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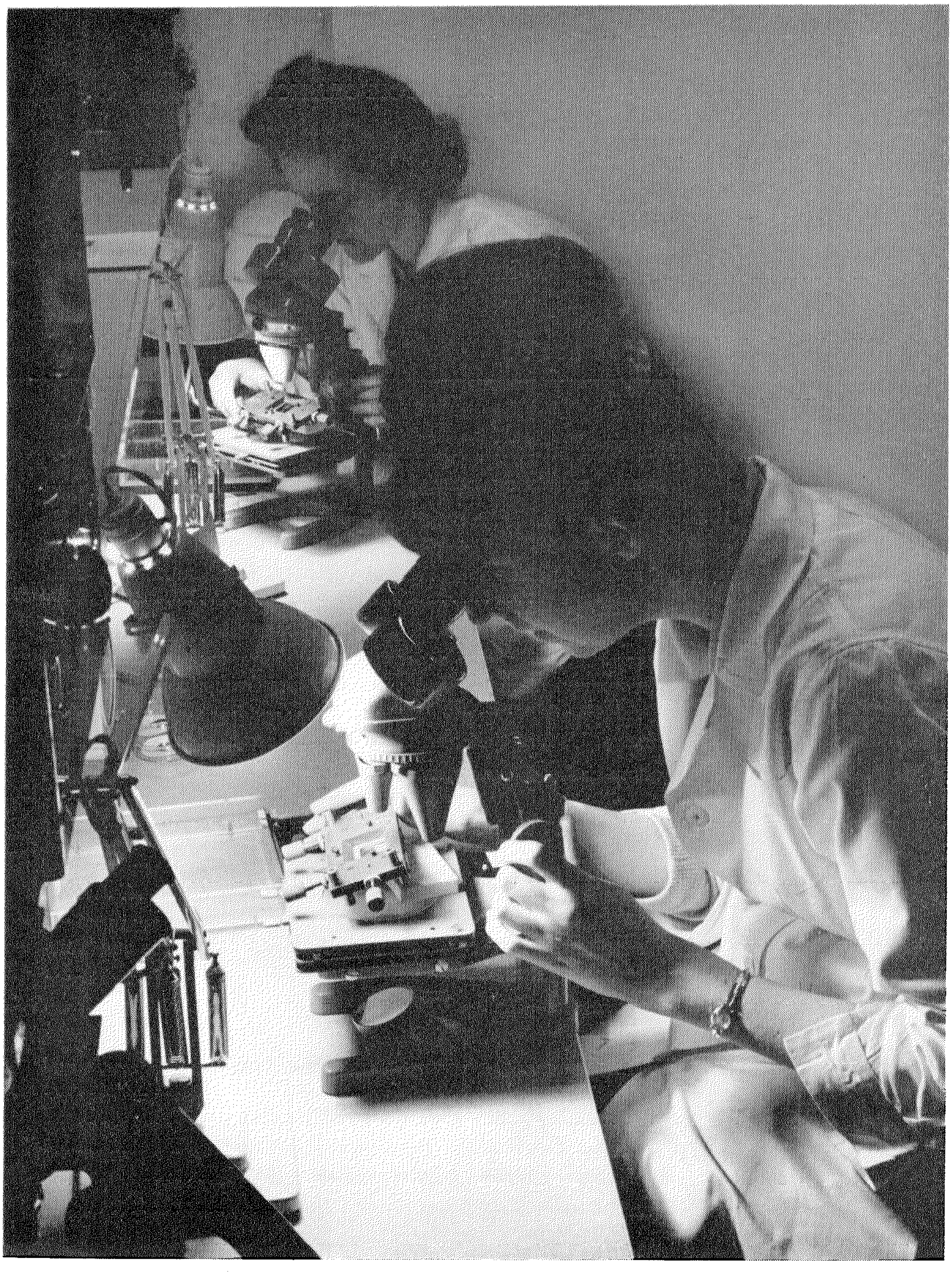
Notes

EDITOR, H. P. Westman **Subscription: $2.00 per year; 50¢ per copy**



Dark-room in which the 1000 elements for planar epitaxial transistors formed on the surface of a 25-millimeter (1-inch) silicon disk are lined up for receiving an etch-resistant coating at the Standard Telephones and Cables plant in London.

This Issue in Brief

Vordac for Precise Navigation over Very-High-Density Air-Traffic Routes—The problem of operating aircraft safely becomes more intense as the air-traffic density increases. It is necessary to predict future requirements and provide in advance for each major increase in traffic. VORDAC is a specific design for this purpose.

The Eurocontrol Association has set up a target specification of bearing information to within 1 degree and distance to within 1·5 nautical miles (2·8 kilometres) for distances within 200 nautical miles (370 kilometres) of the beacon station. Present distance-measuring equipment will provide the required accuracy for distance but the existing very-high-frequency omnidirectional ranges are not adequate for the required bearing information.

A new very-high-frequency omnidirectional range operating on the rho-theta system of polar co-ordinates uses the Doppler effect by connecting the transmitter at the beacon station sequentially to each aerial of a circular array and also transmits a sideband at the fifth harmonic of the reference signal to provide both "coarse" and "fine" bearing information. Compatible with the present omnirange receivers, this system greatly reduces site errors, the inaccuracies stemming from reflecting bodies near the beacon antenna, and increases instrumental accuracy.

A track computer utilizing chiefly the indicators normally found in a rho-theta system permits the pilot to navigate orbitally round the beacon, fly a radial path to it, or fly a non-radial linear track that passes on either side of the beacon. It may also correct for the measurement of distance at slant range, which is significant only if an aircraft is near the beacon and also at a high altitude.

Datarama provides for reporting essential information to the ground controller, over a normal telephone line if necessary. Each of 100 aircraft may be interrogated every 20 seconds and the data stored for use by a computer. The ground beacon may interrogate all aircraft in the order of their bearing disposition or may concentrate on a certain area. The VORDAC is also capable of providing a selective calling system and the ground station may query a specific aircraft, for which 1000 different addresses are available.

The existing very-high-frequency omnidirectional ranges and distance-measuring equipment, both ground and airborne, may be modified and added to in an orderly application of these new and more-accurate facilities for greater safety in flight.

Submarine-Coaxial-Cable Manufacture at Southampton—The construction of a new submarine-cable factory at Southampton was initiated in 1954 by Standard Telephones and Cables. The plant is accessible to both highways and railways and a 400-foot (122-metre) gantry permits cable to be passed directly to a ship tied up at the quayside.

Three major types of submarine cable are manufactured. All use polythene of high molecular weight and low density for the insulant. Initially, telegraph cable was manufactured in small quantities for repair and maintenance purposes. Then conventional coaxial telephone cable with external armouring was made and later large quantities of the new light-weight armourless deep-sea coaxial cable were produced.

For telegraph use, a stranded centre conductor is surrounded by the insulant and current return is through the sea. An outer layer of steel wire armouring bedded in jute protects the cable against breakage, chiefly during laying.

For telephony, coaxial design is used with an outer conductor and a smoother centre conductor. Armouring may be as for the telegraph cable or, in a newer design, the strength member is a stranded steel wire covered by copper tape for the centre conductor, surrounded by the insulant, an outer conductor of copper tapes, and finally a polythene sheath. No outer steel armouring is required.

By permitting a strand to be jointed a safe distance from any other jointing and by butt welding tapes, any length of cable may be produced.

Polythene is extruded onto the centre conductor and must be cooled slowly to avoid contraction voids. This requires long water-filled cooling troughs.

The copper tapes are preformed by shaping dies before being applied to the cable and in some designs the sides are folded together in an interlocking or box seal.

Careful inspection and measurement at all stages of manufacture are necessary to ensure the high quality and uniform characteristics required for undersea installation. Finished cable is stored under water during the time required to complete an order, which may take many months.

Forward-Scatter Microwave Link Between Italy and Spain—This first commercial forward-scatter microwave radio link was inaugurated in 1957. It operates over a 380-kilometer (236-mile) path between Sardinia and Minorca at frequencies between 730 and 880 megacycles per second. Tests of the path at frequencies near 240 and 300 megacycles per second between 1954 and 1956 indicated the feasibility of the system and were confirmed at the higher frequencies now in use.

Using single paraboloidal reflectors 20-meters (66-feet) in diameter about 75 meters (246 feet) above sea level at each terminal with 500-watt transmitters, the transmission from Sardinia is at 730 and 830 megacycles per second with vertical polarization and the return path is covered at 780 and 880 megacycles per second with horizontal polarization.

Only frequency diversity is used and the outputs of the two receivers at each station are added linearly, the receivers being kept at equal gain.

Additional improvement is obtained from the use of compandor circuits.

Extensive measurements of received signal strength indicate that propagation when very-rapid fading occurs follows the Rayleigh law almost exactly independently of time for periods up to 1 or 2 hours and for slow and rapid fading the distribution approaches the Rayleigh law more closely for longer than for shorter periods of time.

Poorest propagation occurs in March with very-rapid and rapid fading during much of the time. Noise measurement in the telephone channels confirmed this.

The system provides 5 telephone and 3 telegraph channels simultaneously and through additional conventional circuits links Italy and Spain directly. No circuit interruptions due to propagation occurred during the year in which these tests were made and no interruptions were reported during the 3 years of service. Data show that during March and February, the poorest months, a signal-to-noise ratio better than 50 decibels was obtained 98.6 and 99.1 percent of the time.

Telecommunication Network of Edisonvolta Group in Italy—The Edisonvolta power network is in northern Italy. There are 23 remote power houses and substations controlled from a supervisory center in Milan. Among other equipment, there are over 200 circuit breakers the opened or closed operating conditions of which are reported automatically to Milan.

The telephone and remote-control network uses carrier over the 220- and 130-kilovolt power lines and both carrier and voice-frequency channels over telephone lines and cables.

In the telephone network, each remote station has a 3-digit number that is dialed on a standard telephone set. Some are connected directly to Milan and others are reached through automatic exchanges. If a direct path is busy, a call will be rerouted automatically around the occupied channel.

In the remote-control network, the number of units to be reported on or controlled in the largest station is smaller than a hundred and each such operating unit is identified by a two-digit number. Each digit is converted into a 5-bit code group that always has two 1's and three 0's. If for each position in the 5-bit code groups, the tens and units bits are taken as a pair, the results will be either 0-0, 0-1, 1-0, or 1-1 to which may be assigned 1, 2, 3, or 4 pulses, respectively. Thus the two series of 5-bit code groups for a two-digit number are converted to a single series of five groups having between 1 and 4 pulses each, the sum of which is always 11, providing a parity check of transmission errors.

At each station, the transmission is under control of a locally generated timing base that determines the pulse length, space between pulses, and time between trains of pulses. The time between pulse trains is standardized and by means of a counter is compared with the time base at the receiver, a further check on the transmission system. All essential information in requesting data or ordering a change is automatically retransmitted from the receiver back to the transmitter and confirmed before the action is taken.

Relays operating a mimic diagram at the supervisory center are of a magnetically locking type. If the 24-volt power supply is interrupted, the relay retains its position; it is operated to the other condition by a current in another winding creating an opposing magnetic field. Thus, if there is a temporary power failure at the remote station, it is unnecessary to make a complete inventory of the positions of every item indicated on the mimic diagram when power is returned.

Only about 3 seconds are required between the issuance of an order to a remote station and its completion. In about 6 seconds, information on the operating conditions of 10 pieces of equipment in a remote station can be reported to the supervisory center. Only 2 operators are required at the supervisory center in Milan.

Principal Uses of Coherent Light—All photons that constitute perfectly coherent light must be emitted at regularly spaced time intervals with identical frequency, phase, polarization, and direction of motion. No sources of such light are known but the laser approaches these requirements more closely than does any other source. In producing highly concentrated beams of small divergence for communication purposes, coherent light has great advantages over radio waves as is readily evident from the ratio of their wavelengths.

Light receivers would be based on the photomultiplier and the minimum detectable signal is determined by the granular aspect of light and by the dark current of the photomultiplier and the extraneous light reaching its cathode. For the corresponding radio case, the thermal noise level at the antenna determines the minimum detectable signal. The radio receiver has the lower minimum detectable signal level.

Much work needs to be done in methods of modulating light. Both the Kerr cell and the Pockels effect in certain crystals require a modulating signal of the order of 20 kilovolts. Modulation at 1000 megacycles per second of nearly 100 percent has been obtained and at a few percent at 15 000 megacycles per second.

Propagation of light through the atmosphere is disturbed by clouds, fog, rain, and snow. Temperature differences cause variations in the refractive index and thus will bend the light beam, making tracking of emitter and receiver difficult. Light beams may be transmitted over distances approaching 100 kilometers in a protected path such as that inside a pipe with mirrors to care for bends. Outer space being beyond atmospheric limits also offers interesting possibilities for signaling to space vehicles over millions of kilometers.

Transmission through clear water under optimum conditions is limited to about 1500 meters regardless of the power employed. Fiber optics, in which propagation is through dielectric guides, are unsuitable even for a few kilometers.

The sharpness of the light beam, the time coherence of the light, and the rapid rise time of the pulses recommend coherent light beams for radar applications. With a wavelength of 0.7 micron and a target moving at 1 kilometer per hour, a Doppler frequency of 800 kilocycles per second results, permitting speed measurements from a single pulse in a moving-target radar. Atmospheric disturbances would still be troublesome on earth but not necessarily in space.

A kilowatt of coherent light concentrated on an area of 1 square micron would produce a power density of 10^{11} watts per square centimeter and an electric field of nearly 10 million volts per centimeter. Such fields may provoke important interactions with matter. Intense thermal effects and welding may be useful in the micro domain.

Under high concentration, the pressure of radiation could be significant. High-pressure ultrasonic waves could be transmitted to matter over a light beam through modulation.

Biological effects are not considered but could be of great importance.

Hollow-Cathode Generator of Nanosecond Light Pulses—Light pulses in the nanosecond time range are useful for testing optical transmission systems and photoelectric devices. Among many means of producing these brief flashes are electric discharges in gas. This paper reports on such sources using a hollow cylindrical cathode and a ring-shaped anode immersed in either xenon or hydrogen.

The performance of the generator is strongly influenced by the circuit in which it is tested so 3 different test circuits were used, each most suited to either the upper frequency limit at which the tube may be pulsed, the maximum light output, or increasingly longer pulses to and including continuous light output. The light output was measured by a photomultiplier and the duration of the pulses was measured with an oscilloscope.

The rise time of the pulses measured between 10 and 90 per cent of peak intensity and with different gases is quite linear and varied from 2.5 to 6 nanoseconds. With corrections for the test equipment, these values were calculated to be from 1 to 3 nanoseconds. The trailing edge of the pulse is exponential and persists for several microseconds but at a very small fraction of the peak intensity. The pulse duration is considered to be the time between half-peak-amplitude points. The duration between the 10-per-cent points is about twice this.

The pulse duration increases with the capacitance of the capacitor that discharges through the light generator, increases linearly with the reciprocal of the gas pressure, decreases linearly for the square of the discharge voltage for xenon but remains approximately constant for the square of this voltage for hydrogen.

The peak light output increases rapidly with the capacitance of the discharge capacitor but then levels off above about 30 picofarads. In general, the light decreases with increasing gas pressure. A maximum occurs around pressures of 20 to 30 millimeters of mercury, being more pronounced with xenon than with hydrogen This may be due to wandering of the glow discharge. The light output increases with the square of the discharge voltage and is more marked for xenon than for hydrogen.

Time jitter varies greatly and for optimum conditions with either gas is less than 5 nanoseconds and may be as low as 1 nanosecond. An increase in discharge voltage always reduces jitter.

With the most favorable tube and circuit, pulsing frequencies of 5 megacycles per second have been produced with peak light output of 10^{-} lumen. Another tube and circuit have produced a peak light output of 2.6 lumens and a peak brightness of 1800 stilbs with a maximum pulsing rate of 17 kilocycles per second. Another tube and circuit produced a rise time of less than 2 nanoseconds, a duration of 3.2 nanoseconds, peak light output of 0.2 lumen, peak brightness of 140 stilbs at a repetition frequency of 30 kilocycles per second.

Lasers—Laser is a term derived from maser the initial letters from the expression Microwave Amplifier by Stimulated Emission of Radiation, with light replacing microwave in the newer term.

The physical laws that control the absorption and emission of electromagnetic waves lead us to associate radiation of a known frequency to an energy difference that is proportional to this frequency and also to consider physical elements as occupying various quantified levels of energy. Radiation falling on these materials may be absorbed or emitted if its frequency corresponds to the energy difference between these various levels.

At thermal equilibrium, the lower energy levels have the greatest population. In both maser and laser action, this population is reversed and means for accomplishing this are described. Photon emission results from the return of the electrons from the higher to the lowest energy level.

Tunnel-Diode Memory—A memory or store may use one tunnel diode per bit as the bistable element. The threshold of operation of the diode is based on the peak current immediately preceding the negative-resistance region, which current may be precisely controlled in the manufacture of the tunnel diode.

An experimental memory to store 8 words of 24 bits each has been constructed of commercial tunnel diodes, transistors, and other components, and has a work cycle including both writing and reading of 100 nanoseconds.

The speed is limited by the access circuits rather than the diodes. The small power dissipation of 1 milliwatt per memory cell and less than 0.15 milliwatt per tunnel diode permits full advantage to be taken of micromodule and integrated-circuit design to conserve space and weight.

Equations are given for the computation of optimum values and tolerances of circuit elements. The design stresses large tolerances on voltages, resistances, and peak currents of the tunnel diodes. The sum of all three tolerances can approach ±20 percent for acceptable operation.

Transistor amplifiers are used for both driving the tunnel diodes and for read-out. The tunnel diode is the major cost item and tends to limit such designs to small high-speed systems such as used as buffer memories in digital computers employing large but slower memories.

Note on Tunnel Diodes for Majority Logic Circuits—The high operating speed of the tunnel diode and its two stable states of operation suggest its use for logic circuits.

A binary adder for 2 words of 8 bits each was operated from a 4-phase clock and elementary addition was performed in not over 25 nanoseconds. The speed is limited by the diode junction capacitance and with commercial tunnel diodes does not exceed that obtainable from conventional diodes and transistors. Higher-speed tunnel diodes approaching picosecond operation may become available commercially.

Close tolerances on components and voltages and the present cost of tunnel diodes make their use over conventional systems questionable. They may, however, be justified for use in the presence of nuclear radiation.

Recent Engineering Developments

New Factory in Maddaloni, Italy—A new factory was inaugurated on 1 April 1962 at Maddaloni in the province of Caserta, near Naples, Italy. One of the most modern plants in the entire recent growth of Italian industry, this 130 000-square-foot (12 090-square-meter) building, shown in Figure 1, houses 500 employees engaged in the manufacture of 350 000 telephone subscribers' sets per year in addition to transmission equipment and other products. Planned additions will triple the floor area and quadruple the number of employees.

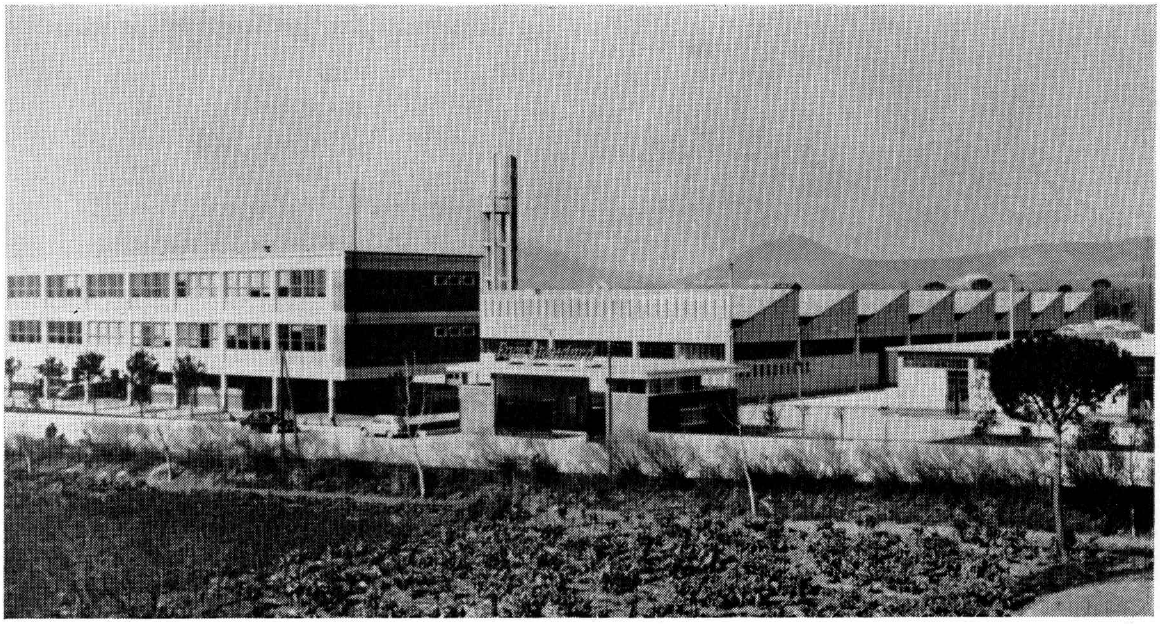
The placement of the factory is in keeping with the program of the government to stimulate the industrialization of the southern part of Italy.

The inauguration ceremonies, shown in part in Figure 2, were attended by His Excellency Emilio Colombo, Minister of Industry and Commerce, representing the Italian government; His Excellency Giovanni Leone, Chairman of the Chamber of Deputies; His Excellency Crescenzio Mazza, Under Secretary of State of Posts and Telecommunications; Mr. H. S. Geneen, President of International Telephone and Telegraph Corporation; and many members of the Posts, Telegraph, and Telephone Administration, armed forces, local authorities, and major Italian industries. These distinguished guests were received by Carlo Della Rocca and Carlo Roda, respectively, Chairman of the Board and Managing Director of Fabbrica Apparecchiature per Comunicazioni Elettriche Standard, whose new plant, already fully in production, was being inaugurated.

Fabbrica Apparecchiature per
Comunicazioni Elettriche Standard
Italy

Netherlands Completes Automation of Telephone Service—The Netherlands issued a series of postage stamps to commemorate the cutover within 11 days of each other of the last two

Figure 1—New factory at Maddaloni, Italy, near Naples of Fabricca Apparecchiature per Comunicazioni Elettriche Standard.



exchanges completing automatic operation of all its central offices.

The first telephone exchange in The Netherlands was installed by Bell Telephone Manufacturing Company in 1881. Later, Netherlandsche Standard Electric Maatschappij was established and these two companies have collaborated in the complete automation of the national system in which 7A, 7D, and 7E rotary played an important part.

In the Frisian town of Warffum, a street has been renamed A. G. Bellstraat, a name that was first used in Hoogeveen for a street on which the Netherlandsche Standard Electric Maatschappij plant is located.

Netherlandsche Standard Electric
Maatschappij
The Netherlands

New Factory Near Paris—Mr. Jacques Marette, French Minister of Post and Telecommunications, presided over the inauguration on 22 June 1962 of a new plant of Compagnie Générale de Constructions Téléphoniques. This modern factory, shown in Figure 3, is in Massy, a suburban town 10 miles (16 kilometers) south of Paris.

Senator Jacques Richard; Representative Robert Wagner; Messrs. Ivan Cabannes, General Secretary of the Post and Telecommunications Ministry; Raymond Croze, Director of Telecommunications; Pierre Marzin, Director of the Telecommunication National Research Center; and many other top-ranking officials of the Ministry and of the armed and nationalized services were present.

Figure 2—At the inauguration of the new Maddaloni factory, from left to right, are Mr. Carlo Roda; Don Salvatore D'Angelo, Assessor for Public Works of Maddaloni; His Excellency Emilio Colombo, Minister of Industry and Commerce of Italy; Count Carlo Della Rocca de Candal; and Mr. H. S. Geneen, President of International Telephone and Telegraph Corporation. Messrs. Roda and Della Rocca are Managing Director and Chairman of the Board, respectively, of Fabbrica Apparecchiature per Comunicazioni Elettriche Standard, whose new plant was being dedicated.

Mr. Queffeleant, recently appointed president of the company, greeted the visitors and presented the new factory, which employs 510 workers.

The 64 580 square feet (6000 square meters) available for offices and shops house 85 punch and hydraulic presses rated from 12 to 250 tons, modern thermoplastic moulding machines, automatic lathes, drilling, milling, and screw machines, and other special automatic machines originated by the company. Concentrated in this factory is the production of Pentaconta crossbar parts and other components needed by associated companies in France and elsewhere. Annually, the plant can produce 57 million relay springs, 5.5 million multiswitch assemblies, 2.2 million windings, and other piece parts.

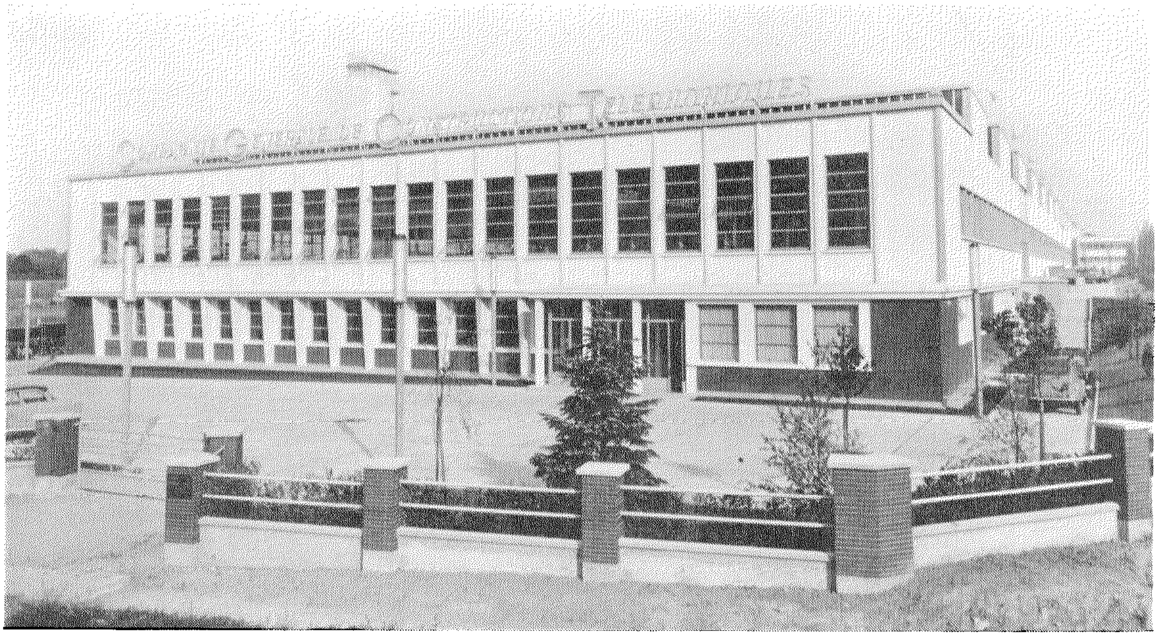
Compagnie Générale de Constructions Téléphoniques
France

Stantec System at Brussels Airport—Rapid and accurate weather forecasting is essential to effective and safe operation of aircraft, particularly when entering or leaving an airport. The meteorological services of the Belgian Régie des voies aériennes selected a Stantec electronic computer for use in this work at the Brussels airport.

On 4 May 1962, when the equipment was placed in service, addresses were delivered in behalf of the Régie des voies aériennes by Mr. Lecomte, its general director, and Mr. Quoinlin, chief meteorologist and director; for the Belgian minister of communications by Mr. Delaure, and for Bell Telephone Manufacturing Company, by its president and managing director, Mr. Van Rooy.

Bell Telephone Manufacturing Company
Belgium

Figure 3—This new plant at Massy, France, of Compagnie Générale de Constructions Téléphoniques is devoted to the production of piece parts for telephone switching equipment.



Pentaconta Telegraph and Telex Exchange in Beirut—Mr. Rachid Karame, Prime Minister of Lebanon, personally inaugurated on 10 April 1962 the first Pentaconta automatic telegraph and telex exchange in the world. This event is illustrated in Figure 4.

Initially equipped for 50 directions, the exchange connects the Beirut telex network to various other important cities, such as, Paris, New York, Berne, Cairo, and Rome. It will soon be expanded to 100 directions with equipment now in manufacture.

Equipment for similar exchanges is being built for several French customers, including the Navy, and for some countries in Africa.

Compagnie Générale de Constructions Téléphoniques
France

Semiconductor Symposium—A symposium was held on 16 April 1962 in London to discuss some recent work on tunnel diodes and microwave diodes.

One of the developments is a range of tunnel-diode integrated circuits suitable for high-speed logic, memory, and counting operations.

The logic elements are based on a pair of matched tunnel diodes connected by strip leads to a network of tightly packed low-inductance resistors. Type *CK5*, which is in pilot production, is shown in Figure 5. Comprising four resistors and a matched pair of tunnel diodes, it is operable as a gate or as a shift register at clock frequencies of several hundred megacycles per second. The body dimensions are 10 millimeters (0.4 inch) square by 5 millimeters (0.2 inch) thick.

Counting units consist of a chain of tunnel diodes having peak currents so graded that they switch sequentially in response to input pulses. Type *CK50* has 10 diodes with connections to both ends of the chain and from the next-to-

Figure 4—His Excellency Rachid Karame, Prime Minister of Lebanon, cutting the ribbon at the inauguration of the telegraph and telex exchange of Radio Orient Beirut.

last diode for counting to 10 and resetting. Its body dimensions are 6 millimeters (0.24 inch) square by 16 millimeters (0.63 inch) long.

The memory elements use tunnel diodes having closely controlled peak currents mounted with resistors for assembly into fast-access-storage matrices. Type *CK26* mounts a diode and two resistors in a body 12 by 10 by 4 millimeters (0.47 by 0.4 by 0.16 inch). This flat design permits tight packing to minimize propagation delay in the read direction.

The microwave developments include two diodes for frequency-modulated communication links operating at 6 gigacycles per second. One is a low-level low-noise down converter and the other performs the reverse function of modulating a new microwave carrier after intermediate-frequency amplification at 70 megacycles per second. Both are formed point-contact germanium diodes mounted in hermetically sealed cartridges having reversible end caps to permit choice of polarity. Both have useful properties not generally found in diodes.

The low-level mixer has the unusually low intermediate-frequency impedence of 100 to 150 ohms, permitting direct broad-band matching to the low input impedance of the intermediate-frequency amplifier with a minimum over-all noise figure. The conversion loss is less than 4.5 decibels (0.5 neper) and the diode-noise-temperature ratio is typically 1.5.

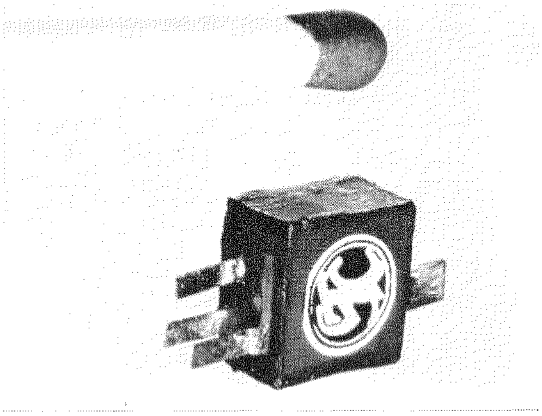


Figure 5—Semiconductor integrated circuit combining two matched tunnel diodes and four resistors used as a logic element.

The up converter provides amplitude limiting by means of a built-in predetermined saturation level. The recommended intermediate-frequency driving level, corresponding to a rectified driving current of 8 milliamperes, ensures limiting of 14 decibels (1.6 nepers) or better. Typical loss figures for conversion from super high frequency to super high frequency are 8 to 9 decibels (1 neper) with a maximum of 11 decibels (1.3 nepers). By deliberate degradation of the rectification capability of this diode, interfering harmonics of the intermediate frequency in the super-high-frequency region may be reduced to −120 decibels (−14 nepers) referred to 1 milliwatt. The specified input power-handling capacity of 32 milliwatts at super high frequencies

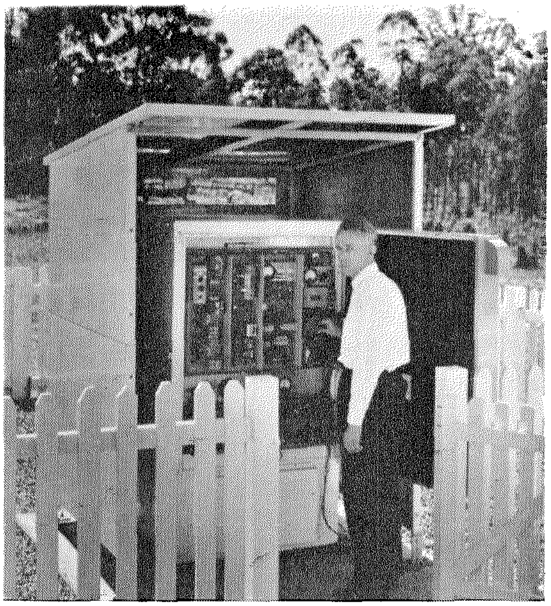


Figure 6—First transistor-operated radio beacon for aerial navigation. It operates from self-contained batteries charged from wind-driven generators and is mounted in a solar-screened cabinet. It is being field tested near Sydney, Australia.

can be greatly exceeded, the diode being unharmed by an input power of 300 milliwatts.

Standard Telephones and Cables
Standard Telecommunication Laboratories
United Kingdom

Transistor-Operated Aerial Navigation Beacon—The first completely transistor-operated radio navigation beacon, which is shown in Figure 6, is undergoing field trials at Mount McQuoid, the holding area for jet aircraft using Mascot airport at Sydney, Australia. It was developed in Australia for the Department of Civil Aviation.

Such beacons will be important at many small infrequently used airports that presently lack these radio aids because of high cost. No special buildings are needed. The equipment can be operated for long periods without maintenance. It receives power from built-in batteries charged by wind-driven generators. Operation is assured over the Australian temperature ranges from 14 to 140 degrees Fahrenheit.

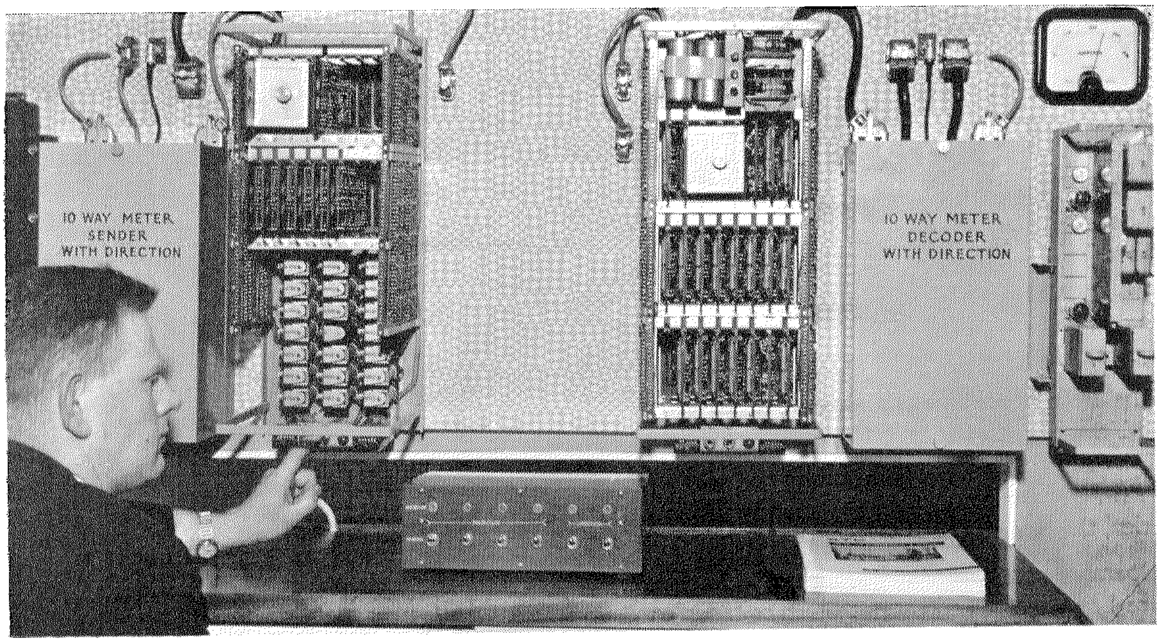
Omnidirectional aerial systems are used. The transmission is at frequencies between 200 and 415 kilocycles per second. The beacon is identified by the automatic telegraphic transmission of call letters. Regular aircraft direction finders or radio compasses are used for reception.

Standard Telephones and Cables Pty.
Australia

Coder-Decoder for Telemetering—The sending equipment shown in Figure 7 scans impulsing sources from as many as 10 different indicating meters. The information is transmitted in time-division multiplex over a voice-frequency channel to the decoder for display on a meter. This transistor-operated equipment was developed for the Central Electricity Generating Board.

