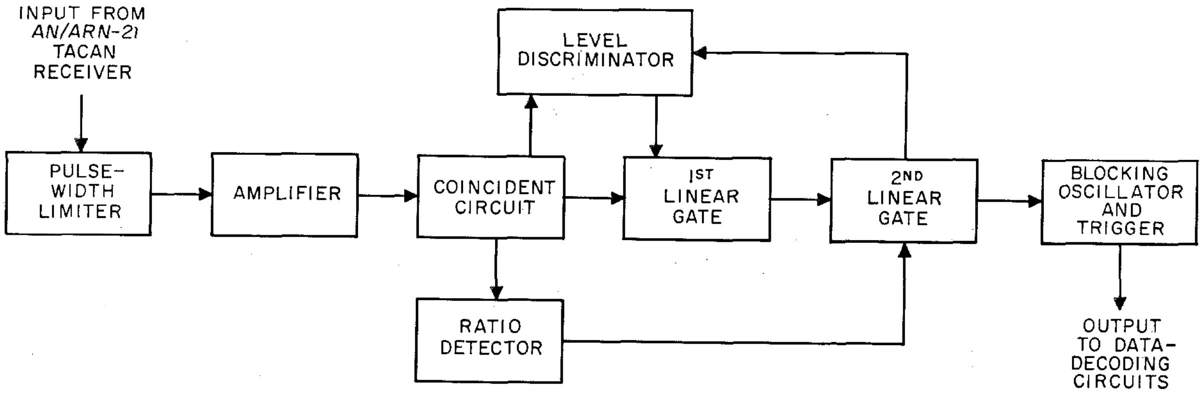

Figure 2—Pulse-pair decoder.

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[1] R. I. Colin and S. H. Dodington, "Principles of Tacan," *Electrical Communication*, volume 33, pages 11–26; March, 1956: page 18.

[2] S. H. Dodington, "Airborne Tacan Equipment AN/ARN-21," *Electrical Communication*, volume 33, pages 60–64; March, 1956: page 60.

Figure 1 shows the desired area of acceptance for 12-microsecond pulse pairs as a function of the amplitudes of the two pulses of a pair. Ideally, the area of acceptance should be a contour enclosing the signal level. This contour would move back and forth along the line of equal pulse amplitudes. However, because of the practical limitations of size and weight, the area shown in Figure 1 was chosen as a reasonable approximation to the ideal.

Figure 3—Oscillograms showing at the right the 3.5-microsecond limited pulses resulting from the action of the short-circuited delay line on the long pulse shown in the left part of the picture.

Long noise or interference pulses could create serious trouble by driving stages beyond their linear range, appearing as pulse pairs, or masking actual pulse pairs. To guard against such signals, a circuit was incorporated into the decoder to limit the length of any incoming signal to 3.5 microseconds without discarding actual signal pulses that may occur during the noise pulse. It became evident early in the development of the data link that the major portion of a subchassis would have to be allotted to the pulse-pair decoder. A block diagram of the decoder appears in Figure 2.

Pulse-width limiting is accomplished by a 1.75-microsecond short-circuited delay line. This method has the obvious advantages over a simple resistance–capacitance differentiator of maintaining a flat top during the receipt of a pulse and still reducing a long pulse to a negligible amplitude after 3.5 microseconds. The effectiveness of this circuit is shown in Figure 3. To improve the signal-to-noise ratio, this delay line is preceded by a short section of line having a rise time only slightly shorter than the expected rise time of the received pulses.

In the amplifier, the pulses are increased to as high a level as practicable with the available supply voltages. The use of high-level signals helps to overcome the difficulties presented by the finite grid bias of the tubes used in the ratio-detector and level-discriminator circuits.

A schematic diagram of the ratio detector and coincidence circuit appears in Figure 4. Negative-going pulse pairs are coupled into the circuit through the center-tapped transformer *T1* and pass through a resistive network, *R1* and *R2*, giving a 3:1 attenuation at the input to a 6-microsecond delay line. Idealized waveforms are shown in Figure 5. The first pulse of a pair is reflected from the end of the 6-microsecond open-circuited delay line and returned to the input 12 microseconds later, so as to reinforce the second pulse. Tubes *V1* and *V2* are normally conducting. As shown in Figure 5, a positive output cannot be obtained unless both tubes are rendered nonconducting by the receipt of a negative pulse pair of the proper amplitude ratio. A single pulse will drive one tube into the positive-grid region, thereby giving a negative output. The requirement for tube *V1*

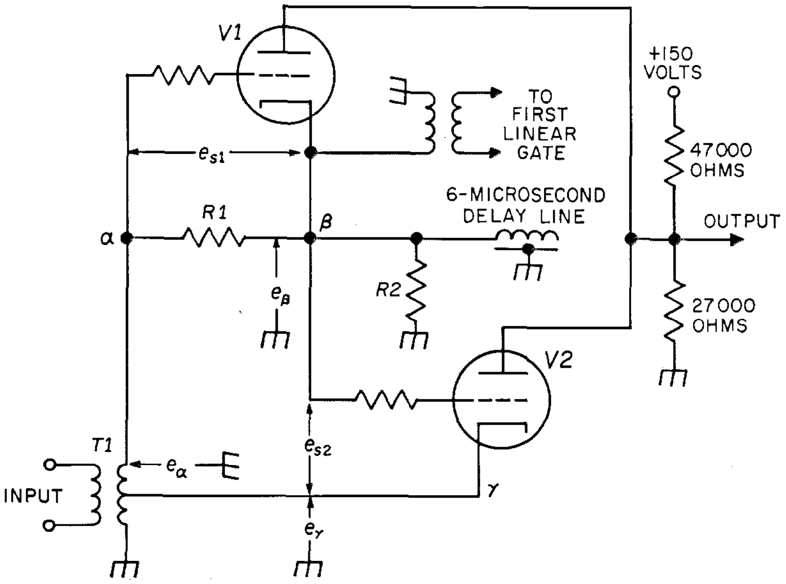

Figure 4—Ratio detector and coincidence circuit for decoding pulse pairs.

being driven to cutoff is

$$3B > A + B$$
$$2B > A$$
$$B/A > 1/2$$

Tube *V2* will be cut off if

$$(A + B)/3 > B/2$$
$$2(A + B) > 3B$$
$$2A > B$$
$$2 > B/A$$

where A and B are the amplitudes of the first and second pulses, respectively.

The requirement for acceptance of a pulse pair by the ratio detector are

$$2 > A/B > 1/2$$

and the pulses must be spaced 12 microseconds apart.

The curve of Figure 6 shows the area of acceptance for pulse pairs having 12-microsecond spacing. Rejection of low-amplitude pulse pairs is handled by the level discriminator and will be discussed later. The pulse amplitudes were measured at the input to the pulse-pair decoder and, therefore, the deviations from the ideal curve include the effects of exceeding the linear range of the amplifiers preceding the ratio detector.

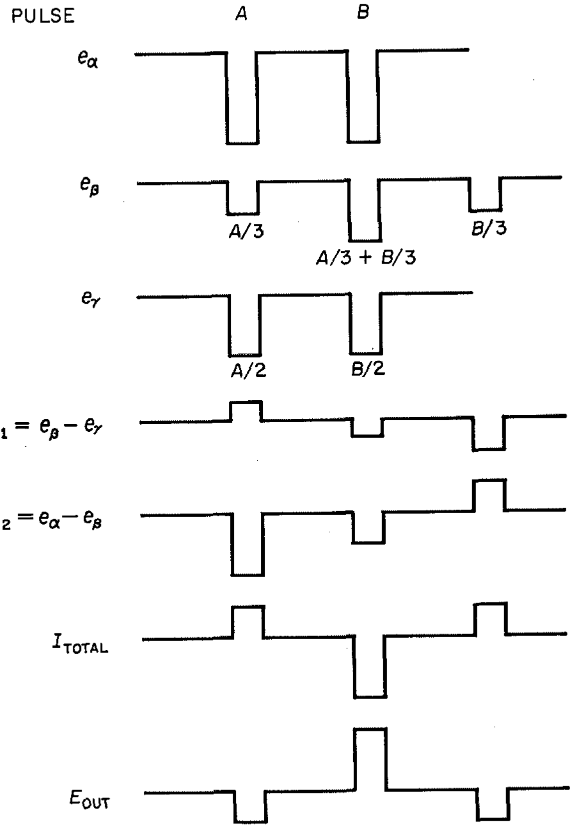

Figure 5—Idealized waveforms for ratio detector in decoding two pulses of equal amplitude with 12-microsecond spacing.

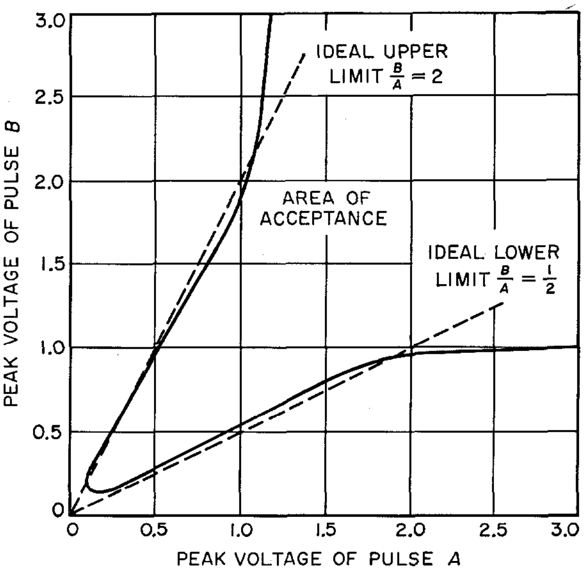

Figure 6—Area of acceptance of 12-microsecond pulse pairs for the ratio detector.

A ratio detector of this design serves the twofold purpose of detecting a 12-microsecond spacing between pulses and also accepting only those pulse pairs whose amplitude ratio is within the proper limits. The use of an open-circuited delay line allows 12-microsecond decoding with a 6-microsecond line, giving a saving in size and weight that is of prime consideration in airborne equipment.

The pulse triplet appearing at the input of the delay line goes to the first linear gate and also to the level discriminator. In the gating circuits, the triplet is gated against the output of the level discriminator and then against the output of the ratio detector. Each of these gates consists of a pentode with sufficient feedback to insure linearity over a range of at least 10:1.

The output of the second gate will contain only the reinforced second pulse of the pair, and its amplitude will be proportional to the sum of the amplitude of the two pulses. This signal then passes to an envelope detector and from there to the level discriminator to produce a direct voltage against which the pulse triplet appearing at the input to the delay line is compared.

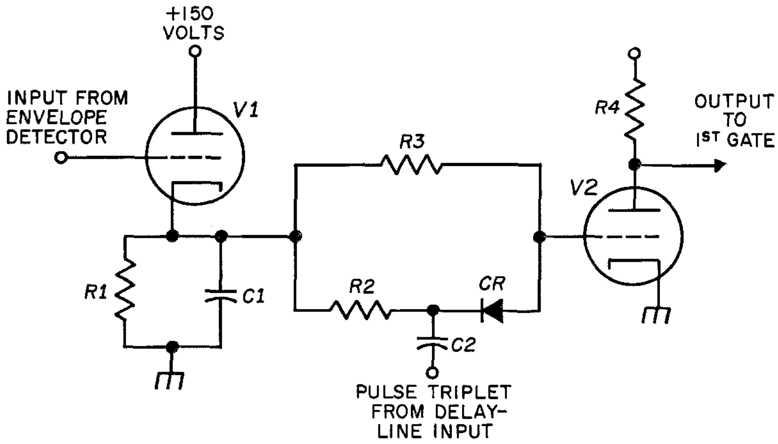

Figure 7—Level discriminator.

Figure 7 shows the schematic diagram of the level discriminator. The cathode of *V1* is held at a direct voltage determined by the output of the envelope detector. The anode of diode *CR* is clamped at ground potential by the grid of *V1* through a blocking bias on the diode equal to the cathode voltage of *V1*. Negative pulses whose amplitudes exceed this level make *CR* conductive and pass to the grid of *V2*, producing the positive output for the first linear gate. The time constant of *R1–C1* is such that the discharge may follow the fastest fall in the input signal, which occurs at the negative-going zero crossing of the 15-cycle component of the modulation envelope.[1,2]

Figure 8 shows the magnitude of the direct voltage at the cathode of *V1* in Figure 7 and the amplitude of the reinforced pulse plotted against the amplitude of the input signal.

Because of the limitations on the linear range of the amplifiers, it is possible for an extremely high-level single pulse to cause an output from the pulse-pair decoder. Tests indicate that pulses in excess of 12 volts will cause this trouble. However, the automatic-gain-control of the *AN/ARN-21* will hold the video signal below this value.

2. Delay Lines

Delay lines are used for decoding digital data and sequencing analog data, establishing pulse widths and spacings, and differentiating pulses. The required delays are as short as 1.75 microseconds for differentiation and as long as 2000 microseconds for sequencing. Ratios of delay-to-rise time are comparable to commercially available lines with shorter delays. To reduce size and weight, both positive and negative pulses are used on a line to double its effective use.

Because of the code structure used in the system, taps had to be provided at various intervals along the line to provide gating waveforms for decoding. These taps were placed at intervals equal to twice the permissible delay tolerance for the particular circuit under consideration. In this way, little reliance need be placed on manufacturing tolerances. This requirement set

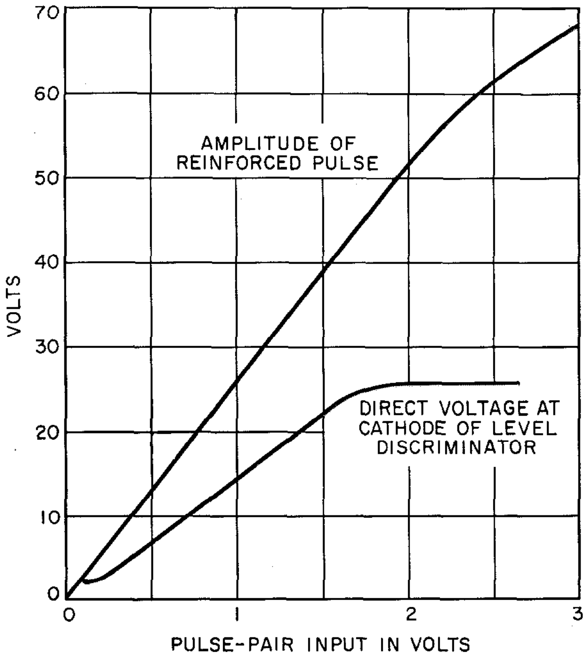

Figure 8—Signal levels in the level discriminator.

a maximum delay per section for a particular line.

The requirements for the lines, in addition to the usual requirements of delay-to-rise time and attenuation were as follows.

A. Small size and weight commensurate with the quality requirements for the line.

B. Taps at intervals along the line to actuate decoding gates.

C. Negligible undershoot because of the dual-polarity consideration.

D. Negligible delay changes with temperature changes.

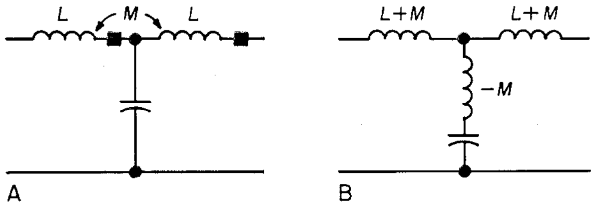

Figure 9—Delay-line section using a tapped coil. The equivalent electrical circuit is shown at *B*.

The long delays involved dictated the use of lumped-parameter lines. In the interests of size for a given-quality line, these lines consist of *M*-derived low-pass filters using $M \approx 1.27$. This value of *M* is achieved by use of coupled circuits in which a mutual inductance having a negative value is used for the shunt arm.[3] The schematic diagram of such a circuit appears in Figure 9.

The final design made use of the familiar unsymmetrical Pierce circuit, in which the coil is tapped near one end.[4] Schematic diagrams of this circuit and its equivalent appear in Figure 10.

Advantage was taken of the small size, light weight, and reproducibility of printed wiring for the interconnection of inductors and capacitors.

Ferrite pot cores offered the advantages of small size, light weight, high permeability, and reasonably flat temperature characteristics in the range from −55 degrees to +85 degrees centigrade. These cores may be stacked, one upon the other, to provide an extremely compact unit.

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[3] J. Millman and H. Taub, "Pulse and Digital Circuits," McGraw-Hill Book Company, New York, New York; 1956: page 296.

[4] Page 298 of reference 3.

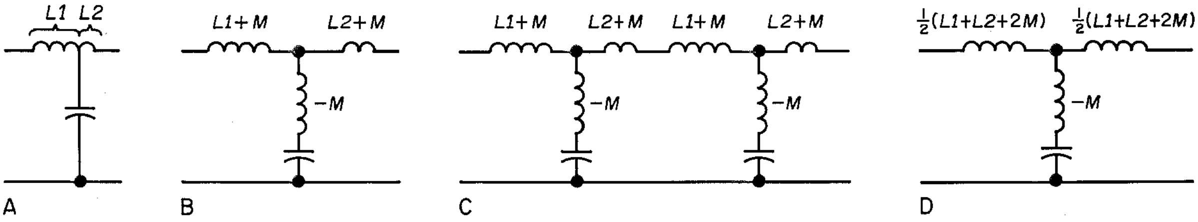


Figure 10—Unsymmetrical sections of delay line. *A* is the line using a tapped inductance. *B* is the equivalent electrical circuit. *C* is composed of two cascaded sections and *D* is its electrical equivalent.

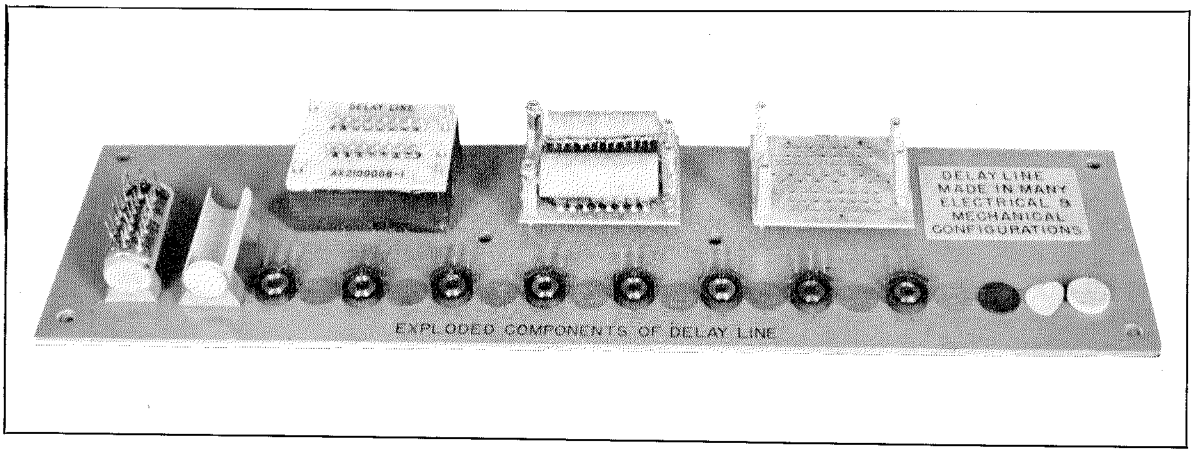


Figure 11—Photograph showing construction of delay lines.

An air gap was provided by the use of 0.01-inch (0.25-millimeter) mica spacers between adjacent cores. Approximately 60 percent of the reluctance of the path is in the air gap, which reduces the effects of variations in the characteristics of the cores due to temperature changes. The ferrite pot cores are provided with a three-terminal cap, which is cemented to the core. Leads from the coils are connected to these terminals.

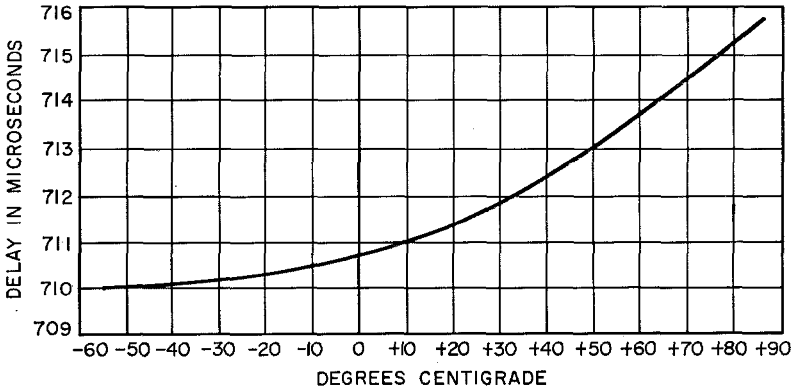


Figure 12—Effect of temperature on a prototype delay line designed for a 700-microsecond delay.

Two different types of assemblies have been used. The older method made use of a melamine tube in which the cores and mica spacers were stacked. A new method makes use of three rods fastened to end plates to support the cores. In each case, a circular spring is used to provide even pressure over the entire core.

The core assemblies and the capacitors are then placed in position on the printed board. Views of the delay-line construction appear in Figure 11. Stycast casting resin is used for encapsulating the unit.

The characteristics of the various lines are summarized in Table 1. Figure 12 shows the delay as a function of temperature for a prototype 700-microsecond line.

TABLE 1

DELAY-LINE CHARACTERISTICS

Total Delay t_d in Micro-seconds	Rise Time t_r in Micro-seconds	Decay Time t_d in Micro-seconds	Characteristic Impedance Z_0	Attenuation in Decibels	Number of Sections
711.9	14.90	15.87	4 700	8.4	160
2574.8	40.62	42.80	12 000	21.94	192
6.05	0.89	0.58	1 500	Negligible	14

Careful quality control in the manufacture of the coils is necessary to prevent excessive mismatches that could cause undersirable reflections on the line. Glass capacitors are used throughout in the interest of size, stability, and temperature characteristics and are supplied by the manufacturer within capacitance tolerance of 1 percent.

The photographs of Figure 13 show a pulse at intervals along the 700-microsecond line.

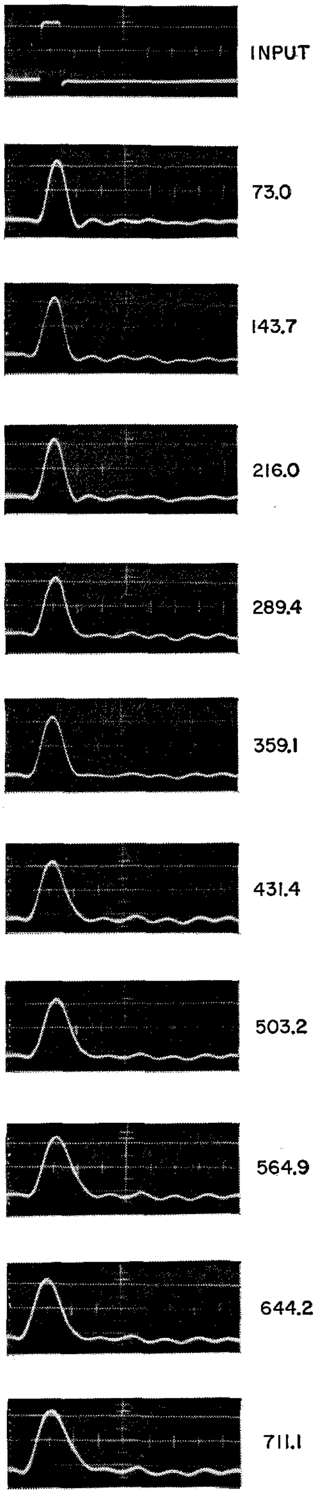


Figure 13—Pulse waveforms along the line at the indicated delays in microseconds.

3. Delay-Line Drives

To understand the problem of delay-line drives, the manner in which the delay lines are used will have to be explained. The delay lines are of the lumped-parameter type and by using positive and negative pulses, each line is used twice to conserve space and weight.

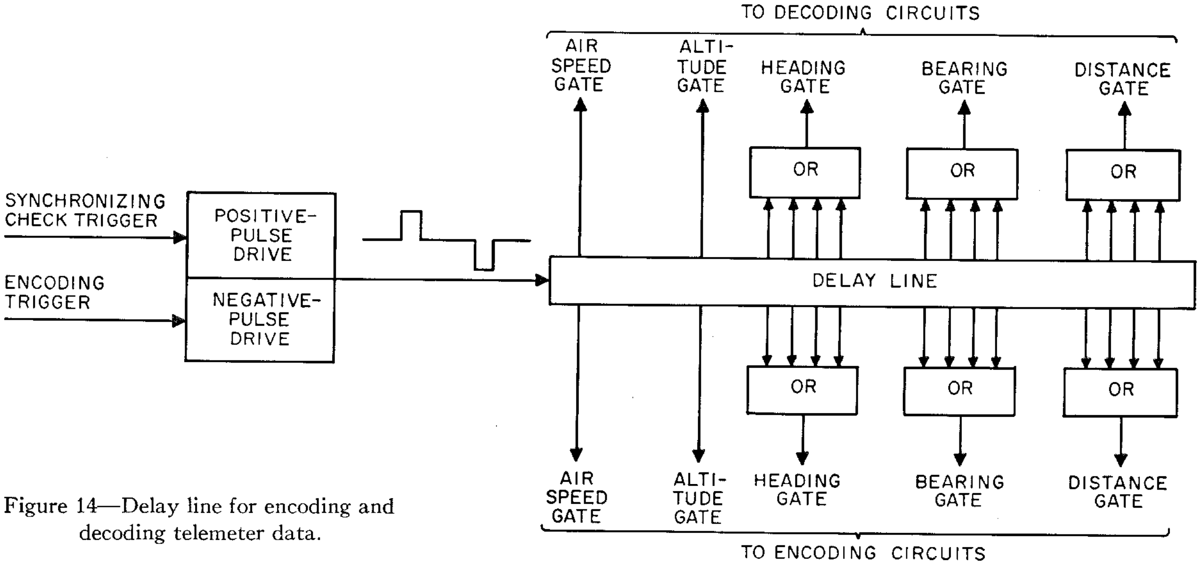


Figure 14—Delay line for encoding and decoding telemeter data.

A 700-microsecond delay line, consisting of 10 sections, decodes both the address and the discrete data in the surface-to-air message. The discrete data are composed of the ready-made messages, modes, scale changes, and new commands. The timing of these pulses is shown on the pulse code diagram.

There is a 1500-microsecond delay line that decodes the telemeter data and also encodes the air-to-surface telemeter data.

Figure 14 is a simplified diagram of the 1500-microsecond delay line. A positive pulse is transmitted along the delay line to generate decoding gates and a negative pulse is used to generate encoding gates. The 700-microsecond delay line is used in a similar manner to generate address decoding gates and discrete-data decoding gates.

The problem of pulse overshoot becomes important because of the use of positive and negative pulses to open selectively the *and* gates tapped off the delay line. If the negative undershoot from a positive pulse is great enough in amplitude, it will falsely activate the telemeter-data encoding circuits. This condition can also exist between the negative pulse and the telemeter-data decoding circuits.

The attenuation of the lines is appreciable because of the great time delays. For the 1500-microsecond delay line, an input pulse of 225 volts is needed to obtain a usuable pulse amplitude at the end of the line. For the 700-microsecond delay line, this problem is not so severe.

Figure 15 is the schematic of the drive circuit for the 1500-microsecond delay line. Tube *V2* is a blocking oscillator generating the positive drive pulse. It is plate-triggered by *V1*. A signal is tapped off the delay line and, through *V3*, turns off the blocking oscillator. This arrangement gives a very-constant pulse width. This same principle is used on the negative-drive blocking oscillator but, because of the negative polarity, the stopping pulse has to be inverted by *V7*. The driving blocking oscillators are designed so that maximum power is transferred to the delay line.

Resistors *R1* and *R2* divide the voltage swing across the plate of *V2* to impress 2/5 across the primary of transformer *T1* and the remaining 3/5 across the upper primary winding of transformer *T2*. About 25 volts are reserved for the blocking-oscillator-tube drop. Resistors *R1* and

R2 also provide sufficient damping for the blocking oscillators. Sufficient damping in this case means reducing the undershoots to a value that does not falsely activate the *and* gates connected to the delay line. Resistors *R3* and *R4* serve the same purpose for the negative-drive circuits.

The delay lines are terminated by a resistor equal to the characteristic impedance of the lines. Therefore no reflections occur at the end of the line. No effort is made to match the source impedance to the characteristic impedance of the delay lines. The voltage level generated by the source is of primary concern.

The 1500-microsecond delay line has a characteristic impedance of 12 000 ohms and the drive pulses are 225 volts in amplitude and 125 microseconds in duration. All vacuum tubes are of the subminiature type and the plate supply is 150 volts.

4. Telemeter-Data Decoder

The telemeter-data decoders operate on wide-deviation pulse-time modulation. There are five identical decoders. In the received message, there is a time interval allocated to each of the five telemeter-data units. These time intervals are established with respect to the start pulses that precede each message. Figure 16 shows the position and width of these time intervals in the message structure.

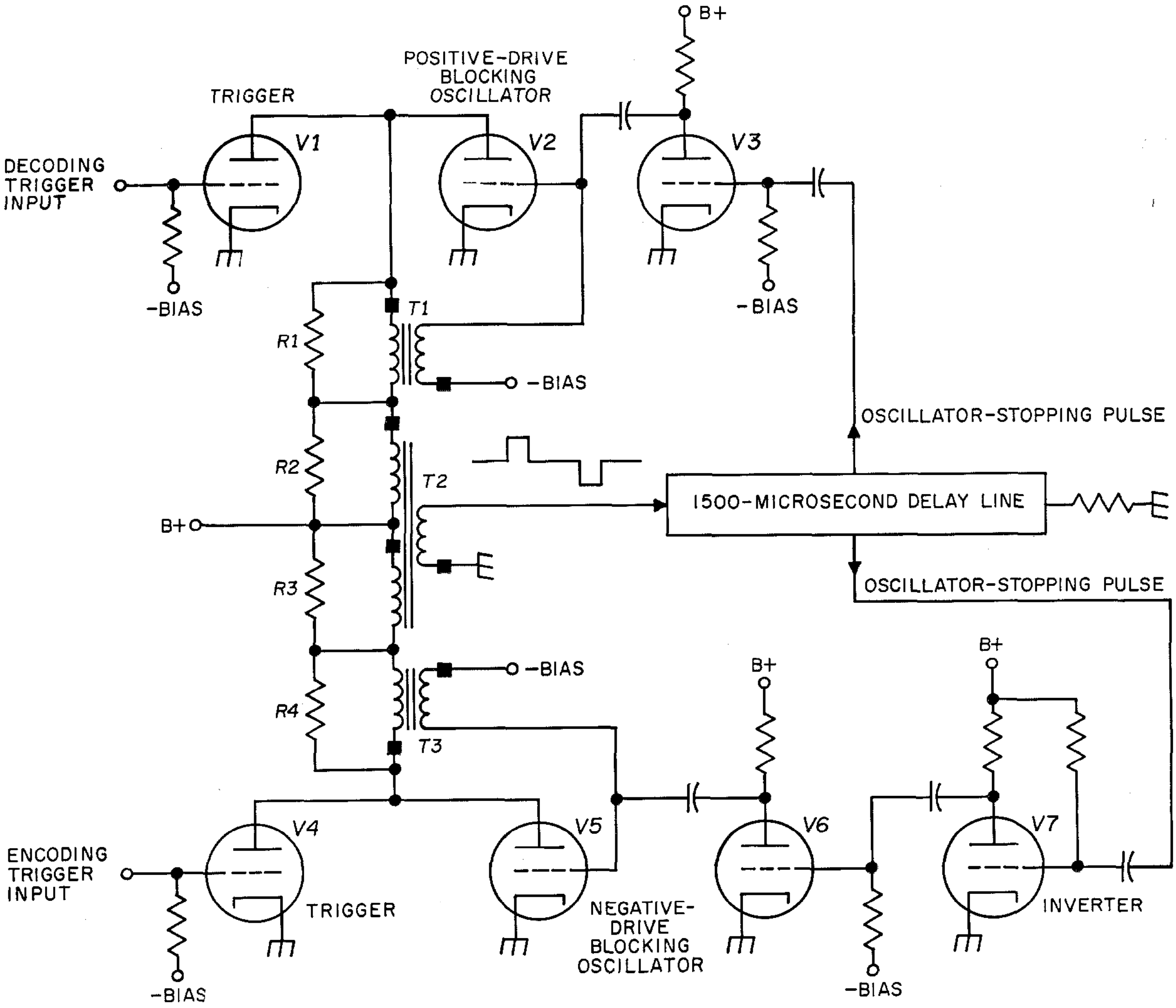


Figure 15—Drive circuit for the delay lines. This is a functionally symmetrical arrangement in which the upper half provides the positive drive pulses and the lower half the negative pulses.

The time intervals for the air-speed and altitude orders are equal to one quarter of the period of the 2700-cycle master time-base frequency, while heading, bearing, and distance time intervals are equal to one period of the 2700-cycle wave.

In each of the time intervals, the time position of a single pulse is varied and is to be interpreted as analog information that is displayed as a shaft position in an indicator. The indicator display may be either of the pointer or counter-wheel type.

To illustrate, assume we are concerned with the bearing order telemeter data having a range of 0 to 360 degrees. If the single pulse in the bearing order is at the right-hand end of the time interval as shown in Figure 17A, the bearing order indicator will read 0 degrees. If the pulse is in the center of the time interval, the indicator will be at 180 degrees as shown in Figure 17B. If the pulse is located a quarter of the way from the left-hand end, the indicator will be at 270 degrees as shown in Figure 17C.

Telemeter data are available to the decoders once and only once for each received message. The equipment receives messages at five different rates, which vary from one message every 6 seconds to 10 messages per second depending on the mode of operation of the system. For example, when put into the approach mode by the surface equipment, the *AN/ARN-26* receives messages at the rate of 10 times per second. In the traffic-control mode of operation, messages will be received at the rate of once every $3\frac{1}{3}$ seconds.

The desired dynamic range of the telementer-data decoders on any one message is ±30 degrees. In other words, assume the bearing order has been 0 degrees for 10 consecutive messages. On the next message received, the bearing order pulse position can be changed by any amount up to ±30 degrees; the airborne indicator pointer will move to the new bearing order position on receipt of this one message.

For air-speed orders, the dynamic range is ±217 knots (±403 kilometers per hour); for altitude, it is ±1700 feet (±519 meters) on the 5000-foot (1525-meter) scale; for heading, it is ±30 degrees; and for distance, it is ±16.6 miles (±30.8 kilometers). These order changes of

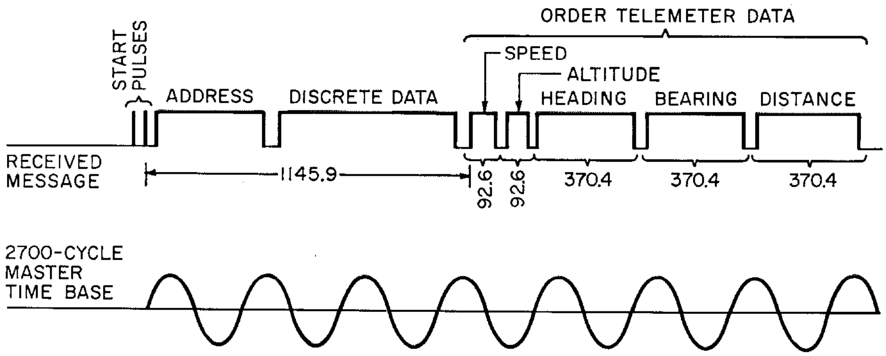


Figure 16—Structure of the surface-to-air message. The numerical values of time are in microseconds.

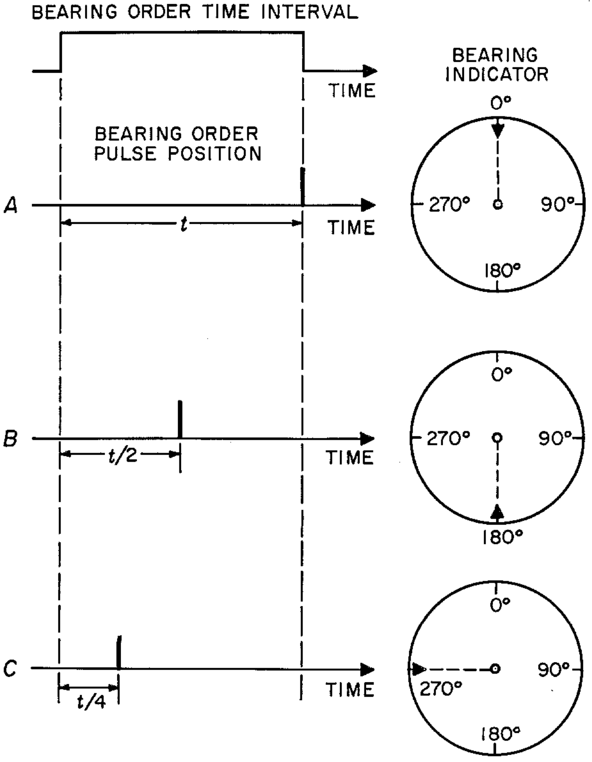


Figure 17—Pulse-position modulation is used for information on the angular position of a shaft. The full time interval *t* is 370.4 microseconds.

telemeter data correspond to equivalent values of pulse-time modulation.