Standard Telephones and Cables
United Kingdom

Figure 7—Coder-decoder for telemetering the indications on 10 different meters over a voice-frequency channel by time-division multiplex.



Rapidata System—In the Rapidata system, information is first punched on tape and then read by a photoelectric reader for high-speed transmission over a telephone channel. It is recorded on magnetic tape at the receiver and may then be punched on tape or printed at a lower speed.

The French Posts, Telegraph, and Telephone Administration has approved the use of Rapidata on leased circuits. Among the industrial installations now in service are some that include full electronic remote control. A more-recent design provides for error correction to improve transmission accuracy.

Compagnie Générale de Constructions Téléphoniques
France

Rome International Telephone Exchange—On 28 April 1962, the Rome international telephone exchange was cut into service. Based on Pentaconta techniques, the exchange includes 60 desks for operators handling semiautomatic outgoing traffic. It is connected to 216 international incoming and outgoing lines, 54 national lines, and 76 junctions with the local exchange.

Fabbrica Apparecchiature per
Comunicazioni Elettriche Standard
Italy

Pentaconta in Spain—The first Pentaconta 1000 automatic telephone exchange in Spain was put in service last March in Igualada, about 45 miles from Barcelona. It has a capacity of 2000 lines. Presently connected to Barcelona through a manual toll switchboard with operator dialing, it is to be integrated into the full national automatic network next year.

The Pentaconta equipment was manufactured in France by Compagnie Générale de Constructions Téléphoniques and installation, adjustment, and testing were done by Standard Electrica, the Spanish associate company.

Operation has been so satisfactory that plans are being made for the introduction of similar exchanges in the Madrid and Barcelona local areas early in 1963.

Standard Electrica
Spain

Carrier Telephone System for Mine Railways—The *Z1G* carrier telephone system, shown in Figure 8, provides two separate frequency-modulated channels for communication between a fixed station and the various locomotives used in a mine. The fixed station is directly connected to a two-conductor transmission line that is coupled by loop antennas to the mobile stations in the locomotives. All the locomotive stations transmit on the same frequency and receive the fixed station on another frequency.

The fixed station may be used as a relay to permit one locomotive station to communicate with another or with all other locomotive stations simultaneously. The ability to communicate quickly with all operating units of the mine railway improves safety and reliability, increases traffic flow, and reduces operating costs.

Standard Elektrik Lorenz
Germany

Arnhem Automatic Telex Exchange—On 2 April 1962, the 250-line automatic telex exchange at Arnhem was placed in service, following the cut-over of the Bois-Le-Duc district exchange on 8 June 1961 and the Groningen office on 19 September 1961. The present network of separate automatic telex exchanges was developed since the war by the Posts, Telegraph, and Telephone Administration in cooperation with Bell Telephone Manufacturing Company and Nederlandsche Standard Electric Maatschappij. It also includes offices at Amsterdam, Rotterdam, and The Hague and now serves 5500 private telex subscribers. The outgoing traffic of the Netherlands accounts for 95 percent of all the fully automatic telex connections made in that country.

In placing a telex call, the subscriber presses a calling button and receives a number identifying the register at the exchange to which his

Figure 8—Mine locomotive operator speaking over the *Z1G* frequency-modulated carrier telephone system. The loudspeaker is permanently mounted above his shoulder.

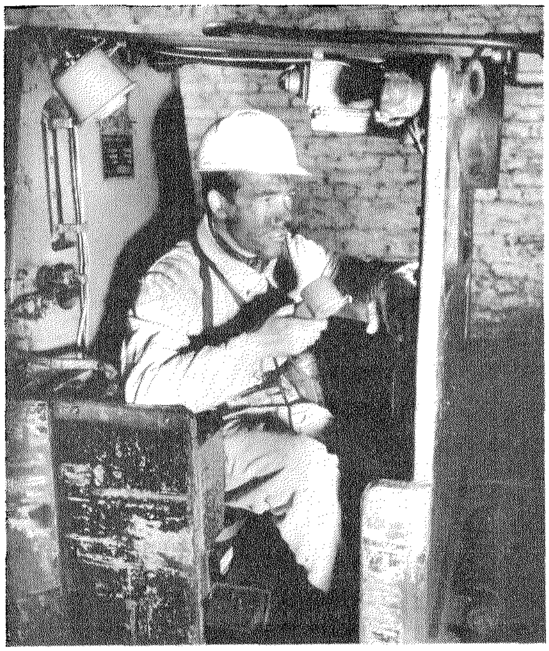
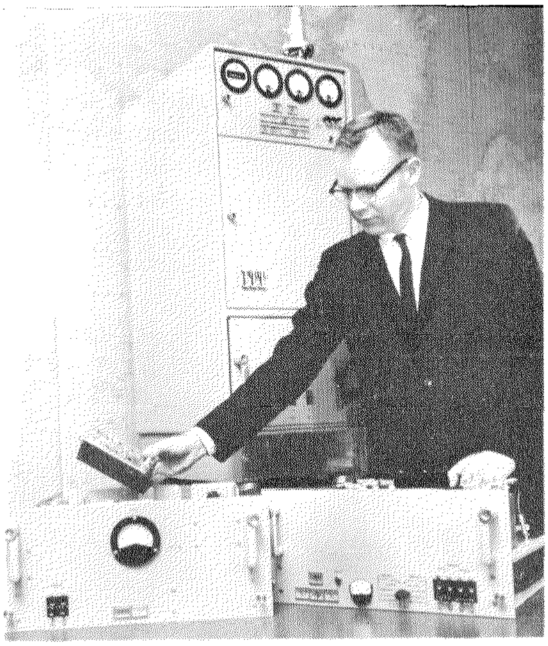


Figure 9—Compact light 1-kilowatt microwave transmitter using only one vacuum tube, a klystron. The full use of solid-state components makes it only about a tenth the size and weight of a conventional transmitter.



teleprinter has been connected. He then sends the number of the station to be called and a designated symbol that initiates the automatic search for and connection to the desired subscriber's station.

The rapid expansion of the telex service requires the building of additional district exchanges and the enlargement of the Amsterdam, Rotterdam, and The Hague offices that now provide for 2000, 1200, and 1000 lines, respectively.

Netherlandsche Standard Electric
Maatschappij
The Netherlands

Small Light Microwave Transmitter—Using only one vacuum tube, a 1-kilowatt klystron, the transmitter shown in Figure 9 has been developed for the bands from 1.7 to 2.4; 2.5 to 2.7; and 4.4 to 5.0 gigacycles per second. It is about a tenth the size and weight of conventional 1-kilowatt equipment.

Full use is made of long-life solid-state devices for power supplies and all control and driving circuits. Models are available for single- or three-phase operation at 50 or 60 cycles per second. The amplifier is 40 by 17 by 24 inches (102 by 43 by 61 centimeters) and weighs 370 pounds (168 kilograms). The modulator and radio-frequency units are each 8¾ by 17 by 24 inches (22 by 43 by 61 centimeters) and together weigh less than 75 pounds (34 kilograms).

Its low power drain and transportability make it suitable for remote sites, tropospheric scatter systems and path-loss measurements, mobile service, and active satellite systems.

ITT Federal Laboratories
United States of America

Lillo Subscriber's Set—Production has been started on a new light-weight subscriber's telephone set. The version shown in Figure 10 is a desk set and a corresponding wall set is also available. They may be had in various colors.

Notwithstanding its reduced size, the electroacoustic performance is excellent. The electrical circuit is standard and line equalization may be included by installing silicon carbide varistors. The ringer is combined with the induction coil and may be adjusted readily by the subscriber. The mechanical design ensures easy manufacture and maintenance.

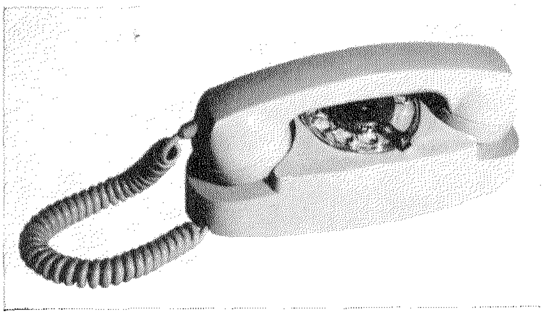


Figure 10—Lillo subscriber's desk set and the corresponding wall set are available in several colors. Despite its small size, the ringer is included and may be easily adjusted by the subscriber.

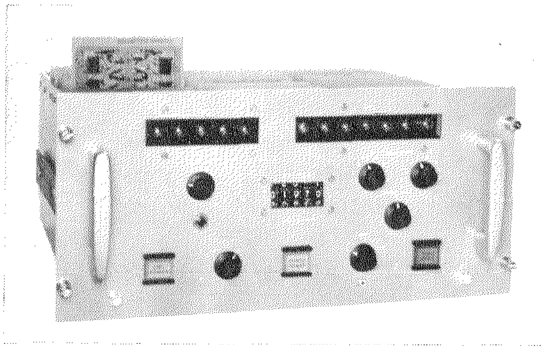


Figure 11—This data reduction unit for Doppler measurements shows the elapsed time in tenths of microseconds for a selected number of cycles of a wave that may vary in frequency from moment to moment.

Fabbrica Apparecchiature per
Comunicazioni Elettriche Standard
Italy

Medium-Speed Data Equipment—Development has been completed on equipment for error-detection and error-correction transmission of data over switched circuits at 600 bauds and at twice this speed over leased channels.

Transmission is in blocks of 240 information elements, 12 checking bits, and a block number. The receiver checks for the proper parity pattern and sends a decision signal to the transmitter to continue if parity has been attained or to repeat the incorrect block and the following block if the check for parity fails.

The equipment operates from punched paper tape using the standard 5-, 6-, 7-, or 8-unit codes. Series transmission is provided but a converter is available for parallel transmission. A clean-tape unit to delete erroneous blocks and redundancy bits without leaving gaps will be available.

Start-stop equipment for operation at 50 bauds has also been developed. It checks for errors by retransmitting the received material back to the sending terminal. Any inconsistency results in the retransmission of the erroneous and three following elements. A clean-type unit is provided.

Serial transmission is from punched tape and code regrouping equipment permits 6-, 7-, or 8-unit codes to be transmitted over connections suitable only for 5-unit codes.

Firm recommendations on data transmission systems have not yet been ratified by the Comité Consultatif International Télégraphique et Téléphonique.

Standard Telecommunication Laboratories
United Kingdom

Doppler Data Reduction Unit—The equipment shown in Figure 11 is an aid in tracking satellites and space vehicles through the Doppler effect. The Doppler affected frequency is compared with an internally generated clock frequency of 10 megacycles per second, which may be aligned with the standard-frequency signals broadcast from *WWV*.

A switch permits the selection of a specific number of cycles of the varying frequency to be sampled at intervals of a few seconds. The elapsed time in tenths of microseconds for the selected number of cycles is shown immediately on a 7-digit numerical indicator.

The time of day in seconds is displayed on a 5-digit indicator. Provision is made for recording the information on either perforated or magnetic tapes.

ITT Federal Laboratories
United States of America

Small-Diameter Coaxial Cable—A new design of small-diameter coaxial cable, type 174, has the center conductor supported by a polythene dielectric shell rather than the expanded polythene used in the type 163 cable. Both types are shown in Figure 12.

With regard to the recommendations of the Comité Consultatif International Télégraphique et Téléphonique, the new cable is within the diameter range of 4 to 4.5 millimeters (0.16 to 0.18 inch) for systems to provide 300 telephone channels and in impedance uniformity it meets the requirements for the 9.5-millimeter (0.38-inch) cables that carry 960 channels. Its general qualities are considerably higher than required. It is suitable for television transmission.

Standard Telephones and Cables
United Kingdom

Very-High-Frequency Preamplifiers—Two preamplifiers have been developed for receiving signals from space vehicles. One of them uses vacuum tubes and may have its center frequency anywhere between 50 and 250 megacycles per second. The other, shown in Figure 13, uses solid-state components and can have its center frequency between 50 and 500 megacycles per second. The bandwidth can be between 0.7 and 7 percent as required.

The operating power is 25 watts for the vacuum-tube system and less than 1 watt for the solid-state model. Optionally, each design may include complete operating spare circuits with switching between the circuits being done by coaxial input and output relays. A power of 100 watts is needed during the switching period.

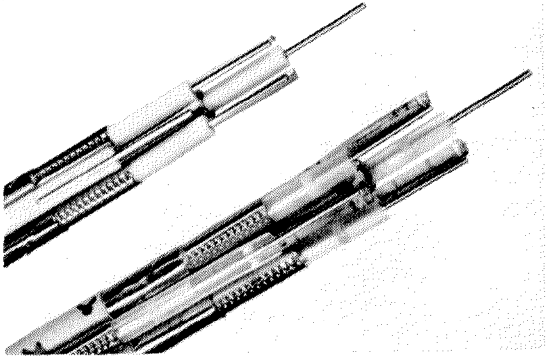


Figure 12—Type 163 coaxial cable with its expanded polythene insulation is shown above the new type 174 cable with its polythene dielectric in shell form.

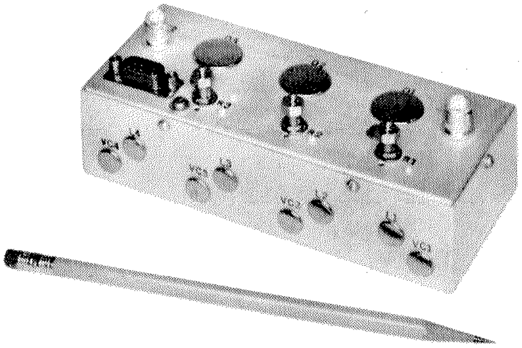


Figure 13—Solid-state very-high-frequency preamplifier for reception of signals from satellites.

A typical unit designed for 162 megacycles per second has a bandwidth of 1 megacycle per second at 3 decibels below peak response and 60 megacycles per second at 60 decibels down. The minimum gain is 50 decibels and the noise figure is 3 decibels.

ITT Federal Laboratories
United States of America

Cavity for Coaxial-Line Oscillator Tube—A compact simple-capacitance-tuned cavity has been developed for use with the well established coaxial-line oscillator tube *V190/1M* for the range from 500 to 930 megacycles per second, the output power varying between 0.2 and 1 watt.

The new cavity, type *495-LVA-202,* is only a third the length of previous cavities and is shown in Figure 14. As the *V190/1M* tube operates uniquely with its coaxial line terminated in an open circuit, frequency modulation or control can be effected by changing the drift-tube potential while maintaining the resonator voltage constant.

Standard Telephones and Cables
United Kingdom

Waveguide Delay Lines—The small losses and low voltage standing-wave ratios characteristic of waveguides make them attractive as delay elements in radar, in simulators, and for noise measurement by correlation techniques.

To reduce space requirements, 40 feet (12.2 meters) of waveguide have been wound into a coil only 16 inches (406 millimeters) in diameter and 1 inch (25 millimeters) thick. Several coils may be connected together without special fittings to obtain increased delay as shown in Figure 15. For X-band use, the attenuation is less than 10 decibels per 100 feet (30 meters) and the voltage standing-wave ratio is less than 1.20.

ITT Federal Laboratories
United States of America

Quick-Release Waveguide for H-Wave Tubes—Quick-release fittings for H-wave oscillators, originally developed for 7-gigacycle-per-second portable television transmitters, are now being used on all these tubes. Tubes must be replaced when faulty or if the operating frequency is to be changed.

Four different tubes are required to provide 1 watt of output between 5.8 to 7.8 gigacycles per second. Each tube may be tuned over part of this band by mechanical adjustment of its cavity; it may also be tuned electrically at least 8.5 megacycles per second to each side of the cavity-determined frequency. With an output of 200 milliwatts, the entire band can be covered with a single tube by mechanical adjustment of its cavity.

H-wave tubes differ from Heil tubes in that the electron bunching occurs across a short-circuited section of waveguide rather than in a hollow section of a short-circuited coaxial line. The interaction gaps being in series instead of parallel, higher efficiency is obtained.

The frequency stability of the H-wave tube avoids in many cases the need for automatic frequency control. Electric tuning potentials are applied to the beam drift tube, which is isolated from the direct-current sources. Operation at only 500 volts gives outputs of the order of 1 watt. Simple air cooling is adequate. As may be seen in Figure 16, the tubes are packaged with their focusing magnets. Cavity tuning is by a micrometer-controlled dumb-bell-type short-circuiting element. Output is into *WG14* waveguide through an adjustable-stub matching section.

Standard Telephones and Cables
United Kingdom

Phosphor Data Chart—A wall chart on the "Typical Absolute Spectral Response Characteristics of Aluminized Phosphor Screens" is available on request from ITT Industrial Laboratories Division, Post Office Box 2208, Fort Wayne, Indiana.

The chart, which is 18 by 22 inches (46 by 56 centimeters) and printed in 14 colors, shows wavelength versus spectral efficiency for the most common phosphors and also tabulates data on chemical composition, color, persistence, peak wavelength, luminous efficiency, and quantum yield.

ITT Industrial Laboratories Division
United States of America

12-Channel Voice-Frequency Telegraph System for Telex—The frequency-modulated telegraph system WT100/FM240 provides 12 channels for teleprinter signals between telex subscribers.

Solid-state electronic devices provide for all amplifying and switching functions to ensure long-time performance without adjustment or maintenance. No mechanical relays are used.

The standard telephone channel is divided into 12 telegraph channels. The system complies with all recommendations of the Comité Consultatif International Télégraphique et Téléphonique for frequency-modulated voice-frequency telegraphy. Each channel may be operated at 100 bauds with level variations between +1.0 and −2.0 nepers (+8.7 and −17.4 decibels) referred to 1 milliwatt without notable effect on the quality of operation.

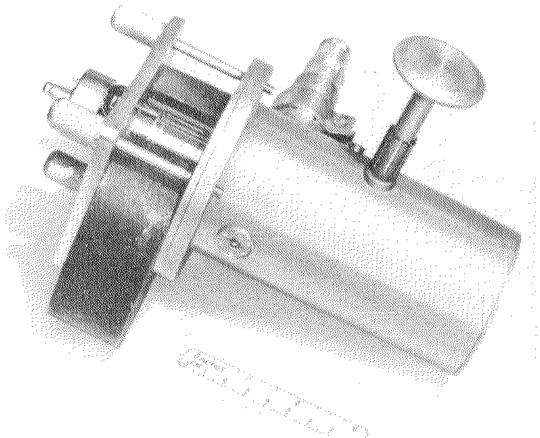


Figure 14—The coaxial-line oscillator tube is shown in position at one end of the new cavity. Output is taken from the type *N* coaxial socket on the far side of the cavity. The knob at the top is for adjusting the tuning capacitor and will be replaced by a micrometer control in the production model. Drift-tube voltage is applied through the small disc feed-through capacitor on the near side.

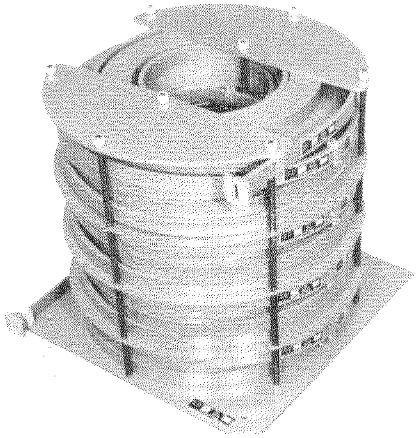


Figure 15—Each coil is 16 by 1 inch (406 by 25 millimeters) and contains 40 feet (12.2 meters) of waveguide. As a delay structure, several coils are compactly stacked and joined with regular connectors to provide the required delay.

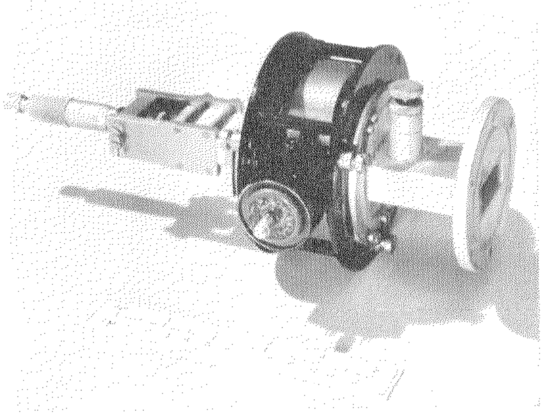


Figure 16—H-wave oscillator tube with its integral focusing magnet, tuning cavity, and output waveguide. The new quick-release fittings may be seen on the waveguide flange in contact with the tube.

The plug-in units shown in Figure 17 are made up of replaceable printed-circuit cards. They may be mounted on shelves, which can in turn be combined into racks.

Standard Elektrik Lorenz
Germany

Tape Reader for Model 75 Teleprinter—An attachment for the model 75 teleprinter for the automatic reading of information punched in 5-track paper tape has been put into production. It avoids the need for a separate transmitter unit, and it can be used to transmit or make additional printed copies from prepunched tape.

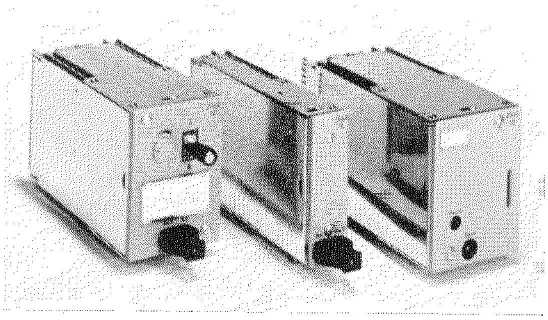


Figure 17—Units for a 12-channel frequency-modulated telegraph system to operate over a standard telephone channel. They are designed for teleprinter operation among telex subscribers.

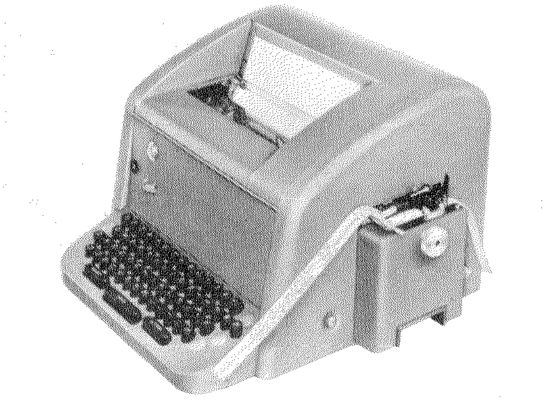


Figure 18—The tape-reader attachment is at the right side of the Creed model 75 teleprinter.

The reader, which may be seen in Figure 18, operates at the maximum speed of the teleprinter, be it 60, 66, 75, or 100 words per minute. Depending on the requirements of the teleprinter, the reader can produce conventional telegraphic single-wire sequential output on either a polar or neutral basis or operate in the multiple-wire parallel mode. It can be arranged for remote control from the distant station, the form in which the Canadian army recently ordered model 75 teleprinters.

Creed and Company
United Kingdom

Pneumatic Tube for Nuclear Reactor—A special pneumatic tube system has been designed for the reactor at Wurenlingen of the Swiss Federal Institute for Nuclear Research. It uses about 300 meters (984 feet) of tubing.

The conventional cylindrical carrier has been replaced by an aluminum sphere having a diameter of 52 millimeters (2 inches) and weighing 50 grams (1.8 ounces) including a small container. This shape is better suited than the

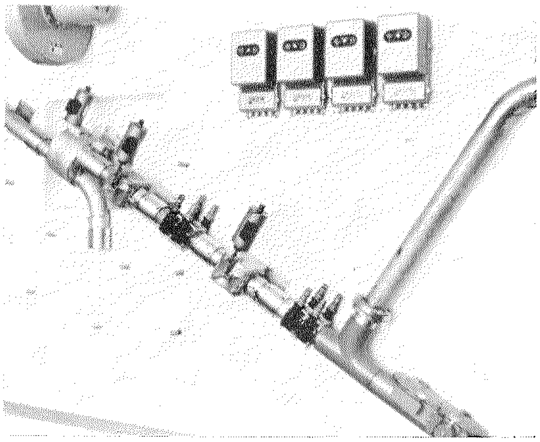


Figure 19—Part of the pneumatic-tube installation for the atomic reactor of the Swiss Federal Institute for Nuclear Research.

cylinder to the mechanical manipulators employed for the handling of irradiated matter.

A typical section of the installation is shown in Figure 19. Photoelectric cells and associated light sources, which are provided in duplicate at the sending and receiving ends as a safety measure, report the position of each carrier to a control circuit.

The carriers are entered into and removed from the reactor by manipulators. On leaving the reactor, they fall by gravity through the tube to a storage position. In an emergency, the balls may be sent to a lead-lined container to confine radiation. Routine testing and suitable alarms insure safe operation.

Standard Telephone et Radio
Switzerland

ELECTRICAL COMMUNICATION Now Available in French and German

Electrical Communication is now published in three languages; English, French, and German. The French edition is titled *Revue de Telecommunications* and the German edition *Elektriches Nachrichtenwesen.* All editions will carry substantially the same material and will be identified by the same volume and number, the first joint publications being volume 37, number 3, 1962.

Vordac* for Precise Navigation Over Very-High-Density Air-Traffic Routes

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In the United States, the Federal Aviation Agency issued in October 1961 the "Project Beacon," a report of the Task Force on Air Traffic Control. This report takes stock of the navigational situation and states that the present system of the International Civil Aviation Organization of very-high-frequency omniranges, with the addition of distance-measuring equipment, will be adequate for the volume of traffic expected over most of the United States in the next 10 to 15 years. It adds, however, that a more-precise navigational means will be required to permit all-weather helicopter operation and reduction of the lateral separation of airways over a few very-high-density routes.

In Europe, the Eurocontrol Association, made up of air-navigation experts from Belgium, Federal German Republic, France, Luxemburg, Netherlands, and the United Kingdom, published on 5 April 1961 a provisional operational specification for air-traffic control.

Although they recognize that the present very-high-frequency omnidirectional ranges known as VOR supplemented by distance-measuring equipment will have to be used up to 1975, the Eurocontrol Association consider that it will be necessary to introduce a new or improved navigational-aid system before long to reduce separation minima, permit sufficient flexibility in the routes of controlled aircraft flights, and take care of the evolution of automatic or semiautomatic air-traffic-control systems by 1965.

The system in most common use is the very-high-frequency omnirange and distance-measuring equipment called VORDME, which was standardized by the International Civil Aviation Organization on 8 April 1960 and is scheduled to be installed in all Eurocontrol countries. It is thus of prime importance to consider whether this system could be modified to meet the Eurocontrol specification.

An ideal system should provide on-board flyable courses without the need of a computer on the ground and every part of such a system should be capable of operating independently.

A thorough investigation of possible systems has been carried out by Le Matériel Téléphonique (France), Standard Elektrik Lorenz (Germany), and Standard Telephones and Cables (United Kingdom). These companies in association with ITT Federal Laboratories (United States) hold the greatest number of patents on electronic aids to navigation and have had a major role in the development of the radio compass, instrument landing systems, very-high-frequency omnidirectional ranges, distance-measuring equipment, and TACAN.

A study of the fundamental principles of all navigational systems for control of upper air space shows that the accuracy and area coverage obtained are interdependent, the accuracy limiting the coverage.

1. Accuracy and Coverage

The specification of the Eurocontrol Association calls for position accuracy of ±1·5 nautical miles (2·8 kilometres).

Numerous evaluations carried out on multilobe rho-theta systems during the past 10 years show that the accuracy, indicated in Figure 1, with a 95-per-cent probability, is as follows:

---

* VORDAC stands for Very-High-Frequency Omnidirectional Range and Distance-Measuring Equipment for Area Coverage. It consists of a standard International Civil Aviation Organization distance-measuring equipment and the increased-accuracy very-high-frequency omnidirectional range described in this article. It is compatible with present omnirange receivers.

Bearing θ, between $\pm 0 \cdot 5$ to ± 1 degree

Range R, better than $\pm(0 \cdot 1 + 2 \times 10^{-3} R)$ nautical miles.

These accuracies have been confirmed in France by the results obtained by the Centre d'Essai en Vol de Brétigny on the TACAN system (Report 1 of 29 June 1959).

1.1 ACCURACY OF DISTANCE-MEASURING EQUIPMENT

The distance-measuring portion of the VORDME system will, in 95 per cent of cases, give a distance accuracy better than that demanded by the Eurocontrol Association ($\pm 1 \cdot 5$ nautical miles or $2 \cdot 8$ kilometres) where the range is within 200 nautical miles (370 kilometres) of the station. In fact, in its present form, the distance-measuring equipment would have an error E not exceeding $1 \cdot 5$ nautical miles up to a distance R given by the equation:

$$E = 1 \cdot 5 = (0 \cdot 1 + 2 \times 10^{-3} R)$$

for $R = 700$ nautical miles (1296 kilometres).

1.2 VOR ACCURACY

To meet the Eurocontrol requirements, it would be necessary to improve the instrumental accuracy of the omnidirectional range to indicate bearing to within 1 degree or better.

Evaluation of omnirange equipments installed on unfavourable sites has shown that substantial bearing errors can occur in certain directions and similar errors occur when using conventional short-base direction-finders. Radical improvements have been obtained using wide-aperture systems based on the Doppler principle. In consequence, Standard Elektrik Lorenz have taken advantage of their experience on Doppler direction-finders now in production to engineer a wide-base very-high-frequency omnidirectional range, also on the Doppler principle, to reduce bearing errors for stations situated on unfavourable sites.

Besides, Doppler very-high-frequency omniranges have already been commissioned by the Federal Aviation Agency in the United States at Marquette, Michigan, and at Rikers Island, New York City. Its Bureau of Facilities and Materiel, which installs and maintains navigational aids and electronic equipment, has evaluated the performance of Doppler omniranges for approximately two years.

A Doppler omnirange ground station utilizes 50 antennas placed in a circle 44 feet ($13 \cdot 4$ metres) across. The centre of the circle is the centre of the building. Within the building a motor-driven device, called a distributor, connects the signal to each antenna in turn, and, in effect, simulates the rotation of a single antenna at a radius of 22 feet ($6 \cdot 7$ metres). The simulated rotation is needed to provide relative motion between the antenna and the aircraft receiver, thereby producing modulation due to the Doppler effect.

Engineers of the Federal Aviation Agency point out that the new type very-high-frequency omnidirectional range will permit the placement of the antenna at an unfavourable site, such as Rikers Island, where costly relocation or modification of structures, gas tanks, skyscrapers, or bridges cannot be carried out.

An evaluation [1] shows that the errors due to obstacles near a conventional VOR are reduced to approximately ⅕ when a wide-base Doppler system is used, but that the instrumental accuracies of both conventional and Doppler equipments are approximately the same.

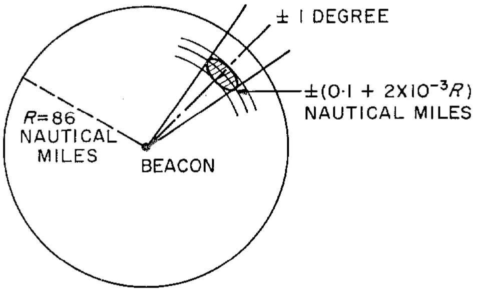


Figure 1—Required accuracy of VORDAC system within a range of 86 nautical miles (159 kilometres). Angular accuracy must be within ± 1 degree and distance accuracy within $\pm(0 \cdot 1 + 2 \times 10^{-3} R)$ nautical miles.

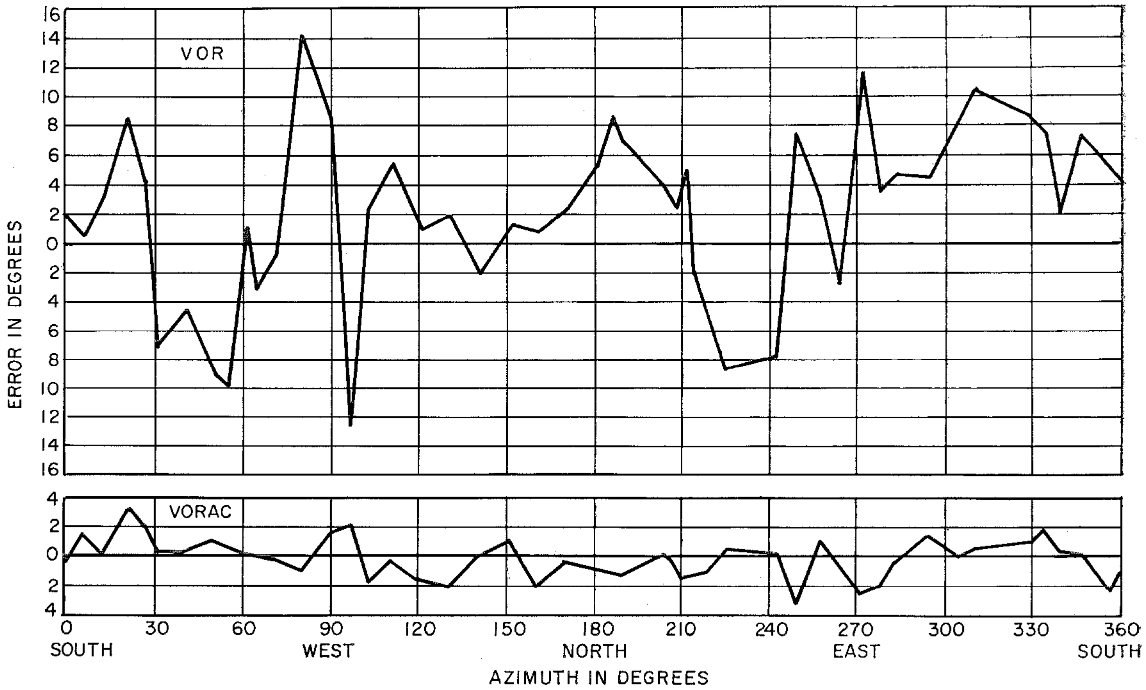


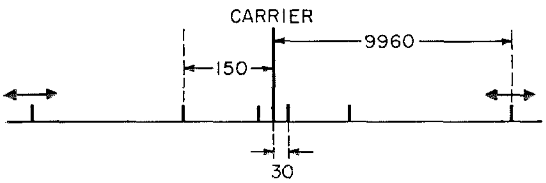
Figure 2—Bearing errors for a conventional very-high-frequency omnidirectional range intentionally installed on a very bad site at top and corresponding errors below for a VORAC installation on the same site.

In 1957, Standard Telephones and Cables demonstrated the possibility of reducing both the site and instrumental error of an omnirange by establishing a "coarse" and "fine" technique by the introduction of a new signal having a rotating multilobe polar diagram of field strength. In this system, now known as VORAC, the purely instrumental component of error was reduced by a factor of 10, by the use of a 10-lobe radiation pattern, and site errors were reduced by a factor of 5, owing to the theoretical and expected figure for a radiation pattern comprised of 5th-order sidebands. This improvement in accuracy involved the addition of a small unit to the normal VOR airborne receiver.

The graph in Figure 2 shows the result of a flight trial carried out at New Southgate in April 1957. Normal VOR errors were particularly large as the site was intentionally chosen to be bad—much worse than in any normal installation. In fact, the aerial array was erected in the New Southgate factory premises. The error curve of VORAC shows that the use of 5th-harmonic sidebands has reduced site errors by a factor of 5. The curve was obtained by taking bearings at approximately every 10 degrees from an aircraft orbiting the experimental station. Purely instrumental errors are completely masked by the exceptionally large errors resulting from the bad site.

Calibration curves obtained on a typical VOR installation are very similar to the VORAC error curve illustrated, disregarding zero setting error in the airborne receiver. It will be seen that if multilobe technique is applied to normal VOR having a basic error curve as shown, the error will be reduced to about 0·7 degree maximum. The VORAC instrumental error was reduced by a factor of 10 by the use of a 10-lobe radiation pattern, but in general 5th-harmonic technique

Figure 3—Frequency spectrum of the Doppler omnidirectional ground beacon. The values indicated are in cycles per second.



will reduce both site and instrumental errors by a factor of 5. Production VOR airborne receivers can measure phase to an accuracy of ±2 degrees. In a 5-lobe system utilising a vernier-scale technique, an addition to the receiver would enable the instrumental error to be reduced to ±0·4 degree.

This bearing accuracy can be assured even on very unfavourable sites, by associating the Doppler very-high-frequency omnidirectional range manufactured by Standard Elektrik Lorenz with an equivalent harmonic-utilisation system. It happens that the use of this principle also enables the desired reduction in instrumental error to be obtained since use can be made of the harmonics present in the radiated signal. The radio signal transmitted from the Doppler omnirange beacon consists of:

(A) A carrier wave having an omnidirectional pattern.

(B) 2 sidebands at 30 cycles per second also having omnidirectional characteristics, providing the reference signal.

(C) 1 or 2 sidebands at 9960 cycles per second transmitted, in turn, from each of a commutated circular array of aerials. The sidebands are frequency modulated at 30 cycles per second with a deviation of ±480 cycles per second, the phase of the modulation varying with the bearing.

It will be recalled that in the classical VOR system, the 30-cycle-per-second sidebands carry the bearing information and the 9960-cycle-per-second modulation provides the reference.

To increase the instrumental accuracy, it is proposed to introduce a new pair of reference sidebands spaced 150 cycles per second from the carrier. This second reference signal is the 5th harmonic of the first. This entails only a very small change to a normal Doppler very-high-frequency omnidirectional range.

Figure 3 shows the spectrum of the radiated signal.

The sidebands added to the system will have no effect on the normal airborne receiver whose operation and performance will be unaltered. However, the addition of an adaptor to the existing receiver enables the 5th-harmonic reference signal to be used. In the receiver, this 150-cycle-per-second reference signal is used in conjunction with a 5th harmonic of the bearing-dependent signal, extracted by the use of a special harmonic discriminator, to augment the accuracy of the instrument whilst maintaining all the advantages of the wide-aperture Doppler omnidirectional range. New airborne equipment would not, of course, require an adaptor.

1.3 AREA COVERED WITH REQUIRED ACCURACY

The performances quoted enable coverage to be obtained with the required accuracy of ±1·5 nautical miles (2·8 kilometers) within a circular area of radius R_o centered on the beacon. See Figure 4.

$R_o = 1\cdot5 \cot 1$ degree $= 86$ nautical miles (159 kilometres).

The surface area covered $S_o = 23\,200$ square nautical miles (79 376 square kilometres).

From this, maximum distance between beacons can be calculated so that an over-all area coverage within an accuracy of better than ±1·5 nautical miles (2·8 kilometres) is obtained as shown in Figure 4.

Distance $d = 86\ (3)^{\frac{1}{2}}$ nautical miles
$= 150$ nautical miles (278 kilometres).

However, it is likely that the bearing accuracy will reach in most cases to within ±0·5 degree corresponding to $R_o = 172$ nautical miles (309 kilometres), $S_o = 92\,800$ square nautical miles (318 295 square kilometres), and $d = 300$ nautical miles (556 kilometres). Thus, at the maximum range of 300 nautical miles, the position accuracy will remain between ±1·5 and ±3 nautical miles (2·8 and 5·6 kilometres).

1.4 Correction of Slant Range

In both ground-based systems available, that is, distance measurement by polar co-ordinates or difference in distance using hyperbolic co-ordinates, the distance measured is slant range between aircraft and ground stations and will differ from the surface or geographical distance.

Figure 5 illustrates these errors for the two principal systems using polar and hyperbolic co-ordinates.

For the proposed system using polar co-ordinates, a correction of the slant range can be carried out very simply by means of a trigonometrical computer giving surface range directly.

$$BG = R \cos a$$
$$\text{and } \sin a = h/R.$$

Sin a is determined by introducing the height h derived from the airborne altimeter into electrical resolvers or voltage dividers.

It will be seen from a study of the curves of error of slant range relative to height and ground distance, Figure 6, that correction of the slant range would only be necessary on a high-flying aircraft in the immediate vicinity of a beacon.

A study of the curves shows that all aircraft flying under 10 000 feet (3048 metres) can approach to 5 nautical miles (9·3 kilometres) of a beacon before the error exceeds ¼ nautical mile (0·46 kilometre). The limit at 20 000 feet (6096 metres) is 20 nautical miles (37 kilometres).

1.5 Cone of Silence

When passing over beacons, the bearing information will drop out due to the cone of silence although distance continues to be registered.

With the high-accuracy Doppler omnirange, this cone of silence is almost negligible from an operational point of view since, at 80 000 feet (24 384 kilometres), it is only about ±2 nautical miles (3·7 kilometres).

In any case, a navigational computer that integrates the accumulated flight information before entering the cone of silence will enable the pilot to overcome even this temporary lack of cover over beacons.

1.6 Helicopter Navigation

The many advantages of the VORDAC system, particularly its independence from atmospheric interference, give it a particular importance for helicopter navigation, flying as they do at low altitude in areas of high radio interference. The line-of-sight propagation proposed is that used with success for television and very-high-frequency aircraft links. After some delay whilst the characteristics of line-of-sight propagation were studied, Europe is now largely covered by a television network, and air area coverage is now such that 90-per-cent-efficient communication coverage between pilot and traffic con-

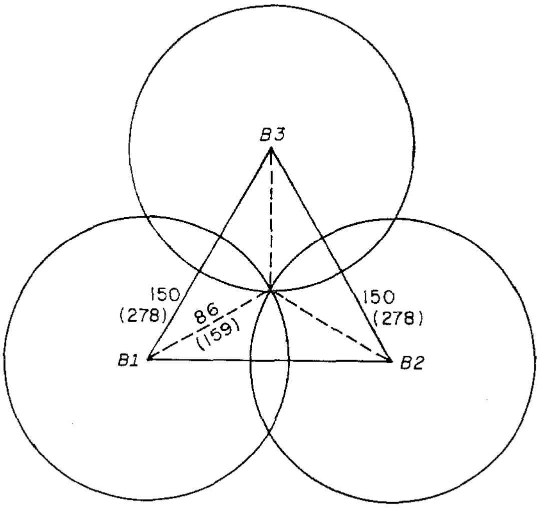


Figure 4—Area covered by Doppler omnirange with an accuracy within 1·5 nautical miles (2·8 kilometres). The distances shown are in nautical miles (kilometres).

trollers has been established using very-high-frequency links.

A further consideration is that medium-frequency navigational systems utilise very-high towers for their aerials. A VORDAC aerial situated at the same height would give the accuracy required by the Eurocontrol Association up to 50 nautical miles (93 kilometres) for a helicopter approaching at 500 feet (152 metres) and 86 nautical miles (159 kilometres) for a helicopter en route.

The principal advantage of the VORDAC system for helicopter guidance will be in use at the heliport itself or on the landing platform of the postal building, where a VORDAC beacon will give more-accurate information than a medium-frequency chain, the aerials of which will inevitably be at some distance from the site.

2. Track Computer on a Non-Radial Route

2.1 INTRODUCTION

The polar co-ordinates derived from the VORDAC navigational system immediately supply the necessary information to fly on a radial route to or from a ground station.

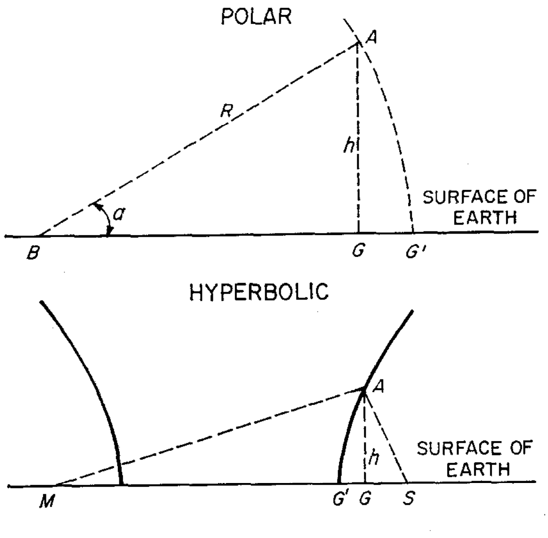


Figure 5—Corrections of slant range. G is the correct position and G' is the apparent position. For polar co-ordinates R = radio slant range to station B. $BG = R \cos a$ and $\sin a = h/R$. For hyperbolic co-ordinates, $G'A$ = geometrical hyperbolic line (elevation). The difference in distance $MG' - SG' = MA - SA$.

However, it is frequently necessary to fly on other routes and it is proposed to add a simple, cheap, and light addition to the normal rho-theta indicator to enable routes involving any linear non-radial track to be followed.

This article describes the function of the track computer proposed for the VORDAC system. The accuracies given in Section 2.4.2 are quoted on the assumption that wide-aperture very-high-frequency omnidirectional range systems are used having accuracies better than ±1 degree.

Additions to the airborne equipment can be more or less complicated depending on the type of indicators used, the nature of the output required, and the degree of accuracy necessary. In more-elaborate types, the wind speed could be taken into account to correct heading, and also height when calculating ground range from the slant range given by the rho-theta navigational system.

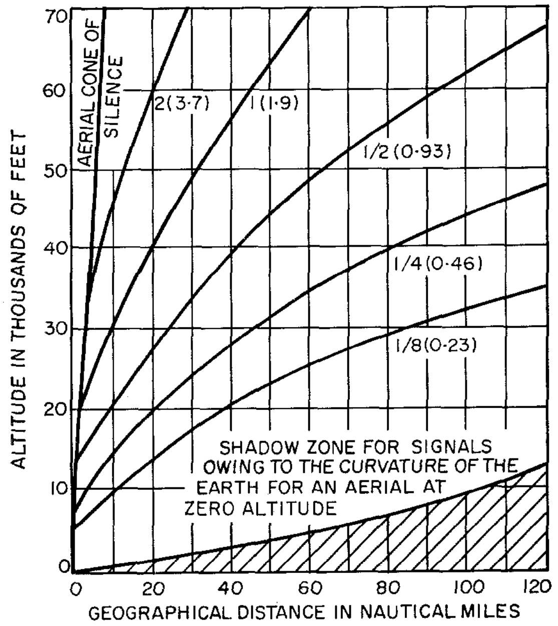


Figure 6—Slant-range error curves. The error in nautical miles (kilometres) is given for each curve.

The VORDAC track computer described was developed along simple lines to provide a left-right course error indication on the conventional VOR localiser indicator. It does not correct for slant range. In addition it provides an orbiting facility that enables the aircraft to fly on a circular track centered on a beacon with the same error indications as for a normal track.

2.2 THEORY

All the necessary calculations are carried out by a small number of components, which are built into the mechanical section of the VORDAC indicators (resolvers, voltage dividers, detectors, et cetera). The only components necessary for this track computer are a voltage divider, switch, and adjustable resistors to control the sensitivity.

2.2.1 *Normal* VORDAC *Working*

As shown in Figure 7, the actual position of an aircraft is defined in the VORDAC system by the distance ρ and the magnetic bearing θ of the aircraft from the beacon. The bearing azimuth θ is always positive between 0 and 360 degrees and increases clockwise.

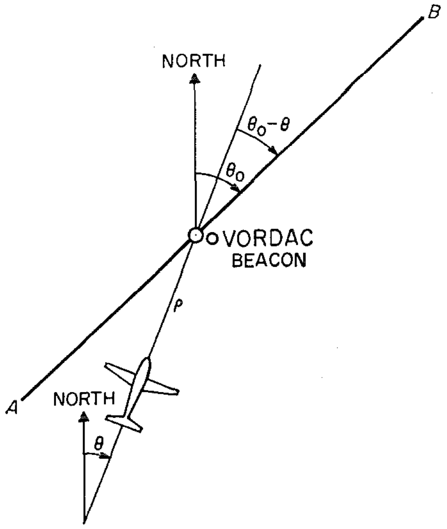


Figure 7—Radial track on VORDAC beacon.

2.2.2 *Definition of a Non-Radial Linear Track*

The linear track AB in Figure 8 is defined by:

(A) The angle θ_o between magnetic north from the beacon o and the track AB. AB is positive for an aircraft flying from A to B and θ_o is positive clockwise, as θ is shown.

(B) The lateral distance $oH = \rho_0$ from the beacon at a right angle to the track AB.

(C) The position of the beacon relative to the track (left or right).

2.2.3 *Track-Computer Equation*

For all points such as M' on the ideal track AB, the distance OM' $(OM' = \rho')$ and the bearing θ are given by:

$$\rho' = \frac{\rho_o}{|\sin OM'B|}. \tag{1}$$

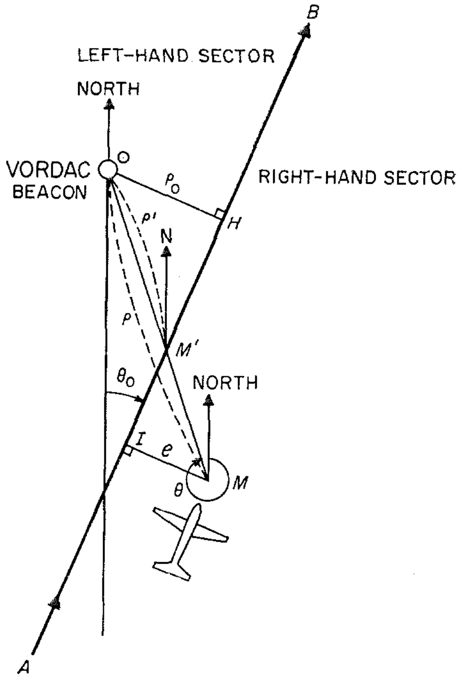


Figure 8—Non-radial track on VORDAC beacon.

Now $OM'\,B = \theta_o - \theta$, so we obtain

$$\rho' = \frac{\rho_o}{|\sin(\theta_o - \theta)|}. \qquad (2)$$

An aircraft at point M has a distance error from the ideal track AB of $e = MI$, which is given by:

$$e = MI = |(\rho - \rho')\sin MM'I|.$$

Thus the necessary flight-correction equation for a non-radial linear track is given by:

$$e = |\rho \sin(\theta_o - \theta)| - |\rho_o|. \qquad (3)$$

Considering the values of the signs; when the beacon is on the left of the ideal track, we have θ varying between θ_o and $\theta_o - \pi$.

Sin $(\theta_o - \theta)$ is always positive when the beacon is on the left and negative when the beacon is on the right. As ρ is always positive, ρ_o should be taken as positive for a beacon on the left and negative for a beacon on the right to cancel the error term:

$$\rho \sin(\theta - \theta_o) - \rho_o.$$

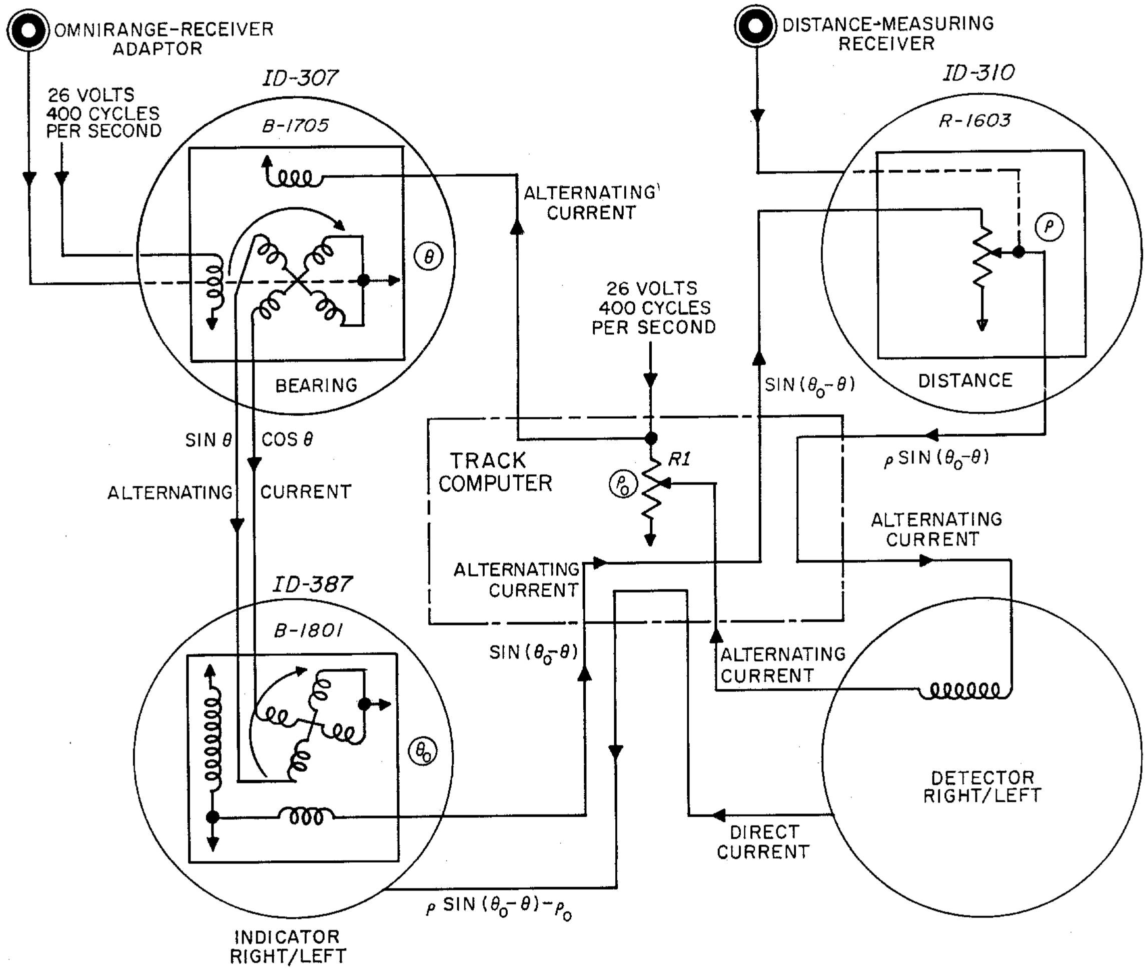


Figure 9—Vordac track computer.

2.3 DESCRIPTION

2.3.1 *Working on Non-Radial Routes*

The computer of Figure 9 was developed to utilise components already existing in various sections of the VORDAC equipment without further modification and to introduce the necessary additional components either in the computer itself or in the external cabling.

The error distance e from the required track is obtained as indicated in (3).

The distance ρ is obtained from the distance-measuring indicator and is derived as the magnitude of a 400-cycle-per-second voltage via a voltage divider on the distance-measuring indicator; θ is measured by the bearing indicator and is available on the resolver of this indicator. The pilot manually injects the value ρ_o on the track computer itself by operating the adjustable resistor *R1* and also θ_o via the phase-shifter on the omnidirectional magnetic indicator, B-1801.

Figure 9 shows the electrical connections between the various elements of the VORDAC airborne equipment.

It will be seen that the angle θ is derived from the 400-cycle-per-second supply via resolver B-1705, which has both a sine and cosine output: the resolver B-1801 calculates $\sin(\theta_o - \theta)$ giving the output on its stator and voltage divider R-1603 derives $\rho \sin(\theta_o - \theta)$, which is then combined with ρ_o in the right/left detector. The direct-current output from this detector is proportional to $\theta = \rho \sin(\theta_o - \theta) - \rho_o$, and operates the omnirange right/left indicator.

The schematic has been simplified to clarify its function and no mention has been made of other essential characteristics such as the beacon right/left switch, sensitivity adjustments, and indicator-flag functioning.

2.3.2 *Operation on Radial Routes*

In the radial position, normal connections between the transmitter, receiver, and indicator are established. It should be noted that the above analysis shows that the deflection of the vertical pointer of the magslip (1D-387) is proportional to the *angular* deflection of the required route when following a radial track and proportional to the offset distance when following a non-radial track. The sensitivity is adjusted separately in each case.

2.3.3 *General Characteristics of the Computer*

The computer is shown in Figure 10. The offset distance is adjustable from 0 to 100 nautical miles (0 to 185 kilometres). Its dimensions are as follows:

Height: 5·4 centimetres (2⅛ inches)
Width: 12·5 centimetres (4¹⁵⁄₁₆ inches)
Depth: 7 centimetres (2¾ inches)
Weight: under 900 grammes (approximately 2 pounds).

If altitude correction is added to the computer, its volume becomes 500 cubic centimetres (approximately 30 cubic inches) and its weight increases to 1 kilogramme (approximately 2·2 pounds).

2.4 ACCURACY

2.4.1 *Practical Results*

Over-all errors are made up of errors due to the inaccuracy of the VORDAC system and to instrumental errors in the computer and associated circuits in determining the terms ρ, ρ_o, θ_o, and θ.

Flight tests with a prototype computer of the type described have shown that a practical accuracy of about 2 nautical miles (3·7 kilometres) at a distance of 60 miles (111 kilometres) from the beacon can readily be achieved.

It is possible to determine what accuracy could be obtained using more-accurate equipment based on the same general working principles.

2.4.2 *Accuracy Limits*

If it is supposed that the system is made up of stations 150 nautical miles (278 kilometres)

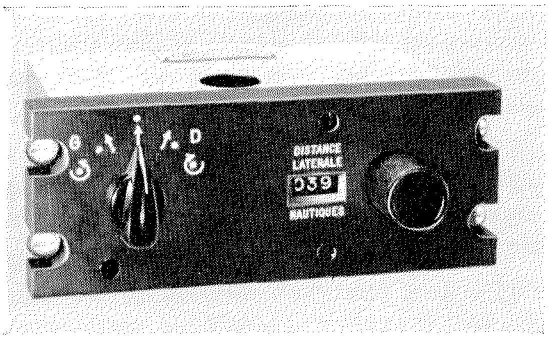


Figure 10—VORDAC track computer. At the left is the operating control, the functions being, from left to right, left orbiting, left non-radial, radial, right non-radial, and right orbiting. The lateral or offset distance control is at the right with the selected distance in nautical miles appearing in the window.

apart at the apex of equilateral triangles, the maximum distance of any aircraft from a ground station would be $150/3^{\frac{1}{2}} = 86$ nautical miles (159 kilometres).

At this distance the VORDAC error will be defined by the boundary of an elongated ellipse perpendicular to the line joining the aircraft and the station. Its half width is $\pm(0{\cdot}1 + 0{\cdot}17) = \pm 0{\cdot}27$ nautical mile (0·5 kilometre). This is the VORDAC distance error. Its half length defines the VORDAC bearing error and is $\pm(2\pi 86/360) = \pm 1{\cdot}5$ nautical miles (2·8 kilometres).

Thus the over-all accuracy limit is ±1·5 nautical miles (2·8 kilometres). To take full advantage of this accuracy, the computer should contain a high-accuracy distance indicator and take into account the height of the aircraft relative to the beacon in the case of high-altitude flying.

2.5 CONCLUSION

The composition of the computer described for operation on a non-radial track demonstrates clearly that the use of polar co-ordinates is most suitable for engineering of simple apparatus. This track computer enables the pilot to select his course on any desired point using conventional right/left indications.

3. Transmission of Flight Information

The Eurocontrol Association states that the navigational system will have to be capable of being integrated into an over-all system of air-traffic control, telecommunication, and navigation; in particular, the position of the aircraft will have to be capable of being transmitted to the ground by the system itself or of being introduced automatically in a special system of air-to-ground transmissions. The detailed specification indicates that the airborne parts of the navigational system must be compatible with an automatic or semi-automatic data-link system transmitting position information to the ground air-traffic-control organisation without degrading the basic accuracy of position information already specified.

3.1 DATARAMA SYSTEM

Interrogating aircraft on the common VORDAC station frequencies by utilising their position coordinates enables the ground controllers and the pilots to be presented simultaneously with an automatic indication of the position of the aircraft. The call is made by a message transmitted from the ground containing position information in a coded state. A circuit in the airborne equipment compares the coded information with the actual aircraft position. If coincidence is obtained the aircraft automatically transmits its identity and an interchange of messages with the ground then occurs.

Secondary radars and datarama belong to this class of equipment, a characteristic of the latter being that the position information is transmitted in elemental digit form.

At present secondary radar is recommended by the International Civil Aviation Organization. Primary radar gives the distance and bearing of the aircraft. An airborne transponder permits identification of the aircraft. It is envisaged that altitude will be reported via the same transponder. The next stage could be datarama. A number of patents have been filed on datarama-type systems operating with respect to Figure 11 as follows.

(A) The VORDAC navigation system and the altimeter enable the pilot to determine the position of his aircraft.

(B) The distance-measuring airborne transmitter is used to transmit air-to-ground signals and messages and the receiver is used for ground-to-air signals and messages.

(C) The first air-to-ground transmission consists of a response signal having a position in time sequence that is characteristic of the aircraft position.

(D) On receipt of this signal by the beacon, a code is transmitted that locks the aircraft equipment onto the beacon for a long enough period to exchange the necessary coded-message information; first air to ground and then ground to air. Similar coded data-link exchanges occur successively with all aircraft in the vicinity as they are interrogated in turn according to their position.

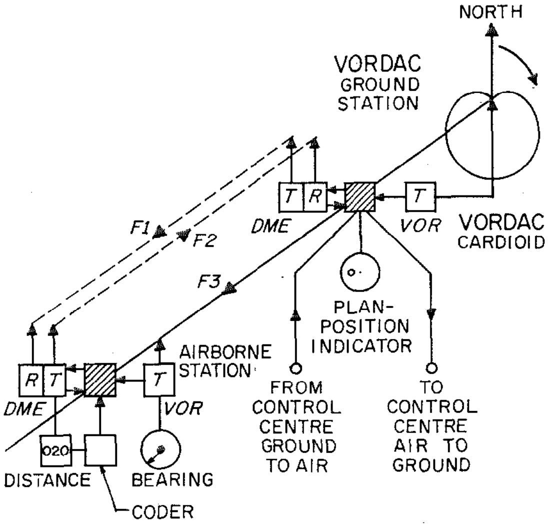


Figure 11—Datarama transmission of flight information. The airborne station replies when called by the ground station. The VORDAC cardioid pattern rotates at 30 revolutions per second. DME indicates distance-measuring equipment and VOR is very-high-frequency omnidirectional range. *R* and *T* are receiver and transmitter respectively.

(E) At any time, the ground station can cease automatic routine space scanning and, by designating a certain area for immediate contact, interrogate all aircraft flying within this area.

(F) As the bandwidth required for the transmissions is small it is possible to use a normal telephone line to supply the information received on the ground to the automatic traffic-control centres.

The airborne equipment required is reduced to a minimum since it is possible to establish at the ground station information on altitude, distance, and bearing on receipt of a single response signal, by restricting the transmission of such a signal to aircraft present in a 500-foot (152-metre) altitude layer at a height *h*, for example.

Interrogation in this fashion results in an accuracy of flight information reporting as follows:

Bearing: 1 degree
Distance: ½ nautical mile (0·9 kilometre)
Altitude: 500 feet (152 metres)

The capacity of the system is 100 aircraft for a total exploratory time of 20 seconds.

3.1.1 *Use of Datarama Information*

The ground stations translate into digital form the aircraft position co-ordinates determined at the instant of reception of a reply pulse. These, with accompanying call-sign and messages, are then transmitted to the control centre over a normal telephone line. The decoding and utilisation of the information is carried out at the centre, feeding the flight data into the air-traffic-control computer.

On receipt of a call-sign, using existing techniques, coded messages bearing the same call-sign are automatically extracted from the memory store and transmitted to the aircraft concerned after the termination of the air-to-ground message.

Information from the VORDAC station to the control centre is transmitted in binary form. Distance and bearing of each aircraft are translated into binary counts. The call-sign and coded information are then transmitted to the control centre from the VORDAC in binary form at 750 bauds via a normal telephone link.

The integration of these flight reports into an over-all system of air-traffic control such as the one recommended by Project Beacon using the combined civil and military networks would be simplified as VORDAC position reports from the plane to the ground through datarama include the conventional data given by radar, that is, slant distance, azimuth, and height.

Since the transmissions of aircraft information and ground information share a common frequency, there will be no increase in the bandwidth required.

The datarama could, therefore, double the amount of information received on the ground from an eventual radar network with no extra load on the communication frequencies.

3.2 SELECTIVE CALLING

However, the VORDAC system is also capable of an address data-link for interrogating aircraft by their identity. On receiving its address followed by an instruction message from the ground, the aircraft will reply, after a certain time, by giving its position co-ordinates followed by its message. The message exchange is carried out using digital code techniques.

The ground station transmits a pulse train every 2 milliseconds consisting of elementary binary signals distinguished, for example, by having two different lengths. A time base in the airborne equipment is synchronised at the repetition frequency of these signals, and the air-to-ground reply is then derived from this time base.

The following information is received by the aircraft:

(A) A temporary address, 1000 of which can be allocated to aircraft in the control zone. These addresses are allocated when the aircraft receives its clearance or by very-high-frequency communication in case of emergency.

(B) Flight instructions such as flight direction, climb or descend, alter speed, or a request for a report on the communication channel.

(C) Aircraft distance from the beacon with an accuracy to within 1 part in 1000 or ±0·2 mile in 200 miles (0·91 in 910 kilometres).

Distance is obtained on the ground by measuring the propagation time between transmission of a message and receipt of its answer.

The pulse train transmitted from the aircraft contains, for example, information on altitude, heading, speed, bearing of VORDAC station, and a request for communication with the ground.

The ground station transmits the information extracted from the memory, where it is located after each temporary address, as well as distance calculated during the exchange of previous messages.

The distance is obtained in two steps. A coarse primary measurement is obtained from the sending pulse of each pulse train. The fine measurement is made by comparing the phases of the message pulses. Using this method it is possible for light aircraft to be supplied with distance information without requiring distance-measuring equipment.

The airborne equipment can be the normal very-high-frequency communication system with the addition of a coder/decoder unit. On the ground, coder/decoder units and distance-measuring equipment would have to be added to the communication system together with the necessary additions to the control-centre computer.

4. Establishment of Vordac

4.1 GROUND EQUIPMENT

4.1.1 *Navigation*

The European establishment of TACAN beacons, 60 of which are now functioning and 230 are planned for installation by 1965, will then be sufficient to enable the accurate navigation contemplated by Eurocontrol to be available to military aircraft equipped with TACAN.

The largest concentrations of TACAN beacons in Europe coincide with areas where traffic is particularly heavy, and this will enable still greater accuracy to be obtained than that covered by our proposal.

Referring to VORDAC for civil aviation, it is proposed to progressively equip those VOR stations that will operate in conjunction with distance-measuring equipment or TACAN, with wide-based systems to provide the same bearing accuracy as does TACAN, within 1 degree or better. It will be sufficient to modify some 35 existing VOR stations in this way and add another 9 in conjunction with existing TACAN stations. Some of these latter would simply involve resiting in accordance with the plan for British and French national requirements.

The production in Europe of the new Doppler omnirange equipments will commence in 1963.

4.1.2 *Transmission of Flight Information*

For traffic purposes, an additional equipment would progressively be installed on the ground near each beacon to establish the required link between the control-centre computer and the navigational system. Present indications are that these equipments will be available by 1965.

4.2 AIRBORNE EQUIPMENT

4.2.1 *Navigation*

The present program for equipping military with TACAN will be completed before 1965, and the accuracy required by Eurocontrol will thus be available before that date.

With regard to civil aircraft, users will have the choice either of providing an additional unit to their airborne VOR equipment to enable full use to be made of the improved instrumental and performance accuracy available with the wide-based omnirange, which would enable airlines to keep existing VOR receivers and use them also for receiving normal instrument-landing-system localiser signals, or of completing their airborne distance-measuring equipment by fitting additional units for TACAN bearing.

4.2.2 *Transmission of Flight Information*

An additional modulator of small dimensions would be added to the airborne distance-measuring equipment to respond to ground interrogation for identity, altitude, and messages.

It would not be necessary to cover the transmission of distance and bearing as this information would be available on the ground in digital form from the rho-theta interrogation process. This process considerably simplifies the amount of extra airborne equipment required and reduces the contents of the air-to-ground messages.

5. Conclusion

The present proposal shows a method of progressively equipping aircraft to achieve the navigational accuracy required by Eurocontrol and establish a flight-information link with the ground.

The VORDAC extension to the VORDME system would enable Eurocontrol to benefit from the compatibility in the upper air space with navigational systems standardised by commercial aviation through the International Civil Aviation Organization and the military North Atlantic Treaty Organization.

Furthermore, airlines presently equipping with VORDME airborne units will not be obliged to acquire yet another type of airborne system that will necessarily be bulky and expensive.

6. References

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Reliability Principles and Practices

S. R. Calabro of International Electric Corporation is the author of a book on Reliability Principles and Practices. Its 16 chapters and 7 appendixes are under the following titles.

CHAPTERS

1. An Introduction to the Reliability Concept
2. Measures of Central Tendency and Dispersion
3. Probability and Its Application to Series and Parallel Reliability (Redundancy)
4. The Normal Distribution
5. Binomial Distribution
6. The Poisson Distribution and the Exponential Failure Law
7. Reliability Data
8. Analysis of Reliability Data
9. Maintainability and Availability
10. Sampling Methods
11. Reliability Sampling and Control Charting —Time Samples
12. Reliability and Availability Prediction Methods
13. Principles of Reliability Design
14. Reliability Specifications
15. United States Government Requirements
16. Management of a Reliability Program

APPENDIXES

1. Definitions Frequently Used
2. Special Techniques
3. Reliability Control and Acceptance Procedure
4. Quality Control System Requirements
5. Reliability Monitoring Program
6. Guides for Reliability Organization
7. Tables

The book is 6.25 by 9.25 inches (15.9 by 23.5 centimeters) and contains 360 pages of text, 3 pages of bibliography, and an index of 7 pages. It is published by the McGraw-Hill Book Company, 330 West 42 Street, New York 36, New York, and the price is $10.50.

Submarine-Coaxial-Cable Manufacture at Southampton

ERIC BAGULEY

Standard Telephones and Cables Limited; London, England

1. Introduction

A decision to extend its telephone-cable manufacturing facilities by building a new factory at Southampton was made in 1954 by Standard Telephones and Cables. Up to that date all types of telecommunication cables, with one notable exception, were in production at the North Woolwich and Newport factories. The exception was the long-distance submarine telephone cable, which, following the successful laying between Key West and Havana of the first repeatered cables [1] in 1950 and the publication at that time of plans for the first transatlantic telephone cables [2], now had a reasonable expectation of becoming a product with a rapidly expanding market. From the cable point of view the use for carrier telephony of coaxial cables at sea was a necessary and logical extension of their widespread application on land.

As a matter of fact, coaxial telephone cables were used for short sea crossings before they were used on land. At audio frequencies immersion in the sea very much reduces the susceptibility to noise and crosstalk from external fields, and the simple cylindrical structure of the coaxial pair fitted conveniently into the well established steel-wire armourings of the 19th-century submarine telegraph cables.

When in 1927 the first radiotelephone link between Great Britain and the United States was commissioned, it soon became evident that there was more potential traffic than could be handled by radio. At this time the maximum route length of the submarine coaxial cable was around 100 nautical miles (185 kilometres). This limitation was not allowed to persist without considerable development effort being expended both by the Bell Telephone Laboratories in the United States and the ITT Laboratories in England.

During the period from 1927 to 1931, a cable group at the ITT Laboratories in Hendon, England, examined in detail all probable, and some improbable, means for achieving a single-telephone-channel submarine coaxial cable either for the 1800-nautical-mile (3334-kilometre) hop from Ireland to Newfoundland and, for what was then known as the "island-hopping" route via Scotland, Faroes, Iceland, Greenland, and Newfoundland, where the longest hop was below 1000 nautical miles (1852 kilometres). The improbable methods included the installation of thermionic-valve amplifiers on rafts or buoys in mid-Atlantic.

The probable method was a continuously loaded coaxial cable [3] based on the then recently discovered nickel-iron magnetic alloys and on the best possible dielectric that could be achieved chemically and physically from gutta percha and paragutta, the only waterproof insulating materials then available. Accurate assessment of the transmission characteristics of the cable was essential, and as cable engineers well know, accurate transmission equations for audio-frequency propagation along coaxial pairs are quite formidable, even before considering the effect of wrapping magnetic tapes round the centre conductor. Following the theoretical work, came extensive laboratory tests on experimental cores and cables under conditions simulating the pressures and temperatures to be expected in deep water. By 1931 there still were difficulties, but confidence was growing in the practicability of laying a transatlantic telephone cable. The capital investment would have been high, but not excessive, for a reliable telephone circuit between London and New York. Unfortunately the economic crises of the early 1930's intervened and the necessary financial backing was not forthcoming. Thus ended the first development projects devoted directly to long-distance underwater telephony.

During the succeeding 20 years, development effort was concentrated on the evolution of multichannel carrier telephone land cable systems [4]. This comprised two distinct, but complementary, products; the cables in which the air-spaced coaxial pair has become the most efficient and most widely used transmission line [5] and the electronic channelling equipment at the terminals. Here one of the most significant developments was the negative-feedback amplifier.

As soon as carrier systems were working satisfactorily on land cables it became necessary to consider how such systems could be adapted to sea crossings. The intermediate repeater presented the major problem, and, pending an acceptable solution, submarine cable systems had to be only one repeater section in length between land terminals. Thus sending-end levels were as high, and receiving levels were as low, as could be worked, and devices for compressing speech channels so as to increase the number available were tried out.