The order telemeter-data decoders must store information for an infinite time since they are used in a static type of system as contrasted to a searching form of operation. The indicators are not activiated until a change in order is sensed. In the searching type of system, the indicators are normally activiated and are searching for an order signal on which they can lock. The static type of system is valuable because if transmission is interrupted temporarily, the last-received telemeter-data order will continue to be displayed. This is also helpful when operation is in a mode that produces only one message every 6 seconds.

Figure 18 is a block diagram of the telemeter-data decoder. It is essentially a sampling positional servomechanism system whose input is a single pulse, the time position of which can be varied through 370.4 microseconds. This input goes to a pulse-phase detector, which also receives a signal from a resolver in the indicator. The resolver in the indicator is energized by the sine and cosine 2700-cycle master time base. The output from this resolver is a constant-amplitude 2700-

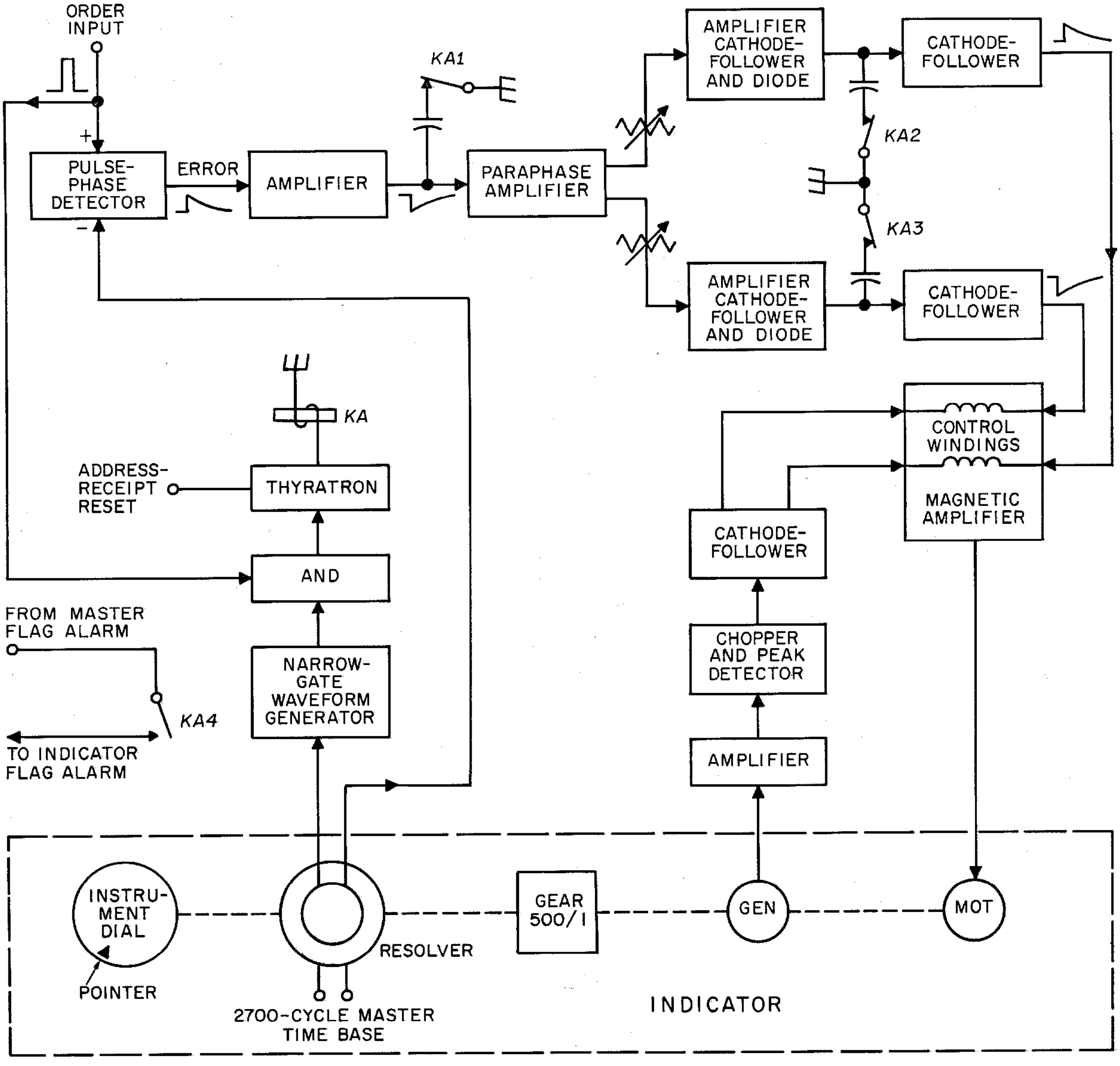


Figure 18—Telemeter-data decoder.

cycle sine wave whose phase varies linearly with the angular position of the rotor. The rotor of this resolver is on the same shaft as the indicator pointer. Therefore, the phase of the 2700-cycle sine-wave output from this resolver is an index of the position of the indicator pointer.

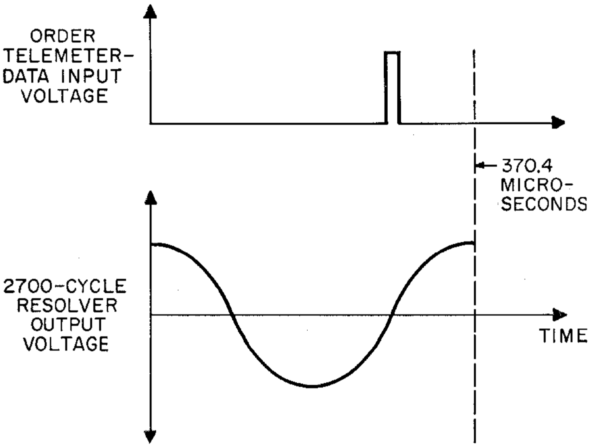


Figure 19—Pulse-phase detector inputs for zero error.

The 2700-cycle output from the resolver is compared to the order telemeter-data input pulse by the pulse-phase detector. The output from the pulse-phase detector is an error signal whose polarity and amplitude is dependent on the time difference between the order telemeter-data input pulse and the positive-going zero crossing of the 2700-cycle resolver output. Figure 19 is an illustration of the signal inputs to the pulse-phase detector when zero error exists.

Returning to Figure 18, the pulse-phase-detector output error signal is amplified and stretched by an electronic amplifier. The amplitude and duration of the output from the amplifier depends on whether the telemeter-data decoder is in the coarse or fine range of operation. For a given error-signal input to the amplifier, the output signal will be smaller in amplitude but longer in duration in the coarse range than in the fine range of operation.

The same amplifier is used for both the coarse and fine ranges of operation. Internal connections of the amplifier are changed by means of the narrow-gate relay *KA* to produce either type of output signal. This relay is energized only when the indicator pointer is within ±7 degrees of the order position.

A 2700-cycle output signal from the resolver goes to a gate waveform generator. The time position of the output pulse from this generator is a function of the indicator pointer position. The width of the gate is equivalent to 14 degrees of the indicator dial. The output from the gate generator will coincide with the order telemeter-data pulse when the indicator is within ±7 degrees of its order position. The output from the gate generator is called the narrow gate and is gated against the order telemeter-data input pulse. The output from this *and* gate will energize the narrow-gate relay through a thyratron to cause the system to switch from coarse- to fine-range operation.

The narrow-gate relay is released on the address receipt, which occurs when an *AN/ARN-26* message is received. This relay will be energized again immediately if the order telemeter-data pulse in this received message is coincident with the narrow gate. If coincidence does not exist, the relay is allowed to drop out; the system will revert back to the coarse range of operation.

By utilizing this coarse-and-fine-range principle, a two-speed positional servomechanism system is realized. The coarse range gives the system a large dynamic range, and the fine range gives the system a small steady-state error.

The output from the electronic amplifier goes

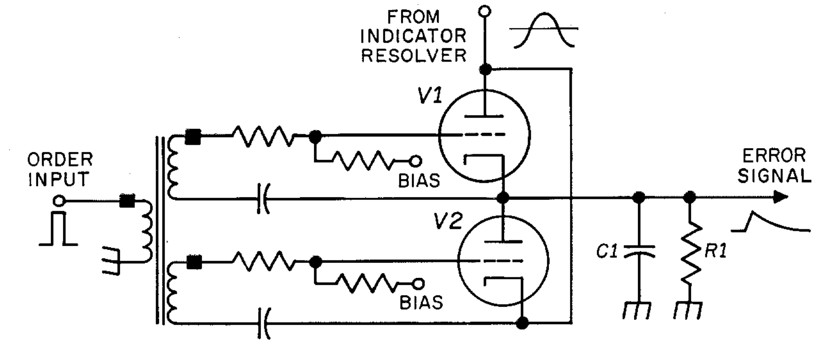


Figure 20—Pulse-phase detector circuit.

to a difference amplifier, the output of which goes to a magnetic amplifier to drive the two-phase motor in the indicator. The motor can be made to rotate in either direction, depending on the phase of the 400-cycle output signal from the magnetic amplifier. The phase of the output from the magnetic amplifier depends on the polarity of the original error signal from the pulse-phase detector. If the error signal is of positive polarity, the motor will rotate the pointer of the indicator in a decreasing direction and vice versa if the error signal is of negative polarity. This allows the servomechanism to close the error in the shortest direction.

Tachometric feedback in an internal loop in the servomechanism is used to decrease the combined time constant of the magnetic amplifier and drive motor. This decreases the response time of the servomechanism.

Figure 20 is a schematic diagram of the pulse-phase detector and Figure 21 shows the waveforms when a negative or positive error signal is generated.

Tubes *V1* and *V2* are biased below cutoff. The amplitude of the order telemeter-data pulse is sufficient to drive the grids of both tubes to cathode potential. For the case under discussion, the polarity of the sine-wave output from the indicator resolver is positive when the telemeter-data pulse occurs. Therefore, *V1* will conduct for the duration of the pulse and build up a positive charge across capacitor *C1*. Capacitor *C1* is discharged through resistor *R1*. The discharge time constant of *C1* and *R1* is many times greater than the charging time constant of *C1* and the plate resistance of the tube, resulting in pulse stretching as shown in Figure 21B. A negative error signal is obtained in a similar manner but with *V2* conducting instead of *V1*.

This error signal passes from the pulse-phase detector through two stages of amplification to a paraphase amplifier. The effective gain of the first stage of this two-stage amplifier can be of two different values. When in the coarse range of operation, the gain of this amplifier is low. When in the fine range of operation, the gain is high. This change of gain is obtained by removing a bypass capacitor from across the output of this first amplifier stage. As mentioned previously, the fine range of operation goes into effect automatically when the servomechanism system has an error of less than ±7 degrees.

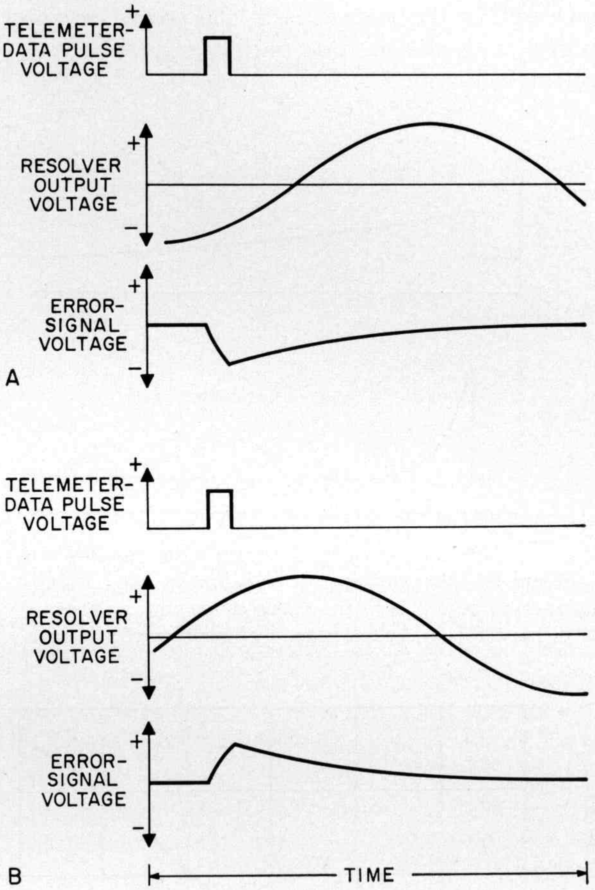


Figure 21—Waveforms in pulse-phase detector corresponding to negative *A* and positive *B* error signals.

The paraphase amplifier separates positive and negative errors into separate channels to increase the dynamic range. The output from the paraphase amplifier will activate one or the other of two error-signal channels. A control in each of the two outputs from the paraphase amplifier gives a manual adjustment on the gain of each channel. One adjustment varies the gain of the amplifier that causes the indicator pointer to move to a higher scale value and the other adjustment varies the gain when the indicator moves to a lower scale value. These adjustments are necessary to allow for slight gain differences in the electronic and magnetic amplifiers. They also allow for differences that will occur between various types of indicators. The gain adjustments are made to maintain a one-to-one relation between the order movement and actual indicator-pointer movement for one message received by the airborne equipment.

The signal in each of the two channels is again amplified, stretched, and passed through cathode-followers. The amplitude and duration of the signal out of the cathode-follower depends on whether the system is in the coarse or fine range of operation. The output waveforms are shown in Figure 22.

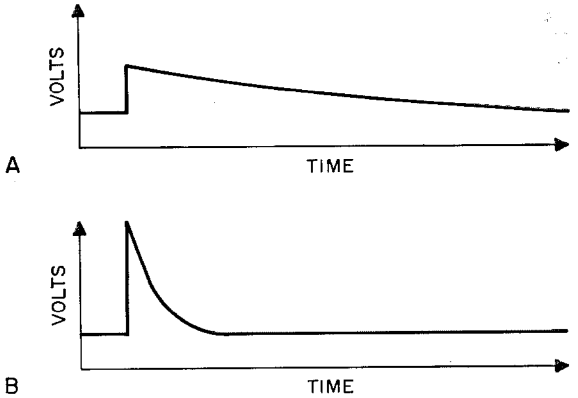


Figure 22—Waveform of error signal at the cathode-follower output. *A* is in the coarse range with an error of 10 degrees. *B* is in the fine range with an error of 5 degrees.

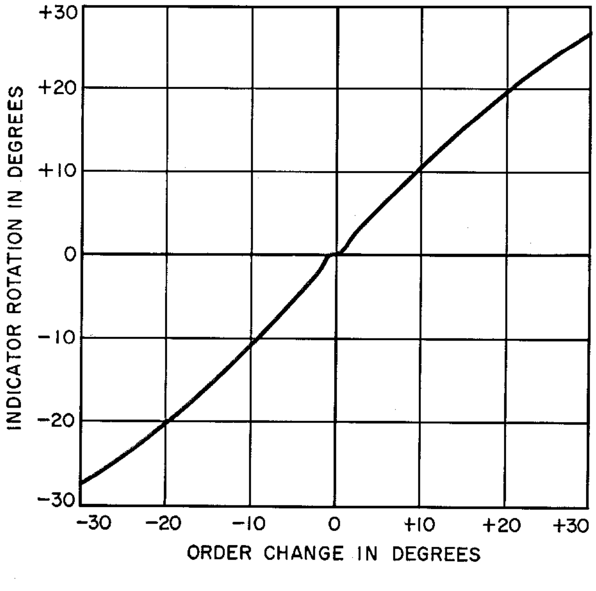


Figure 23—Order change plotted against indicator movement for one message in the coarse range of operation for the bearing indicator.

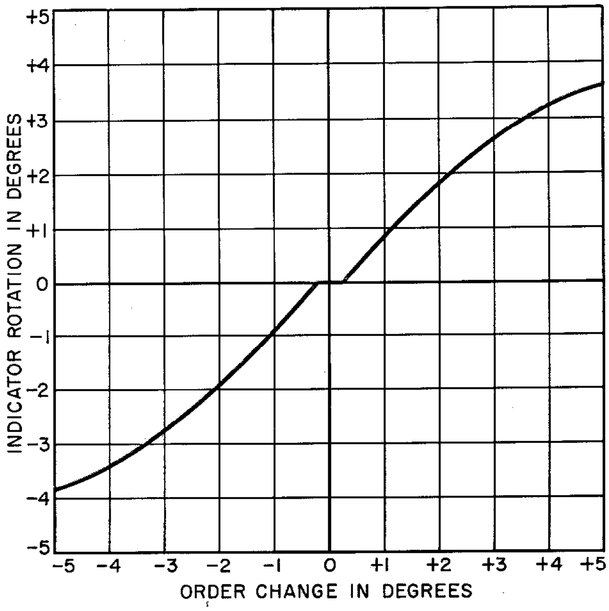


Figure 24—Order change versus indicator movement in the fine range of operation.

The output signal from the cathode-follower goes to the magnetic-amplifier control winding, the other end of which is energized by the tachometric feedback circuits and subtracts from the original error signal.

Magnetic amplifiers were selected in preference to electron-tube power amplifiers because they are passive elements and, therefore, more reliable. The power-gain-to-volume ratio of the magnetic amplifiers is considerably greater than that of the electron-tube power amplifier. A power gain of 2000 was obtained from the magnetic amplifier.

The alternating-current tachometer generator output signal is amplified, chopped, and peak detected. There are two possible outputs from the tachometer circuits—one output occurs when the generator is rotating in one direction and the other output occurs when rotating in the other direction. These two tachometer output signals are supplied to cathode-followers similar in design to those used in the error-signal channels. The output signals from these tachometer cathode-followers are of the same waveform as the signal output of the error-signal cathode-followers.

As seen from Figure 18, the net signal across the magnetic-amplifier control winding is the difference between the error-control signal and the tachometer-feedback signal. This is a conventional difference-amplifier circuit. Two control windings are needed on the magnetic amplifier—one for each direction of rotation of the indicator pointer.

There are two outputs from the resolver in the indicator—one to the pulse-phase detector and the other to a gating waveform generator. The output from the gate generator goes to an *and* gate, the other side of which goes to the telemeter-data order pulse. When coincidence occurs between these two pulses, the output from the *and* gate fires a thyratron. The thyratron energizes the narrow-gate relay *KA*, which changes the servomechanism system from coarse to fine range of operation.

Under the control of *KA*, the indicator flag alarm is green only when the system is in the fine range of operation.

Figure 23 is a plot of the amount the bearing-indicator pointer moves when ordered to a new bearing position. This plot is based on the receipt of one message from the ground station in the coarse range of operation. Figure 24 is a similar plot made when the system is in the fine range of operation. The four telemeter-data order decoders have the same characteristics with appropriate change of scale units.