In 1943 the intermediate repeater put out to sea, with the installation by the British Post Office of one submerged repeater in the shallow waters (35 fathoms or 64 metres) of the Irish sea [6], with a consequent increase from 24 to 48 channels over the submarine coaxial cable between Anglesey and the Isle of Man. This repeater was contained within a heavy steel case and was lowered to the sea bed by ship's derrick. It was not suitable for, nor intended to be used in, deep water, where of necessity the submarine cable itself must provide mechanical support to the repeater during its passage from ship to sea bed. The British Post Office had, and still has, an attractive market for shallow repeaters [7] due to the geographical position of the British Isles within 20 to 300 miles (32 to 483 kilometres) of the northern European mainland.

In the United States the development of submerged repeaters started on the basis that it was essentially a deep-sea problem associated with the deep-sea type armoured cable evolved and perfected by the telegraph companies; and its first commercial achievement was the flexible repeater used in the first long-distance deep-sea carrier telephone cable, the 1956 transatlantic cable.

In Great Britain, extended use of the rigidly housed submerged repeater in shallow waters had demonstrated its capabilities and reliability, and it became evident that a similar construction should be used in deep water; and that if in deep water it could not be handled with the telegraph type armoured cables, then it would be necessary to develop a new type of deep-sea cable. The first details of a new light-weight deep-sea cable were published by the British Post Office in 1956 [8] and in 1958 the member countries of the British Commonwealth agreed to sponsor a round-the-world cable of this design. Such, briefly, were the expectations of the market for submarine telephone cables in 1954 when the Southampton factory was planned.

2. Southampton Site

Submarine cables are not packaged for delivery from stock. Normally all the cable for a given project, which may total 1000 nautical miles or more, will have to be coiled down in the manufacturer's works and stored under water until a 6- or 7-month manufacturing programme is completed. Then a cable ship will call at the works, and will expect to take delivery of the whole job in a matter of 2 or 3 weeks over a haulage line between ship and works. For the production line itself, continuous processes and long lengths from each process, with the minimum possible number of joints in the components of the cable, are desirable. It is not usually possible to carry out all the processes of manufacture in one machine line. The product is its own conveyor belt, which facilitates grouping of two or more operations in one machine line wherever practicable. Between machine lines, storage accommodation for comparatively large quantities of the partly made cable must be provided to maintain a high over-all rate of production.

In this way the special facilities required for the new product line may be assessed as ample cable storage space in the form of tanks, pans, and creels, ample supplies of fresh water for cable storage, and thirdly, easy access to ocean-going ships at all times.

A site in the New Docks at Southampton was selected as best meeting the over-all requirements. The provision of an overhead gantry about 400 feet (122 metres) long would give direct access from factory site to quayside.

Ships of all sizes can be handled here at practically all states of the tide. The quayside is a straight sea wall nearly 2 miles (3·2 kilometres) in length built across the arc of a bay in the estuary of the River Test to the west of the town of Southampton. There are extensive railway facilities and good roads connecting with the main trunk roads of the country. An aerial view of the factory taken in 1960 appears in Figure 1 and shows the gantry to the left of the factory buildings. On the extreme left the bow of a ship tied up at the quayside may be seen.

3. Armoured-Submarine-Cable Design

The design requirements of submarine cables in general are dominated by the mechanical, rather than the electrical, performance to be achieved.

For submarine telegraph cables the manufacturing unit may be 1000 miles (1852 kilometres) or more, and one ship may be required to take the cable and lay it non-stop in some remote ocean during an optimistically forecast spell of fair weather. Here the simplest fault during laying or during service may take weeks to repair; weeks both costly in ship time and in lost traffic revenue. To guard against such losses, rigorous factory quality control of all materials and all processes must be applied to the simplest and smallest structure that will provide the necessary transmission line. Hence long-distance submarine cables invariably contain only one conductor.

At the very-low operating frequencies of the telegraph systems the physical form of the conductor does not affect its electrical performance appreciably, and it has become accepted practice to use a copper 6- or 7-wire strand. During the stranding operation a joint in one of the wires may not be made within a specified minimum distance of a joint in any of the other wires, a form of insurance against total mechanical failure of the strand at faulty wire joints.

For all modern submarine cables the insulant for the conductor is polythene of high molecular weight and low density. It is applied to the conductor by a screw-type extruder. The optimum ratio of core diameter to conductor diameter

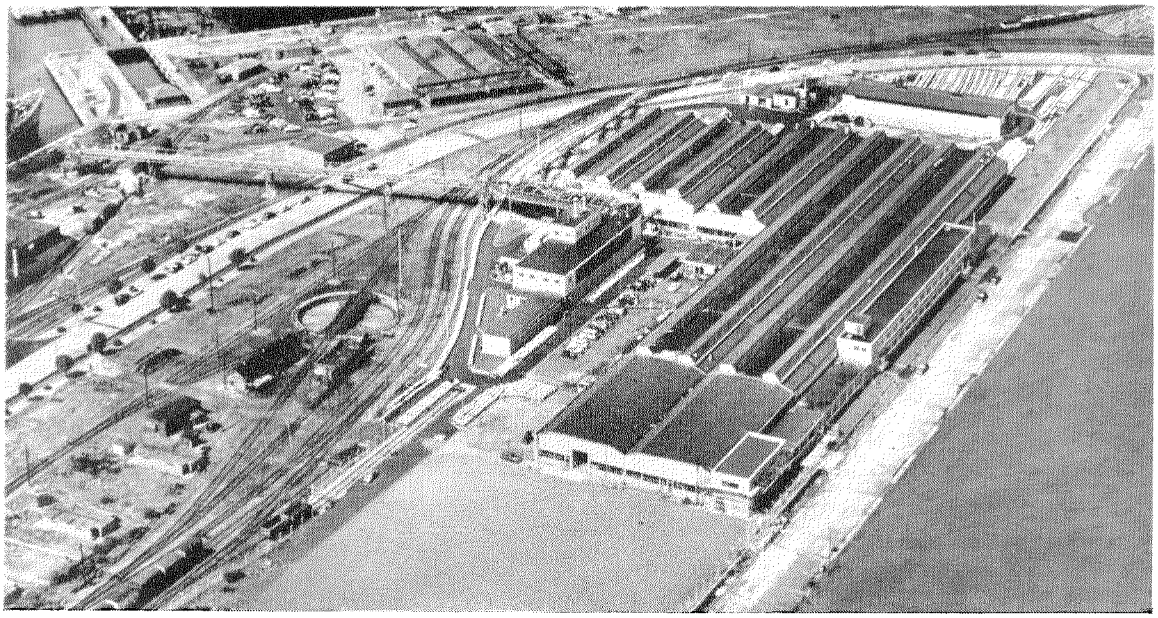


Figure 1—Aerial view of the Southampton cable factory.

D/d for minimum attenuation is much lower, about 2 for the sea-return telegraph core, than the 3·6 for high-frequency coaxial core with copper return conductors. A layer of jute is applied to the core to form a bedding for the layer of armour wires, and two layers of tarred jute outside the armour wires complete the cable. The size, strength, and number of armour wires are dependent on the depth of water and the nature of the bottom at the intended location of the cable. For deep water, a layer of 15 to 20 high-tensile steel wires about 0·10 inch (2·5 millimetres) in diameter is used whereas for shallow water, a layer of 9 to 15 low-tensile steel wires from 0·20 to 0·30 inch (5·1 to 7·6 millimetres) in diameter is usual. These two types of cables are shown on the left of Figure 2. Where the cable crosses the tide line and beach, two layers of these large wires may be used.

To convert the telegraph cable design to a coaxial carrier telephone cable, it is desirable to have a centre conductor with a cylindrical outer surface to minimise its high-frequency resistance, and, as has been noted, it should be smaller in diameter for a given size polythene core. The outer conductor is normally a layer of 6 copper tapes with edges near butting, applied with a long lay, and bound with a short-lay thin copper tape, and with a water-proofed cotton tape to inhibit electrolytic corrosion between copper and steel after immersion. The jute bedding, armour, and outer servings placed over the coaxial core are designed in the same way as those of the telegraph cable, and serve the same purposes. Figure 2 shows third from left a sample of the first shallow-water coaxial cables made at Southampton.

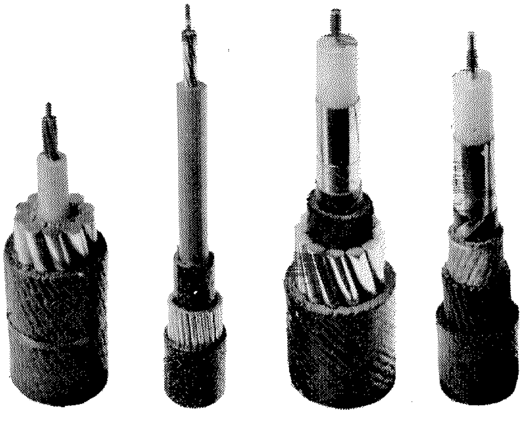


Figure 2—The two cables at the left are for telegraph use and those at the right are coaxial cables for telephony. The first and third cables are for installation in shallow water whilst the second and fourth samples are armoured with thinner but stronger steel wires for deep-sea service.

After making this design assessment it was decided that production facilities could be planned for combining the manufacture of telegraph and telephone cables. Most of the machines would be common to both and could be placed in service most easily by first producing short repair lengths of the simpler telegraph cable.

4. Armoured-Submarine-Cable Manufacture

4.1 General Layout

All the production machines and their auxiliaries, with the exception of the two extruders, and all the intermediate storage tanks are on the ground floor of a single-storey building. Because of the long water-filled cooling troughs required, the extruders are mounted upon a steel platform 10 feet (3 metres) above ground level. At the cold ends of the water troughs, which are suspended from the roof steels, the take-away core haulers are mounted upon a second 10-foot (3 metre) high platform. For the final storage tanks, a second building, directly adjoining the first building, was built with a higher roof to accommodate the cable-hauling gantries 20 feet (6·1 metres) above floor level, and spanning the 35-foot (10·7 metre) diameter storage tanks that project 3 feet (0·9 metre) above and 22 feet (6·7 metres) below floor level.

Site services such as boilers, air compressors, and power supplies are housed in buildings detached from the production unit, and a separate building has recently been added to house incoming raw materials.

4.2 TELEGRAPH CABLE CONDUCTOR

For the simple 7-wire, 6-round-1, telegraph strand a small tubular-type stranding machine previously used for power cables was installed. Coils of fully annealed copper wires 0·032 to 0·076 inch (0·8 to 1·9 millimetres) in diameter are supplied to wire-winding machines and wound onto the strander-machine bobbins. By programmed reloading of the stranding machine, any desired length of conductor strand may be produced independently of bobbin capacity, and lengths around 10 nautical miles (18·5 kilometres) were wound onto the large take-up drums.

4.2.1 *Telephone Cable Conductor, Tape Wound*

For the type of centre conductor used in the early telephone coaxial cables, comprising a helical layer of copper tapes closely fitting round a copper centre wire, a special stranding machine was developed and built. The development problem here solved was the production of very long lengths of accurately dimensioned conductor in which the soft copper tapes and wires had not been stretched or scratched, and had retained high electrical conductivity; and with the complete conductor so packaged on the drums as to ensure smooth and scratch-free run-off into the insulating extruder next along the line. For transport between machines all drums are trucked on frames rather than subjecting them to the more usual, but more hazardous, rolling around on the shop floor. In 1958, some 700 nautical miles of conductor were manufactured on this machine for the Florida-Puerto Rico cable to the order of the American Telephone and Telegraph Company and to the same general design as for the first transatlantic telephone cable. Off the north coast of Puerto Rico several miles of the cable are at a depth of 4500 fathoms (8230 metres)—the deepest to date for a carrier telephone cable.

4.2.2 *Telephone Cable Conductor, Solid Wire*

The tapes-round-wire conductor was an extension of the "safety in number" philosophy of the telegraph cable. Judged electrically, rather than mechanically, it has the disadvantage of about 3·5 per cent higher effective resistance at megacycle-per-second frequencies than a single wire or tube of the same material and diameter. It is also more costly to manufacture. In consequence, one of the new approaches to submarine-cable development was the problem of the single centre conductor.

The essence of the problem is assurance that hundreds of miles of copper wire free from mechanical weakness due to dross, impurities, crystalline faults, or joints can be produced with demonstrable proved integrity. A study of modern practices based on electrolytic copper refining, with vertical casting, topping of bars and shaving of rods before drawing into wire indicated that pieces of wire free from dross and impurities could be obtained. A piece of wire in this context is the joint-free length drawn from one wire bar weighing about 400 pounds (181 kilogrammes). For submarine-cable work this is not a long enough length of wire to be handled efficiently. Since heavier wire bars are not really available, longer lengths are now based on welding the shaved rods together before starting the wire drawing process. This makes the drawing a continuous process, and the length is only limited by the weight that can be handled and transported. Drums containing 1-ton (2240-pound or 1016-kilogramme) pieces of copper wire are currently being supplied to Southampton. The wire is of the correct diameter and within the specified diameter tolerances. It is in the fully work-hardened state (2-per-cent elongation) resulting from the drawing process.

At the cable factory the hard wire is taken off the supply drum and wound on to a copper-lined process drum in preparation for annealing. During this rewinding it is carefully inspected for cleanliness and surface finish; the diameter and roundness are measured at frequent intervals. Approved drum lengths are then given a slow low-temperature anneal in an inert atmosphere. The result is high conductivity (101·5-per-cent) copper wire with an elongation of around

35 per cent. There is a risk here that self-welding between the turns of wire on the drum will occur if the wire is too tightly wound. A further inspection is necessary, and the soft wire is taken off the annealing drum and wound on to the extruder supply drum. Careful limitation of the winding tension applied to the soft wire is provided by means of a catenary-arm servo control gear.

This new centre-conductor technique was first used for a shallow-water cable supplied to the British Post Office for laying in 1958 across the English Channel, between Bournemouth, England, and St. Helier, Jersey, a route length of 140 nautical miles (259 kilometres). The coaxial core was 0·620 inch (15·8 millimetres) in diameter over the polythene, and the centre conductor was 0·160 inch (4·1 millimetres) in diameter. Two-way submerged repeaters at 12-mile (22·2-kilometre) intervals provide 120 telephone channels of 4 kilocycles per second each.

In 1958 a contract code-named Scotice [10] was received for a complete 18-channel 4-kilocycle-per-second system to connect Gairloch in Scotland with the Faroes and Iceland, over a total route length of about 700 nautical miles, and in depths to 1000 fathoms. For this project a new design of 0·460-inch (11·7-millimetre) diameter coaxial core with a single-wire centre conductor 0·128 inch (3·3 millimetres) in diameter was offered and accepted, and the cable and repeaters were laid successfully in November–December 1961.

4.2.3 *Telephone Cable Conductor, Box Seam*

A third type of centre-conductor for armoured shallow-water cables was called for by the British Post Office in connection with the new light-weight deep-sea cable. This conductor was required to simulate the shape of the attenuation-frequency curve in the spectrum from 50 to 600 kilocycles per second obtained from the steel-wire-strand copper-taped centre conductor of the light-weight cable. The production development problem was to devise means for tightly wrapping a soft copper tape 0·010-inch (0·25-millimetre) thick round a 19-wire strand of low-tensile black annealed steel wires, 0·2 inch (5·1 millimetres) in overall diameter. It was specified that the copper tape should be secured in position by having its edges folded into a box seam, as used extensively in making tinplate cans and boxes. Carrying out the double interlocking fold in soft copper tape as a continuous operation running at 20 to 30 feet per minute required painstaking machine development. The working solution had 10 pairs of shaped rollers, each pair making only a comparatively small change in the cross-sectional shape of the tape. Figure 3 shows the copper tape and the 19-wire strand entering the box-seaming unit.

A problem came back to this composite conductor from the core extruder. The box seam is not airtight, and since the 19-wire steel strand inside it contains a fair amount of air, the heating up at the extruder head caused recurrent air blows in the polythene. The box seam was made airtight by running-in a polythene monofilament in such a position that it became trapped in the internal fold of the seam [11].

The first major try-out of the conductor was in the 0·620-inch (15·8-millimetre) coaxial core with 0·200-inch (5·1-millimetre) box-seamed conductor for 550 nautical miles (1019 kilometres) of shallow-water cable supplied to and laid by the British Post Office in 1960 between England and Sweden. This is also the first direct telephone cable between the two countries and the first project for which Standard Telephones and Cables manufactured all the cable, all the submerged repeaters, and the terminal equipment for 60 channels each of 4-kilocycle-per-second bandwidth.

4.3 CORE

4.3.1 *Telegraph Cable Core*

A 4·5-inch (114-millimetre) extruder with a cooling trough 120 feet (36·6 metres) long was

Figure 3—Box seaming machine. A 19-strand steel wire and a flat copper tape pass through 10 pairs of shaping rollers, some of which are visible at the lower right, to shape the tape round the wire and form a box seam to secure it.

installed for telegraph cable cores where the amount of polythene per unit length is small because of small diameter and low optimum *D*/*d* ratio. The extruder dimension is the internal diameter of the barrel containing the screw that forces the molten polythene into the head and out round the centre conductor when passing through the head at right angles to the axis of the screw and barrel.

It is not necessary to maintain exacting control over the diameter of the core. The transmission requirements can be met by specifying a minimum for the core diameter and an average weight per nautical mile, ±2 per cent, for the polythene applied to the centre conductor. Lengths of conductor were weighed before and after extrusion to determine the weights of both copper and polythene. The extruder screw was run at constant speed, and the diameter of the core was controlled by varying the speed of the centre conductor at the extruder head. Cooling-water temperature was adjusted to cool the core sufficiently slowly to avoid contraction voids round the centre conductor.

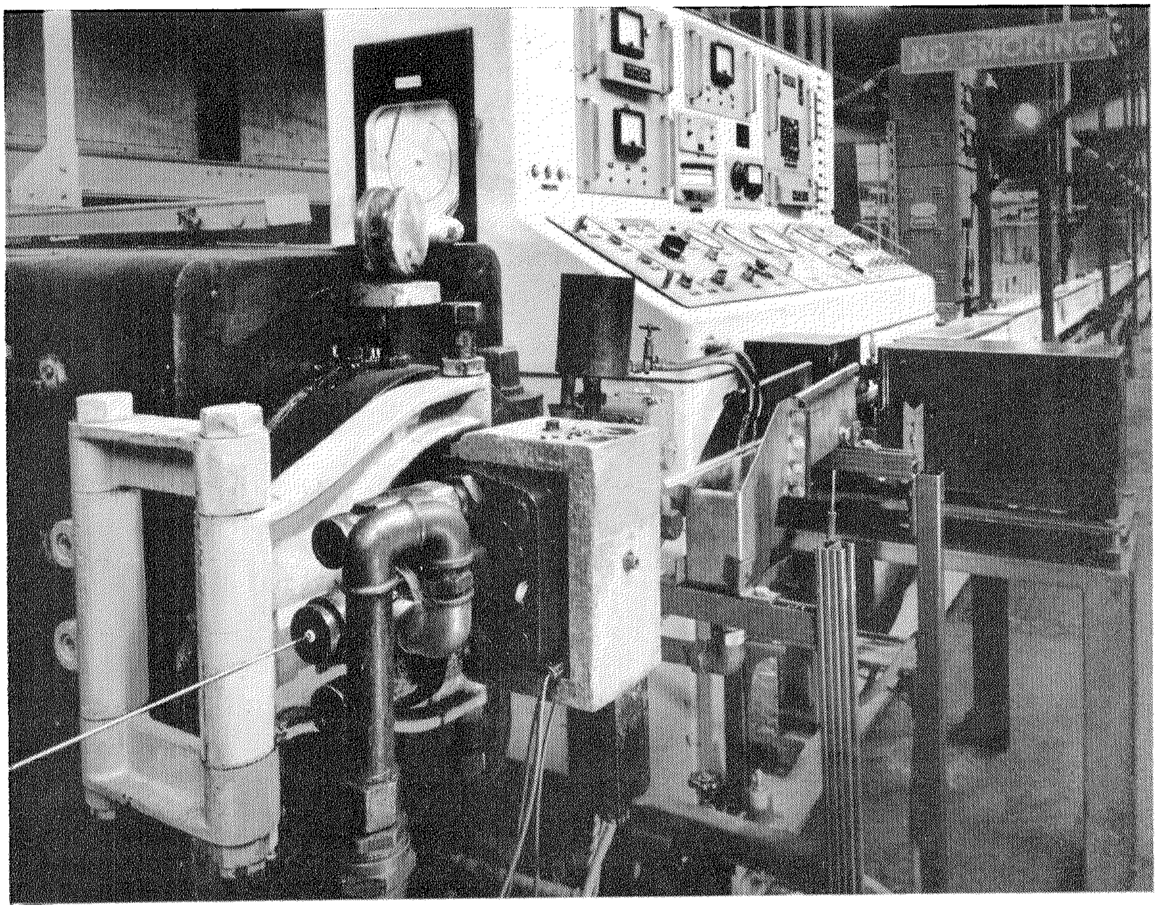


Figure 4—Polythene core extruder. The centre conductor enters at the lower left and is coated with polythene in the extruder head. The coated conductor passes through a light gauge in the two black boxes, which check the diameter, and then into the long cooling trough. The control console is just behind the extruder.

Of over-riding importance was the need for cleanliness in handling the polythene whilst loading it to the extruder. Very-high dielectric resistance is required of telegraph cables to facilitate the detection of incipient faults in circuits thousands of miles long. Polythene has a very-high dielectric resistance, which can be upset by contamination with even small quantities of extraneous matter.

4.3.2 *Telephone Cable Core*

It is required to have the centre conductor of a telephone cable uniformly and tightly covered with polythene in one operation by an extrusion process automatically controlled and with provision for continuously charted records of diameter and capacitance. The dielectric shall be visibly free from voids, impurities, and inclusions. It shall be possible to pass every length of core through a ring gauge of 0·010-inch (0·25-millimetre) larger internal diameter than the nominal core diameter. At any point the measured diameter shall be within ±0·007 inch (0·18 millimetre) of nominal, and the average of 5 pairs of readings taken not more than 4 feet (1·2 metres) apart shall be within ±0·003 inch

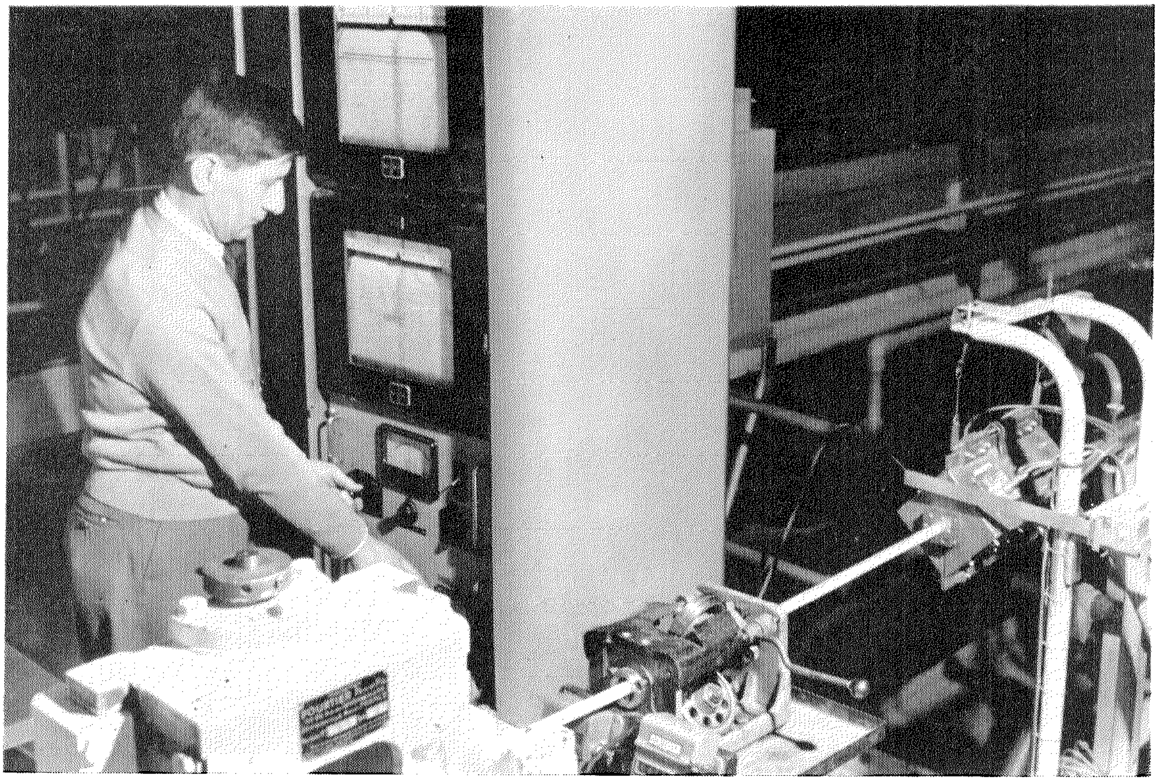


Figure 5—Take-up platform with recorders for diameter and capacitance per unit length of the core is at the cold end of the long cooling trough.

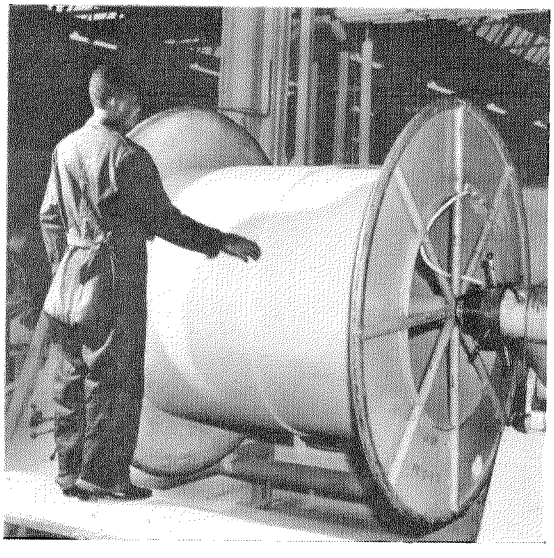


Figure 6—Take-up drum on which the polythene coated centre conductor is wound before going to the next operation.

(0·08 millimetre) of nominal. The difference between the maximum and minimum diameters in a plane normal to the core axis shall not exceed 0·001 inch (0·025 millimetre). Polythene taken from the core shall show no significant change in permittivity and power factor due to extrusion.

The manufacturing facilities installed to cope with this problem comprised a 6-inch (152-millimetre) extruder with 360 feet (110 metres) of cooling trough, a supply stand for the drum of conductor, a servo-controlled input capstan, a tension-controlled output capstan and a double take-up stand for the core drum. The extruder head is shown in Figure 4 with the main control console behind the barrel and head. Con-

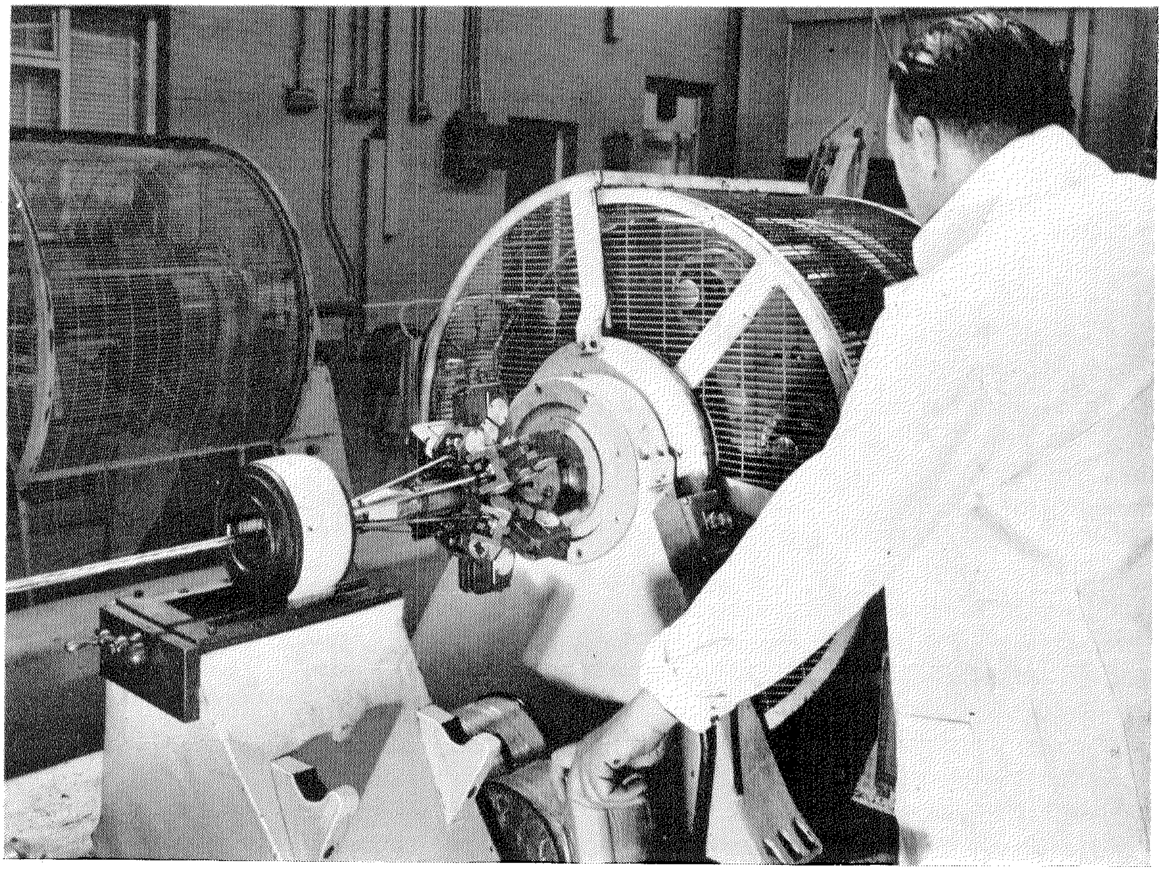
Figure 7—The completed core is examined at this inspection bench, where it can be stopped at will to check for faults indicated on the charts from the extruder measurements. A light box is used to inspect for inclusions or impurities in the polythene.

ductor enters the head from the left and core leaves it from the right. The start of the trough is by the diameter-measuring light gauge in the two black boxes. The light gauge, developed by the British Post Office Research Station, scans the hot polythene core as it passes through a gate and generates a command signal proportional to the vertical diameter of the polythene. At the cold end of the cooling trough a capacitance-measuring electrode system, based on a Bell Telephone Laboratories development, is installed. This generates a command signal proportional to the capacitance per unit length of the core. Local development was concerned with the building of a servo-drive mechanism for the input capstan controlled by the two command signals. The core diameter is a function of the ratio of conductor speed (input-capstan speed) to extruder screw speed. Both command signals are recorded throughout each extrusion run, and the two charts, diameter on top and capacitance, are shown in Figure 5 on the take-up platform, where the core leaves the cold end of the cooling trough and is wound onto the take-up drum shown in Figure 6.

A 10-nautical-mile (18·5-kilometre) length of core requires about 50 hours for extrusion, and it is not expedient to stop the extrusion to correct minor failures to conform to specified diameter or capacitance. Corrections may usually be made on the run, and reliance is then placed on a post-extrusion examination of the core to check for conformance with specifications. This auxiliary inspection or panning operation, shown in Figure 7, consists in running the completed core length off the take-up drum across an inspection bench. Here the core may be started and stopped at will, the diameter may be measured at stated intervals and a careful check made at any location along the core where the extruder charts indicate possible deviations from normal. The core is passed across a light box to check for freedom from inclusions or impurities in the polythene, and the operation concludes with mechanically acceptable core coiled down in an 8-foot (2·4-metre) diameter transportable pan in preparation for the electrical tests.

About 2500 nautical miles (4630 kilometres) of core have been produced in the past three years. Most of it has been of 0·620-inch (15·8-millimetre) simulator conductor of Section 4.2.3. During this time the electrical parameters of the insulant have been improved. It is now accepted that modern high-molecular-weight polythenes may be used without first being blended with plasticisers such as polyisobutylene or butyl rubber, which are electrically inferior to polythene. The only remaining additive is a trace of anti-

Figure 8—Application of the 6 outer-conductor copper tapes requires preforming to the curvature of the core before passing into the closing die. This is one of 6 heads that apply conducting and binding tapes and the jute bedding.



oxidant to protect the polythene during its brief warm-up in the extruder.

4.4 Coaxial Core

4.4.1 *Plain Coaxial*

Two machines were designed and installed for applying to the core the outer conductor tapes, binding tapes, and jute bedding. There are 6 heads and the one for applying the outer conductor tape is shown in Figure 8. This applies 6 copper tapes, 0·012 to 0·016 inch (0·3 to 0·4 millimetre) thick, and each one is preformed to the curvature of the polythene core before passing into the closing die and on to the core. The second head carries one pad of copper tape 0·003 inch (0·8 millimetre) thick and not less than 1 inch (25·4 millimetres) wide, which is applied at an angle of 45 degrees with a 15-percent overlap. The third head, in a similar manner, applies one proofed cotton tape. Fourth and fifth are jute heads, each with 35 spindles. There will be one or two layers of jute yarn, dependent on the type of armour to follow. Shallow-water heavy armour has two layers, and deep sea armour one layer. The sixth head has 3 jute spindles only, and is used to apply an open whipping of jute thread over single layers of bedding. This prevents the bedding jute from "bird-caging" in the armouring machines. The served coaxial core is hauled through the machine by a 2-wheel capstan, from whence it goes up into the pulley way in the roof of the building, and along to one of the 8 intermediate storage tanks. At this stage the coaxial core is cut to the required repeater section length for the job, and the first transmission tests are made on each completed coaxial core after a 24-hour soak in water. Repeater-section lengths vary from 12 nautical miles (22·2 kilometres) for a 0·620-inch (15·8-millimetre) 120-channel system to 36 nautical miles (66·7 kilometres) for the first transatlantic 36-channel telephone system.

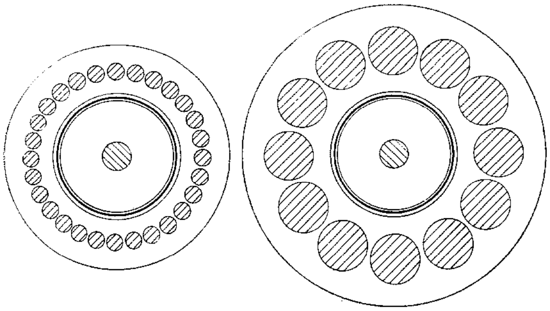


Figure 9—Cross sections of armoured cables for deep sea at left and shallow water at right. The centre conductor is surrounded by polythene. The next three layers are of outer conductor and binder tapes. The armour wires are laid on a jute bedding and an outer jute serving completes the cable.

Designing the jute bedding, which is common to both telegraph and telephone cable, is more a matter of accumulated experience than straightforward trigonometry. When the armour wires are applied to the served core they will bed into the jute to form a ring of wires, as shown on the cross-section drawings of Figure 9. If there is insufficient jute in the bedding the wires will touch each other and lock together, and the completed cable will be very stiff and unmanageable during coiling and laying. Should there be too much jute, it will not be possible to compress the ring of wires to the correct over-all diameter. There will be excessive gaps between wires, and under tension the wires will tend to pull together with the core forced out to one side and going round the wires. The objective is gaps between wires of between 5 and 10 per cent of the wire diameter, and the result is a stable structure handling easily like a rope. Factors taken into account are the quality of the jute yarn, the count of yarn, the amount of preservative, cutch, or tar in the yarn, the number of ends applied, the length of lay, and the diameter over the layer of jute.

4.4.2 *Screened Coaxial*

It was noted in the introduction that a coaxial pair under water is effectively screened by the water from external noises from radio or static and from feed-back crosstalk at the submerged repeaters. As this protection does not obtain at the shore ends of cables or with entrenched cable on land between beach and terminal station, present practice specifies screened coaxial cores for these sections of cable.

Screening comprises 5 ferromagnetic soft-iron tapes of high initial permeability applied outside the proofed cotton tape of the plain coaxial core on a machine having the basic chassis of the coaxial machines. Up to 6 single tape heads can be set up as required. A second proofed cotton tape is applied over the iron tapes. The screened core is then passed through the 4·5-inch (114-millimetre) extruder and enclosed within a polythene sheath of 0·10-inch (2·5-millimetre) radial thickness to protect the iron tapes from corrosion after cable installation. The jute bedding for the armour is applied over the polythene sheath, either by passing through a serving machine or by setting up jute heads at the supply end of the armouring machines.

4.5 ARMOUR

In the interest of low production costs, the two armouring machines were chosen as being the largest and fastest available in 1954.

For the deep-sea-type armour a 36-bobbin machine was installed. The bobbins are mounted in floating yokes within the main carriage of the machine, which, by means of sun and planet gearing, keep the bobbin spindles horizontal as the bobbins rotate with the main carriage. Twisting of the armour wires about their own axis is minimised by this arrangement. Each bobbin carries 300 pounds (136 kilogrammes) of steel wire, and the main carriage, fully loaded, will run at 120 revolutions per minute. The angle of lay for deep-sea armour is about 10 degrees from the longitudinal axis, a compromise restricting the amount of cable twisting under tension (small angle) and avoiding risk of bird-caging during handling (large angle). The corresponding lengths of lay are from 12 to 20 inches (30 to 51 centimetres) depending on the size of the coaxial core to be armoured. At the forward end of the main carriage is a ring of guide pulleys and the lay plate, on which any number of ceramic-lined bushes up to 36 may be mounted and spaced regularly round the perimeter of the plate [12]. The number of bushes corresponds to the number of wires in the armour and the bushes ensure that the wires approach the cable in equiangular array. Separate from, and immediately beyond (in the product line of flow sense), is the closing-die stand. A split long land (around 1:6 ratio internal diameter to length) die is here secured on a movable holder adjustable by screw along the cable axis. Given the correct jute bedding, as already noted, and the correct internal die diameter for the size and number of armour wires, it should be possible to pass the wires through the closing die on to the served core without exerting excessive centripetal pressure on the wires. Hence, no scraping of tar coating or galvanising. The final adjustment for good armouring is the positioning of the closing die with respect to the lay plate.

The concluding operations of the armoured cable are concerned with protecting the steel wires from abrasion and corrosion. Hot compound bases on coal tar or petroleum bitumen is poured on the layer of wires, followed by a layer of tarred jute, a second pouring of compound, a second layer of tarred jute, and a third pouring of compound. To prevent adjacent turns of the cable sticking together in the storage tanks, a coating of whitewash (aqueous solution of calcium carbonate) is applied over the third compound layer.

The cable is hauled through the armouring machine by passing three or four turns round the 10-foot (3-metre) diameter capstan. A take-away sheave on a platform over the capstan maintains back tension on the cable leaving the capstan. The sheave is driven by an hydraulic motor, which can be set to maintain a constant tension, and which stalls without damage when the armouring machine is stopped. From the sheave the cable passes to the gantries over the main storage tanks and is coiled down in one of them.

The 24-bobbin armouring machine has a layout similar to that described but with a different main carriage, comprising 6 bays of 4 bobbins each, instead of 6 each. The bobbins are much larger and will carry up to 1 ton (2240 pounds or 1016 kilograms) each of large-gauge 0·20- to 0·30-inch (5·1- to 7·6-millimetre) diameter galvanised steel wire.

Auxiliary operations for both armouring machines are catered for in the same building. These comprise tar-dipping of coils of galvanised steel wire and of bundles of jute yarn, winding of tarred wire on to the machine bobbins, and winding of the hanks of tarred jute on to spools.

When each length of armoured cable is completed, the water level in the storage tank is raised to submerge it, and after a 24-hour soak during which the cable will attain the temperature of the water, it is tested electrically to a rigorous specification concerning conductor resistance, dielectric resistance, capacitance, attenuation, impedance uniformity, and velocity of propagation.

In the period from 1956 to 1961 approximately 3000 nautical miles (5556 kilometres) of telegraph and telephone cable passed through the armouring shop.

5. Light-weight Submarine Cable—Design

When it became known that the light-weight cable developed by the British Post Office for the first United Kingdom to Canada cable, called Cantat [13], had been adopted at the 1958 Commonwealth Communications Conference for a round-the-world telephone cable system, it was decided to extend the factory at Southampton to provide manufacturing facilities for the new cable, which the existing armoured-cable plant could not handle. It was kept in mind that the light-weight cable would be used in deep water and that armoured shallow-water cable would still be required.

The strength member of the lightweight cable is inside the centre conductor. It has a 19-wire high-tensile-steel strand swagged or compacted down to increase the steel content of the cross-section. This steel heart is supplied by a wire rope manufacturer to meet a breaking strength of 4·5 tons (4572 kilogrammes) minimum. The length of lay of the wires is about 3 inches (7·6 centimetres) and the direction is left hand.

Around the steel heart is a single layer of 0·032-inch (0·8-millimetre) steel wires having a tensile strength of about 120 tons per square inch (787 megagrammes per square centimetre) applied with a nominal 3-inch (7·6-centimetre) right-hand lay. The centre-conductor copper tape, 0·010 inch (0·25-millimetre) thick, is box seamed over this layer of wires in the manner already described in 4.2.3.

The completed centre-conductor assembly has a breaking strength of not less than 7 tons (7112 kilogrammes) and it is about ⅓ inch (8·5 millimetres) in diameter except at the box seam. The core is solid polythene to a diameter of 0·99 inch (25·2 millimetres) and 6 aluminium tapes applied to it with a long lay form the return conductor for the coaxial pair. Over these are short-lay wrappings successively of polythene tape, aluminium foil, corrosion-inhibitor impregnated cotton, and polythene terephthalate tape. The cable is completed with an extruded polythene oversheath of 0·1-inch (2·54-millimetre) radial thickness and 1·30-inch (33-millimetre) external diameter.

In developing the cable the principal objectives have been, firstly, freedom from twisting under applied tension to avoid looping and kinking at sea bottom in deep water, and, secondly, light weight per unit length in sea water. By getting this last down to 0·6 ton (610 kilogrammes) per nautical mile, only about 20 per cent of the tensile strength of the cable is required to support its own weight during deep-water laying. The remaining strength is available to cope with the dynamic stresses due to weather and with the weight of the submerged repeaters whilst suspended on the cable between ship and sea bottom. Figure 10 is a photograph of a sample of the cable.

A third design objective was good adhesion between the inter-layer surfaces in the cable cross section. These are steel to copper, copper to polythene, and polythene to aluminium. When the cable is subjected to tension during laying, it is gripped externally by the cable gear of the ship. This load has to be transmitted through the inter-layer surfaces without slip to the strength member in the centre of the cable.

6. Lightweight Submarine Cable—Manufacture

6.1 General Layout

The phase 2 manufacturing facilities are based upon a target set for production development to 40 nautical miles (74 kilometres) of cable per week.

The new product line differs from the armoured-cable product line in that there are no facilities for the electrical testing of lengths of cores, or of coaxial cores, under water prior to coaxial taping or oversheathing. From the results obtained during the manufacture of core for armoured cables, it had become apparent that the electrical core tests were not really necessary for the assessment of core quality. The diameter and capacitance charts from the extruder line and the careful physical examination during panning are sufficient to ensure that only acceptable core goes forward to the coaxial taping machines. It was demonstrable similarly that electrical tests under water on completed lengths of coaxial core prior to armouring or oversheathing were not necessary for quality control. A considerable saving in capital investment followed customer acceptance of these changes. Instead of steel storage pans or tanks with water laid on and off, all the new storage facilities between machines were lightly framed plastic-laminate-sheathed creels.

6.2 Centre Conductor

The stranding of 24 steel wires round the steel heart must be carried out in tandem with the box-seaming operation on the copper centre-conductor tape because the 24-wire layer would bird-cage if coiled or reeled without an external binder. Two standard 12-bobbin floating-yoke carriages coupled together form the stranding unit, Figure 11. The box-seaming unit was developed from the smaller one first used for the 0·20-inch (5-millimetre) diameter simulator conductor described in Section 4.2.4. As a result of core-extruder changes, the polythene monofilament used to seal the box seam was discarded. To improve the interlayer adhesion, printing wheels were fitted, one to apply a streak of epoxy resin to the steel strand and the other a streak of hardener to the inside surface of the copper tape. The streaks mingle after box-seaming and the resin sets and forms a steel-to-copper bond.

For the first light-weight cable made in Southampton only one centre conductor machine was commissioned, and the completed conductor was taken up on to large steel drums having a capacity of approximately 10 nautical miles (18·5 kilometres) each. When the second machine was commissioned the take-up facility was changed from drums to transportable steel pans of larger capacity than the drums. The centre conductor is coiled down horizontally into these pans from an overhead sheave, and, since the capacity is greater than half the present light-weight cable repeater section length, 26 nautical miles (48·2 kilometres), it is possible to set a production target of only 1 core joint per section against a specification limit of not more than 5.

6.3 Core

The core-extruder facilities provided for armoured cable are basically all that is required for the 0·990-inch (25·2-millimetre) light-weight cable. There is, compared with the 0·620-inch (15·8-millimetre) core, a larger amount of polythene to be applied per unit length. This the 6-inch (152-millimetre) extruder could handle at increased screw speed, without reduction in line speed, but for the limitations in speed imposed by the rate of cooling necessary for maintaining core diameter, core roundness, and conductor concentricity within the specified ±0·015-inch (0·38-millimetre) tolerances. On the first 6-inch (152-millimetre) extruder the line speed had to be reduced about 30 per cent. For the second extruder, larger cooling troughs were installed to enable it to be run at normal line speed on 0·990-inch (25·2-millimetre) light-weight core.

It was anticipated that the larger centre-conductor assembly would increase the hazard of air inside the copper tube blowing out into the polythene under the influence of heat from the polythene. To deal with this, both extruders have had their input capstans enclosed within a massive low-pressure chamber, maintained by air pumps at near vacuum. Whilst passing through this chamber most of the air is removed from the conductor, and no blows in the polythene occur, even when a short piece of copper tape is missing from the steel strand. A fault of this kind resulting from a copper-tape failure is most economically repaired during panning after extrusion. Neither the stranding machine nor the extruder is held up by the repair, and, perhaps more important in light-weight cable, the repair can then be made without cutting the steel centre strand.

Cores from the extruders are coiled down in dry creels and on completion are panned for examination in the manner of Section 4.3.2 into another creel. The capacitances per unit length of the ends of core lengths are noted from the extruder charts, and the core lengths are allocated into jointing sequence so as to minimise impedance mismatch at the joints.

6.4 COAXIAL

The light-weight coaxial-cable machines differ only from those already described in having lapping heads specifically designed for tapes of different sizes and different materials. The heads for the 6 aluminium return tapes are much larger than the corresponding copper-tape heads so that they can take large bobbins containing long lengths of tape. A machine is shown in Figure 12. Jointed lengths of core are supplied continuously to the coaxial machines, and cuts are made in the completed coaxial core to give the required repeater section lengths, which are then coiled down one section per creel.

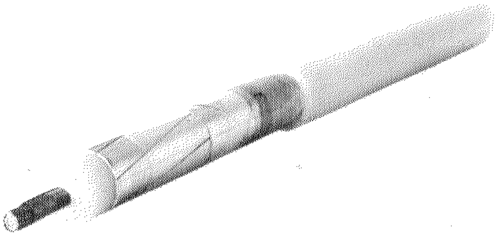


Figure 10—Sample of the light-weight coaxial cable designed by the British Post Office for the 80-channel telephone system between the United Kingdom and Canada.

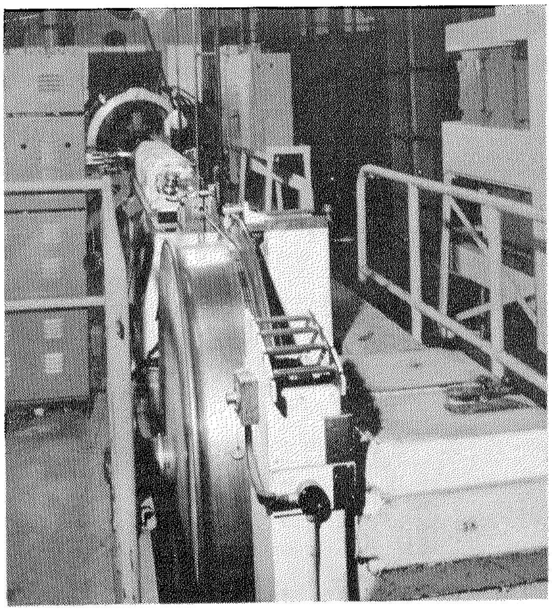


Figure 11—This equipment strands 24 steel wires round the steel heart and then box seams the copper conducting tape over this for the centre conductor, which is also the strength member, of the light-weight submarine cable. No outer armour is used.

6.5 OVERSHEATHING

It is not difficult to set up an extruder to produce a polythene sheath 0·10-inch (2·5-millimetre) thick and of 1·3-inch (33-millimetre) external diameter over a coaxial core of unvarying diameter. There are two techniques, and the choice depends on whether the thickness or the diameter of the sheath is considered to be the more important. For constant diameter, the "smearing-on" technique, in which the pressure in the extruder head forces the polythene centripetally on to the coaxial core and through a die fixing the diameter, is preferred. At Southampton, it is considered more important to maintain the radial thickness of the sheath by using the "tubing-on" technique. Here a sheath of constant thickness, but of too large a diameter, is formed in the extruder head, and this is pulled down on to the core as it leaves the head. Tape-wrapped coaxial cores are not smoothly cylindrical, and the more-robust sheath is the one that follows the ups and downs of the tape wrappings.

The major production problem with oversheathing is continuity. With a 4·5-inch (114-millimetre) extruder, it takes nearly 4 days continuous operation to sheath a 26-nautical-mile (48·2 kilometre) length of light-weight cable. If for any reason the extruder has to be stopped during a run, the piece of cable in the extruder may be seriously damaged by heat. Loose tapes on the outside of the coaxial core may be pushed back into a pile-up that jams in the extruder. Dampness in tapes or in the polythene supplied to the extruder results in a sheath full of water-vapour voids. Minute particles of burnt polythene at the die outlet can gradually build up into hard lumps (drool) that break off from time to time and make holes in the sheath. Process developments have taken care of these problems, and over 1000 nautical miles (1852 kilometres) of light-weight cable in 26-nautical-mile (48·2-kilometre) sections were oversheathed acceptably in the first year of production.

7. Jointing

7.1 GENERAL

Development of jointing techniques for submarine cable ranks equally with cable development. As of chains, it may be paraphrased that the strength of a submarine cable is that of its weakest joint. Functionally, there are two kinds of joint: firstly, those that are inherently weaker than the parent materials joined and are acceptable either because the parent is not load-bearing or because the parent is only one of a number of components in a load bearer. Examples of these are a repair joint in the copper tape surrounding the steel strength member in the light-weight cable. A copper ferrule may be conveniently soft-soldered into position to bridge a gap. There are in total 43 high-tensile steel wires in the steel strength member; any one of these

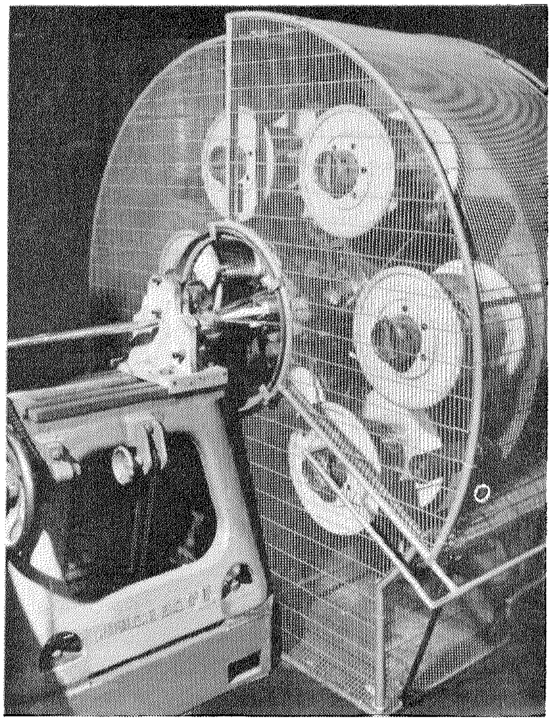


Figure 12—Applying the 6 aluminium outer-conductor tapes to the polythene core of the light-weight coaxial cable.

wires may be jointed by welding, providing that not more than one weld occurs in a plane normal to the axis of the strand, and not within several feet of welds in any of the other 42 wires. Welding anneals work-hardened steel, and the weld may have only 25 per cent of the wire strength.

The second kind are joints required to be as strong as the parent materials. In high-tensile steel, this means steel ferrules crimped over butting wires or strands by means of hydraulic presses producing 200 to 500 tons per square inch (1311 to 3278 megagrammes per square centimetre). For copper tapes prior to the box-seaming operation, a silver-soldered or brazed joint is necessary; and, additionally, the joint must not be thicker than the tape. A similar type of joint is required for the single copper centre wires of armoured cables.

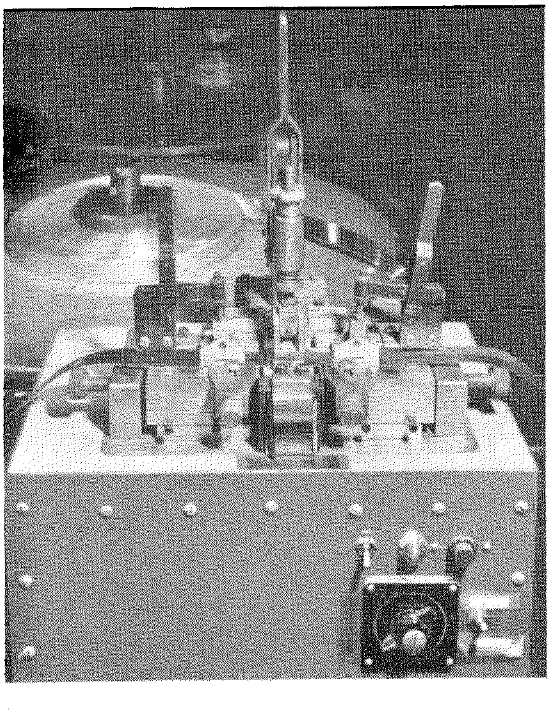


Figure 13—Brazing machine for copper tape. The tape ends are cut clean and square, then butted together with a strip of silver brazing alloy that is heated by an automatically controlled electric current passing through the tape ends.

7.2 Copper Jointing

The development of butt-brazing techniques [14] for wide copper tapes 0·010 to 0·015 inch (0·25 to 0·38 millimetre) thick has produced particularly elegant machines tailored to specific sizes of tape. It is first necessary to cut the tape ends clean and square and then align them in guides accurately butting together with a strip of silver brazing alloy sandwiched between them. Heat for the braze is provided electronically by passing current transversely to the tape axis from an electrode on top of the butt to an electrode underneath. The control panel enables the applied voltage to be pre-set, and switched on and off automatically for a specified time interval. The brazing machines for the light-weight cable centre-conductor tape are shown in Figure 13.

7.3 Polythene Core Joints

Joints in the polythene of the cores and oversheaths are welded joints in the second category. They do not degrade the mechanical properties of the components jointed. For cores, an appropriate joint is first made in the centre conductor, with the core polythene removed for 2 or 3 inches (51 or 76 millimetres) on either side. A split stainless-steel mould is then placed in position over the gap, and overlapping the two core ends. The internal bore of the mould is slightly greater in diameter than the cores. It is electrically heated in the middle, and water-cooled at each end. An injection gun comprising a compressed-air cylinder with piston and an electrically heated cylinder charged with polythene are connected to the mould. When both gun and mould have attained specified temperatures, the compressed air is admitted to force the new molten polythene charge into the mould. Providing that a carefully worked out programme is followed, the new hot polythene will form a perfect weld with the core polythene, and after a specified cooling period the mould may be removed. There is no appreciable change in diameter at the joint. The light-weight cable core-jointing machine developed at Southampton is shown in Figure 14.

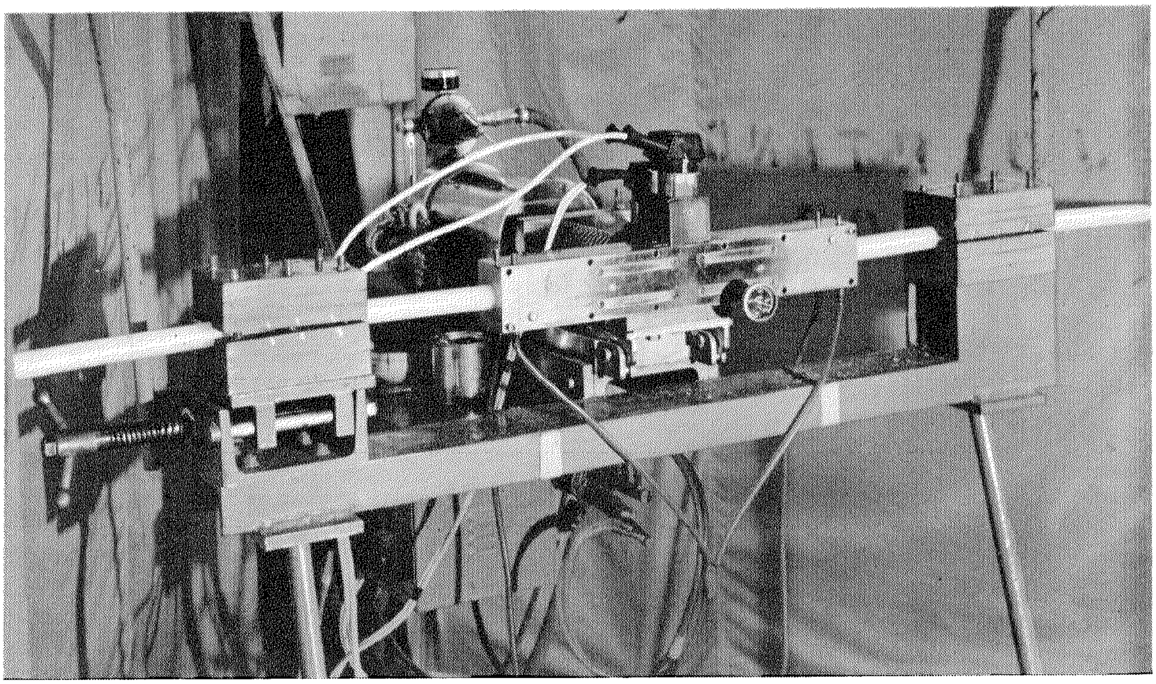


Figure 14—Machine for moulding polythene core in making cable joints. The mould is heated at the middle where the new polythene is to be applied and water cooled at the ends. A charge of polythene is driven by a compressed-air gun into the stainless-steel mould, where it welds perfectly with the existing cores.

7.4 POLYTHENE SHEATH JOINTS

Three techniques for sheath repairs and joints have been evolved. A small hole in a sheath may be patched by pressing a pellet of polythene into it under a heated clamp [15]. For a gap between sheath ends not more than about 0·5 inch (13 millimetres) long, a ring mould is fitted, and a ring injection is made in the same manner as a core joint [16].

To make a complete joint between two lengths of light-weight cable, a sheath joint has been developed in which split lengths of sheathing taken from spare cable are fitted to the joint and heat-welded longitudinally by enclosure within a split internally heated cylindrical clamp. Ring injections at each end of the "new" piece of sheath complete the joint.

8. Conclusion

A brief account has been given of some of the production development problems associated with the commissioning of the new submarine-cable plant at Southampton during the period 1955 to 1961. The major cable projects completed and loaded to customers' cable ships during this period were as follows.

(A) Anglo-Belgian Cable, 1958.
60 nautical miles (103 kilometres) of 0·935-inch (23·8-millimetre) coaxial cable. 120 standard 4-kilocycle-per-second channels.

(B) Channel Islands Cable, 1958.
140 nautical miles (259 kilometres) of 0·620-inch (15·8-millimetre) coaxial cable. 120 standard 4-kilocycle-per-second channels.

(C) Puerto Rico-Florida Cable, 1959.
Part of deep-sea cable. 715 nautical miles (1324 kilometres). 36 standard 4-kilocycle-per-second channels.

(D) Anglo-Swedish Cable, 1960.
530 nautical miles (992 kilometres) of 0·620-inch (15·8-millimetre) simulator coaxial cable. 60 standard 4-kilocycle-per-second channels.

(E) Cantat A3 Cable, 1960.
65 nautical miles (120 kilometres) of 0·620-inch (15·8-millimetre) screened simulator coaxial cable. Installed overland in Newfoundland to provide 60 standard 4-kilocycle-per-second channels.

(F) Scotice Cable, 1961.
690 nautical miles (1278 kilometres) of 0·460-inch (11·7-millimetre) coaxial cable. 18 standard 4-kilocycle-per-second channels.

(G) United States–Bermuda Cable, 1961.
700 nautical miles (1296 kilometres) of 0·990-inch (25·2-millimetre) coaxial cable. 60 standard 4-kilocycle-per-second channels.

9. References

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10. Acknowledgment

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Forward-Scatter Microwave Link Between Italy and Spain

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A 6-channel microwave radio link utilizing forward-scatter propagation now operates between the islands of Sardinia and Minorca. Supplemented by existing communication paths between these islands and the mainland, it provides direct communication between Italy and Spain without using the relatively long land routes through France.

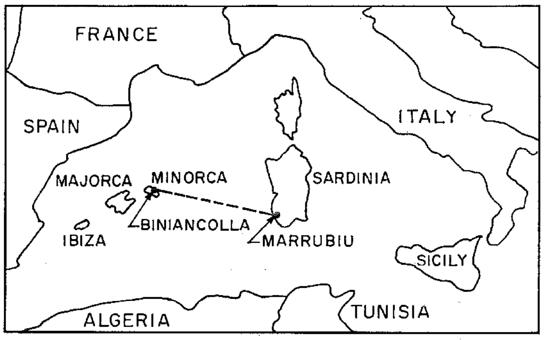


Figure 1—Sardinia-Minorca forward-scatter microwave link.

This link uses radio frequencies of the order of 800 megacycles per second. Culminating a series of propagation tests [1] made between 1954 and 1956 at about 240 and 300 megacycles per second, it was officially inaugurated on 4 September 1957 and then constituted the first commercial use of forward-scatter microwave transmission.

A series of tests from the spring of 1958 to the spring of 1959 not only proved the feasibility of commercial telephone service over forward-scatter paths, but also produced valuable information on propagation characteristics in the Mediterranean and on the behavior of the equipment.

1. Description of the Link

As shown in Figures 1 and 2, the Minorca terminal is installed at Biniancolla, at an altitude of about 75 meters (246 feet) above sea level.

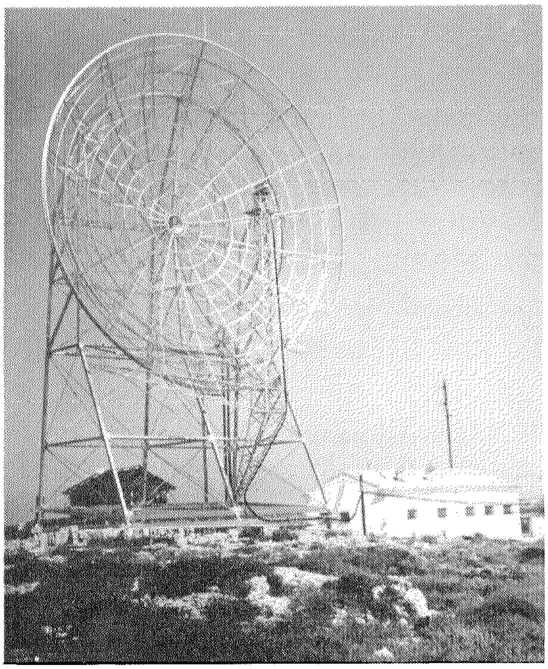


Figure 2—The Majorca station employs a 20-meter (66-foot) paraboloid.

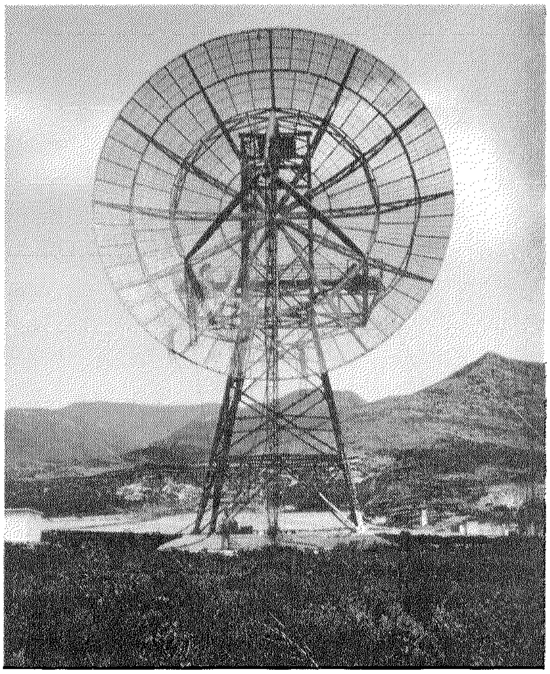


Figure 3—Sardinia plant with 20-meter (66-foot) paraboloidal antenna.

The Sardinia terminal is installed near the west coast of that island in the vicinity of Marrubiu (Oristano), at an altitude of 70 meters (230 feet) above sea level. It is shown in Figure 3.

There are no obstructions in the propagation paths from the antennas of either terminal. The air distance between terminals is about 380 kilometers (236 miles).

As shown in Figure 4, transmission from Sardinia is at 730 and 830 megacycles per second with vertical polarization. From Minorca, 780 and 880 megacycles per second are used for transmission with horizontal polarization. Each transmitter is rated at 500 watts output. The paraboloidal reflector at each terminal is 20 meters (66 feet) in diameter.

In each direction, 6 channels are provided in the 12-to-36-kilocycle-per-second base band. The bandwidth of the receivers is 200 kilocycles per second and they produce a noise factor of 9 decibels.

In addition, the telephone multiplex system has been provided with devices for compressing and expanding the dynamic characteristic to allow an improvement of about 20 decibels in the signal-to-noise ratio.

2. Diversity System

The diversity system employs linear addition of two received signals. The useful signal is formed from the sum of the voltages of the two component signals. Noise powers also are summed.

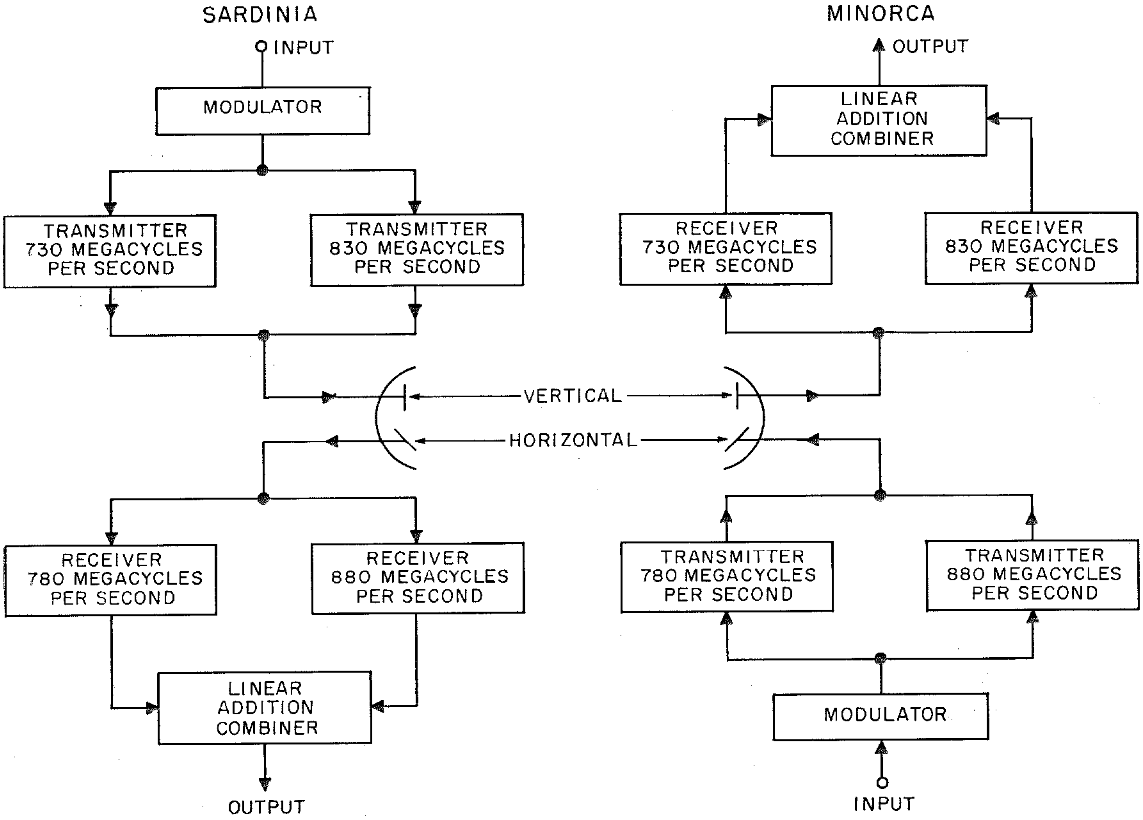


Figure 4—Circuit arrangement of the link.

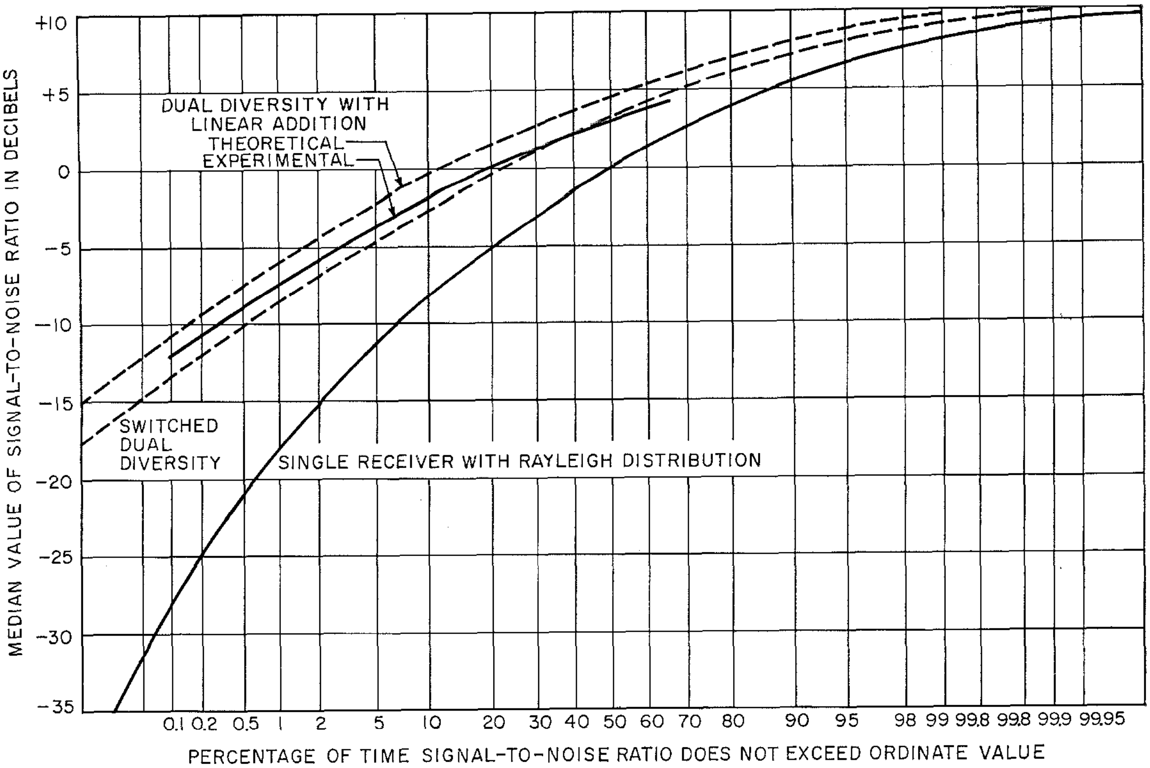


Figure 5—Theoretical and practical improvement of double-frequency-diversity systems. Signal-to-noise ratio distribution with respect to the median value as a function of the percentage of time.

The two receivers are kept at equal gain by a common sensitivity control.

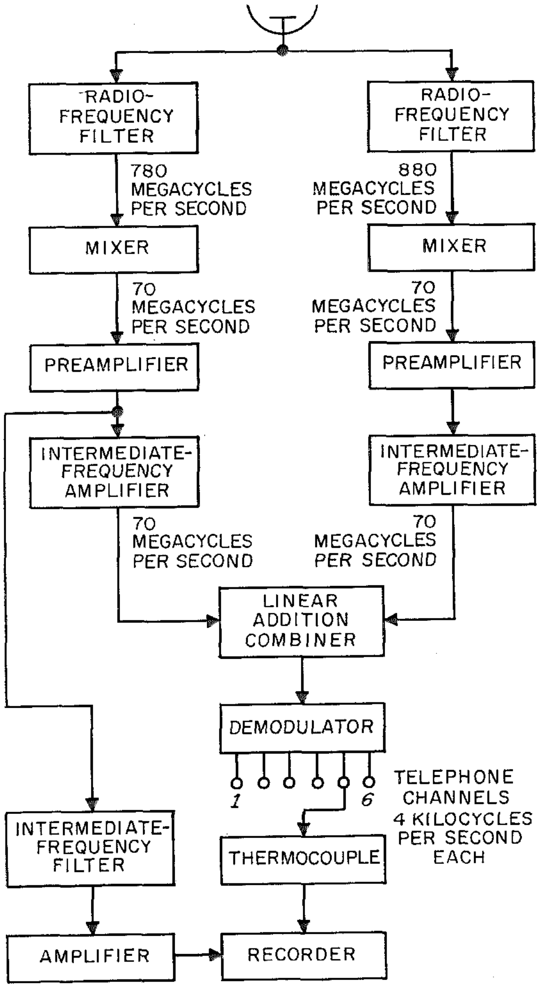
Compared with switched diversity, the signal-to-noise ratio is improved by 3 decibels when the signals are equal, while a drop occurs when one of the signals falls to the threshold level.