Oscillographic recordings were made of the response of the bearing order indicator to step input changes of 120, 30, and 5 degrees at various message rates. Figures 25, 26, and 27 are these recordings. A voltage divider mounted in the indicator gave a direct voltage proportional to the pointer position. This voltage controlled the deflection of the oscillograph, which was calibrated before each run, and therefore recorded the indicator-pointer movement versus time. Time and message-receipt markers are shown.

In conclusion, it can be said that the telemeter-data decoders possess the characteristic of infinite time storage of information. They are normally inactive and are actuated only when there is a change in the order data. They have a dynamic range on receipt of one message of ±30 degrees and a sensitivity of ±0.25 degree. There is practically a one-to-one relation between the order change and indicator movement on receipt of one message, up

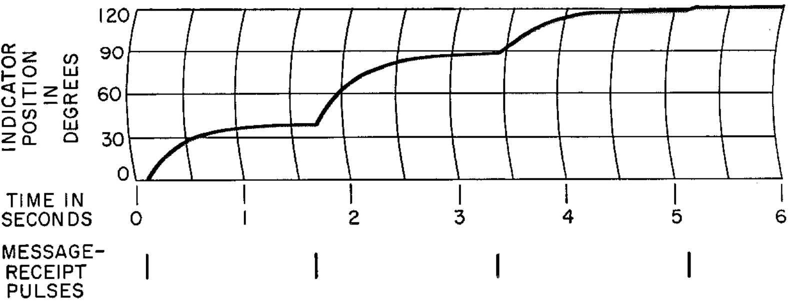


Figure 25—Response of order indicator in the bearing instruments for a required change of 120 degrees presented at the rate of one message per 1.7 seconds.

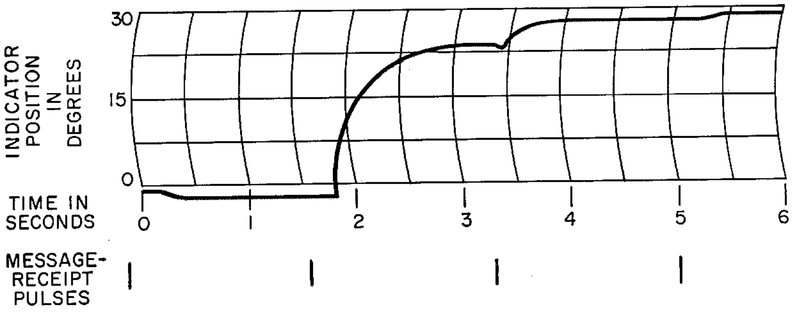


Figure 26—Response of order indicator for a 30-degree change at one message per 1.7 seconds.

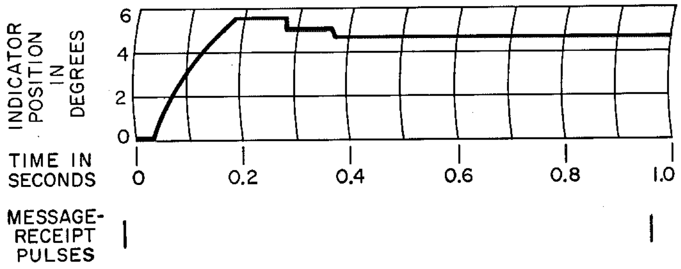
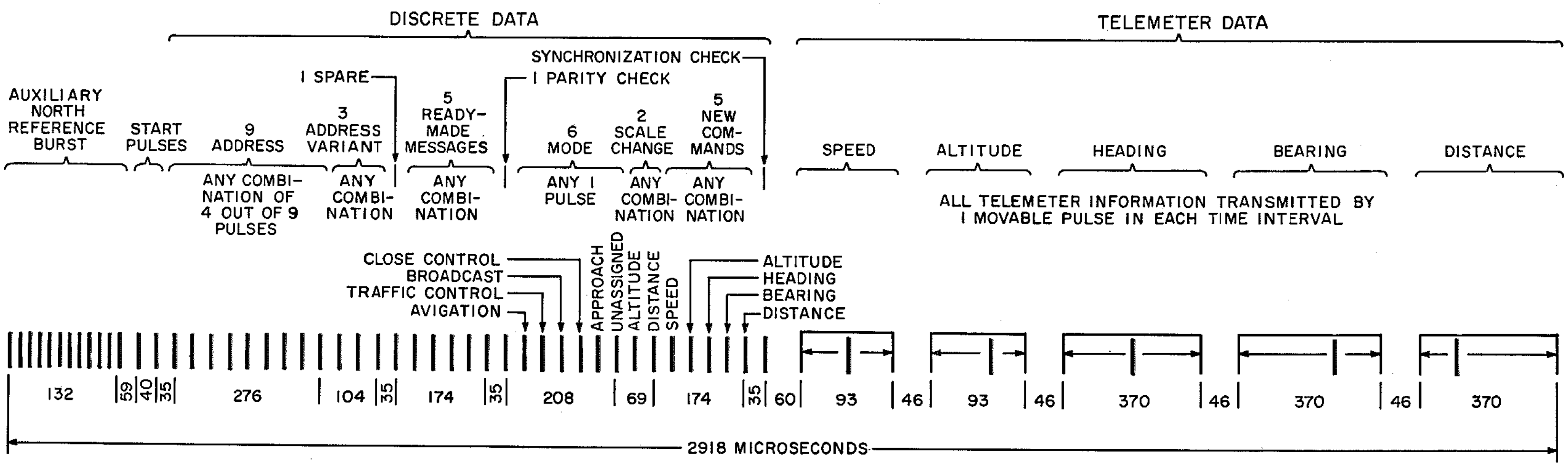
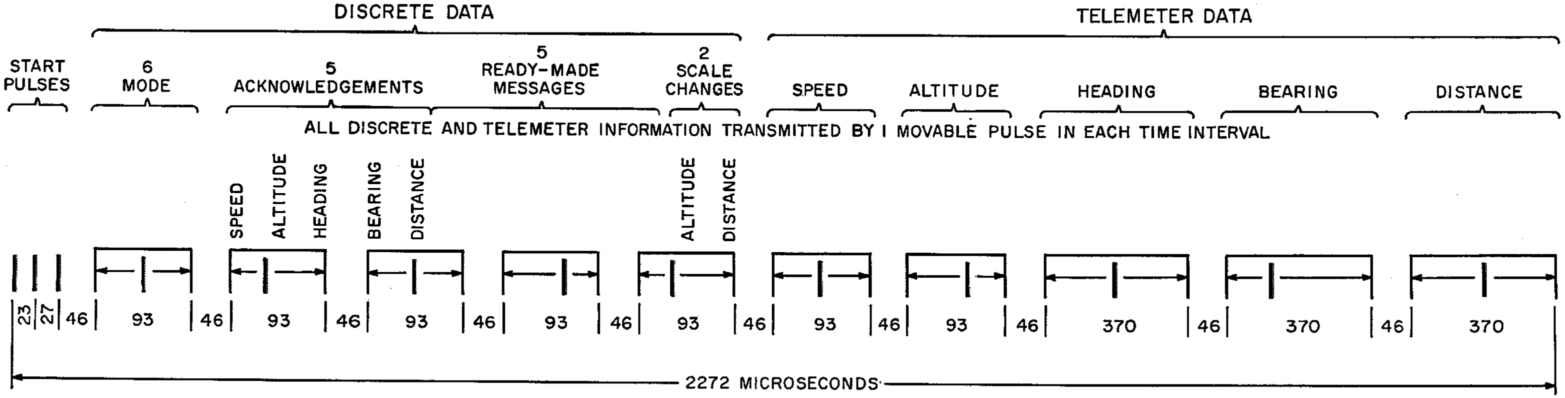


Figure 27—Response of order indicator for a 5-degree change at one message per second.



A. GROUND-TO-AIR MESSAGE



B. AIR-TO-GROUND MESSAGE

Figure 28—Data-link message pattern. Rounded figures are given for the time intervals.

to the dynamic range of the system. The servomechanism will always close the error in the shortest direction. The flag alarm on the indicator will be red until the error is less than ±7 degrees, when it will turn green. The system has a coarse and fine range of operation, the fine range being activated automatically when the error is less than ±7 degrees. The coarse range is used to give large dynamic range to the system, and the fine range is used to increase the sensitivity of the system.

5. Time Base and Power Amplifier

One of the major features of the design philosophy of the data link is its complete compatibility with the tacan system with no deterioration of range and bearing accuracy. This is achieved by time multiplexing the data-link information in the tacan channel by the use of pulse coding and flywheel synchronization of the airborne time base with the clock at the surface beacon.

The information from surface to air and from air to surface is transmitted to two forms—digital, through the presence or absence of a pulse at a precise time interval, and analog, by wide-deviation pulse-time modulation. The phase-locked time base provides the time reference necessary for decoding the surface-to-air analog data and encoding the complete air-to-surface message.

The locking method finally evolved was to transmit a synchronizing pulse pair after every auxiliary reference burst. The auxiliary reference burst in the tacan signal, a feature of the fine-bearing technique employed, is a group of 6 pulse pairs, each a 12-microsecond twin, and each pulse pair 24 microseconds apart. See Figure 28. This pulse group occurs 135 times a second less every 9th burst. Thus, the synchronizing pulse pairs, called the start pulses, are transmitted at a 135-cycle rate with one pulse pair out of every 9 omitted.

The decoded start-pulse pair is used to phase-lock a stable oscillator in the airborne master time base. In this manner, the master time base becomes a yardstick with which to measure the elapsed time between the start pulses and the pulses that make up the coded message.

The frequency of the time-base oscillator was chosen to be 2700 cycles. This value was selected on the basis that it is a harmonic (20th) of the start-pulse frequency and that the maximum time (including transit time) required to transmit and receive a message in its entirety is achieved within the period of the 135-cycle start pulses. The surface-to-air and air-to-surface message lengths are related in time to the period of the master time base since the total two-way message length is approximately 14.5 periods. Thus, if the time-base frequency were lower, for example the 9th harmonic, it would be impossible with the same message-code structure to complete a two-way transmission between the beacon and an aircraft 200 nautical miles (370 kilometers) distant before the next start-pulse pair would be transmitted.

Similarly, consideration must be given to the highest harmonic of the 135-cycle pulse pairs that may be used for determining the frequency of the time base. The telemeter-data decoding technique utilizes a resolver that shifts the phase of a sine wave and compares its positive-going zero crossing to the telemeter-data pulse. Therefore, to avoid ambiguities in the telemeter-data decoding and to keep the circuit techniques simple, the time interval allotted to any telemeter-data pulse must be equal to or less than the period of the time base. A basic limitation of the accuracy of the telemeter-data units is thus determined by the period of the time base. For example, the distance order pulse is transmitted within an interval of 370.4 microseconds. The pulse position transmitted over a 1-megacycle-wide radio-frequency channel can be decoded to within ±0.5 microsecond. Hence, the inherent error of the telemeter unit is 0.13 percent. A shorter period, that is a higher base frequency, would increase the inherent error proportionally. The resolution accuracy of determining where the pulse is within a time interval is not the only error to be considered. A detailed discussion on telemeter errors will be found elsewhere in this paper.

From the above considerations, it may be concluded that the lowest frequency of the time base is determined by the message length and wave-propagation time and the highest frequency by the accuracy requirements of the telemeter-data unit. Therefore, the optimum frequency that may be selected is the 20th harmonic of 135 cycles or 2700 cycles.

There are errors, however, that are due to the time base. They result from time-base jitter, temperature instability, harmonic content, and variations of amplitude of the output signal. The design-center short-time stability of the oscillator was 1 part in 10^5; in 20 cycles, the oscillator would drift a maximum of 0.074 microsecond. The design center for jitter measured at the positive-going zero crossing was ±0.3 microsecond. The total harmonic content was to be below 0.1 percent and the amplitude variation to be less than 0.25 percent. These values have been obtained in the field.

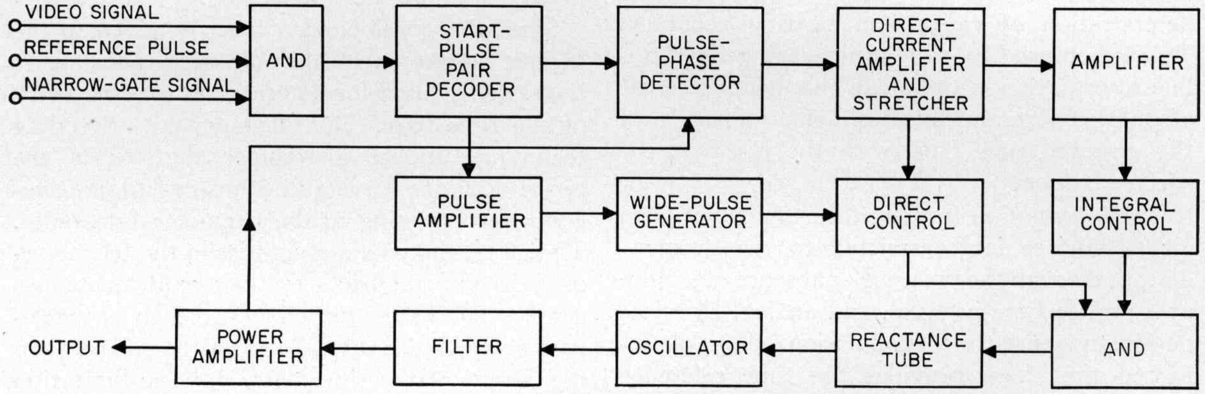


Figure 29—Block diagram of the master time base and power amplifier.

The block diagram of Figure 29 shows the method finally used to achieve the above specifications. In essence, the circuit consists of a pulse-pair decoder, pulse-phase detector to compare the phase of the 2700-cycle signal to the decoded start-pulse pair, error-signal amplifiers and stretchers, and direct control and integral control circuits that operate on the suppressor-grid of a Miller reactance-tube circuit to stabilize the frequency of the local oscillator.

5.1 Circuit Techniques

The video-signal output from the airborne tacan receiver and a reference pulse generated within it are transmitted over separate cables to the data-link unit. An astable multivibrator, used to place a protective gate around the start-pulse pair, is triggered in the reference-pulse decoder. The video signal is decoded and reshaped by a pulse-pair decoder and a blocking oscillator into 5-microsecond 100-volt pulses. The decoded start-pulse pair, the reshaped video signal, and a narrow-gate signal provide three inputs to a pentode *and* gate. The narrow-gate signal is deactivated until two or more start pulses are decoded. It then places a 10-microsecond gate around the decoded start-pulse pair. If three or more start pulses are missed in succession, then the fine reference gate is removed until once again two or more successive start pulses are decoded.

The regenerated start pulse is then compared with the 75-volt sine wave from the power amplifier in the pulse-phase detector shown in Figure 20. Some residual 2700-cycle signal due to direct coupling through tube capacitance is present at the first amplifier after the pulse-phase detector. This signal is sinusoidal and can easily be nulled out by a network in the cathode of the first amplifier.

The signal from the pulse-phase detector for a 1-microsecond error is

$$E_e = 75(2)^{1/2}\omega t[1 - \exp(-t/T)],$$

where $\omega = 16\,950$

$T = 100 \times 10^{-6}$

$$E_e = 1.79[1 - \exp(1/100)] = 0.018 \text{ volt}.$$

In addition, this signal has a decay time constant of 2.2 milliseconds. The error signal goes to a triode amplifier using subminiature tube *5719A* because of its low microphonic-noise output. The gain of this stage is about 28 giving

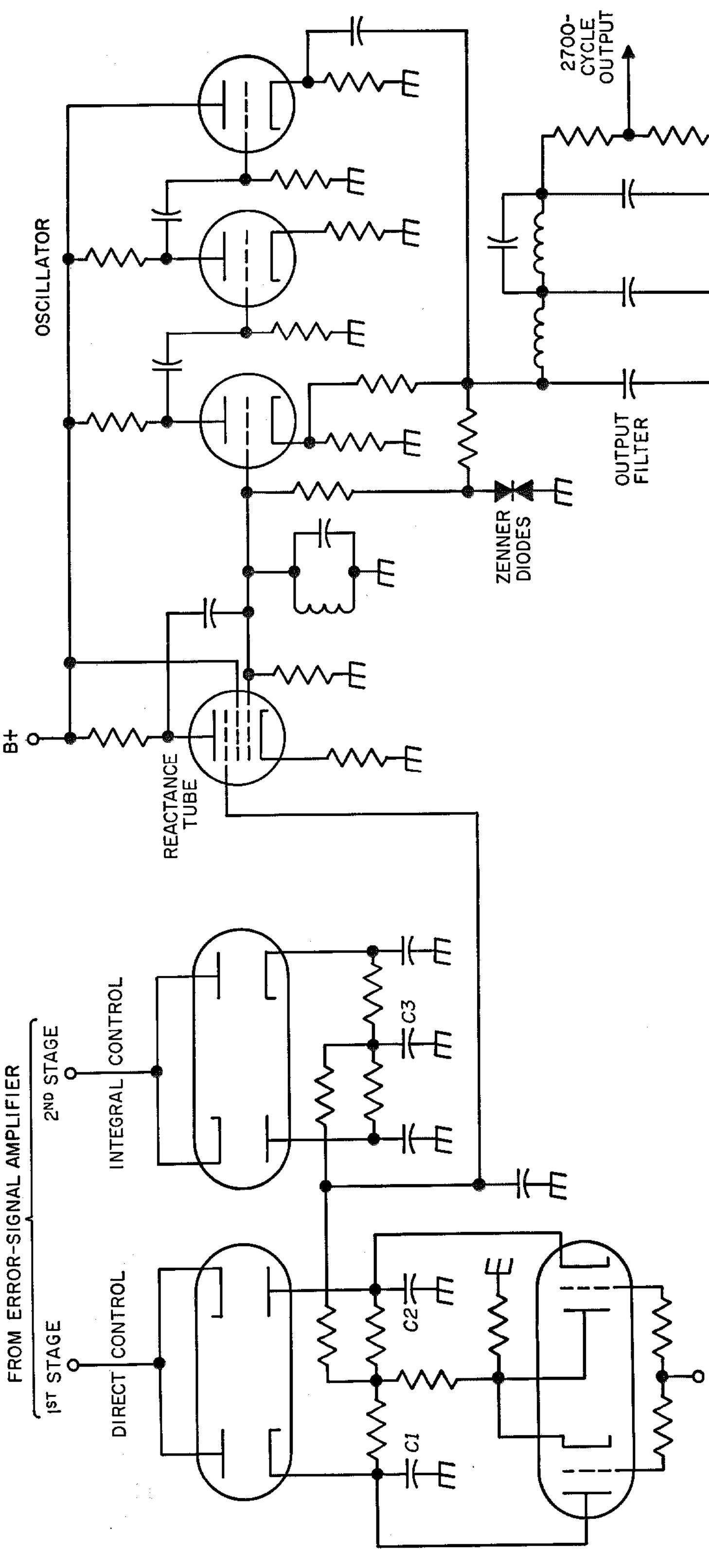


Figure 30—Circuit of time-base oscillator.

a 0.5-volt error signal that is stretched to about 2.5 milliseconds. The error signal is further amplified by a transformer-coupled stage. The error signal in the primary of the transformer is coupled to the direct-control circuit; the secondary signal, inverted and amplified by a factor of 5, is coupled to the integral-control circuit.

The direct-control circuit shown in Figure 30 consists of dual diodes in a peak-detecting and summing circuit; a positive error charges *C1* and a negative error charges *C2*. The error signals on *C1* and *C2* are removed by discharging the capacitors to ground each time a start pulse is received. The start pulse is amplified and applied to the reset-pulse terminal. In this manner, the direct-control error signal is proportional to the error measured at each start pulse; no stale information is retained in the direct-control circuit.

There is no damaging effect due to discharging the direct-control circuit each time a start pulse is received because of the time lag of the circuits amplifying the new error signal.

The integral-control circuit consists of an error-peak-detecting circuit and a summing network coupled to a 2-microfarad capacitor. The time constant of the integral-control circuit is approximately 1 second; thus, almost true integration of the error signal results.

The error signal from the direct-control and integral-control circuits is summed through two resistors and the resultant direct-current signal is applied to the suppressor grid of a Miller-type reactance circuit. The reactance circuit is across the tuned inductance–capacitance circuit of the 2700-cycle oscillator.

Oscillator amplitude stability is maintained by a Zener diode in the regenerative feedback path. The output signal from the oscillator is highly distorted and to achieve the required low harmonic content of 0.1 percent, the signal is passed through a two-section filter.

The 2700-cycle signal from the filter goes to a power amplifier. The power amplifier was designed with an open-loop gain of 1500. Feedback was incorporated around the amplifier for a net closed-loop gain of 32.6. Thus, with a 2.3-volt signal input, a 75-volt output signal is obtained. The power-amplifier output signal is then compared with the decoded start pulse in the pulse-phase detector as shown in Figure 29. This produces an error signal that is used to phase-lock the local oscillator as described above. A 75-volt quadrature signal is also obtained by integrating the 75-volt signal in phase with the decoded start pulse.

6. Magnetic Pulse Formers

A regenerative pulse former was next investigated. As shown in Figure 31, it consists of a resistance–capacitance network *R–C2* across a saturable reactor *L2*. The inductance–capacitance network *C1–L1* is tuned to resonate at 2700 cycles, thus provided nearly constant current drive of *L2*.

The results obtained from this circuit may be explained by referring to the curve in Figure 31. The solid line i_1, i_2 is the current during that part of the 2700-cycle input wave when the positive-going wave crosses the zero line. Except for small values of current near zero, *L2* is saturated and may be considered as a virtual short-circuit. The minimum current required to saturate the core is I_s. Thus, prior to t_1, all the input current, i_1, flows through *L2* and the voltage across *C2* is zero. At t_1, the core becomes unsaturated ($-I_s$) and *L2* presents a high impedance to the flow of current, which is maintained sinusoidal by *L1*, *C1*. Capacitor *C2* then charges slowly until t_2 when i_2 is again sufficiently large to drive the core into the saturation region ($+I_s$).

The resulting decrease in voltage across *L2* due to its sudden change in impedance permits *C2* to discharge through *L2* and produce the output voltage pulse i_3R. The discharge of *C2* through *L2* is regenerative in nature. Thus, as the effective inductance of the saturable core reduces due to its approach to saturation, the discharge from *C2* accelerates the rate of saturation. The net results of the regenerative action of the capacitor *C2* is to generate a pulse with a rise time of the order of 1 microsecond and an amplitude of 5 to 20 volts depending on the value of *R*.

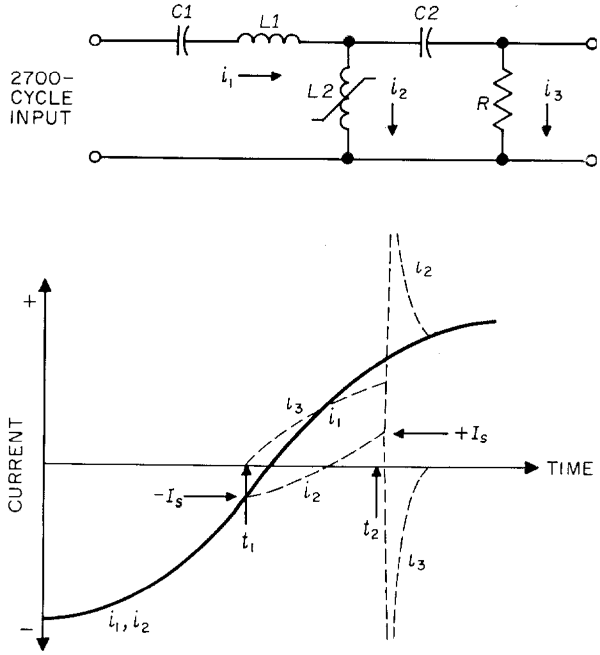


Figure 31—Regenerative pulse former.

Tests indicated that it was not necessary to use a tuned circuit with the saturable inductor but that a resistor would suffice.

To maintain a pulse-position accuracy of ±0.5 microsecond, it was found necessary to maintain the output amplitude to within ±0.5 percent.

To achieve a rise time of 1 microsecond in the output pulse, Δt has a maximum value of approximately 2 microseconds or slightly less then 2 degrees expressed angularly. Saturation reversal must occur during a current amplitude change ΔI of I_{max} sin 2 degrees. The core thus must be saturated when the current has reached 0.017 I_{max}.

Selection of the core material must be based on two parameters.

A. The incremental permeability in the unsaturated region will determine the effective inductance of the coil and hence the amount of current that will flow for a given magnitude of source voltage.

B. The magnetizing force required to saturate the core.

Since the time required for the reversal of saturation-flux polarity should be as small as possible, it is apparent that both of the above factors should be minimized. Unfortunately, a brief survey of available core materials indicates that a low incremental permeability is characteristic of materials that are difficult to saturate while those materials most readily saturated possess relatively high incremental permeability. Thus it was concluded that the saturable transformer was not applicable to this problem.

The temperature sensitivity of the magnetic pulse generators was found to be about 1 microsecond for a 2700-cycle signal and a temperature change of 50 degrees centigrade. The drift rate could have been reduced through the use of capacitors with the proper temperature coefficient. In actual practice, however, it was found satisfactory to use the same regenerative pulse-forming circuit throughout the equipment. The effect of temperature drift was not noted in the air-to-surface pulse code structure.

The regenerative magnetic pulse formers were used for gate generators driven from phase-shift networks and rotors of resolvers; thus, a pulse is generated that is a function of resolver-shaft position.

Data-Link Airborne Instrumentation

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COCKPIT presentation requires that the standard basic flight and positional information be presented to the pilot, together with data-link information, without duplicating any of the existing instruments. This information consists of the following: air speed, altitude, bearing, radio–magnetic compass (heading), and distance. For an effective two-way data link, it is essential to relay these flight functions to a surface station and display them with no loss in accuracy.

It is also necessary that the surface station be able to order the pilot to perform changes in aircraft heading, speed, altitude, et cetera, to carry out effectively a particular mission. The commands of the surface station are transmitted to the aircraft and presented on the actual flight instruments. This enables the pilot to determine his *status quo* quickly and to effect any necessary maneuver by comparison of his measured information with the command information sent by the surface controller.

The system philosophy requires that a data-link instrument contain the basic flight-instrument mechanism, whether it be a servomechanism or a bellows-actuated visual presentation, a relaying device to telemeter this function, and a receiving servomechanism to present the commands visually. It is necessary that the mechanisms for these functions be incorporated in a standard 3.25-by-3.25-inch (8.25-by-8.25-centimeter) case to replace existing instruments.

A typical instrument, the air-speed indicator, is shown in schematic form in Figure 1. The standard sensitive air-speed bellows mechanism has a special brushless electric pickoff on its output shaft for telemetering measured air speed. It will be noted that the bellows output is directly presented to the pilot to ensure the reliability of this function.

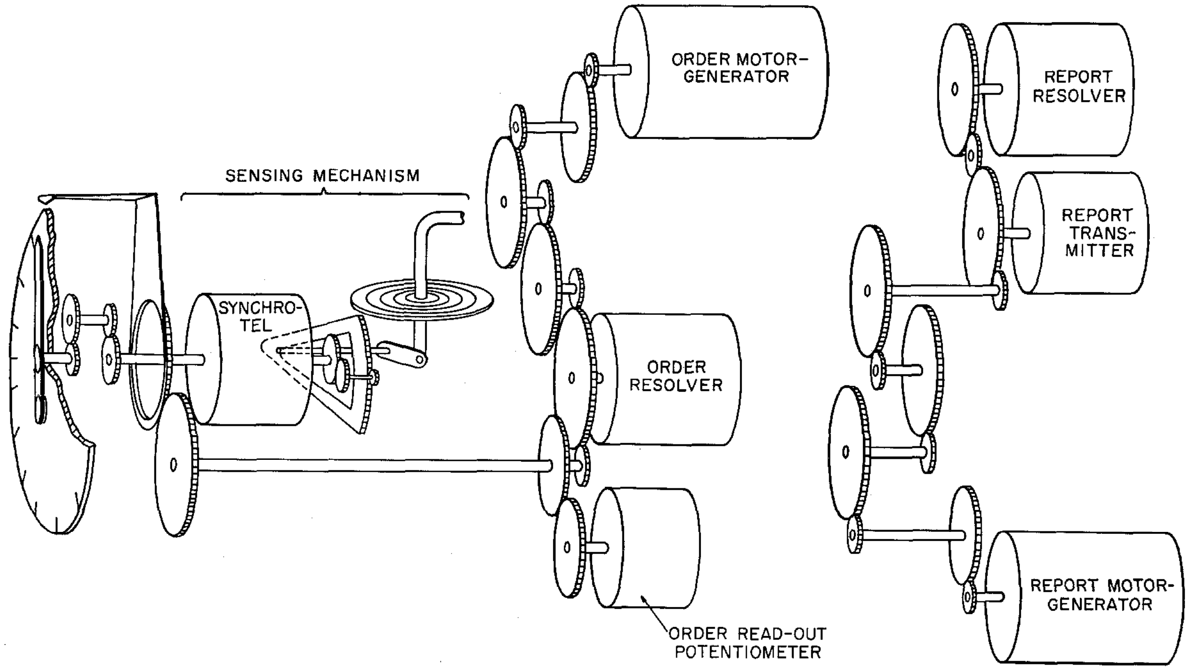

Figure 1—Mechanical arrangement of data-link air-speed indicator. There is an electrical coupling between the synchrotel and the report transmitter.

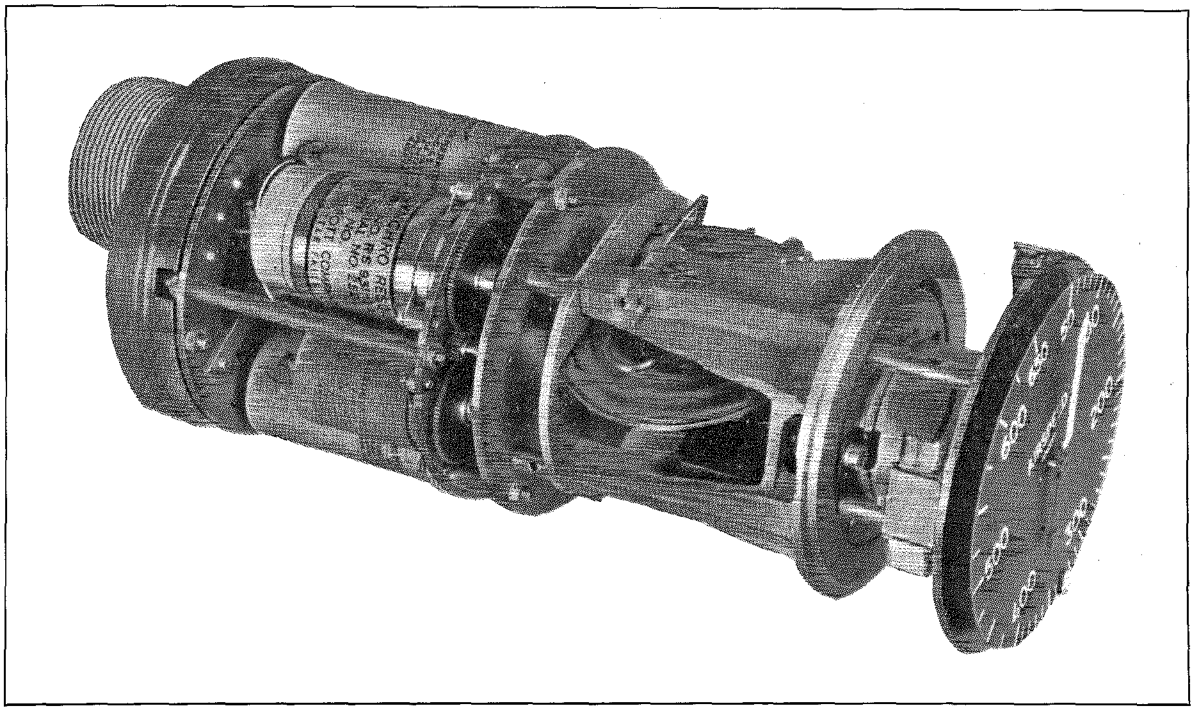

Figure 2—Air-speed indicator with cover removed.

Figure 3—Top row shows bearing, distance, radio-magnetic-compass, air-speed, altitude, and ready-made-message indicators. Below is the control box and the panel for sending ready-made messages.

The command servomechanism has been incorporated in the standard case directly behind the bellows mechanism and its output shaft is carried forward to the instrument dial to move a peripheral arrowhead. Figure 2 shows the modified air-speed indicator with the cover removed.

The front faces of the 6 basic data-link instruments are shown in Figure 3 together with the ready-made-message panel for air-to-surface communication.

1. Indicator Design Considerations

The mechanical design of the airborne instruments was established after careful consideration of the accuracies required, particularly with respect to the number of complete servomechanism gear trains necessary in each instrument.

The design incorporates a minimum of 2 and a maximum of 4 servomechanisms with backlash requirements of the order of ±1 minute of arc between measuring components and ±7 minutes of arc between drive motor and error detector.

Space limitations in the standard instrument package and drive-motor power limitations would not permit use of spring-loaded gearing. Many of the airborne instruments would have been objectionably long if conventional gearing methods were employed. A study of the gearing tolerances and the accuracy necessary to produce gear trains that satisfied the backlash specifications without employing antibacklash springs showed that available precision machines with 100-percent inspection of parts could be used. Also, this study revealed that the saving in assembly time would be substantial.

1.1 CLOCK-GEARING APPROACH

The mechanical design was patterned after the basic clock gear trains that employ spaced bearing plates with the gear train sandwiched between. A high-lead brass alloy is used for the plates and provides the best bearing surface for the stainless-steel gear shafts. Major dimensions of the plates and the bearing holes are held to tolerances of the order of +0.0002, −0.0000 inch (+0.005, −0.000 millimeter).

1.2 GEARS

The decision to employ precision gearing necessitated manufacture of precision class-*2* gears. The Fellows fine-pitch gear shaper is capable of producing these if close tolerances are maintained with respect to the gear-blank mounting hole and the machine mounting arbor. Also, the gear-blank outside diameter must be concentric with the mounting hole.

A precision gear can be classified as such only after careful inspection. The inspection consists of first, measuring the gear-tooth space using precision Van Keuren wires and a high-precision micrometer. The gear is next rotated through one revolution while in intimate contact with a master gear or rack of known accuracy and the resulting radial displacements or variations in center distance during the rotation are measured by a dial indicator. This is a composite check giving the combined effect of runout, pitch error, tooth thickness variation, profile error, and lateral runout.

Only gears that meet the tolerance of precision class *2*—total composite error of 0.0005 inch (0.013 millimeter) and tooth-to-tooth composite error of 0.0003 inch (0.008 millimeter) are selected; however, it is statistically interesting to note that better than 95 percent of all gears manufactured under the precautions stated meet this specification.

1.3 SHAFTS

Stainless steel shafts are employed exclusively in all instrument gear trains. The tolerances of +0.0000, −0.0002 inch (+0.0000, −0.005 millimeter) for bearing diameters and +0.0004, −0.0000 inch (+0.010, −0.000 millimeter) for press-fit diameters are achieved through the use of precision turning machines. All diameters that must be held within 0.0002 inch (0.005 millimeter) are machine-burnished to final size.

To reduce the number and complexity of the gear-blank holding fixtures, it was decided to press-fit all gears on their shafts rather than to cut the gears integrally with their shafts. The only problem in press-fitting is in maintaining the gear-hole size during the pressing operation. There is a very-pronounced tendency for the shaft to shave metal from the gear hole, thereby reducing the effective fit and causing eccentricity between the shaft and gear since the shaving does not occur uniformly around the hole. This

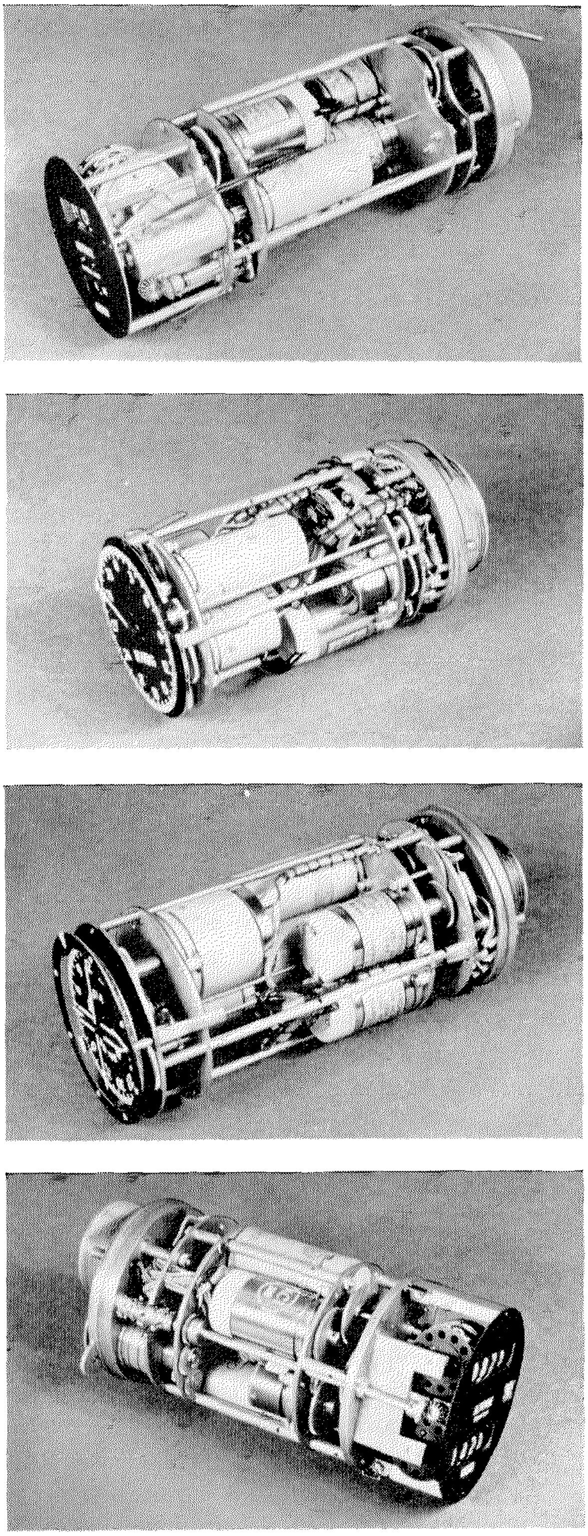

Figure 4—Internal packaging of instruments: from top down, for distance, bearing, radio–magnetic compass, and altitude.

can be entirely eliminated by a 5-degree taper on the end of the shaft. This method of separately cutting gears and shafts is very attractive economically since a rejected gear does not entail the loss of its associated shaft.