From the standpoint of probability, it has been found that, regardless of the time percentage, the signal-to-noise ratio always improves by 0.9 decibel as compared with switching. This is the case when there is no correlation between the signals and they vary in time in accordance with Rayleigh's law.

The linear-addition system is therefore more efficient than the switching system and at the same time it eliminates the problems associated with switching. Moreover, it has been preferred because of its greater simplicity and dependability over the ratio squarer, which in theory should produce an ultimate improvement of 0.6 decibel in the signal-to-noise ratio but is much more complicated and critical in its operation.

The theoretical behavior of the various diversity systems is shown in Figure 5 for the case of double diversity and for signal distribution according to Rayleigh's law. The experimental results are also shown. This curve has been plotted for very low levels of received signals, which after all is the range of greatest interest for it predominates in scatter propagation. The similarity between the theoretical and experimental curves is very striking and this proves indirectly that for short time intervals the received field with scatter propagation actually obeys Rayleigh's law, as we shall demonstrate below on the basis of direct measurements.

Figure 6—Received-signal-measuring equipment at the Sardinia terminal.



3. System of Measurement

Measurements were taken with the link in service and with sufficient care to avoid loss of service. Some tests were made out of service to determine the characteristics of the link.

Figure 6 shows the measurement system. Measurements were limited to the Minorca-Sardinia direction. No special apparatus was provided at the Minorca terminal.

Measurements were taken of the intermediate-frequency carrier level, the noise on the telephone channel, and the diversity efficiency.

To measure the carrier level, the signal was taken from the output of the intermediate-frequency preamplifier before being subjected to the action of the automatic sensitivity control in the main intermediate-frequency amplifier. The 70-megacycle-per-second signal, filtered and linearly amplified, controlled a recorder calibrated to give directly the signal power at the receiver input in decibels below 1 milliwatt.

Furthermore, since the Minorca transmitter was not kept at a constant power during the entire test but was generally lowered from the rated value when favorable propagation permitted, the data of the curves were corrected to refer at all times to a value of 300 watts of transmitted power.

Noise was measured on telephone channel 5, having a frequency band from 28 to 32 kilocycles per second, by means of a thermocouple with a one-minute time constant. The current from the thermocouple also controlled a second pen on the recorder.

For this measurement, the expandor was disabled at the output of the channel to eliminate the action of noise reduction in the absence of the audio signal but on the curve allowance was made for the 20-decibel improvement provided by the compandor and for the noise reduction produced by the psophometric effect.

The efficiency of the diversity system was checked by means of noise measurements taken with short time constants lasting from 1 to 2 minutes, with fields averaging slightly more than the threshold value, and by successively excluding and inserting one of the radio signals. In this way, two curves were obtained that, when analyzed, made it possible to calculate the noise distribution in the presence and absence of double diversity by the same values of the average received field.

4. Received Field for Short Time Intervals

The propagation data can be analyzed by calculating the annual and monthly distribution from the median hourly levels of received signals and by knowing the law of distribution of the instantaneous levels for periods of one hour. This law of distribution was checked during the earlier tests at 240 megacycles per second and since the received field at that frequency turned out to be very similar to that found at 800 megacycles per second, that law of distribution was held to be valid for the latter frequency, too.

The measurements were taken at high speed by an electronic analyzer that scanned the signal 128 times a second. Separated into 9 measurement levels, each measurement was recorded in a binary counter acting as a totalizator for that level. Analyses were thus made for time intervals between 1 minute and 2 hours.

Figures 7–9 are for measurements taken at time intervals of 6, 18, 30, 60, and 120 minutes to show how the instantaneous values vary with the length of the time intervals.

Each figure is for a different type of propagation, characterized by slow, rapid, and very-rapid fading. The values in each time interval include the data from the preceding time interval. As a reference, points representing the Rayleigh field distribution are given.

These figures show very clearly that for very-rapid fading the distribution behaves almost exactly according to Rayleigh's law and is independent of time within the order of 1 to 2 hours. For slow and rapid fading, the distribution approaches Rayleigh's law more closely for somewhat-longer time intervals than for very-short periods. A study of Figures 10 and 11 will confirm this.

Figure 10 shows the area in which the distribution curves are concentrated during one hour, referred to the median value, for slow, rapid, and very-rapid fading.

Figure 11 is similar but for an interval of only 1 minute.

It is evident from these distribution curves that the received fields for time intervals of one hour conform to Rayleigh's law to quite an extent, whatever the type of propagation. On the other hand, for the very-short time intervals of 1 minute, although the distribution curves on the

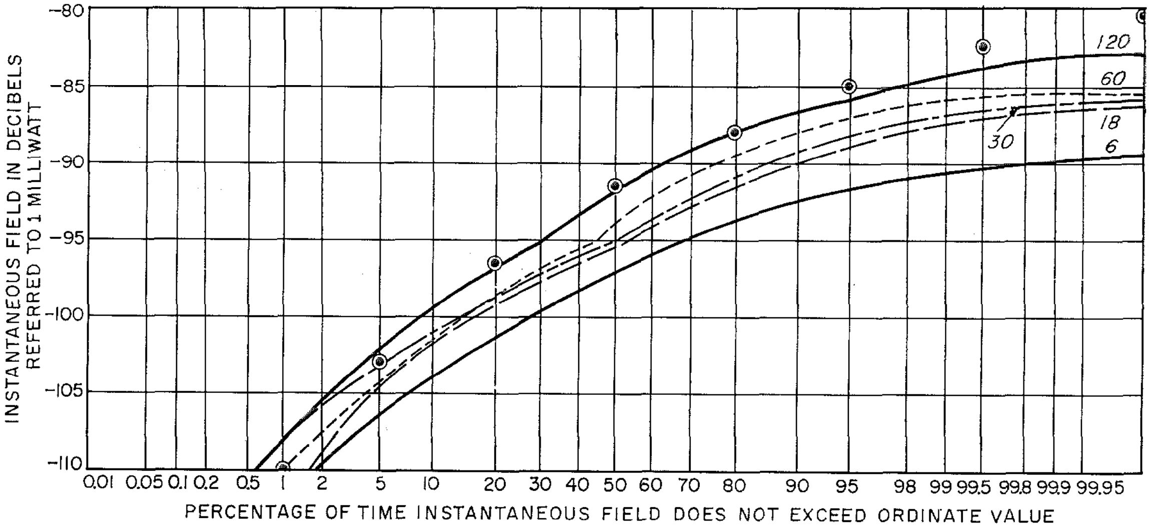


Figure 7—Instantaneous fields for 6, 18, 30, 60, and 120 minutes with slow fading. Rayleigh distribution is shown by the circled points.

average tend to follow Rayleigh's law, they can, taken separately, diverge; this is particularly noticeable in the case of slow and rapid fading.

From the above, it can be deduced that the propagation characteristics of a forward-scatter link can be predicted from a knowledge of the distribution during the various months of the year and from the median hourly level of the received field, taking into account that the distribution of the various instantaneous levels with respect to the median level in a 1-hour period closely approximates Rayleigh's law.

5. Received Field and Signal-to-Noise Ratio

The carrier levels measured at the intermediate frequency were analyzed by calculating for every hour the median hourly level and for each month

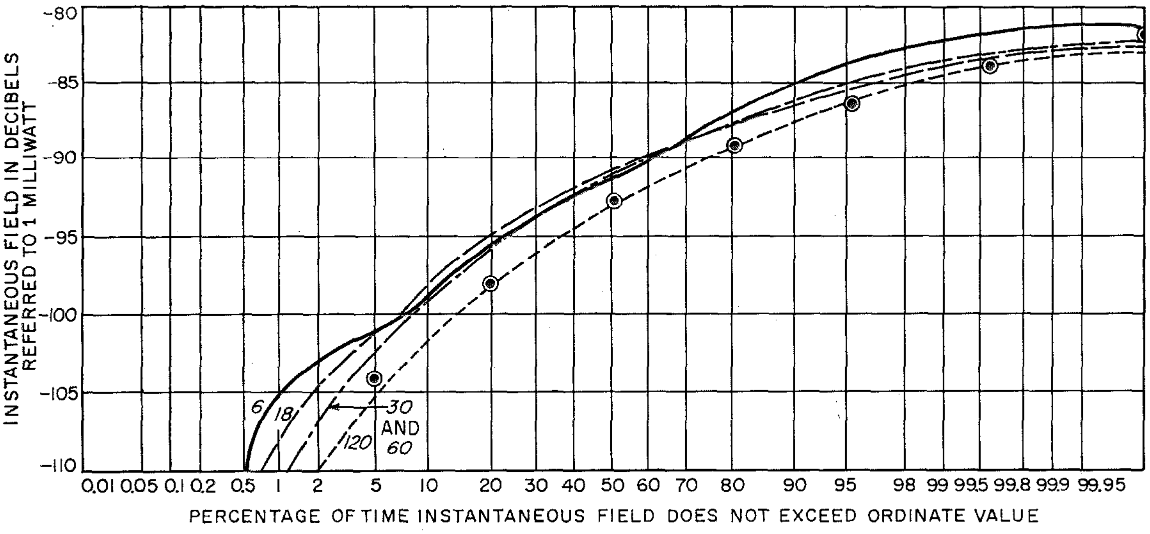
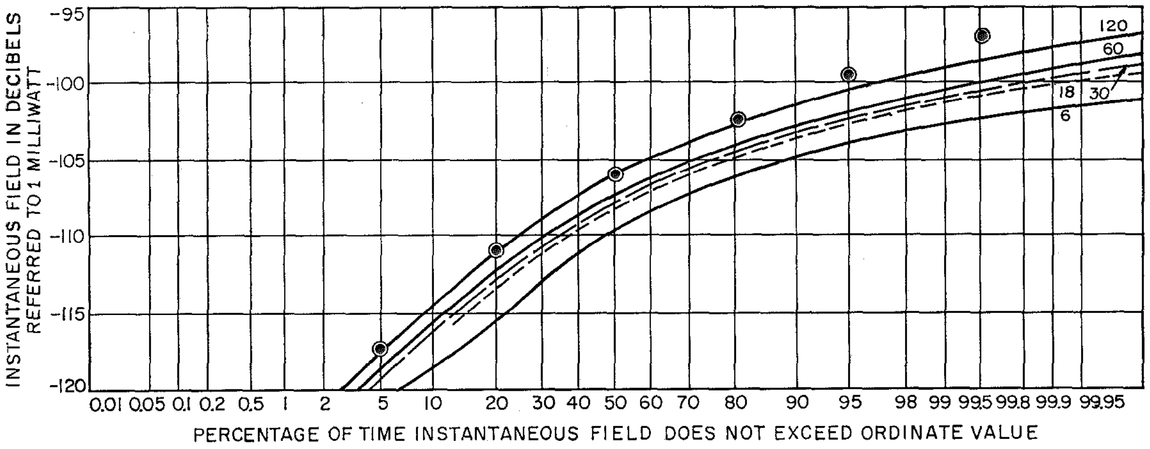
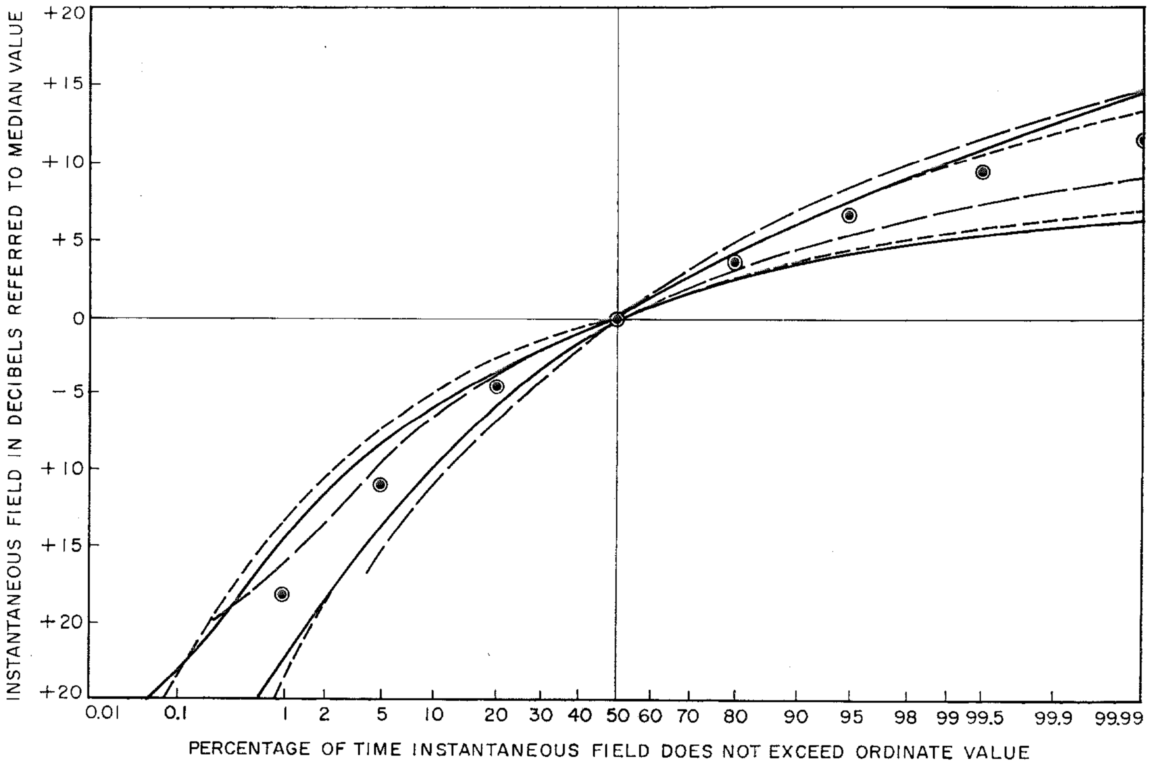


Figure 8—Same as Figure 7 for rapid fading.

Figure 9—Same as Figure 7 for very-rapid fading.




INSTANTANEOUS FIELD IN DECIBELS REFERRED TO MEDIAN VALUE
+20
+15
+10
+5
0
−5
+10
+15
+20
+20
0.01
0.1
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.9
99.99
PERCENTAGE OF TIME INSTANTANEOUS FIELD DOES NOT EXCEED ORDINATE VALUE

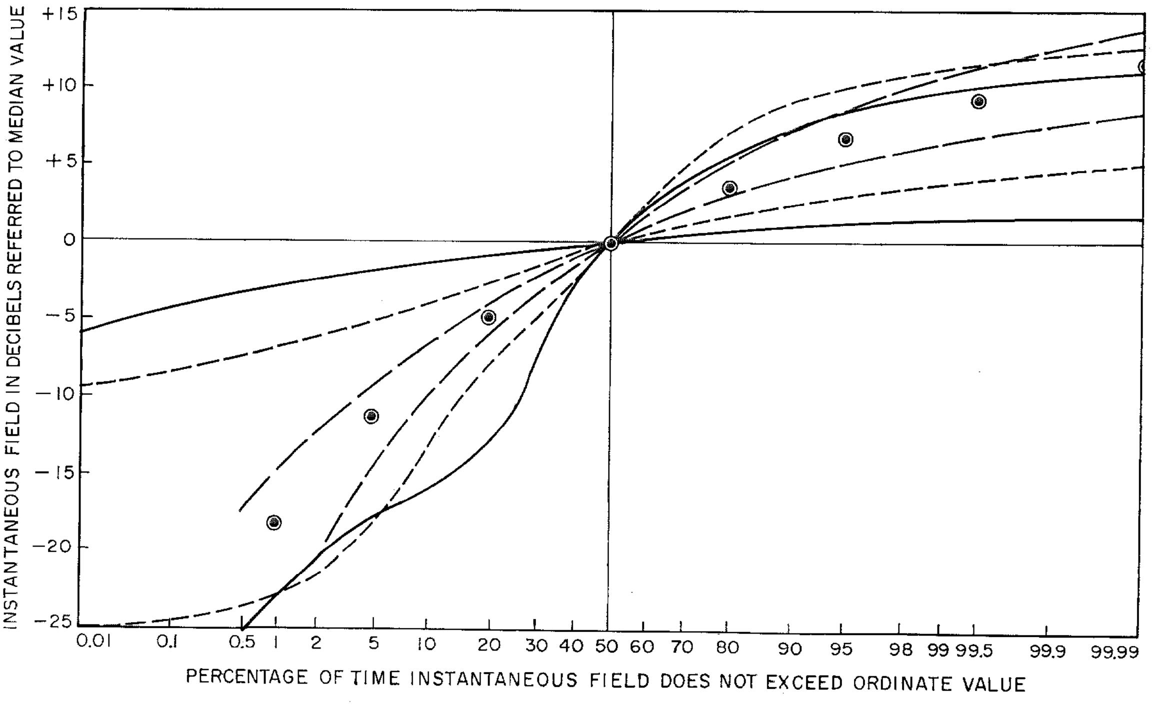

INSTANTANEOUS FIELD IN DECIBELS REFERRED TO MEDIAN VALUE
+15
+10
+5
0
−5
−10
−15
−20
−25
0.01
0.1
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.9
99.99
PERCENTAGE OF TIME INSTANTANEOUS FIELD DOES NOT EXCEED ORDINATE VALUE

Figure 10—Distribution area of the instantaneous fields for 1 hour. The solid lines are for slow fading, the long broken lines for rapid fading, and the short broken ← lines are very-rapid fading.

Figure 11—Same as for Figure 10 but for only ← 1-minute time intervals.

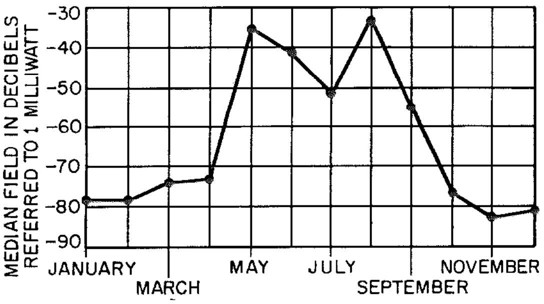


Figure 12—Median field on a monthly basis.

the distribution of the median hourly levels as a function of the percentage of time.

The median hourly level that was exceeded 50 percent of the time was taken as the median monthly level and has been plotted in Figure 12 as the median field received during the various months of the year.

It clearly appears that the median field is at a minimum during the winter and at a maximum during the summer, with rather sharp variations in the spring and in the autumn.

Figure 13 shows how the median hourly field varies during the entire year and for the worst month of the year. The worst month is that for which the minimum levels were found to exist during the major portion of the time.

For the test year, March turned out to be the worst month, with very-rapid or rapid fading

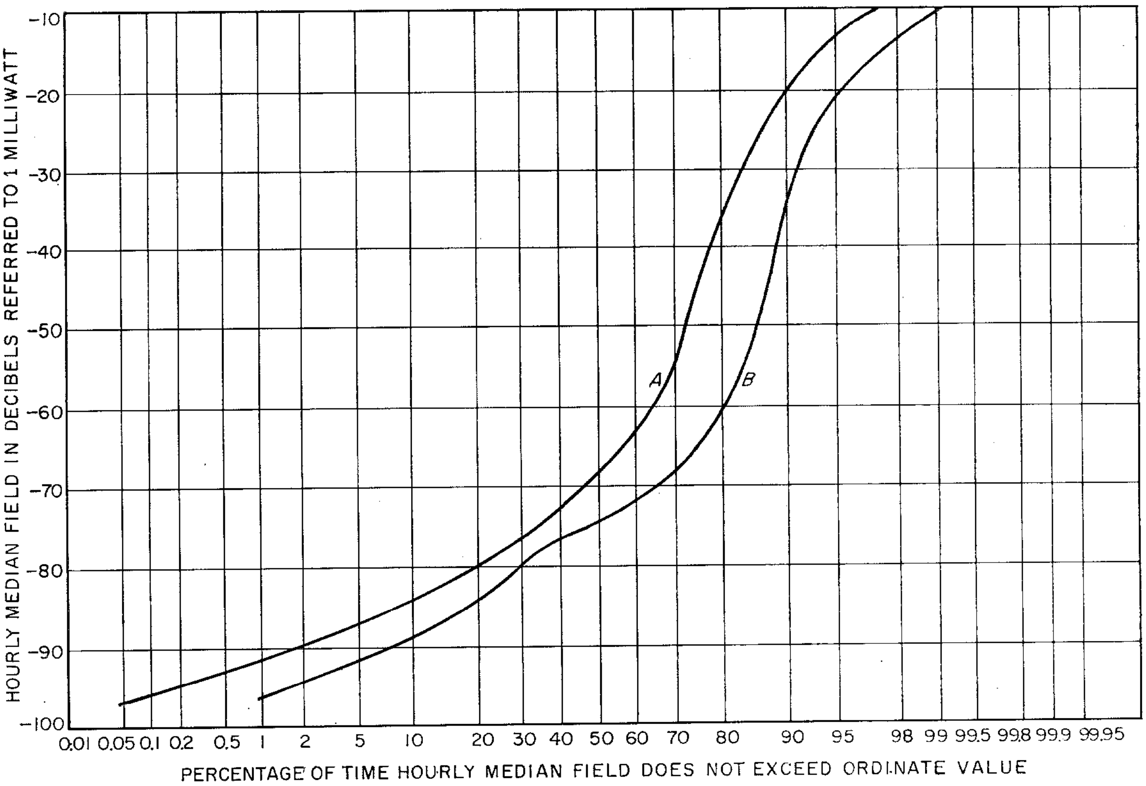


Figure 13—Hourly median field as a function of percentage of time. *A* is for 1 year; *B* for worst month.

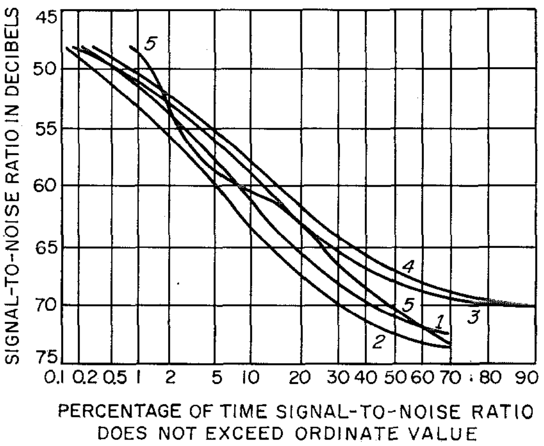


Figure 14—Signal-to-noise ratio on voice channel 5 during the worst months: 1—November, 2—December, 3—January, 4—February, and 5—March.

much of the time. The distribution curve, on the other hand, behaved quite regularly, proving that during the month propagation conditions could be regarded as uniform in character.

During the months when the median field was rather high, the distribution curve showed a much-less-regular behavior due to the fact that the scatter-type propagation periods were offset by periods of various types of propagation.

Finally, Figure 14 shows the noise distribution in telephone channel 5 during those months when the received field was at rather low levels. In these curves, account has been taken of the improvements due to the psophometric factor and to the compandor. A signal-to-noise ratio of better than 50 decibels was obtained 98.6 percent of the time during March, the worst month of the year, while that percentage reached 99.1 for February, the next poorest month.

6. Service Data

Telephone service was established by extending the system from Marrubiu to Rome and from Biniancolla to Madrid with cable circuits and line-of-sight radio links. At the start, it operated only during daytime hours but continuous 24-hour-a-day service is now provided.

Of particular interest is circuit quality in relation to noise and service interruptions due to fading.

Noise data may be derived from Figure 14. In March and February, a signal-to-noise ratio of better than 50 decibels was obtained 98.6 and 99.1 percent of the time, respectively.

Service interruptions due to fading depend for the most part on the percentage of time in which both signals of the frequency-diversity pair drop to the threshold level. To calculate them, it would be necessary here to combine the curve of the median hourly distribution during the worst month with the hourly distribution curve found to agree tolerably well with Rayleigh's law and with the curve of the improvement due to frequency diversity. In this way, it would be possible to obtain the total time in which both signals drop to the threshold level, which is about −98 decibels referred to 1 milliwatt in the link under study. As a matter of fact, no interruption has ever been actually reported during the 3 years of service. The actual interruption time is distributed over a given number of very-short time intervals that take the form of a rapid burst of noise; since these bursts rarely exceed 1 or 2 per call, it is hardly likely that they disturb the user.

7. Reference

1. J. M. Clara and A. Antinori, "Investigation of Very-High-Frequency Nonoptical Propagation Between Sardinia and Minorca," *Electrical Communication,* volume 33, number 2, pages 133–142; June 1956: also Institute of Radio Engineers, Transactions on Microwave Theory and Techniques, volume MTT-3, pages 7–12; December 1955.

8. Acknowledgement

After the initial tests had demonstrated that adequate performance could be achieved, the

system design was completed and the equipment was manufactured and installed. The Italian and Spanish governments cooperated fully in making facilities available.

System engineering and radio equipment were provided by Federal Telecommunication Laboratories (United States). The telephone multiplex equipment, which provides 5 voice channels and 3 telegraph channels simultaneously, was constructed by Fabbrica Apparecchiature per Comunicazioni Elettriche Standard (Italy). The antennas, engine-generators, and many other items required for an installation of this type were provided by Fabbrica Apparecchiature per Comunicazioni Elettriche Standard in Italy and Standard Electrica in Spain.

Fundamental Principles of Transistors

The second edition of the book, "Fundamental Principles of Transistors," by Dr. J. Evans of Standard Telecommunication Laboratories is now available. It is divided into 12 chapters, 3 appendixes, and bibliography, and covers the following topics.

Chapters

1—Introduction
2—Basic Theory of Semiconductors
3—Measurement of Semiconductor Parameters
4—The P-N Junction: Theory
5—The P-N Junction: Methods of Preparation
6—Junction Transistors (Mostly Alloy)
7—Diffused-Base Transistors
8—Measurement of Transistor Parameters
9—The Manufacture of Transistors
10—Special Types of Transistor
11—Silicon and Other Transistor Materials
12—Associated Semiconductor Devices

Appendixes

1—The Point-Contact Transistor
2—Parameters of some Commercial Transistors
3—Identification of Mixed Impurities

The book is 5¾ by 8¾ inches (15 by 22 centimetres) and contains 332 pages and 174 figures. It is available from Heywood and Company of Carlton House, Great Queen Street, London, W.C.2, at 50 shillings, or from D. Van Nostrand Company, 120 Alexander Street, Princeton, New Jersey, at $8.50 per copy.

Telecommunication Network of Edisonvolta Group in Italy

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Edisonvolta, belonging to the Edison Financial Group of Milan, is one of the largest Italian companies producing electric power. The network of power stations, high-voltage lines, and substations of Edisonvolta and of its associated companies is in northern Italy in Lombardy and Liguria and in parts of Piedmont, Emilia, and Veneto. There are about 100 power stations and important substations in the system, which are from a few to some hundreds of kilometers distant from Milan, the control center. The entire network operates as a single system under the management of the head office of the company in Milan.

A complex communication system is required to keep the control center informed of conditions throughout the network and to transmit controlling instructions to the remote equipments.

The development of a centralized supervisory system for the network was essential if operation was to meet both the technical and economic needs of industry. Since 1950, when the network was entirely rebuilt and enlarged, various means have been provided to improve the

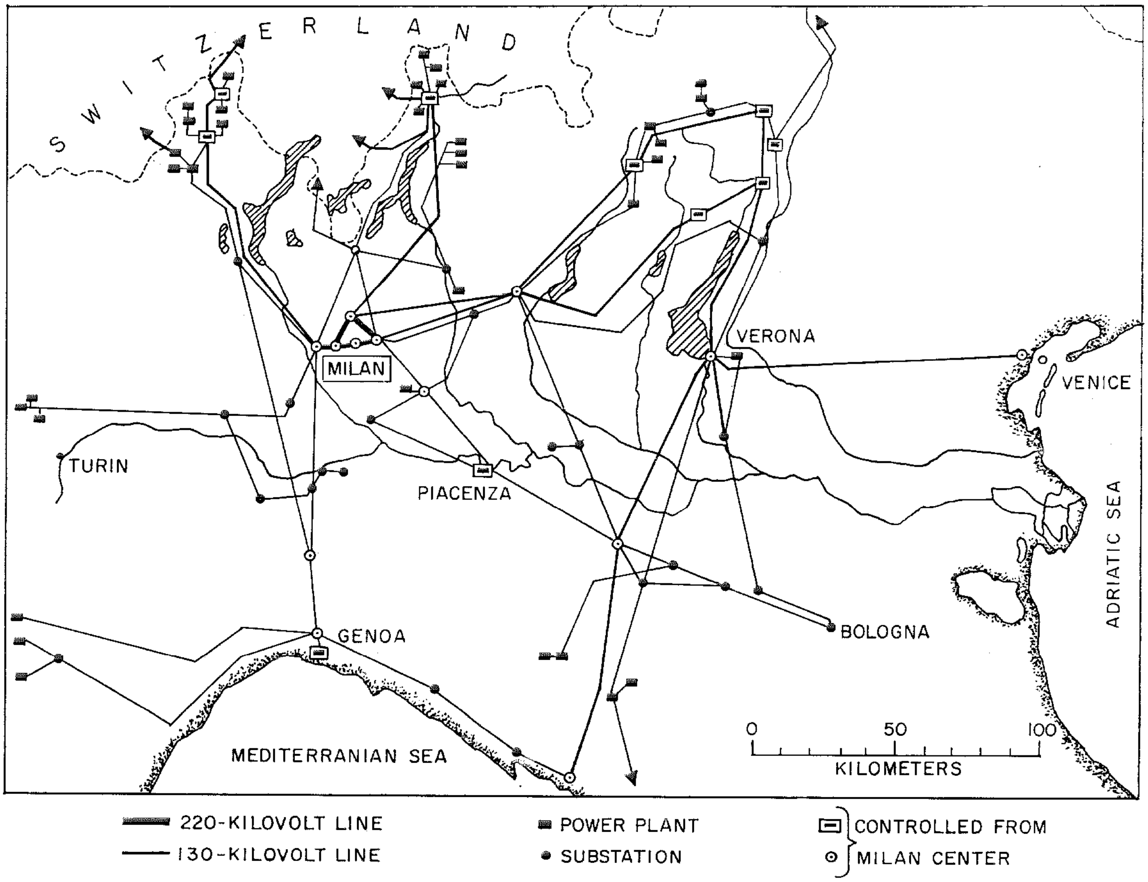


Figure 1—High-voltage power network.

quality of service and to increase the production of useful energy. A very powerful means to improve both continuity and reliability of service is the suitable combining of technical and operational resources. The latter include telephone communication among personnel as well as means for the remote monitoring and control of equipment in the field [1].

1. Power Network

A diagram of the main power network is shown in Figure 1. It will be noted that a number of power stations and substations are directly controlled by the supervisory center at Milan.

2. Telephone System

2.1 Network

The telephone network, shown in Figure 2, connects the power stations, substations, and supervisory centers of the associated companies of the Edison group. The general arrangement enables any given unit to be reached by at least two channels. The central exchange of Milan and the surrounding exchanges are connected by direct channels without intermediate switching.

The network connects a total of 24 automatic exchanges, to which another 30 will soon be added, by means of 72 lines having a total length

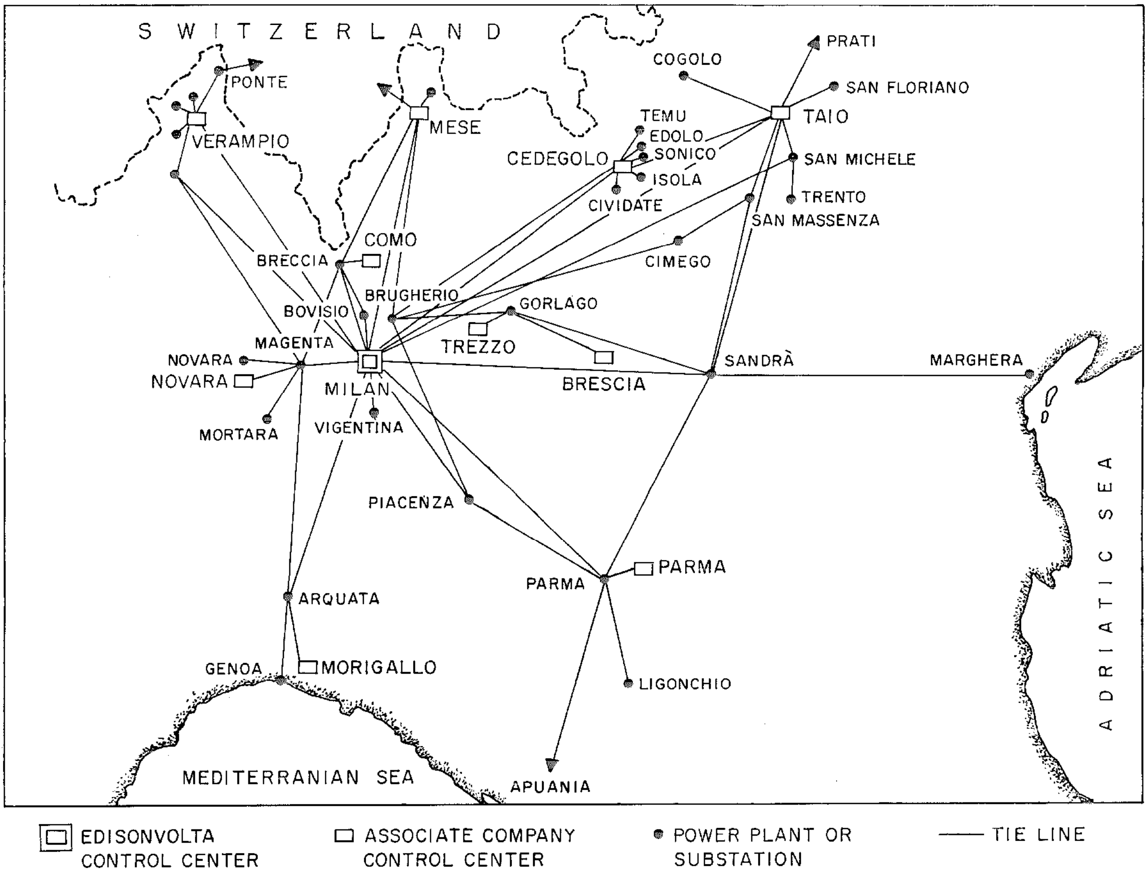


Figure 2—Telephone network.

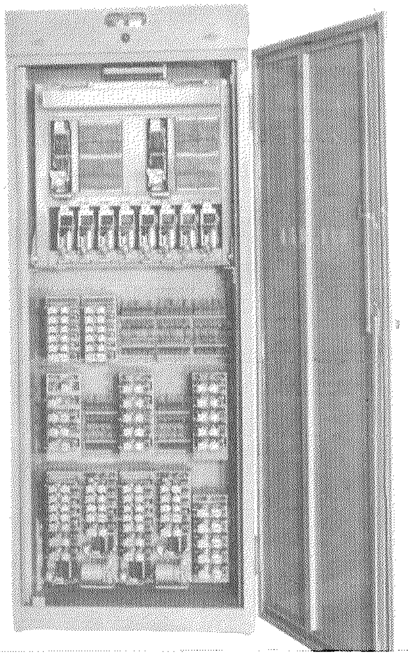


Figure 3—Automatic telephone exchange type 53.

of 4765 kilometers (2961 miles). The circuits are provided by carrier current over high-voltage lines and by carrier current and voice-frequency channels on overhead telephone lines or cables.

Carrier systems have been chosen because of their reliability and comparatively low cost to an electric company that already has its own transmission lines in service. Transmission is reliable with a power of a few watts: Attenuation reaches 20 to 25 decibels. The quality of speech is good despite disturbances on the line due to atmospherics.

Careful maintenance of the equipment ensures that any interruption in communication is probably due to trouble on the lines.

2.2 SWITCHING

Each telephone exchange includes not only automatic equipment for network operation but also a manual set in the watch room of the electric plant for use by an attendant.

The tie lines between the automatic exchanges pass via the operator's set, which permits him to supervise the lines, to listen-in on a call and, if necessary, to disconnect a line. The attendant is therefore able to control the network.