1.4 Special Gear Holders

Besides mounting gears on shafts, it is also necessary to secure gears to electromechanical components. With ordinary gearing, a gear with integral hub can be secured to a component shaft by simply tightening a setscrew in the gear hub. It was found, however, that the component shaft was damaged by the setscrew causing eccentricity that could not be tolerated in precision gearing. It was necessary, therefore, to adopt a system that would not allow the setscrew to come in contact with the component shaft. A split collar mounting the gear is placed on the component shaft and is held in place by an encircling collar containing two setscrews, at right angles, that tighten the split hub against the shaft.

1.5 Packaging

Choice of components for any instrument is dictated by the number to be placed in a specific volume and the required accuracy.

The data-link instrumentation requires positioning servomechanisms to display the basic flight and positional information to the pilot, also encoding this information for telemetering to the surface controller, and receiving servomechanisms to display commands.

To package these in the restricted volume of a 3-inch-(7.62-centimeter-) internal-diameter aircraft instrument, it was necessary to select components that would allow as many as 6 to be assembled on a single 3-inch-diameter gear plate. By mounting these components shaft-to-shaft on both sides of a gear train, or variations such as back-to-back with two gear trains, the available volume was used efficiently (Figure 4).

To attain maximum reliability in any precision device, measures must be taken to eliminate the effects of varying ambient conditions. All data-link instruments are filled with dry nitrogen at one-half atmospheric pressure and hermetically sealed to eliminate moisture. For ease of servicing, a tear strip is incorporated in the cover similar to that in some tin cans, where by tearing out a strip of metal around the circumference, complete separation is accomplished.

The data-link instruments are completely assembled and tested before being put in the instrument case, the final sealing being done at the rear of the case where the effect of heat from soldering will be minimized (Figure 5).

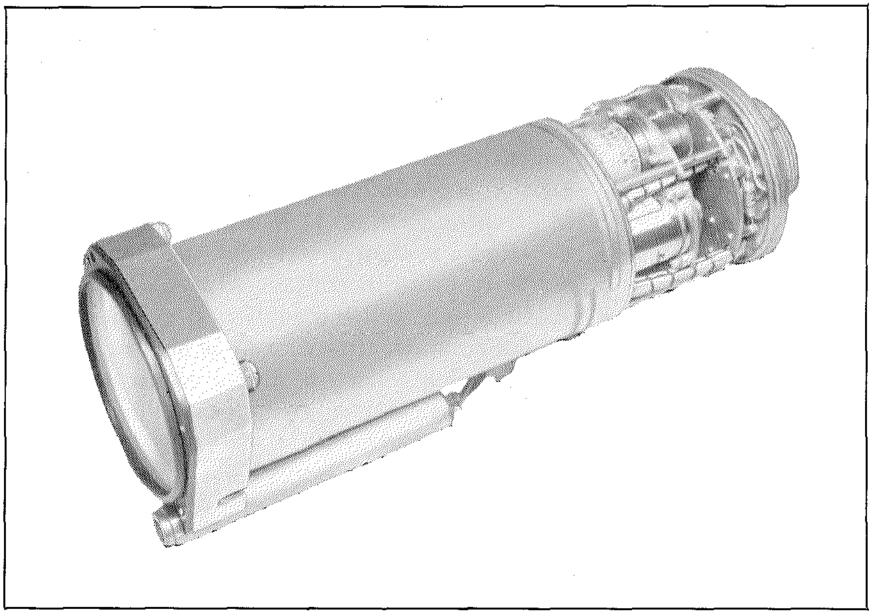

Figure 5—Insertion of an instrument into its cover prior to sealing. The cover faceplate is at the left. The new-command indicator is in the tube attached to the cover.

Each of the instruments has a standard hermetically sealed military-type connecter.

2. *New-Command Indicator*

To ensure reliability of surface-transmitted commands in a data-link instrument display, there are three conditions that must be satisfied.

A. Any new command must be made apparent to the pilot.

B. Any false command must be made apparent.

C. The pilot must be able to acknowledge each new command.

These conditions are satisfied by a 3-aspect indicator mounted on the lower left corner of each instrument. Each of the aspects has a different visual appearance; the new-command aspect is orange with black diagonal stripes, the acknowledge aspect is brilliant green, and the malfunction aspect is a bright red.

During flight, any new heading, bearing, distance, altitude, or air speed transmitted by the surface controller will appear on the order portion of the particular instrument and the new-command indicator will show the orange-and-black aspect. When the pilot has seen this new command and understands it, he then pushes this indicator, transmitting a signal to the surface controller. This transmission will continue for a period of 15 seconds, during which at least two acknowledgments will be received by the surface controller, the slowest rate of transmission being once every 6 seconds. This indicator (Figure 6) has two separate components—the 3-aspect indicator and a 15-second time-delay device.

The 3-aspect indicator slides within a tube and actuates the timer through a hermetic bellows assembly. The indicator is a magnetically positioned wheel supported on jewel bearings. Directly behind this wheel is a coil that can be polarized. When no current is flowing in the coil, the wheel is positioned by two permanent magnets in the wheel support. When a positively polarized voltage is applied to the coil, the indicator wheel will rotate to a mechanical stop. A change in coil polarity will rotate the indicator in the opposite direction. Thus, any one of the 3 conditions can be presented to the pilot.

The 15-second time delay necessary to transmit acknowledgments to the surface controller is mounted in a tube behind the 3-aspect indicator. The time delay is accomplished thermally, using a control rod that increases in length.

When an acknowledgment is sent, the indicator is pushed in and a toggle-actuated contact causes current to flow in a high-resistance heater wire wrapped around a tensioned rod. This rod is spring loaded and holds the transmitting contacts in the normally open position. Contacts are on a pivoting beam, the position of which is controlled by the length of the rod. As the rod increases in length, the acknowledgment-transmitting contacts close. The toggle-operated heater-wire contacts are tripped open by the beam and the rod then starts to cool and return to its original length in approximately 15 seconds; the time can be adjusted, depending on requirements for length of delay.

3. *Ready-Made-Message Box*

In aircraft operation, many of the messages transmitted to the surface are either one word or short phrases such as DAMAGED or RETURNING TO BASE. The data-link ready-made-message sending box permits selection and transmission of these messages. The front panel of this box, Figure 3, has 8 message windows and associated transmitting push buttons. A rotary switch under the windows will select any of 4 groups such as communication (COMM) or tactical (TACT).

As this switch is rotated from one position to another, a new group of messages will appear in the windows; the corresponding encoding switches are brought into use. This gives a selection of 8 messages in any one of 4 groups or 32 different messages of which 31 are actually used. Message plates can be changed in any control box, giving complete flexibility in messages.

The front panel of the message box is of edge-lighted plastic material. All designations and windows are illuminated by filtered red lights embedded in the plastic. These lights are removable from the front.

The message slides are proportioned so that when one slide is visible in the windows, the others are concealed by the bars between the windows. These message plates are mounted on guide pins so that they move in a vertical direction only and are actuated by sliding rods spring-loaded against cams on the rotating

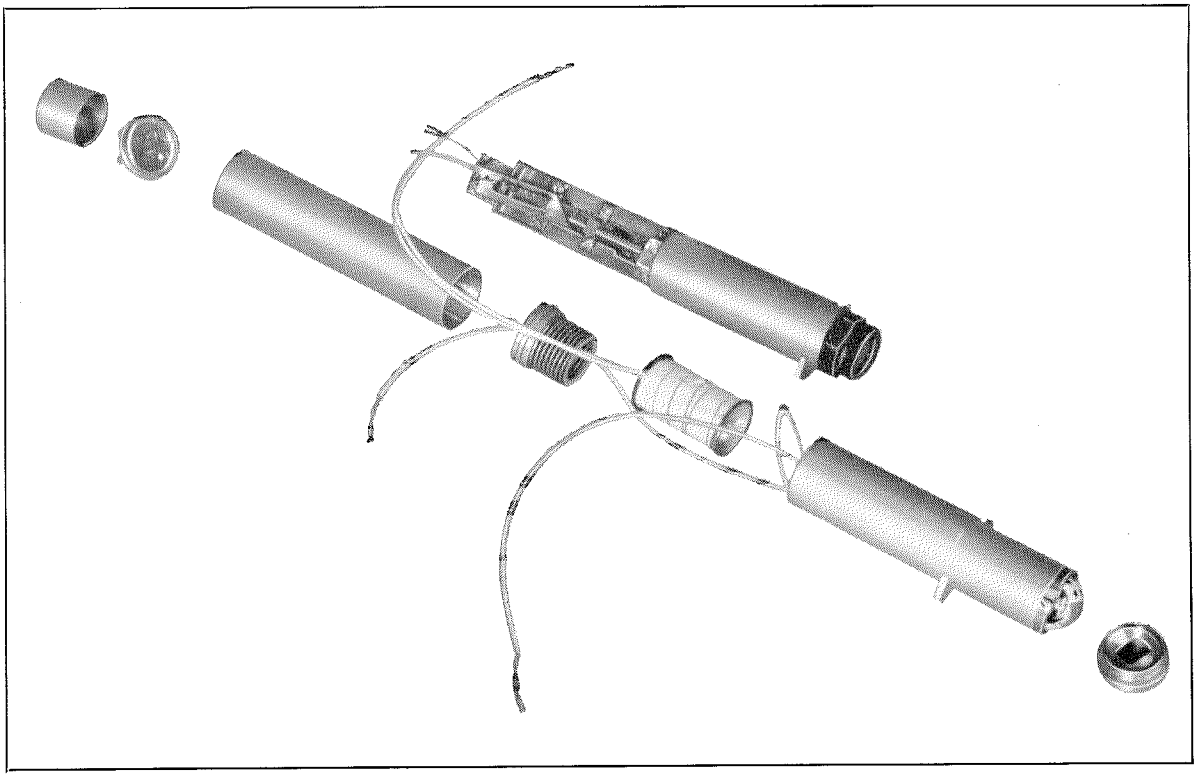

Figure 6—Disassembled 3-aspect indicator.

switch. As the switch is rotated, the message slides are alternately moved into view.

The push buttons actuate microswitches through rod cams. There is a separate set of switches for each group, selected by the 4-position group switch. If a push button is left depressed on a particular message, that message will continue to be transmitted to the surface; however, upon selecting a new group, all of the push buttons are reset. This prevents transmission of false messages.

The control box has been designed to fit in a standard console rack in the cockpit.

4. Ready-Made-Message Indicator

Messages transmitted from air to surface by the data-link message box must be acknowledged or answered by the surface. This is accomplished through the ready-made-message indicator mounted on the instrument panel of the aircraft as shown in Figure 3. The messages, of which there are 31, appear on a tape driven into position by a motor. This message tape is positioned by two binary-coded disks, each message position having an individual code. When the surface controller desires to ROGER a message from an aircraft, he selects the proper binary number for transmission. The drive motor in the indicator of the receiving aircraft moves the tape until the coded disks correspond to the transmitted binary number.

With the data-link message-sending panel and the message indicator, the pilot of a data-link-equipped aircraft can transmit any one of 31 separate messages and receive acknowledgments, answers, or orders from the surface controller.

The coded nature of the messages transmitted between air and surface lends itself to language translation. Since any language can be displayed on the message plates and tapes of the aircraft, the system affords a reliable means of communication between aircraft and air fields of all nations.

Evaluator and Trainer for Tacan Data Link

By WILLIAM B. SUDDUTH and JOHN F. SULLIVAN

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WHILE developing the tacan data link, it became evident that a system capable of simulating test flight operations would be a convenient and valuable addition to the prototype model. Such a system would enable an operator to simulate actual flight practice involving the tacan and data-link equipments. The convenience of such a system is fairly obvious because of the dependence of actual test flight operations on such uncontrollable variables as weather conditions and because of the considerable expense of such activities. It was desirable that the flight-simulator equipment take the form of an airplane cockpit fitted with the necessary controls and display instruments to provide some realism. The following sections describe the design and operational features of the first tacan data-link evaluator and trainer.

1. *Operational Requirements*

The simulator equipment was designed to provide the characteristics believed to be truly necessary for evaluation and training purposes with no unnecessary complications and refinements. The cockpit panel is a simplified instrument panel containing standard attitude and motion displays and was installed in a specially constructed cockpit. No cockpit motion was provided for obvious reasons, and the usual fuel and engine instrumentation was omitted. A complete set of tacan data-link instruments and controls is included in the panel and the standard *AN/ARN-21* and *AN/ARN-26* airborne units are installed in the flight-computer rack. An arrangement is provided making it possible to operate the tacan data-link electronic circuits either through a video cable link with the *AN/URN-6* ground equipment or through the actual radio-frequency link of the *AN/ARN-21* and *AN/URN-3* beacon. The simulator cockpit has throttle, rudder, and stick (aileron and elevator) controls; the stick being interchangeable with a standard wheel-type control. A standard crosspointer course indicator was included to display ground-control-of-approach (GCA) and instrument-landing-system (ILS) indications.

2. *Aircraft Flight Equations*

The flight-simulator computer is intended to take the throttle, aileron, and elevator input signals as controlled by the operator and to perform the simultaneous solution of the aircraft equilibrium equations. The solution of these equations provides the corresponding aircraft behavior in the form of roll, pitch, air speed, heading, altitude, rate of climb, and rate of turn. The aircraft position in the form of tacan distance and bearing from the beacon is then obtained by resolution and integration of the computed air speed. These computed quantities are displayed on the cockpit panel instruments.

2.1 SYMBOLS

D = resultant drag
F = resultant force acting on aircraft
g = acceleration of gravity
h = altitude
K_a = aileron sensitivity coefficient
K_d = resultant drag coefficient
K_e = elevator sensitivity coefficient
$K_{P1} = \partial\gamma/\partial(\dot{\gamma} + \dot{\alpha})$
$K_{P2} = \partial\gamma/\partial(\gamma + \alpha)$
K_t = throttle sensitivity coefficient
$K_{V1} = \partial\gamma/\partial V$
$K_{V2} = \partial\alpha/\partial V$
L = lift
m = aircraft mass
T = engine thrust
V = air speed
x = east–west position coordinate with respect to tacan beacon
y = north–south position coordinate with respect to tacan beacon
α = angle of attack

$\alpha + \gamma$ = pitch angle measured from horizontal
γ = angle of ascent measured from horizontal
ϵ = elevator control displacement
θ = tacan bearing of beacon
ξ = aileron control displacement
ρ = tacan distance from beacon
τ = throttle control displacement
ϕ = bank angle with respect to vertical
ψ = heading with respect to north.

2.2 Approximate Flight Equations

The flight equations have been simplified to neglect various complications. The following are some of the commonly known effects that have been neglected.

A. Precessional moments of the propeller or turbine.

B. Moments caused by noncoincidence of the aircraft center of mass and the aerodynamic center.

C. Inertia cross-coupling moments resulting from simultaneous angular rates about more than one coordinate axis.

2.3 Rectilinear Flight Equilibrium

An aircraft in steady flight is pictured in Figure 1. The axes *1*, *2*, and *3* define a right-handed orthogonal coordinate system originating at and fixed to the aircraft center of mass. Axis *1* is the longitudinal (roll) axis, axis *2* is the lateral (pitch) axis, and axis *3* is the vertical (yaw) axis.

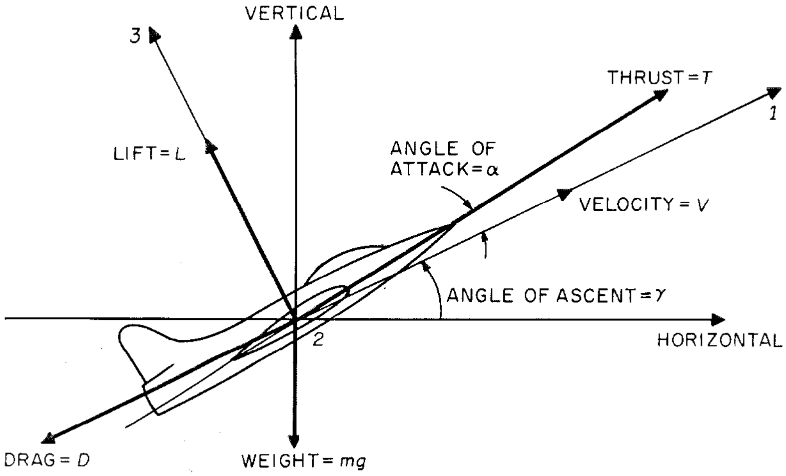

Figure 1—Forces for flight in a vertical plane.

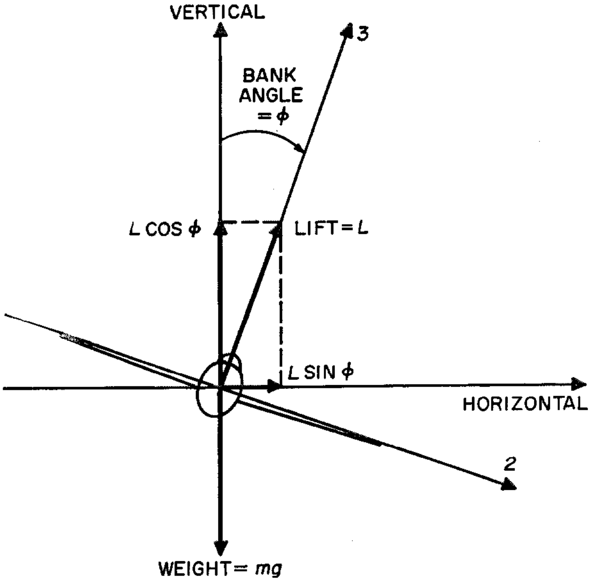

Figure 2—Forces for coordinated turning in a horizontal plane.

The resultant of force components along the *1* axis is approximately

$$F_1 = T\cos\alpha - D - mg\sin(\alpha + \gamma) = m\dot{V}. \quad (1)$$

Similarly, the resultant of forces along the *3* axis is

$$F_3 = L - mg\cos\gamma = 0. \quad (2)$$

2.4 Curvilinear Flight Equilibrium

In the general case of curvilinear motion in a vertical plane, (1) remains unchanged and (2) becomes

$$F_3 = L - mg\cos\gamma = mV\dot{\gamma}, \quad (3)$$

since there is now a radial acceleration along axis *3*.

For the case of coordinated turning in a horizontal plane, the sketch of Figure 2 illustrates the forces involved. The relation between forces in the horizontal plane is then

$$mV\dot{\psi} - L\sin\phi = 0. \tag{4}$$

Also, it is necessary for vertical equilibrium that

$$L\cos\phi - mg = 0. \tag{5}$$

Combination of (4) and (5) yields the turn–bank relation

$$\dot{\psi} = (g\tan\phi)/V. \tag{6}$$

3. Simplified Flight Equations

For the purposes of this flight simulator, it was believed that it would be sufficient to approximate closely the behavior of an aircraft only for straight and level flight. In other respects the aircraft would be fairly realistic but not accurately so in its behavior. The reason for this choice is that evaluation and training for the data link are not dependent on the airplane characteristics directly, but rather involve mainly the computed variables.

Since the angle of attack never exceeds a few degrees, (1) and (3) can be simplified by first approximating,

$$\cos\alpha \approx 1. \tag{7}$$

Furthermore, if the computation is to be accurate only for small values of angle of ascent,

$$\sin\gamma \approx \gamma, \tag{8}$$

and

$$\cos\gamma \approx 1. \tag{9}$$

The resultant drag is very nearly

$$D = K_d V^2 \tag{10}$$

and thrust can be assumed to be proportional to the throttle,

$$T = K_t \tau. \tag{11}$$

By substitution of (7), (8), (10), and (11) into (1), the simplified form is obtained:

$$\dot{V} = \frac{K_t}{m}\tau - \frac{K_d}{m}V^2 - g\gamma. \tag{12}$$

Equation (3) can be replaced by a more-convenient approximation as follows. Since both lift force and angle of ascent are functions of several variables, the resultant force along the *3* axis can be roughly approximated on a linear basis by the relation

$$(\dot{\gamma} + \dot{\alpha}) \approx K_e\epsilon + K_{V1}V, \tag{13}$$

which holds for small values of elevator displacement. The pitch angle can be obtained approximately as

$$\gamma \approx \alpha_0 + K_{V2}V + K_{P1}(\dot{\gamma} + \dot{\alpha}) + K_{P2}(\gamma + \alpha). \tag{14}$$

Equation (6) can be solved fairly easily in its present form without modification.

4. Analog Computation

The computer configuration chosen to solve (6), (12), (13), and (14) is shown in block-diagram form in Figure 3. This computer uses servo integrators and other servo components because of the long information-storage times required. In general, the computation itself is accurate within a few percent.

The coefficients and ranges of variables of this system were chosen to be consistent with a composite average type of aircraft having the following characteristics.

Weight m	= 20 000 pounds (9000 kilograms)
Thrust T	= 7500 pounds (3400 kilograms)
Air speed V	= 650 knots (1200 kilometers per hour)
Bank angle ϕ	= ± 75 degrees
Bank rate $\dot{\phi}$	= ± 20 degrees per second
Pitch angle $\alpha + \gamma$	= ± 45 degrees
Pitch rate $\dot{\alpha} + \dot{\gamma}$	= ± 10 degrees per second
Turn rate $\dot{\psi}$	= ± 10 degrees per second
Position ρ, θ	= 200 nautical miles (370 kilometers) from tacan beacon
Altitude h	= 50 000 feet (16 000 meters)
Rate of climb $\dot{h}$	= + 4500 feet (1400 meters) per minute − 6500 feet (2230 meters) per minute.

For the purposes of this computer, the aerodynamic coefficients can be taken as constant

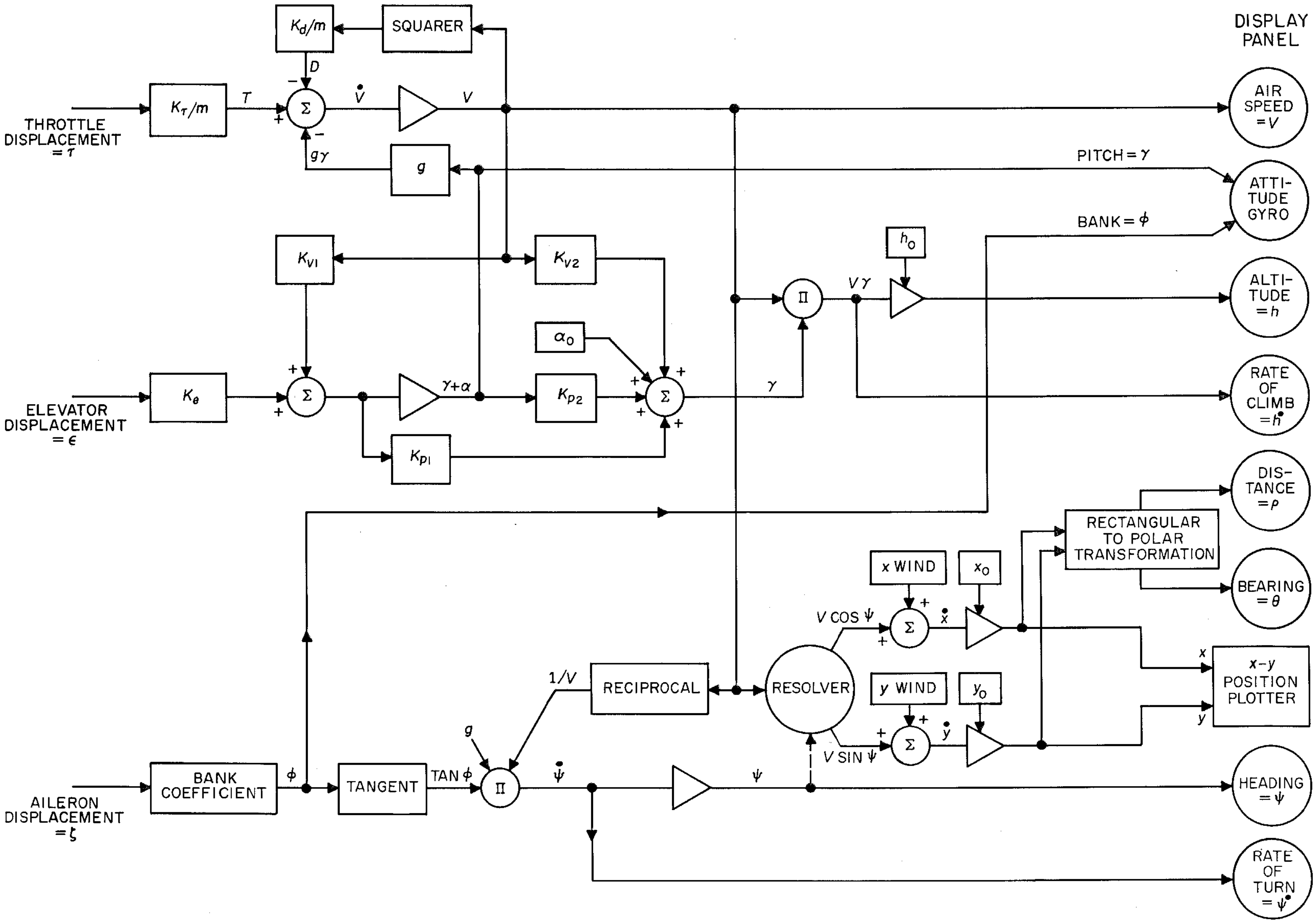

Figure 3—Flight-computer configuration.

and the computer will remain fairly correct for air speeds near a chosen center value. A straight and level flight at a constant air speed of 400 knots (740 kilometers per hour) will produce a flight computation with a minimum error. Therefore, these conditions are advisable for accurate data-link control programs. In other respects, the simulated aircraft behaves reasonably well with much of the natural feeling in the cockpit controls resulting from the computer cross-couplings of the flight equations.

5. *Control and Display Functions*

A photograph of the cockpit control panel is shown in Figure 4. In addition to the instruments shown, there is also a rectangular plotter that displays any of the computed variables on its two axes. The usual use of the plotter is to record the aircraft trajectory with respect to the tacan beacon on a chart calibrated in nautical miles. The analog computer equipment is housed in a separate rack and has controls for setting in the initial position coordinates, variable wind disturbances, and a slewing control for the rapid manual change of altitude.

6. *Conclusion*

The present flight-simulator system was designed and built to serve a fairly restricted purpose that does not require the exact representation of a particular aircraft. If a more-versatile arrangement were required, a similar system could be made with all variable coefficients and scale factors that would represent any aircraft for which these coefficients are known. In addition, the approximate forms of the flight equations could be replaced by more-exact expressions.

The aircraft simulator provides a convenient substitute for actual flight testing of a single aircraft channel of tacan data link. The complete system control loop contains both human pilot dynamics and the simulated dynamic behavior of an airplane. The other use of the system, as a trainer, promotes familiarity with the operation and data display of the airborne tacan data-link installation.

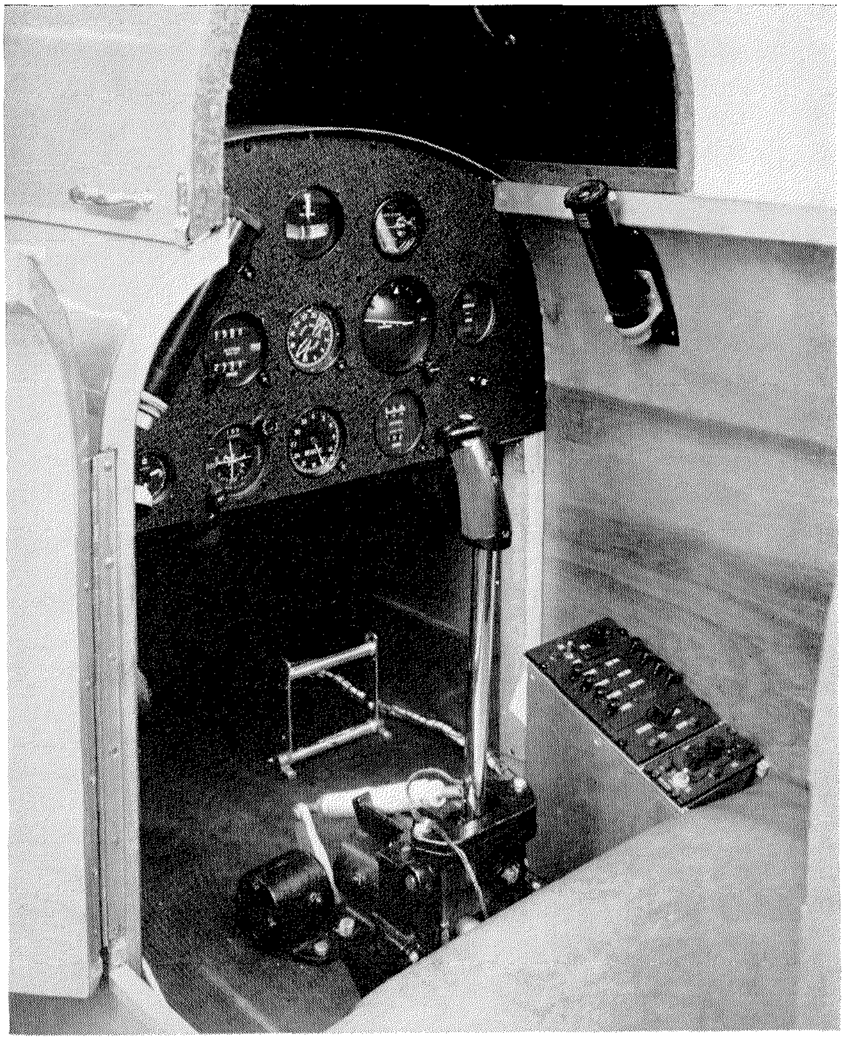

Figure 4—Flight-simulator cockpit.

United States Patents Issued to International Telephone and Telegraph System; February-April 1957

Between February 1 and April 30, 1957, the United States Patent Office issued 48 patents to the International System. The names of the inventors, company affiliations, subjects, and patent numbers are listed below.

J. E. Bosh, Kellogg Switchboard and Supply Company, Dial-Type Impulse Sender, 2 781 666.

E. M. Bradburd, Federal Telecommunication Laboratories, Transmission Systems, 2-781 491.

H. Bretschneider, Mix & Genest (Stuttgart), Arrangement for Use in Conveying Plants Employing Magnetic Destination Characteristics, 2 784 851.

H. Bretschneider, Mix & Genest (Stuttgart), Contact Chain Circuit for Consecutive Preparation of Idle Outlets in Telephone Systems, 2 787 741.

A. E. Brewster, Standard Telecommunication Laboratories (London), Tape Recording Apparatus, 2 780 670.

J. H. Bryant and T. J. Marchese, Federal Telecommunication Laboratories, Traveling-Wave Electron Discharge Device, 2 788-465.

A. G. Clavier and D. L. Thomas, Federal Telecommunication Laboratories, Attenuator for Surface-Wave Propagation, 2 782 382.

G. M. Cresson, International Standard Electric Corporation, Pressure Connector, 2 780-794.

V. J. DeSantis and F. L. Hunter, Federal Telecommunication Laboratories, Electrodes for Electron Discharge Devices and Methods of Making Same, 2 788 460.

S. H. M. Dodington, Federal Telecommunication Laboratories, Multichannel Radio Equipment, 2 790 079.

C. W. Earp, Standard Telephones and Cables (London), Electric Code-Modulation Systems of Communication, 2 783 305.

C. W. Earp, Standard Telephones and Cables (London), Keyed Frequency-Modulation Carrier-Wave Systems, 2 784 255.

C. W. Earp, Standard Telephones and Cables (London), Pulse Communication Systems, 2 786 100.

C. W. Earp, Standard Telephones and Cables (London), Receiving Arrangements for Electric Communication Systems, 2 787-787.

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T. W. Griffithe, Federal Telephone and Radio Company, Method for Making Electrical Terminals, 2 784 532.

E. Heinecke, C. Lorenz A. G. (Stuttgart), High-Efficiency Linear Amplifier, 2 785 235.

R. Helmert, C. Lorenz A. G. (Stuttgart), Circuit Arrangement for Blocking Circuits in Interlocking-Plants Operation with Electric Lockings, 2 787 740.

L. P. Hopkins, Federal Telephone and Radio Company, Latch, 2 784 994.

H. L. Horwitz and M. E. Homan, Federal Telephone and Radio Company, Combination Telephone and Dictation System, 2 787 659.

T. M. Jackson, Standard Telephones and Cables (London), Electric Discharge Devices, 2 780 747.

B. B. Jacobsen and D. L. Thomas, Standard Telephones and Cables (London), Radio Antennas, 2 785 398.

D. K. Keel and C. H. Mayhew, Federal Telecommunication Laboratories, Vinyl Ether and Polymer Thereof, 2 784 175.

J. A. Kostriza, Federal Telecommunication Laboratories, Microwave Coupling Arrangements, 2 790 148.

J. Kruithof, L. J. Nys, and J. L. J. Donceel, Bell Telephone Manufacturing Company (Antwerp), Assembling Arrangement for Commutating Mechanisms, 2 787 668.

A. Lesti, Federal Telecommunication Laboratories, Electronic Switching Apparatus for Telephone Systems, 2 785 230.

A. M. Levine, Federal Telecommunication Laboratories, Color Television Receiver, 2 786 886.

E. M. S. McWhirter and S. B. Ost, Intelex Systems Incorporated, Apparatus for Microfilming Documentary Records, 2-787 190.

E. M. S. McWhirter and S. B. Ost, International Standard Electric Corporation, Apparatus and Method for Comparing Recorded Information, 2 785 388.

M. R. Mauge and J. R. A. F. Escande, Le Matériel Téléphonique (Paris), Apartment Satellite Circuits, 2 787 667.

G. H. Menhennet, Federal Telephone and Radio Company, Squelch Circuit, 2 785 298.

A. T. Nordsieck, Federal Telecommunication Laboratories, Broadband Magnetron, 2-787 734.

H. Oden, Standard Elektrizitäts-Gesellschaft A. G. (Stuttgart), Circuit Arrangement for Automatic Testing of Lines, 2 787 674.

T. Petrides, Federal Telecommunication Laboratories, Phase Detectors, 2 781 489.

V. F. Ragni, Capehart–Farnsworth Company, Stabilized Direct-Current Amplifier, 2-781 419.

E. Richert, Mix & Genest (Stuttgart), Pneumatic-Conveying-System Transmission Tubes, 2 784 922.

D. S. Ridler, Standard Telecommunication Laboratories (London), Gas Discharge Tubes and Circuit Arrangements Therefor, 2 780 751.

K. O. Seiler, Süddeutsche Apparatefabrik (Nürnberg), Process of Smelting Germanium, 2 780 539.

W. Sichak, Federal Telecommunication Laboratories, Antenna, 2 790 169.

W. Sichak and J. J. Nail, Federal Telecommunication Laboratories, Helical Antenna System, 2 781 514.

F. Steiner and E. Dinstl, Vereinigte Telephon- und Telegraphen-fabriks A. G. (Vienna), Operating Mechanism, 2 780 105.

H. Strosche and O. J. Klein, Süddeutsche Apparatefabrik (Nürnberg), Counterelectrode for Dry-Disc-Type Rectifiers, 2-787 745.

V. J. Terry, R. Kelly, R. S. Miller, and P. S. Kelly, Standard Telephones and Cables (London), Regulated Rectifier Power-Supply Equipment, 2 785 371.

V. J. Terry, D. S. Ridler, and D. A. Weir, Standard Telecommunication Laboratories (London), Electric Pulse-Responsive Counter, 2 788 940.

V. J. Terry, D. S. Ridler, and D. A. Weir, Standard Telecommunication Laboratories (London), Telegraph Repeaters, 2 787 657.

H. Wolfson and S. C. Shepard, Standard Telephones and Cables (London), Electric Semiconducting Devices, 2 785 349.

Traveling-Wave Electron Discharge Device

2 788 465

J. H. Bryant and T. J. Marchese

A traveling-wave tube having a helical transmission line in a metallic housing is disclosed. The collector electrode is mounted at one end of the housing; radio-frequency input and output leads provided with terminals at the other end of the housing extend inside to couple to opposite ends of the helical line.