All other subscribers are connected to the automatic exchange. By dialing a 3-digit number on a normal telephone set, they can call or receive calls from each other and from the control center. They cannot interrupt a call in progress.

The organization of the Milan zone is special. Some of the subscribers are directly connected to the automatic exchange of the Milan center and can, of course, communicate with all the subscribers of the network.

The other subscribers are divided into two classes. The first-class subscribers are connected to the main automatic exchange of Milan and have access to the telecommunication network by dialing a prefix. The second-class subscribers obtain service through an intermediate switchboard, which also routes incoming calls to both classes.

After careful investigation of other telecommunication installations used by power systems, the Edisonvolta group selected the system that has been in use for several years by Electricité de France [2].

This system is of the indirect selection type, in which the pulses from the subscriber's dial are received in a register-transmitter that retransmits them to the switching units. These pulses are generated in the register so that, unlike the step-by-step systems, pulse distortion is not cumulative over a number of retransmissions.

Two important advantages are obtained.

(A) Uniform Numbering. Subscribers located in the area covered by the telecommunication network can reach each other by dialing a 3-digit number; numbering is thus greatly simplified.

The network has a capacity of 700 subscribers, 3 of the hundreds digits, 1, 9, and 0, being reserved for special uses. If this capacity is insufficient, two or more networks are combined; the connection from one network to another is made by dialing a prefix. This is the arrangement adopted in the telephone network of Electricité de France.

(B) Automatic Rerouting. A call is switched over one or more alternative routes if the direct route between 2 exchanges is unavailable. This facility increases the efficiency of the lines and makes the meshed layout of the network of maximum usefulness.

It is, of course, advisable not to provide more than 2 or 3 alternative routes. In addition, arrangements are made to prevent the return of a call to a point of departure as a result of rerouting.

2.3 AUTOMATIC EXCHANGE

The Type-53 automatic exchange shown in Figure 3 was designed by Compagnie Générale de Constructions Téléphoniques and meets the specifications of the electricity authorities. It can be connected, of course, with conventional automatic telephone sets and with 2-wire or 4-wire tie lines. Their signaling systems may use direct, 50-cycle-per-second, voice-frequency, or carrier currents. A translator is included in each register, providing maximum flexibility.

With 3-digit numbering, 1 or 2 of the tens figures are allotted to each exchange as needed for its local subscribers. The first 2 digits of a call indicate the direction to be taken from a given exchange.

Regardless of the signaling system on the trunk lines connecting the different exchanges, a uniform operating code shown in Table 1 has been adopted.

TABLE 1
SIGNALING CODE

Impulse	Time in Milliseconds
Seizure	100
Dial	100
Selection	62 mark and 38 space*
Release	500

* Italian Electrotechnical Committee specification.

This code ensures the continuity of the connection between subscribers despite possible disturbances. Release of a call is effected with an impulse of at least 300 milliseconds. Additionally, a timed delay ensures automatic disconnection of a tie line if a brief disturbance simulates a seizure impulse or if the normal release by a subscriber is overly delayed.

2.3.1 *Principle of Operation*

2.3.1.1 *Local Subscriber Connections*

When the calling subscriber lifts the handset, a call relay initiates the hunting of all free registers that have 1 or 2 free junctors at their disposal. The finders of these registers scan the group of lines and the first to find the calling line connects itself to it. The cutoff relay of the calling subscriber is then activated to disengage the other finders. The register then sends dial tone to the caller.

Each of the 3 dialed pulse trains, corresponding to the 3-digit number of the called subscriber, is received on a rotating decimal switch in the register. The first 2 digits control the level on which the translator associated with the register stops. This is the tens level, and the 3rd digit moves the wiper to the called subscriber among the 10 contacts at that level.

If the called subscriber is free, the register is immediately released. The junctor sends ringing current to the called subscriber and ringing tone to the calling party. When the called subscriber lifts the handset, the ringing signals stop as the connection is complete. The power relays of the 2 subscribers being located in the junctor, only the latter remains seized.

If the called subscriber is busy, the register and the junctor are released; the call-and-cutoff relay of the calling subscriber shifts to a lock-out condition and sends busy tone to the caller.

The release of an established call is initiated by the first subscriber to return the handset to the cradle. Busy tone is then sent to the other subscriber by his call-and-cutoff relay.

2.3.1.2 Local Subscriber and Tie-Line Connections

The operation to connect a local subscriber to a tie line starts in a way similar to that described above, but the 3-digit dialed number is assigned to a subscriber at a remote exchange that can then be reached only through a tie line.

The first 2 digits orient the translator to a position that characterizes the tie line through which the called subscriber would normally be reached.

At this state, the wiper associated with the seized junctor is moved by the control wires to the contact in its bank that is assigned to the direction of the line to be seized. The connector seizes a transmitter-receiver equipment through the corresponding tie-line unit of the exchange and awaits the answer-back signal that confirms connection to the distant automatic exchange.

The register then sends the first 2 digits, which were stored in its translator, to the remote exchange. The 3rd digit follows from the register to select the specific subscriber. The register is then released, and the junctor connects the calling subscriber to the tie line by a 2-wire circuit.

2.3.1.3 Tie Line and Local Subscriber Connections

When a receiving equipment is seized by a distant transmitter, it also seizes the corresponding tie-line unit of the local automatic exchange. The beginning of the operation is identical to that for lifting the handset of a local subscriber.

When the finder reaches the level of the calling tie line, it controls the transmission of dial tone that enables the distant register to route the call.

After the 3 digits are received, the local register performs the same operations as in the case of a local subscriber being called by another local subscriber.

2.3.1.4 Transit Connections

For a transit connection in which 2 tie lines are connected together, the first 2 digits of the call indicate that it is not for a local subscriber, but corresponds to a tens digit that can be reached only over a tie line. The rest of the operation is obvious; however, the connection is established on a 4-wire circuit.

2.3.2 Rerouting a Connection

Rerouting a connection around an unavailable tie line is an important feature of the network. Referring to Figure 4, the following sequence of operation occurs when a subscriber of Milan calls a subscriber of Mese.

Milan

The line finder *LF* at Milan finds the calling subscriber.

Seizure of the register and transmission of dial tone.

Dialing by the subscriber and storing of the 3 digits in the register.

Selection by *FC* of the direct Mese line in response to the first 2 digits.

If the direct line is free, the 3 digits are retransmitted to the automatic exchange of Mese.

If the direct line is busy, the connector stops on the line to Breccia.

Breccia

Seizure of the line from Milan by the finder *LF* of Breccia.

Seizure of the register and storage of the 3 digits relating to Mese as retransmitted from Milan.

Selection by *FC* of Breccia of the outgoing line to Mese.

Mese

Seizure of the line from Breccia by the finder *LF* of Mese.

Seizure of the register and storage of the 3 digits retransmitted from Breccia.

Selection by *FC* of the line of the called subscriber.

If the line from Milan to Breccia had been busy, the connection would have been routed through Brugherio by the same process as described for reaching Mese via Breccia.

If the 3rd direction had been busy, the calling subscriber would have received the busy tone.

2.3.3 *Standardized Equipments*

Three types of automatic exchange equipments are standardized and installed according to the required capacity of each electric plant. They are types *B*, *C*, and *D* listed in Table 2. Type *A*, at the Milan center, is actually a combination of two type-*B* equipments.

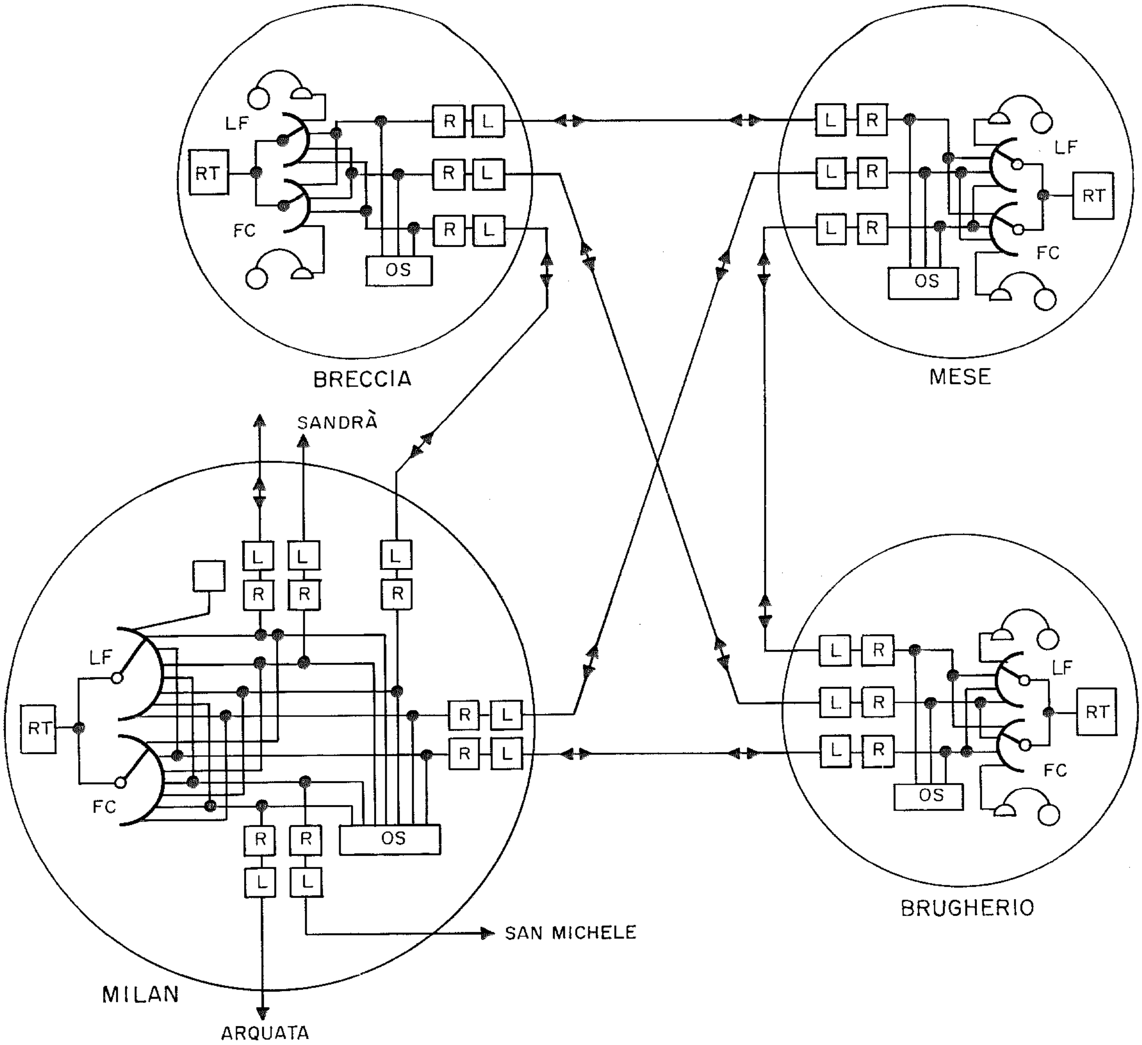


Figure 4—Tie-line selection.

LF—Line Finder
FC—Connector
RT—Register-Transmitter
OS—Operator's Set
R—Repeater
L—Tie-Line Unit

TABLE 2
STANDARDIZED EXCHANGE EQUIPMENTS

	Type A	Type B	Type C	Type D
Subscribers	40	20	10	5
Tie Lines	30	16	8	2
Junctors	12	6	4	2
Registers-Transmitters	6	3	2	1

The different types of equipments are made up of the same functional sets of relays mounted in removable and interchangeable groups.

2.4 Operator's Desk Set

An operator's desk set is provided for each automatic exchange and is designed for use by the attendant in the watch room of the electric plant. It offers the following extra facilities, which are added to an ordinary telephone set.

Supervision of each line when in the busy condition.

Access to an established call and ability to cut off its connection.

Seizure of a line without intervention of the automatic exchange.

Connection of lines from an intermediate switchboard to automatic lines and automatic disconnection at the end of the call.

Connecting several lines for a conference call.

Individual calls through the exchange, with complete release as soon as a call is registered.

Manual operation of lines but only for terminal traffic.

Supervision of maintenance of trunk lines.

A cabinet contains the racks of relays required for each type of line. A rack of any type may be replaced by that of another type without any change in the cabinet wiring.

2.5 Reliability of Connections

The correct operation of the network requires reliable, stable, and quiet switched connections. Not only are the switching principles and quality of the equipment important but the transmission levels and power supply must also receive careful attention.

2.5.1 *Transmission Levels*

Transmission levels at the incoming and outgoing sides of the exchanges and transmission equipments are standardized as shown in Figure 5.

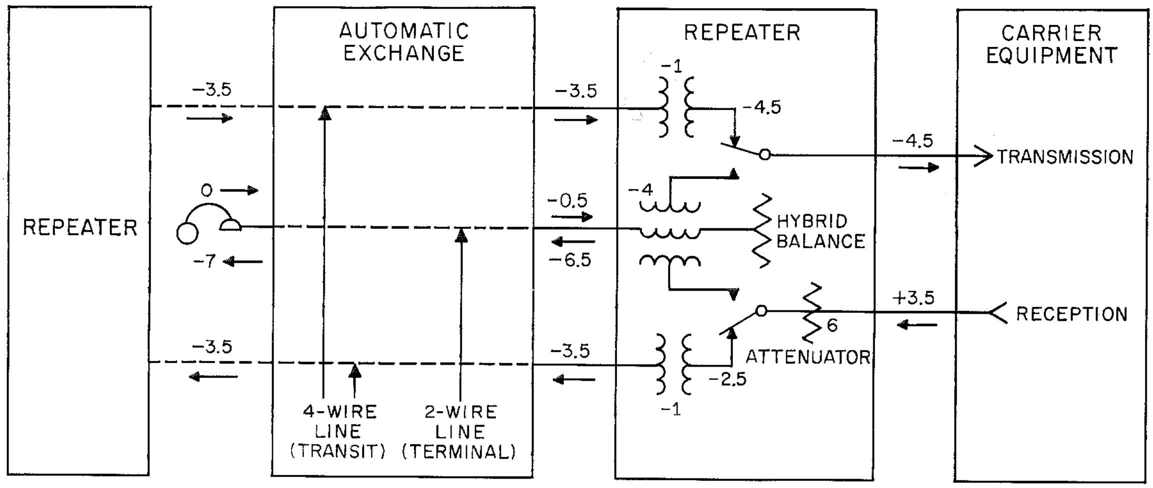


Figure 5—Typical transmission-level diagram. The values are in decibels referred to 1 milliwatt.

If the exchange is far from the transmission equipment or the subscriber, the attenuator is adjusted to compensate for the line attenuation. When the latter is greater than 8 decibels, amplifiers are inserted in the circuit.

Carrier-frequency lines are provided with amplifiers to make up for the line attenuation and automatic volume control holds the level within ±2 decibels.

These arrangements permit most of the telephone lines to operate with an attenuation not greater than 11 decibels.

2.5.2 Power Supply

Power for each automatic exchange and its operator's desk set is derived from a 24-volt storage battery with its charger. The remote control equipment to be described is also supplied from the same power source.

The transmission equipment operates from the alternating-current power network. An automatically started emergency unit ensures power with a minimum interruption period and in some important sites without any break in case of failure of the power network.

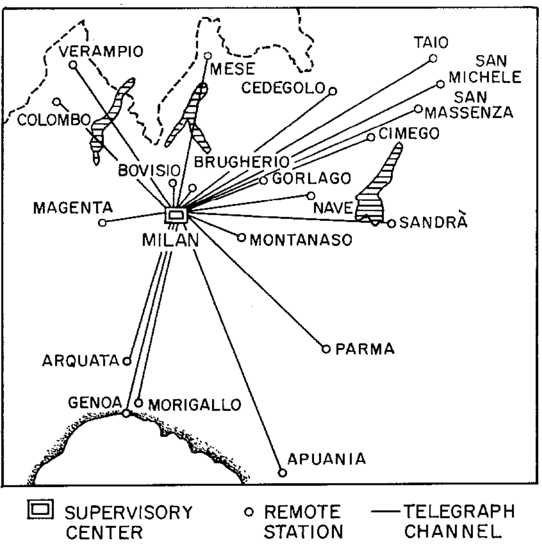


Figure 6—Remote control and telemetering network.

3. Remote Control, Signaling, and Telemetering

3.1 GENERAL

Telephony is only part of the communication system, which also includes remote control, signaling, and telemetering for the electric power network. The remote stations in the power network are shown in Figure 6 and they must transmit the following kind of information during regular operation.

(A) Telemetering

Active and reactive power carried over the main high-voltage lines. Active and reactive power produced at the generating plants. Voltage on the 220- and 130-kilovolt bus bars of the substations.

(B) Remote Control

Remote shift of the active or reactive power being produced.

Disconnection of the telemetering equipment from service.

Instructions to attendants of remotely controlled stations by coded messages (coded orders).

(C) Remote Signaling

Report on changed position, closed or opened, of circuit breakers on high-voltage lines and bus bars.

Reply signals confirming the operation of the above-mentioned controls.

Table 3 shows the distribution of information from the present 23-station network, which it is planned to expand to a 50-station system.

At the supervisory center, the telemetering and position signals appear on a mimic diagram that represents the entire electric power network.

Control switches for telemetering and for coded orders are arranged on a desk conveniently close to the attendant to facilitate his work. The control room at Milan is shown in Figure 7.

TABLE 3

CONTROLLING, SIGNALING, AND TELEMETERING NETWORK

Remote Stations	Tele-metering	Remote Shift and Disconec-tion of Tele-metering	Coded Orders	Circuit-Breaker Signaling
1 Colombo	3	5	5	10
2 Magenta	4	5	5	29
3 Arquata	2	3	5	9
4 Morigallo	2	1	5	6
5 Mese	3	5	10	6
6 Bovisio	6	5	5	20
7 Brugherio	8	8	5	20
8 Gorlago	8	17	5	20
9 Montanaso	2	5	5	11
10 Cedegolo	3	6	10	12
11 Cimego	3	3	5	8
12 Taio	3	6	10	11
13 San Massenza	2	1	5	9
14 Sandra	9	7	10	18
15 Parma	6	7	5	16
16 Apuania	3	1	5	4
17 San Michele	3	3	5	8
18 Nave	1	1	5	5
19 Genova	1	1	5	5
20 Verampio	1	1	10	10
21 Porta Volta	1	1		
22 Piacenza	1	1		
23 Motta	1	1		
Total	76	94	125	237

3.2 TRANSMISSION CIRCUITS

Each station of the network is connected to the control center by a certain number of telegraph channels assigned either to telemetering or to remote control. The remote stations are independent of each other and have their own channels to the control center as well as their telemetering and remote-control equipments.

The telegraph channels adopted are of the frequency-modulation type and meet the regulation requirements of the Comité Consultatif International Télégraphique et Téléphonique. Transmission may be over telephone cables, overhead lines, or by carrier current over power lines [3, 4].

3.3 REMOTE-CONTROL AND SIGNALING SYSTEM

To reduce the required number of telegraph channels, orders and signals are transmitted over only one channel in both directions. The orders and signals must therefore be transmitted in proper sequence.

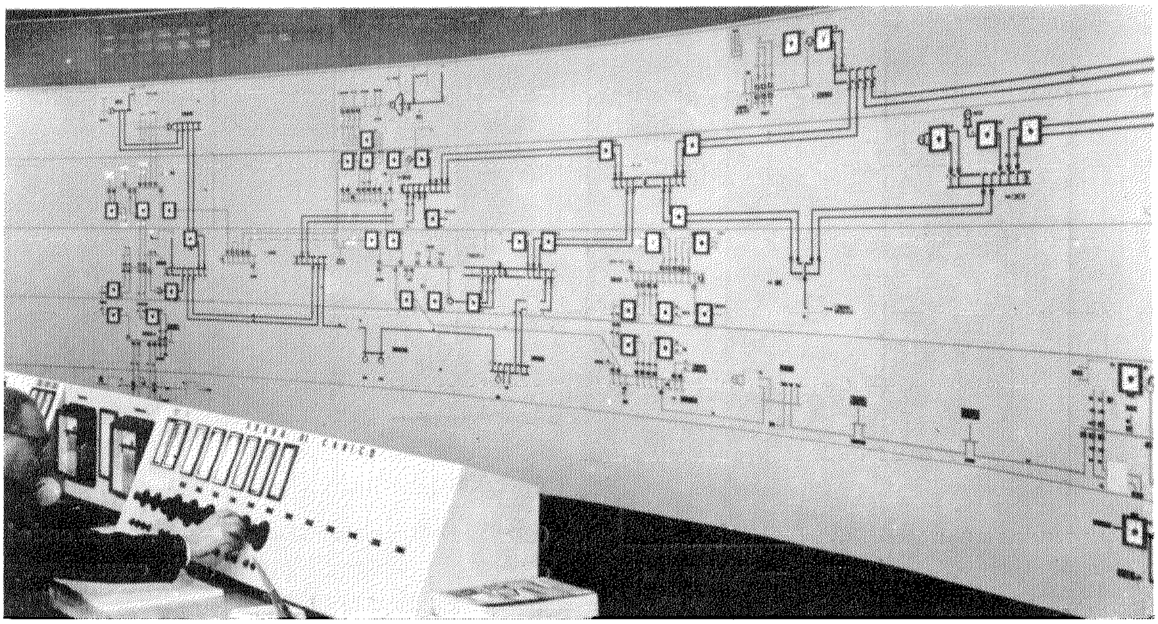


Figure 7—Remote-control room at supervisory center in Milan.

3.3.1 Principle of Selection

The orders and signals listed in Table 3 show that the maximum number of units under remote control or reported on is smaller than a hundred per station. The principle of the system requires confirming reports of each instructed operation, as in all installations by Compagnie Générale de Constructions Téléphoniques [5], and therefore entails transmission of data in both directions. The same equipment must be able to transmit both control and report signals.

The selection of a particular unit out of a hundred units is done in the following way. Each of the two decimal digits of a number identifying an individual unit is converted into a 2-out-of-5 code. This code is made up of digits or bits that can be conventionally called 0 or 1. There must always be 3 of the 0 and 2 of the 1 bits in each code group as in Table 4. Considering both the tens and units bits in each of the 5 positions, there are 4 possible pairs: 0-0, 0-1, 1-0, and 1-1, to which we may assign 1, 2, 3, and 4 pulses, respectively. An example of coding 47 is given in Figure 8.

Each 2-digit number identifying an individual unit to be controlled can be transmitted over a single telegraph channel as a train of 5 groups of pulses, each group being made up of 1, 2, 3, or 4 pulses. It should be noted that the total number of pulses in each set of 5 groups is always 11, which permits an extra check on transmission errors.

TABLE 4
2-Out-of-5 Code

Number	Code Group
1	1–0–0–0–1
2	1–1–0–0–0
3	0–1–1–0–0
4	0–0–1–1–0
5	0–0–0–1–1
6	1–0–0–1–0
7	0–1–0–1–0
8	0–1–0–0–1
9	0–0–1–0–1
0	1–0–1–0–0

3.3.2 Intervals Between Pulse Trains

At the control center and in each remote station, the rate of transmission, length of pulses, and interval between trains of pulses are controlled by a local time base. When transmitted, the interval between two trains had the length of 5 units of the time base. When received, this interval is compared to the rate of the local time base. As the 2 time bases are not synchronized, any phase relation may exist between them.

When the first pulse arrives at the receiver, a counter is started to compare its rate with the locally produced timing intervals. Coordination of these intervals will be effected by the time the 3rd interval between trains has been counted. Thus, there is at least one spare interval for coordination of the time bases, including time for a possible shifting of the phase of the signals.

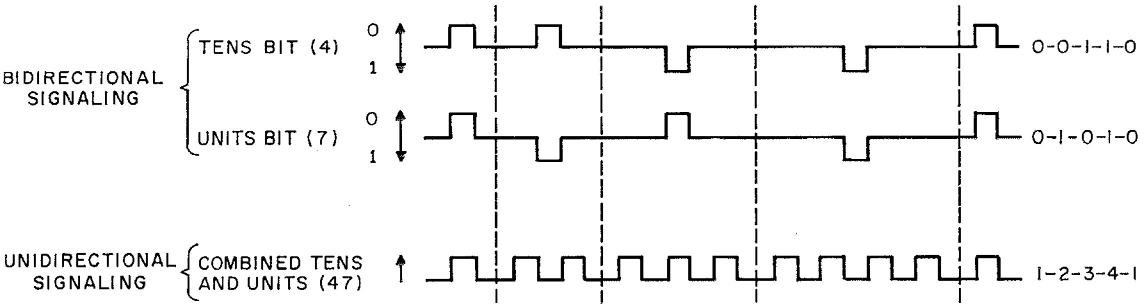


Figure 8—Translation of 2-out-of-5 code into unidirectional pulses. The bidirectional modulation may use two frequencies or other detectable differences.

TABLE 5

CODES EMPLOYED

Number of Pulses	First Code *CC → RS	Second Code RS → CC	Control Code CC → RS	General Check Code CC → RS	Signaling Code RS → CC
1	Individual Check or Signaling	Individual Check	Individual Check	Severed Wires at Control Center	Severed Wires
2	Unblocking	Signaling to Be Transmitted	Not Used	Unit Not Equipped	Not Used
3	Nonprivileged Order	Waiting for Order	Open	Open	Open
4	Privileged Order	Fault at Remote Station	Not Used	Not Used	Not Used
5	General Check	Fault Check	Closed	Closed	Stop

*CC = control center and RS = remote station.

3.3.3 Communication Procedure

The following communications are typical.

(A) Alerting the remote station. This code signal is always transmitted from the control station to the remote station. It identifies whether the operation is to be controlling, signaling, individual check, or general check.

(B) Reply. This code is transmitted by the remote station. It confirms the reception of the preceding operation and indicates that the control center should proceed.

(C) Selection and Comparison. These codes are exchanged sequentially and identify the operating unit to be controlled.

(D) Control. The control code is transmitted either by the control center to make a change at the remote station or by the remote station to signal a new condition to the control center.

Table 5 and Figure 9 show the codes for different cases.

3.4 ADDITIONAL ARRANGEMENTS

Certain other arrangements facilitate the operation of the system and increase its reliability.

(A) Individual Check. As an individual check, the operator at the control center, by depressing the button of a given apparatus, starts the operations of selection and then receives a report on the operating condition of that equipment.

(B) Swift General Check. The operation of a single switch initiates the checking of the operating conditions of all the units of a remote station. They are successively scanned and as each unit is examined its corresponding lamp lights on the control panel. If a unit does not conform to the condition transmitted from the control center, the complete signal train is then transmitted from the remote station.

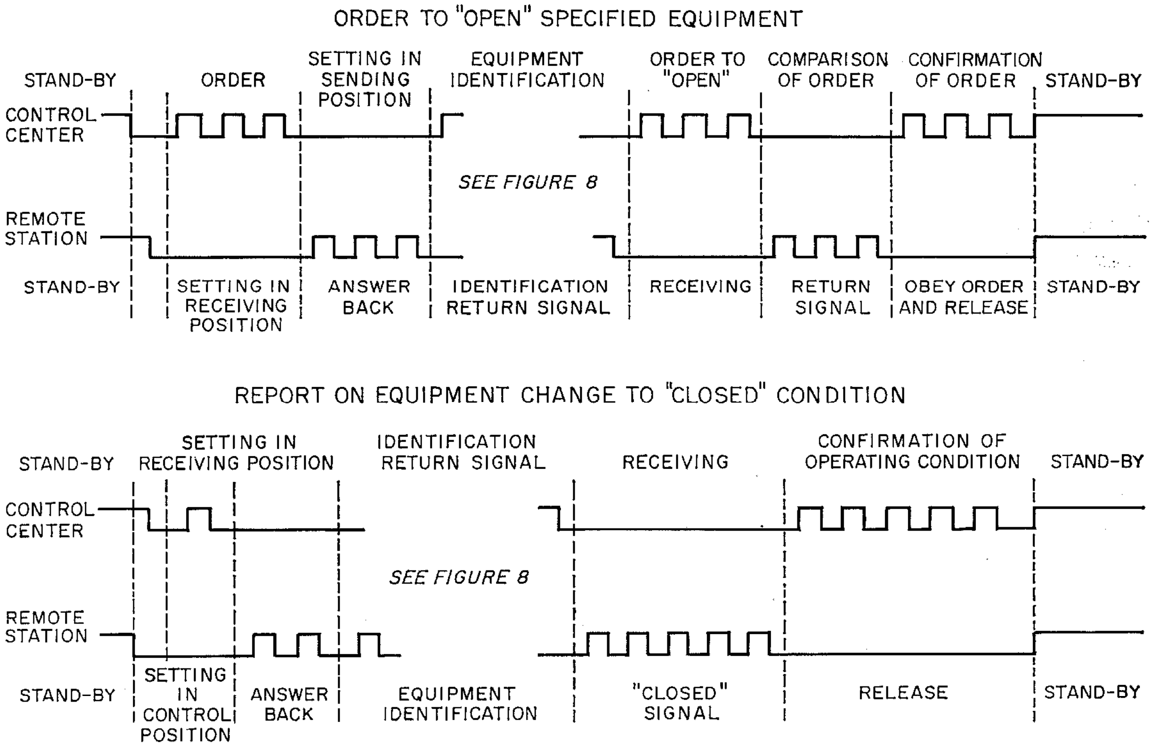
(C) Severed Wires. The changeover contacts that signal the operating condition of each apparatus are connected to the reporting unit by two wires. A failure of the wires, through either open-circuit or short-circuit, could cause an error in the transmitted signal. In such a case, the lamp of the control panel will flicker to indicate that the position of the apparatus has not been determined.

3.5 RELIABILITY

Reliability is ensured by using codes that can be automatically checked as to the proper number of bits in each group transmission and the rate at which pulses are received must be within prescribed limits.

Before a report on the operating condition of an equipment is made, the called station must identify itself and both stations must confirm to each other the identity of the equipment being considered.

Figure 9—Two examples of signaling. At top an order is given to a remote station by the control center and below a remote station reports on a change in one of its elements.



The checking of each operation performed after reception of a coded order provides an extra guarantee of reliability. The release is immediate if the code groups are not properly confirmed. Irregularities such as noncompletion of an order, a wiring failure, or a transmission fault are signaled to the operator of the control center.

3.6 Speed of Operation

The time elapsed between the moment when the operator of the control center gives an order and the time when it is completed is about 3 seconds. A similar time interval is required for a report on a changed condition to go to the control center. A general check of 10 units takes about 6 seconds.

3.7 Components

3.7.1 Relays

The remote control system utilizes only relays in addition to the transmission channels. These relays are designed and manufactured for the Pentaconta telephone system and are characterized by their long service without need for readjustment.

3.7.2 Memory Relays

Continuity and dependability of operation must include provision for the case when the telemetering power supply fails. To avoid the necessity to query all equipment in the system after a power failure, a memory type of relay has been developed. It is derived from the Pentaconta relay, the conventional iron core being replaced by a material having high magnetic retentivity. Operation of the relay occurs normally when current flows in the winding but the relay remains operated when the current no longer flows.

A current of opposite polarity in a second winding is required to cancel the flux and release the armature. Both windings are proportioned so that after the flux has been cancelled and the relay released, it will not operate again even though the supply voltage varies. The relays are mounted in removable racks housed in bays as shown in Figure 10.

3.7.3 *Control Panels*

The large number of pieces of equipment in the installations emphasizes the importance of reducing the size of the elements mounted on the control panels. The control switches are of miniature type and include turn-and-push switches incorporating signal lamps, luminous signals, and luminous strips.

The panel accommodates uniformly sized elements, each of which corresponds to an apparatus in a remote station so that the consistency and continuity of the mimic diagram can be preserved. This is evident from Figure 7.

To facilitate modification of the mimic diagram without interrupting operations, each element is made up of a certain number of plates perforated to receive any type of switch. The sets of plates are suitably arranged, are covered with front plates bearing the mimic-diagram symbols of the units that they represent, and are equipped to indicate the operating conditions of those units.

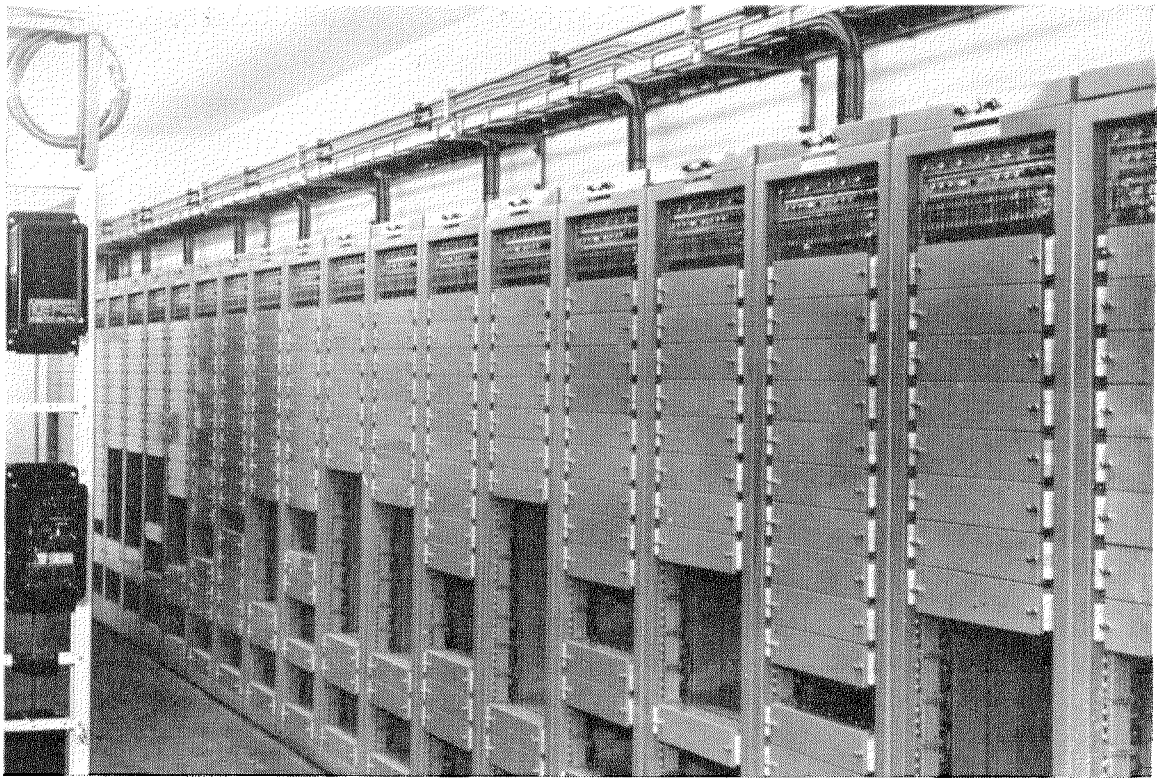


Figure 10—Bays of remote-control equipment in the supervisory center at Milan.

3.7.4 Power Supply

The system is designed to operate on direct current at 24 volts, which may vary by ±20 percent without causing an error.

4. Conclusion

The remote-control system that has been described permits a power network generating about 12 × 10^{12} kilowatt hours of electricity per year and transmitting it over an urban and industrial center of large geographical size to be operated by only a few people.

Centralization of control permits maximum service to the users, as well as increased economy in the generation and transmission of power. Following are some of the features of the system.

(A) Continual information to the operator in the supervisory center in Milan on the actual conditions of the entire installation as represented on a mimic-diagram control switchboard.

(B) Ability of the supervisor to transmit instructions to change operating conditions at the various, and simultaneously if necessary at all, distant power stations and substations.

(C) Rapid exchange by code of all normal service messages and complete availability of telephone connections for special or emergency communication.

(D) Switching and interchange of power to reduce transmission losses and give maximum service.

(E) Supervision of the system from the Milan center by only two operators.

In the present communication installation, there are 24 automatic exchanges under control from Milan. There are 85 telemetering channels. The operating conditions of over 200 circuit breakers are remotely signaled. The system will be extended substantially in the future to the entire network of northern Italy to include approximately 50 to 60 remote stations.

The effectiveness of remote supervision in obtaining continuous and reliable service in the generation and distribution of power is again confirmed. Interest now resides chiefly in the part modern communication apparatus can play in improving the centralized control.

The advisability of centralized control was first suggested by the problem of generating power in several places and distributing it over a large network. The question of the relative costs of generating power in the different stations and of transmitting it to the users has become so very important that the increased operating efficiency of centralized control more than justifies the cost of the extensive supervisory system.

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Principal Uses of Coherent Light

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Light radiation consists of photons coming from atoms returning to their lowest energy state from which they were previously driven by an external energy supply.