Pulse Communication Systems

2 786 100

C. W. Earp

The patent concerns a system of time-modulated pulse communication in which the transmission bandwidth is reduced by coding. The coding is accomplished by applying two trains of pulses at slightly different repetition rates in two separate channels to a comparator and transmitting a time-modulated pulse when there is a coincidence in pulse timing of a pulse of the two trains at the comparator. The phase of one of the trains is altered in accordance with the channel modulation.

Process of Smelting Germanium

2 780 539

K. O. Seiler

In the smelting of germanium under this patent, a quartz crucible is used, the crucible being first coated with a thin film of amorphous carbon by placing it in an oven and cracking a hydrocarbon at a temperature below the softening point of the quartz. This precoating results in increased facility in the smelting process.

Arrangment for Use in Conveying Plants Employing Magnetic Destination Characteristics

2 784 851

H. Bretschneider

A belt-conveyor sorting system is described, the belt being made of magnetic material that is coded by signals producing any of three possible conditions of magnetization to indicate the proper destination of the articles on the conveyor.

Squelch Circuit

2 785 298

G. H. Menhennet

This patent discloses a squelch circuit for reducing amplification in the presence of intolerable noise levels. The signal containing the noise controls a relaxation-type oscillator, its output being integrated and used to bias the amplifier to cutoff when the noise level becomes too high.

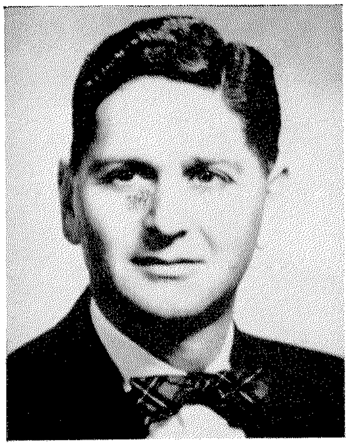
Apparatus and Method for Comparing Recorded Information

2 785 388

E. M. S. McWhirter and S. B. Ost

An apparatus is described for correlating information on a document with one of many similar records on film. An arrangement is provided for sequentially projecting the film images on a screen. Indicia on the document are sensed and recorded in a register and indicia on each successive frame of the film are recorded in a second register. A comparator circuit stops the film when the information in the two registers is identical.

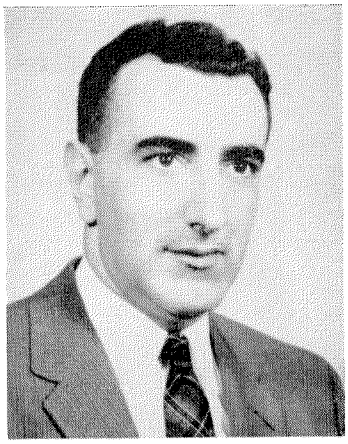
Contributors to This Issue


Ben Alexander

Ben Alexander received the B.A. degree from Cornell University.

Mr. Alexander, acting director of the electronic systems laboratory at Federal Telecommunication Laboratories, has done research and development in long-range navigational systems, inertial navigation, dead-reckoning devices, electronic simulators, and tactical bombing and communication systems. He holds five patents with several others pending.

Mr. Alexander has been a member of the Radio Development Board's Committee on Guided Missiles, Working Group on Self-Contained Guidance Systems, and the Radio Technical Commission for Aeronautics' Special Committees *50*, *54*, *63*, and *74*. He is a member of the Institute of Radio Engineers.


Edmund R. Altonji

• • •

Edmund R. Altonji was born in Brooklyn, New York, on November 13, 1924. He received the B.E.E. degree in 1951 from the Polytechnic Institute of Brooklyn.

On graduation, he joined Federal Telecommunication Laboratories, where he has worked on magnetic amplifiers, servomechanisms, and analog computers. He is a senior project engineer at the laboratories.

Mr. Altonji is a member of the Institute of Radio Engineers and of Eta Kappa Nu.

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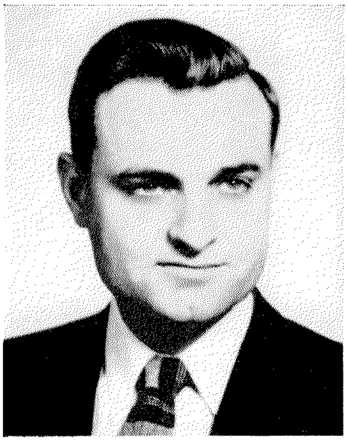

Michael A. Argentieri

Michael A. Argentieri was born on March 10, 1926 in Newark, New Jersey. He received the B.S. degree in mechanical engineering in 1946 from Newark College of Engineering.

On graduation, he joined Kollsman Instrument Corporation, working on aerial navigational equipment until 1953, when he became secretary and chief engineer of McDermott Controls, Incorporated, producing airplane instrumentation devices.

In 1955, Mr. Argentieri joined Federal Telecommunication Laboratories where he is now a senior project engineer in the electronic systems laboratory.

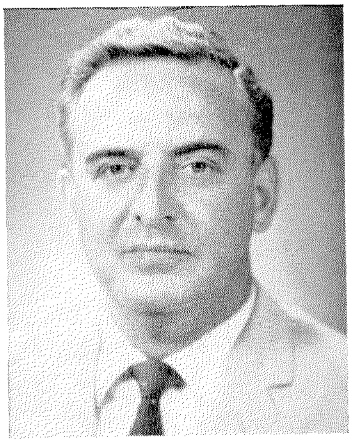
• • •

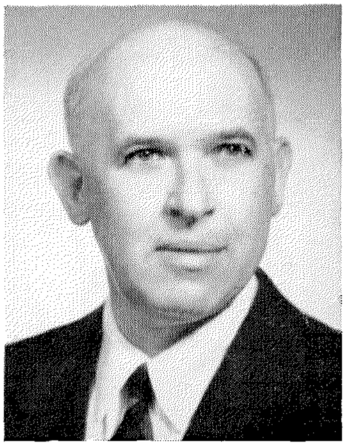
Murray Block was born in Brooklyn, New York, on August 24, 1916. He attended the College of the City of New York, Brooklyn College, and Brooklyn Law School.

Prior to the second world war, Mr. Block was employed by the Civil Aeronautics Administration as assistant chief controller of the New York air-route traffic-control center. From 1942 to 1946, he served in the United States Navy as an aviator. From 1951 to 1954, he was with the Department of the Air Force as chief of the air-traffic-control branch. In 1954 and 1955, he was an air-traffic-control specialist for the Air Force. From 1951 to 1955, Mr. Block participated in many of the committees established to study and improve avigation and air-traffic control.

In 1955, he joined the sales department of Federal Telephone and Radio Company.

He is a professional member of the Air Traffic Control Association and a Lieutenant Colonel of the Air Force Reserve.

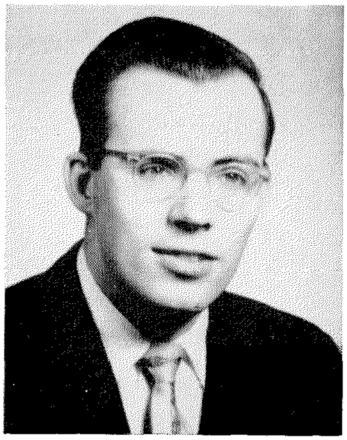

Murray Block



Robert I. Colin

Robert I. Colin was born in Brooklyn, New York on February 16, 1907. He received an A.B. degree from Cornell University in 1928 and an M.S. degree in experimental physics in 1933 from New York University. He studied physics for a year at the University of Frankfurt in Germany as an exchange fellow. From 1929 to 1933, he was a teaching fellow at New York University.

In 1934, he joined the faculty of Hebrew Technical Institute as an instructor in physics and mathematics. In 1941, he became an instructor and then head of the aircraft electrical systems branch of the Air Force Technical School at Chanute Air Force Base that later became the Officers Maintenance Engineering School at Yale University.



Edward A. Kunkel, Jr.

Mr. Colin joined Federal Telecommunication Laboratories in 1944. He served in the aerial navigation department for ten years, then was attached to the central executive department where he is now administrative assistant to the vice president for governmental projects. He has been closely associated with the tacan and data-link program from its inception. He is a member of Phi Kappa Phi. As a participant in Special Committee *31* of the Radio Technical Commission for Aeronautics, he shared in the award of the Collier Trophy to that group for its work on a common system of avigation and traffic control.

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Edward A. Kunkel, Jr. was born in Newark, New Jersey, on September 28, 1928. He received the B.S.E.E. degree in 1951 and an M.S.E.E. degree in 1956 from Newark College of Engineering.

He was with Arma Corporation in 1951 and 1952 and with A. F. Smuckler and Company in 1952 and 1953. Mr. Kunkel then entered the United States Army Signal Corps where he worked as an engineer in the electronic warfare department on various countermeasure problems. He completed his military service in 1955 and joined Federal Telecommunication Laboratories.

Mr. Kunkel is a member of the Institute of Radio Engineers.

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Francis E. Lind was born in Boston Massachusetts, in 1922. He is a graduate of Lowell Institute, Boston.

Mr. Lind came to Federal Telecommunication Laboratories in 1951 as a senior engineer after eleven years with Raytheon Manufacturing Company where he worked on the mechanical design of electronic equipment, radar antennas, and special electromechanical developments.

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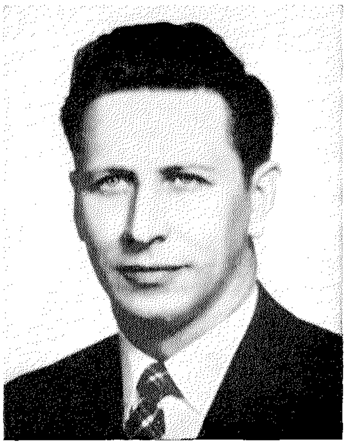

Francis E. Lind

Richard Mead was born in Orange, New Jersey, on March 3, 1926. He received the degree of mechanical engineer from Stevens Institute of Technology in 1950.

From 1950 to 1953 Mr. Mead was employed by the electrical-accounting-machine division of International Business Machines Corporation. He joined the electronic systems laboratory of Federal Telecommunication Laboratories in 1953.

Mr. Mead is a member of the Institute of Radio Engineers.

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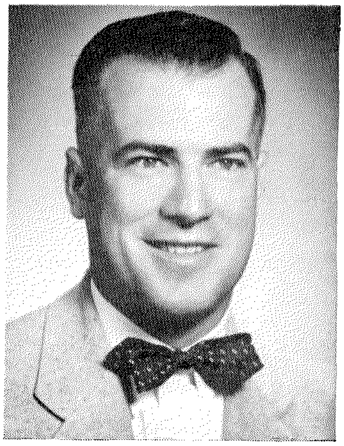
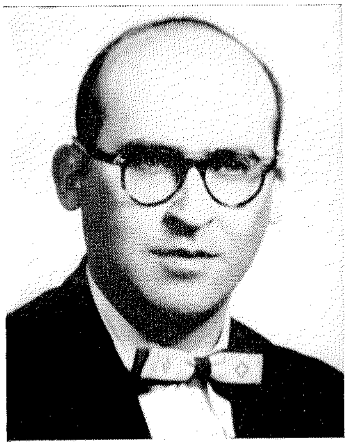
Harold J. Mills graduated from the College of the City of New York in



Richard Mead



Harold J. Mills

1950. He worked for the Philco Corporation until 1951 as a technical representative on the *B-36* radar and computer program at Fort Worth, Texas. He then joined the staff of Bendix Aviation Corporation at Teterboro, New Jersey and contributed to missile and *F9F* autopilot development until the end of 1952. At that time, he became associated with Federal Telecommunication Laboratories. Mr. Mills is now working on digital computers.

He is a member of the Institute of Radio Engineers and of Eta Kappa Nu.

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George W. Reich, Jr.

George W. Reich, Jr. was born on November 10, 1926, in Newark, New Jersey. He received a B.E.E. degree from Clarkson College of Technology in 1950 and an M.S. degree from Stevens Institute of Technology in 1957.

Mr. Reich was associated with the research and development laboratories of the National Union Electric Corporation from 1950 to 1952. Joining Federal Telecommunication Laboratories in 1952, he is now a senior engineer in the electronic systems laboratory.

Mr. Reich is a member of Tau Beta Pi.

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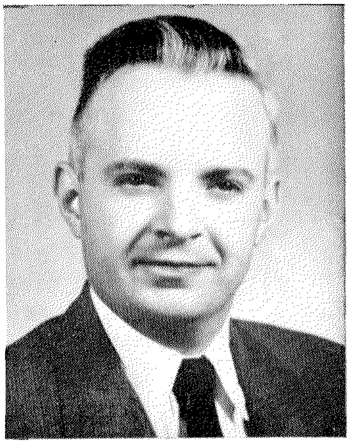

Robert C. Renick

Robert C. Renick was born on May 1, 1924 in Yonkers, New York. He received the B.S. degree in electrical engineering from Lehigh University in 1948.

He joined International Telephone and Telegraph Corporation on graduation and was transferred shortly thereafter to Federal Telecommunication Laboratories where he has been engaged in the development of several avionic systems. At the present time, he is an executive engineer in the electronic systems laboratory.

Mr. Renick is a Senior Member of the Institute of Radio Engineers and a member of Eta Kappa Nu.

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Peter C. Sandretto was born on April 14, 1907, in Pont Canavese, Italy. He received from Purdue University the B.S. degree in electrical engineering in 1930 and the degree of electrical engineer in 1938. He also attended Northwestern University and was graduated from the Command and Staff School of the United States Army.

From 1930 to 1932, he designed aircraft radio equipment at Bell Telephone Laboratories. As superintendent of the communication laboratories of United Air Lines from 1932 to 1942, he pioneered in radio aeronautical problems such as precipitation static, direction finding, instrument approach, and altimetry. During the second world war, he served with the United States Air Force in the American, European, and Asiatic theatres. He is now a brigadier general in the Air Force reserve.

In 1946, he joined Federal Telecommunication Laboratories and is now vice president and technical director for military research and development projects.

General Sandretto is a Fellow of the Institute of Radio Engineers, a Member of the Institute of Navigation, and an Associate Member of the Institution of Electrical Engineers. He has served on committees of the Radio Technical Commission for Aeronautics since its inception in 1935. He is the author of "Principles of Aeronautical Radio Engineering."

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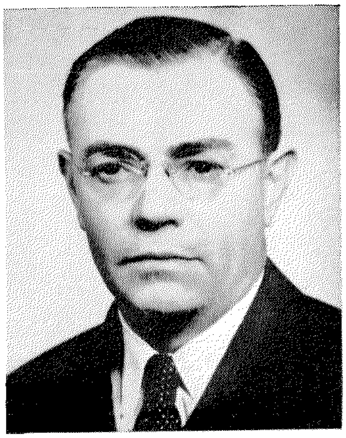
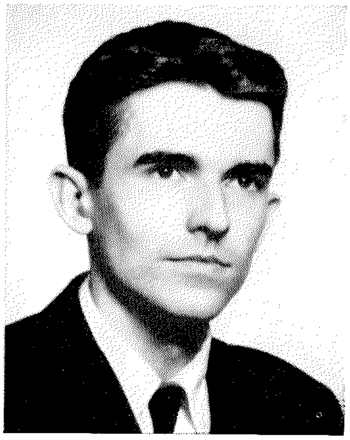


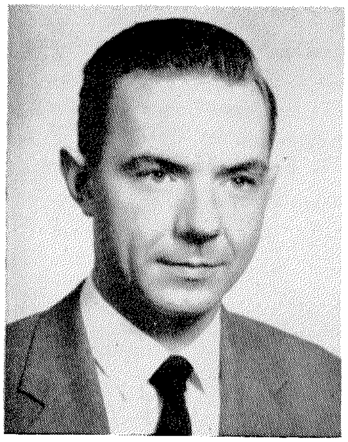
Peter C. Sandretto



William Sudduth

William Sudduth was born in Lakeland, Florida, in 1932. He received the B.S. degree in electrical engineering from Massachusetts Institute of Technology in 1954.

He joined the staff of Federal Telecommunication Laboratories in 1954 and is now engaged in the design and development of inertial navigational systems.



John F. Sullivan

Mr. Sudduth is a member of the Institute of Radio Engineers.

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John F. Sullivan was born in Meridian, Mississippi, on October 7, 1926. He received an M.E. degree in 1949 and an M.S. in electrical engineering in 1952 from Stevens Institute of Technology.

From 1949 to 1952, he was employed by the general laboratories of the United States Rubber Company. Since that time he has been with Federal Telecommunication Laboratories. He has been active in the data-handling and data-transmission fields.

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Fred L. Van Steen was born in Plainfield, New Jersey, in 1930. He graduated from Valparaiso University, Indiana, in 1952 with a B.S. degree in electrical engineering.

Since graduation, he has been associated with Federal Telecommunication Laboratories and is now a senior engineer in the electronic systems laboratory.

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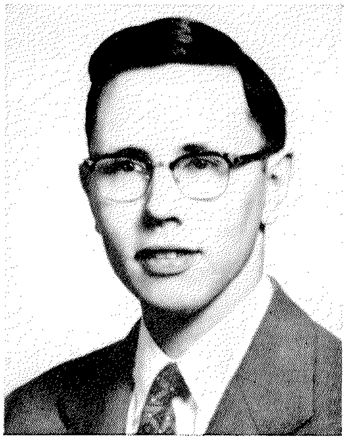
Harry G. Whitehead was born on November 20, 1925, in Bridgeport, Connecticut. He received a B.S. degree in electrical engineering from Newark College of Engineering in 1954.

In 1945, Mr. Whitehead joined Federal Telephone and Radio Corporation where he worked on the *AN/CRN-2A* glide-slope transmitter. He then entered the United States Air Force and served as an instructor in electronics at the Air Force Technical Training School, Scott Air Force Base, Illinois. In 1954, he rejoined the International System to go on the staff of Federal Telecommunication Laboratories.



Fred L. Van Steen

Mr. Whitehead is a Member of the Institute of Radio Engineers, an Associate Member of the American Institute of Electrical Engineers, and a member of Tau Beta Pi and Eta Kappa Nu.

Harry G. Whitehead

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BOLIVIA —
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BRAZIL —
Companhia Radio Internacional do Brasil ... Rio de Janeiro
Companhia Telefônica Nacional ... Rio de Janeiro

CHILE —
Compañía de Teléfonos de Chile ... Santiago
Compañía Internacional de Radio, S.A. ... Santiago

CUBA —
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Cuban Telephone Company ... Havana
Radio Corporation of Cuba ... Havana

PERU —
Compañía Peruana de Teléfonos Limitada ... Lima

PUERTO RICO —
Porto Rico Telephone Company ... San Juan
Radio Corporation of Puerto Rico ... San Juan

SPAIN —
Compañía Radio Aérea Maritima Española ... Madrid

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