In thermal-type sources, atoms are energized by interatomic or intermolecular collisions and then spontaneously lose their energy. The photons emitted are independent of each other and differ in frequency, polarization, and direction of motion. They are distributed at random in time. The radiation thus emitted has the characteristics of wide-band noise. The average amplitude of the radiation is modulated by the fluctuation of the number of photons in a manner analogous to that producing the shot effect in a beam of electrons.

More sharply defined radiation can be obtained from pure elements. In fact, atoms of like nature can be excited only to a number of discrete energy levels and these atoms can be returned to their normal energy state only by a certain number of discrete steps or transitions. Only some of the possible transitions result from a given process. This method of emission takes place, for instance, in the luminescence of gases. The photons thus emitted have one or several preferred frequencies and produce a defined radiation spectrum. In certain extreme cases, there can be emission of only one line, giving a monochromatic radiation. Light thus produced is considerably better defined than light supplied by thermal sources, but it still shows many random characteristics. In fact, the photons emitted, while grouped around the central frequency of the spectral line, have slightly different frequencies, resulting from the interaction between the emitting atom and nearby atoms and from the Doppler effect due to thermal agitation. Moreover, they are emitted spontaneously by the energized atoms, which means that each atom emits a photon without being actually affected by the emissions of nearby atoms. Under these conditions, the photons emitted at any instant have many directions, polarization planes, and phases. This radiation is not directive and assumes the random character of noise although it has a much-narrower spectrum than that from thermal sources.

A perfectly coherent radiation would be one in which the photons were emitted at regularly spaced time intervals or each had an infinite duration, and all had the same frequency, phase, direction, and polarization plane. Such a perfect radiation does not exist, but the light emitted by lasers approaches it considerably more closely than all other known sources. In fact, the photons emitted by a laser do not come from the spontaneous emission of an atom but from an induced emission, which means that the photons produced by one atom induce or stimulate the transitions of other atoms. The created photons are then in phase with the inducing photon and the phase coherence is conserved longer than the duration of a photon.

1. Comparison with Radio Waves

The qualitative analogy between a coherent-light beam and a radio beam would suggest extending the uses of the latter to light beams. However, important differences in their properties, mainly due to the ratio of their wavelengths, are immediately apparent.

1.1 Directivity

First, a very-narrow light beam can be obtained with an optical device of small dimensions acting as the transmitting antenna. With perfectly coherent radiation at a wavelength of 1 micron, a beam of 10 seconds of arc can be made with a lens about ¼ inch (6.4 millimeters) in diameter. Although the imperfect spatial coherence of the wave prompts the use of optical systems of larger size, a considerable advantage remains compared to centimetric or millimetric waves.

1.2 Sensitivity of Receivers

The minimum power needed for the reception of signals is very different because the fundamental limitations of the sensitivity of the two kinds of receivers are due to different phenomena. For the microwave region of the radio spectrum, the minimum detectable signal is defined by the thermal noise level at the antenna. This has the well-known value KTB, in which K is the Boltzmann constant ($K = 1.38 \times 10^{-23}$ joule per degree Kelvin), T is the absolute temperature of the area towards which the antenna is directed, and B is the bandwidth of the receiver.

For light waves, the thermal noise becomes completely negligible compared with another fundamental limitation due to the granular aspect of light, which imposes a minimum level of the received signal defined by hFB, h being the Planck constant ($h = 6.6 \times 10^{-34}$ joule second), F is the frequency of the carrier, and B is the bandwidth of the receiver. At a wavelength of 1 micron, this power equals 2×10^{-19} watt per cycle per second, whereas with a radio-frequency carrier a power of 10^{-21} watt per cycle per second would suffice, if the ambient temperature were 300 degrees Kelvin. This limitation for light is of course also valid for radio frequencies, but it corresponds to energies that are negligible with regard to thermal noise. At optical frequencies, on the other hand, it becomes preponderant. As a comparison, the curves of Figure 1 show the minimum levels necessary for detection of a signal of a bandwidth of 1 cycle per second versus the wavelength of the carrier. The thermal-noise level has been extended into the intermediate zone that exists between radio and light; in fact, the noise level there remains of the same order as in the radio zone.

The above considerations impose a lower limit on the minimum detectable signal, which is independent of the nature of the receiver. For the time being, the best receiver for light waves is the photomultiplier. It is not a perfect receiver and, besides the above-defined fundamental limitation, it is necessary to take into account the photonic efficiency ρ and the dark current, as well as the extraneous light that it can collect. Under these conditions, the minimum power detectable by a photomultiplier has the value

$$P_{min} = \frac{hFB}{\rho}\left[1 + \left(\frac{2(P_o + P)\rho}{hFB}\right)^{1/2}\right]$$

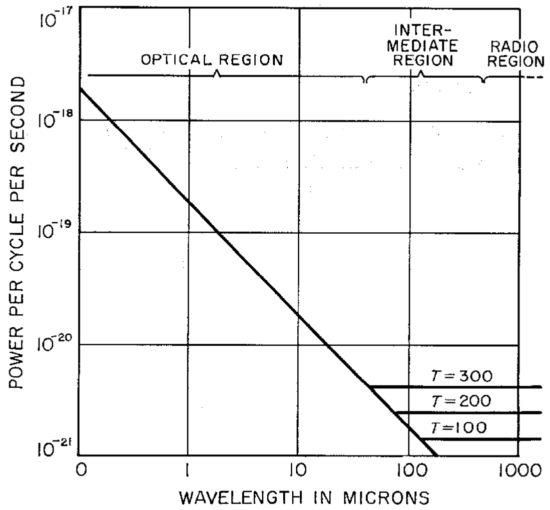


Figure 1—Minimum detectable power as a function of wavelength. T = temperature in degrees kelvin.

in which P_o is the light power equivalent to the dark current and P is the constant power due to extraneous light received by the photocathode.

The above expression shows that, when the bandwidth of the signal becomes large, the second term decreases and can soon be neglected. Thus, for large bandwidths (above 10 megacycles per second in general) and for moderate extraneous light, the photomultiplier is, except for the photonic efficiency, a perfect receiver.

The bandwidth of present photomultipliers is of the order of 100 megacycles per second, but travelling-wave structures make possible bandwidths at least 10 times larger.

To take full advantage of the sensitivity of the photomultiplier, it is thus advisable to protect it as much as possible against extraneous light, by using both very directive input optics and a narrow-band interference-type filter. Such filters exist today with bandwidths of the order of 30 Angstrom units, and it is possible to make them with bandwidths of only a few Angstrom units.

1.3 MODULATOR

Light modulators have not been subjected to intense development probably because of lack of urgent need. This is one of the major problems in the transmission of information over light beams at the present time.

To take full advantage of the possibilities of light beams, the modulation must be of a very-wide band. One of the best-known modulators is the Kerr cell, which uses either nitrobenzine or carbon disulphide. Its operation requires very-high voltages of the order of 20 kilovolts and it is difficult to vary such a voltage rapidly, even if the capacitance of the cell is small.

The Pockels effect, or longitudinal electro-optical effect, that exists in certain crystals permits the design of more-practical modulators. These are made with ammonium dihydrogen phosphate, ADP, or potassium dihydrogen phosphate, KDP. They have the advantage of being in a stable solid state. The necessary modulation voltages are unfortunately of the same order of magnitude as for the Kerr cell, being about 17 kilovolts. Very good results have nevertheless been obtained with such crystals: modulation at nearly 100 percent up to 1000 megacycles per second and with lesser depth at higher frequencies up to a few percent at 15 000 megacycles. However, this modulation occurs with reduced instantaneous bandwidths, which lessens its value. It is easily seen that substantial reactive power is required to ensure modulation with a very-wide frequency band, about 1 kilowatt per megacycle per second of bandwidth. Such modulators are probably better adapted to the production of short pulses, permitting the transmission of coded information, than to direct modulation with wide-band signals.

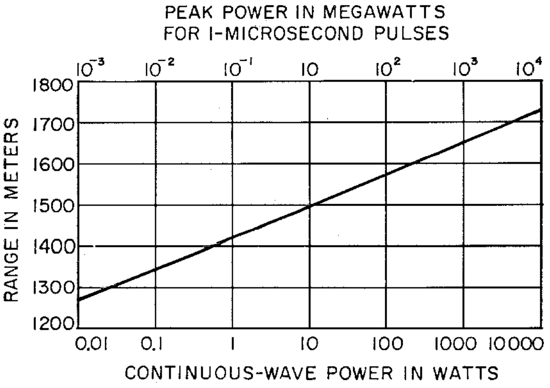


Figure 2—Propagation of coherent light in sea water for a bandwidth of 1 cycle per second with continuous-wave operation and with 1-microsecond pulses.

Other modulation processes, using the Faraday effect, surface displacement of a quartz crystal, or ultrasonic propagation, were tried, but they do not appear to be of practical importance. The latter two in particular are unsuitable for high-frequency modulation.

2. Application to Communication

2.1 General

The light beam can be used as a carrier permitting the transmission of information by means of modulation. Though the power necessary for the detection of a signal is much larger than for radio waves, the high directivity of the beam makes possible long-distance links with small power. The possibility of making highly directive receivers protects them against extraneous light and jamming.

2.2 Propagation Medium

The atmosphere is remarkably transparent for light waves: it transmits about 75 percent of the visible radiation of the sun. However, atmospheric disturbances, clouds, fog, rain, and snow absorb and scatter light giving rise to enormous attenuations. Even in clear weather, the inequalities of temperature of different layers of air result in variations in their refractive indexes and can curve the path of the light beam traversing them, making it necessary either to ensure the tracking of the emitter by the receiver and vice versa or to broaden the directivity properties. Such beams are thus not utilizable with complete reliability unless the path is suitably chosen to avoid these disturbances as in the following two well-defined cases.

(A) By transmitting the beam within a pipe composed of straight sections joined by bends with reflecting mirrors and filled, for instance, with dry nitrogen.

(B) By transmitting the beam in a region that has no atmosphere such as in communication between space vehicles.

Another particularly enticing possibility is transmission through water, especially for the establishment of communication between submarines or between submarines and surface stations. Unfortunately, the transparence of sea water in regions where the water is very clear is only 0.97 per meter for a wavelength of 0.47 micron corresponding to the best transmission. This represents an attenuation of 132 decibels per kilometer. The curve in Figure 2 shows the maximum range, assuming a bandwidth of only 1 cycle per second, versus the emitted power. The result is that no matter what the power may be, the theoretical range under the most favorable conditions is limited to about 1500 meters. Thus, even assuming that a laser is capable of supplying a 0.47-micron continuous wave of sufficient power, the possibilities of providing a practical communication path are very slim.

2.3 Evaluation of Typical Links

From the above considerations, it is possible to evaluate the performances that can be expected in two particular cases to illustrate the possibilities of this type of communication.

2.3.1 *Communication by Pipe*

It is possible to transmit light waves in a dielectric guide, called fiber optics, but the attenuation of several decibels per meter is much too high to permit communication over even only a few kilometers.

It is far more practical to use directed beams with the principal role of the pipe being to maintain a clear and homogenous atmosphere.

The pipe may be filled with dry air or nitrogen under pressure, to maintain its transmission properties against contamination.

Consider a very simple link, having a straight tube 100 kilometers long and 10 centimeters in diameter, the carrier having a wavelength of 1 micron, and being modulated over a bandwidth of 10 000 megacycles per second. The emitter is made up of a neon-helium gas laser, giving a beam with an angular aperture of 0.1 mil. If the receiver has an optical system 10 centimeters in diameter, the attenuation of the communication due only to the divergence of the beam is 40 decibels. The minimum detectable power is 2×10^{-6} watt, taking a photonic efficiency of 10^{-3}, an order of magnitude that is realizable for this wavelength. To have a signal-to-noise ratio of 20 decibels, it is thus necessary to have an emission power of 2 watts, not yet obtained with a gas laser.

Such a link would be possible only by an increase of power of the transmitting laser or by an improvement in the efficiency of photomultiplier. The use of a shorter wavelength, for example 0.4 micron, would permit the use of photomultipliers having a much better efficiency, thus decreasing the necessary transmitted power to 15 milliwatts. In any case, the number of bends and mirrors must remain sufficiently low (a few tens being a maximum) to limit the reflection losses. One of the main difficulties will probably involve ground stability, because the slightest deviation of the beam will prevent propagation.

2.3.2 *Space Transmission*

The problem of range in space transmission is of prime importance, but quite narrow bandwidths suitable for telemetering, for instance, should be acceptable. It is also advantageous to make the beam diverge as little as possible, and, if the optics of emission and reception may be cumbersome, beams having an aperture of a few seconds of arc seem possible.

For high peak power, the emitter can use a ruby laser, which gives a train of short pulses, the envelope of each pulse lasting about 1 millisecond and which produces light energy of at least 1 joule. If the bandwidth of the receiver is 1 kilocycle per second, the pulse train will not be resolved, but will appear as a pulse having a duration of 1 millisecond, and a peak of more than 1 kilowatt. For a wavelength of 0.7 micron, a ruby laser, an existing photomultiplier, and a bandwidth of 1 kilocycle per second, the minimum detectable power has a value of 0.6×10^{-10} watt. It is worthy of note that in this case for a narrow bandwidth, the minimum power is directly linked to the dark current, and it would be of value to cool the photocathode.

With a beam having an angular aperture of 10 seconds of arc (0.05 thousandth of a radian) and a receiver equipped with a telescope having a circular light-gathering area 1 meter in diameter, the maximum range of communication is 80 million kilometers (50 million miles), for a signal-to-noise ratio equal to 1, and thus a usable range of the order of 10 million kilometers for a signal-to-noise ratio of 18 decibels. It should be pointed out that probably such communication is possible only if there is a very precise automatic directional tracking system for the emitter and the receiver. Otherwise, the values of the parameters used for computation are presently realizable. As the beam will take more than 30 seconds to travel 10 million kilometers, the tracking servomechanisms will have a very narrow bandwidth and it will probably be necessary to direct the antennas by a previously computed program, the tracking device acting only as a corrector.

It is still, however, necessary to build a laser having a sufficiently high repetition frequency to be able to transmit a useful signal. Peak powers of 10 megawatts have been attained from a ruby laser but with very low pulsing rates. Pulsing rates of 10 per second have been produced with powers less than a megawatt. A compromise of a few pulses per second and about 1 megawatt of power combined with a reduction in the dark current of the photomultiplier should permit useful ranges of the order of a billion kilometers.

3. Application in Radar

The sharpness of the beam and the time coherence of a coherent light wave lead naturally to its use for the accurate location of targets.

3.1 RANGE-FINDING RADAR

An immediate application is the use of a pulse laser as a radar range finder. In fact, the sharpness of the beam makes it possible to choose a well-defined target in the landscape, such as a vehicle, and to measure its range instantly.

So as not to be hindered by the long duration of the pulse train produced by a ruby laser, only the rise front of the first pulse is used, which of course means a waste of energy. However, Bell Telephone Laboratories have obtained pulses of the order of 1 microsecond with a peak power of nearly 10 megawatts, permitting great useful range. Measurement of the range within 15 meters requires a rise time of the received signal smaller than 0.1 microsecond. The rise time of the transmitted pulse being considerably shorter, the limitation comes almost uniquely from the receiver, which must have a bandwidth of at least 10 megacycles per second. Since the beam is narrow, it will be assumed that it is entirely intercepted by the target, a fraction of its energy then being radiated spherically.

With a ruby laser supplying a peak power of 1 kilowatt at the wavelength of 0.7 micron, a receiving area of 50 square centimeters, and assuming the target has a diffuse scattering factor of 0.1, the maximum range is about 5 kilometers. It is easily seen that daylight is not detrimental: in fact, with a beam having an opening of some ten-thousandths of a radian, the target surface lit up by the laser is at maximum about a square meter, so it receives a power of 1 kilowatt per square meter. The sun, at zenith, supplies the terrestrial surface with 1 kilowatt per square meter distributed over its whole spectrum. But, in a bandwidth of 100 Angstrom units centered at 7000 Angstrom units, the received power is only 1 percent of the total power or 10 watts per square meter. Thus, even with a wide-band filter, the light of the laser is easily detectable.

Such an apparatus is at present under construction. Measurement of the range is obtained by counting pulses at 15 megacycles per second, the result being displayed on numerical indicators.

3.2 MOVING-TARGET RADARS

The Doppler frequencies obtained with light waves are, of course, very high. For a wavelength of 0.7 micron, the Doppler frequency of the signal reflected from a target moving at 1 kilometer per hour is about 800 kilocycles per second. Thus, in a light-pulse radar and for moderate velocities, the speed information can generally be obtained during one pulse, making it possible to detect moving targets very quickly since only one sounding gives an approximate value of the speed.

To realize a light-wave Doppler radar, it would be necessary that a generator having both an excellent time coherence and a high peak power be available. Such a laser does not yet exist, and as the coherence quality of the waves produced by existing lasers is not sufficiently known, it is hardly possible to evaluate *a priori* the feasible performances. With a laser giving a beam coherent during a time of the order of 1 microsecond, it would theoretically be possible to realize a ground surveillance radar capable of surveying a zone of 360 degrees in less than 1 second, that is, at least 100 times better than with centimetric waves.

3.3 LONG-RANGE RADARS

Such light-wave radars can be envisaged if they are free of atmospheric disturbances. In fact, if the transparence of the total layer of the atmosphere is about 75 percent on a very clear day, it diminishes very quickly as soon as clouds appear.

But the small antenna dimensions should make it possible to install radars aboard satellites, for instance, for tracking and guiding space vehicles at least at departure over several thousand kilometers or for detecting ballistic missiles. Assuming that it is possible to make a transmitter having a peak power of 1 megawatt in pulses of 1 microsecond, a beam of 0.1 mil, a wavelength of 1 micron, coupled with a receiver having a light collector of 1 square meter, and equipped with a high-efficiency detector, a 1-square-meter effective surface target should be detectable up to about 4500 kilometers. Location in range with a 1-microsecond pulse and in direction with the 0.1 mil beam will be excellent. To perform tracking, it is possible to use a quadruple receiver, allowing the use of the so-called "monopulse" technique. However, such a design assumes the possibility of making a transmitter having both high peak and high average power.

4. Transmission and Concentration of Energy

4.1 LONG-RANGE ENERGY TRANSFER

The directivity of the beam makes it possible to envisage long-range energy transfer with good efficiency on condition that the medium separating the emitter from the receiver is not absorbent. This is particularly the case for interstellar space. A beam with an aperture of 10 seconds of arc is totally intercepted at 100 kilometers by an aperture 5 meters in diameter. This beam can thus transfer a power of several kilowatts, but it remains to find a receiver capable of transforming with acceptable efficiency the luminous energy thus received into a more-directly usable form, for example, into electric energy.

4.2 ENERGY CONCENTRATION

A monochromatic light beam emitting plane waves (space coherence) can be concentrated by optical means in a spot whose dimensions are of the order of 1 wavelength, making it possible to obtain considerable energy densities. If, for instance, it is possible to concentrate a beam of 1 kilowatt on a surface of 1 square micron (10^{-8} square centimeters), the power density on the illuminated surface will be 10^{11} watts per square centimeter. It is not ill-advised to believe that such fields may provoke important interactions with matter, particularly nonlinear effects. A frequency-multiplication phenomenon has, moreover, been obtained in this way by illuminating a calcium fluoride crystal doped with divalent europium, but with only very-low efficiency.

Intense and localized thermal effects can also be obtained this way, making it possible to produce chemical reactions locally, or to make welds of very small dimensions. Such a technique can thus be applied in the domain of microminiaturization.

Another effect that assumes unwonted importance on a surface thus illuminated is the pressure of radiation. A beam of 1 kilowatt actually produces a force of the order of 0.3 dyne, but concentrated on a surface of 10^{-8} square centimeters, this corresponds to a pressure of the order of 30 kilograms per square centimeter (427 pounds per square inch), and such a result makes it possible to envisage an ultrasonic-wave coupling process in matter. If the beam is deeply modulated at a high frequency, for instance by means of an ammonium dihydrogen phosphate, ADP, crystal placed in a resonant cavity, the radiation pressure will be modulated at the same frequency and could energize ultrasonic waves in matter.

It is likely that the very-high densities of concentrated light energy thus realizable lead to numerous other unusual effects, which constitute a domain not yet completely explored. Important biological effects in particular should be obtainable in a very localized way.

5. Conclusion

Even though of but recent discovery and presenting only a limited number of varieties, lasers seem capable of opening new channels in several domains.

Certainly any early analysis is necessarily very incomplete as some applications are quite likely to appear feasible only after a greater familiarity with coherent light has been acquired; and because of this, it is not inconceivable that the principal role of the laser in the future has not even been contemplated here.

However, the present range of foreseeable possibilities is an indication of the fruitful prospects for coherent-light sources.

Kramar Receives Direction-Finder Award

Dr. Ernest Kramar, head of the navigation department of Standard Elektrik Lorenz, has been awarded the first Gold Honor Pin of the Deutsche Gesellschaft fur Ortung und Navigation for his outstanding work in the field of radio location and navigation.

A member of the Lorenz staff since 1927, he also received the Lilienthal award in 1939 for his contributions to radio aids for the safe landing of aircraft.

Hollow-Cathode Generator of Nanosecond Light Pulses

R. W. LOMAX
J. LYTOLLIS
Standard Telecommunication Laboratories Limited; London, England

The characteristics of light pulses from hollow-cathode discharges in gas under different circuit conditions and with different gas fillings are given. Experimental results show that sources giving light pulses having the characteristics shown in Table 1 can be obtained.

TABLE 1
CHARACTERISTICS OF LIGHT SOURCES

Rise Time	<2 Nanoseconds
Pulse Duration at Half Peak Amplitude	3·2 Nanoseconds
Peak Brightness	140 Stilb
Peak Light Output	0·2 Lumen
Maximum Repetition Frequency	30 Kilocycles per Second
Time Jitter	3 Nanoseconds
Signal-to-Noise Ratio	10^4:1

These results are for discharges in hydrogen. In xenon, the peak light output can be increased to 2·6 lumens and the peak brightness to 1800 stilb, but the pulse duration or width is increased to 14 nanoseconds.

Continuous-wave operation of the discharge in gas up to 5 megacycles per second has been observed, but the light output and signal-to-noise ratio are considerably reduced compared with operation under pulse conditions. The hollow-cathode discharge is not suitable therefore as a light transmitter for broad-band communication but would be satisfactory for a limited class of tests on optical transmission systems. It is also suitable as a test source to assess the response of photo-electric devices.

1. Introduction

This report describes the development of a light source giving pulses of light that meet as nearly as possible the following specification :—

Square shape

Rise time of approximately 1 nanosecond

Pulse width of 5 nanoseconds

High intensity

High repetition frequency

Triggered single-pulse operation.

In addition, it was desirable that the source should be of small physical size.

A device with the above characteristics would be very useful for testing optical transmission systems [1] and would also be useful for testing the response of photo-electric devices.

Numerous ways have been devised by various experimenters to produce light flashes in the nanosecond region, of which the following list is representative :—

Kerr cell

Rotating mirrors [2, 3]

Phosphor excitation [4]

Spark gap [5, 6]

Semiconductor junction devices [7–9]

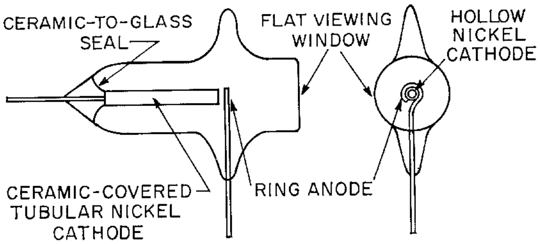
Discharges in gas [10]

Exploding wires [11].

All these different light sources have their merits. Nearly all are capable of giving light pulses with rise times measured between 10 and 90 per cent of peak values in the region of 1 to 3 nanoseconds and many will give pulse durations between half-peak-amplitude values of 10 or less. In general, however, the repetition frequencies of the devices are low, and some give feeble light outputs.

It was decided that a gas discharge device was the type of source that would most nearly meet the specification already outlined, particularly for investigating the performance of an optical pipeline. The gas filling and the pressure to obtain a short-duration light pulse have been discussed by Malmberg [10]. He deduced that a diatomic gas of low atomic weight at high pressure was required.

Figure 1—Hollow-cathode light pulse generator.



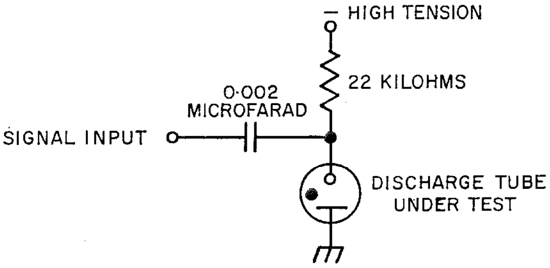


Figure 2—Type *A* circuit for investigating upper frequency limit of gas discharge tubes under test.

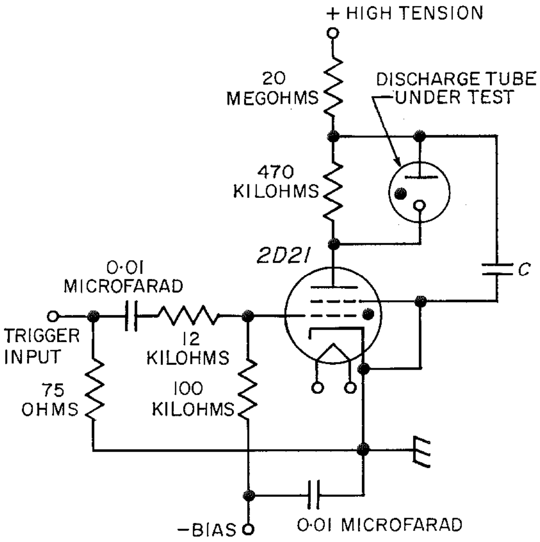


Figure 3—Type *B* circuit employing a charged capacitor *C* to supply discharge current.

2. Gas Discharge Tubes

Gas discharge tubes of some five different types of construction have been made and tested. Discharge tubes having two straight parallel wire electrodes and others with two needle-shaped electrodes pointing towards each other were made. If these were operated with a direct current passing through them, the glow discharge moved up and down the electrodes, not remaining in any particular place. On pulsing an average glow formed along the length of one electrode. The light pulse exhibited some jitter in time.

Most work has concentrated on gas discharge tubes having hollow cathodes. An example is shown in Figure 1. This construction has a low capacitance between the electrodes and the ceramic sheath prevents the glow extending outside the hollow cathode. This keeps the source area small, thereby increasing intensity. Since light is emitted in the forward direction only, the light is concentrated within a restricted angle, so increasing the fraction of the output light that can be collected. Note that the ceramic tube is fused to the glass on the cathode lead to prevent flash over at this point at high voltages.

Gases used in the fillings have been hydrogen, xenon, krypton, helium, and mixtures of neon, argon, and hydrogen. Pressures in the range of 10 to 100 millimetres of mercury were tried. Most measurements have been made with gas fillings of xenon and hydrogen. Xenon has given the largest peak light output and hydrogen has given the pulse with shortest duration.

3. Circuits

As the predominant aim of this development was the production of an intense pulse of short duration at a relatively low repetition frequency, the pulsing circuit has included a rare-gas thyratron that cannot be pulsed above several thousand cycles per second. However to investigate the upper frequency limit of some of the gas discharge tubes alone, the circuit of Figure 2, called type *A*, has been employed.

Figure 3 shows a pulsing circuit, called type *B*, that has also been employed in work reported elsewhere [10]. The *2D21* thyratron is normally biased off. The anode voltage is well above the rated value but those thyratrons used have stood up to this. Anode supplies of up to 4000 volts have been used. *C* is a low-inductance ceramic capacitor. When the *2D21* fires, the gas discharge tube breaks down and capacitor *C*, which has been charged to the high-tension supply voltage, is discharged through it. The capacitor recharging time constant is determined by the value of *C* itself and the anode resistor. This is long enough to ensure that the *2D21* deionises before the voltage on its anode is high enough to start another discharge. Figure 4 shows a modification called type *C* that enables the gas discharge tube to glow on direct current and to be pulsed as well. This reduces time jitter, which is significant for high-pressure tubes.

4. Experimental Results

4.1 APPARATUS

Figure 5 shows the functioning of the equipment generally used in the experiments. The gas discharge tube and pulsing circuit were housed in an aluminium 5-inch (127-millimetre) cubic box. This was linked to a metal box containing the photomultiplier by telescopic brass tubes and a compartment for holding the neutral density filters. The whole of the structure was light tight and painted black on the inside.

In a variation of this, to measure more accurately the peak light output of the light pulse, lenses focused the image of the light source onto a spot 1 millimetre in diameter at the centre of the photomultiplier face.

To measure the characteristics of light pulses having half-peak durations of less than 5 nanoseconds, a Tektronix 545 oscilloscope with a type-N sampling plug-in unit and accessories were used in place of the Tektronix 585 oscilloscope and type-80 probe combination used normally. The former arrangement can measure rise times of 0·6 nanosecond whereas the latter has a rise-time limit of 3·5 nanoseconds. The *56 AVP* photomultiplier used to detect the light pulses has a minimum rise time of 2 nanoseconds and minimum half-peak duration of 2 nanoseconds for its anode-current pulse.

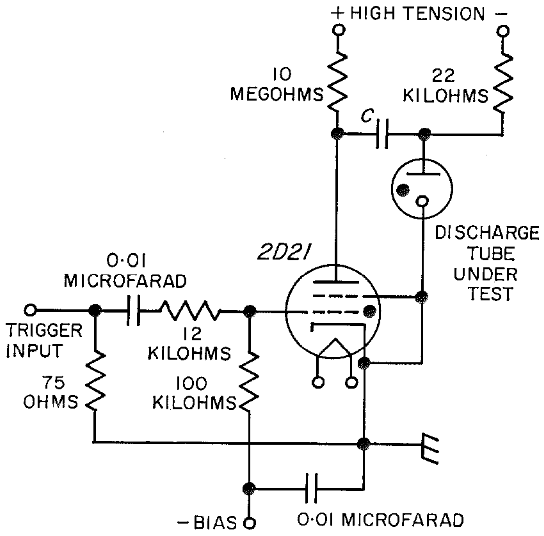
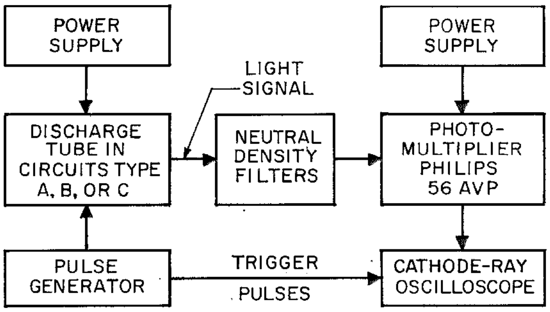


Figure 4—Type *C* circuit, a modification of Type *B* that permits continuous operation on direct current as well as being pulsed.

Figure 5—Functional diagram of the test apparatus.



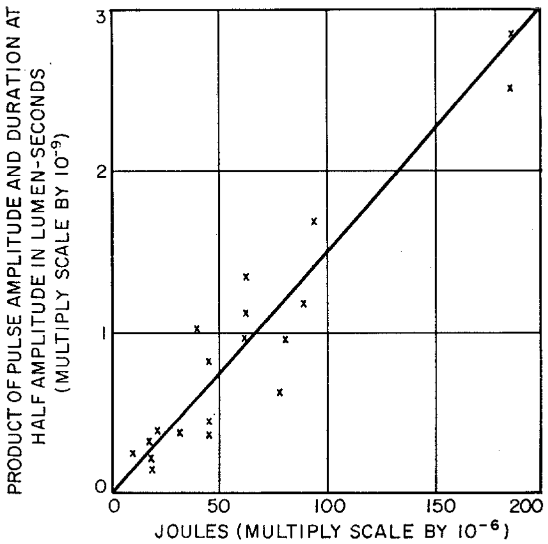


Figure 6—Product of light pulse amplitude and pulse duration at half amplitude plotted against the discharge-capacitor energy for a hydrogen-filled tube tested in circuit *B*.

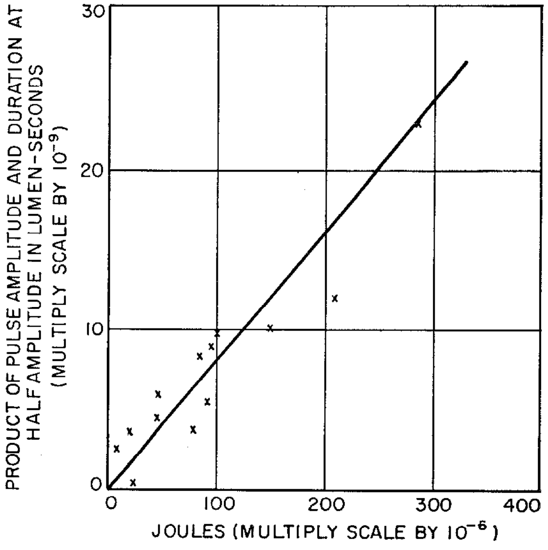


Figure 7—Same as for Figure 6 but for a xenon-filled tube.

4.2 General Results

It has proved difficult to separate the characteristics of the pulse generator from the characteristics of the particular circuit used to drive the device. For instance, the circuit that gives the briefest pulse is not the one that gives the greatest light output because increasing the capacitance of the capacitor that discharges through the light generator not only increases the energy in the discharge but also increases the time constant of the discharge circuit. Any increase in peak light output is therefore attenuated by an increase in pulse duration. It is also necessary, when evaluating results, to take into account the characteristics of the measuring circuit, particularly when time measurements are made.

However, from the results given in detail later, the following general relationships are observed. (A) The product of peak pulse amplitude and pulse duration at half the peak amplitude of the light pulse is directly proportional to the energy stored in the capacitor. See Figures 6 and 7. (B) The efficiency of the energy conversion decreases as the gas pressure increases, see Figure 8. Relationship (A) is a conservation of energy relationship and (B) is explained by an increase of collisions that cause excited atoms to decay by non-radiation processes as pressure increases.

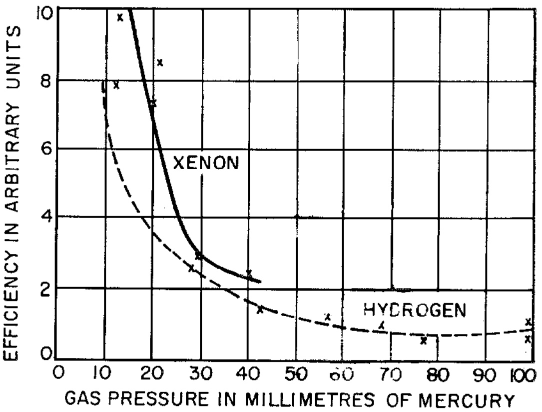


Figure 8—Efficiency versus gas pressure for tubes filled with xenon and hydrogen tested in circuit *B*.

The different gas fillings employed showed no great variation in their pulse characteristics, the main variation being in pulse duration. High-pressure hydrogen fillings produced light pulses with the shortest duration, down to 3 nanoseconds, but the peak light output was an order of magnitude less than that obtainable with the other gases. Xenon, krypton, and the mixture of neon, argon, and hydrogen in similar discharge conditions showed comparable peak light outputs; the highest was roughly twice the lowest. The light pulse half-peak duration depended partially on the pulsing circuit used; values between 3 and 28 nanoseconds were obtained. Xenon was the best of this latter group of gases, and so work was concentrated on xenon- and hydrogen-filled devices.

4.3 Rise Time

The measured rise times of the light pulses produced with different gas fillings and circuit arrangements were all in the range from 2·5 to 6 nanoseconds. The quoted rise times were all calculated by the summation-of-squares method taking into account the rise times of the photomultiplier, oscilloscope, and any associated circuits. The rise-time figures given by the manufacturers of the photomultiplier and oscilloscope have been used. The calculated rise times are all in the 1-to-3-nanosecond range.

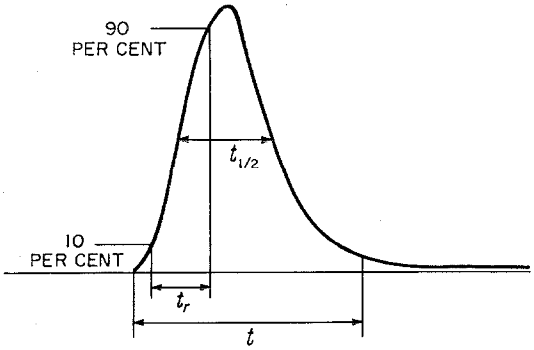


Figure 9—Shape of light pulse.

4.4 Pulse Duration

The general shape of the light pulses is shown in Figure 9. The rapidly rising leading edge is followed by a trailing edge that is exponential in shape. The tail of the trailing edge extends for several microseconds, but is a small fraction of the peak intensity, and the base duration is usually measured to the point where this tail commences; this point is usually fairly well defined. The tail is obviously due to residual ionisation after the high current pulse has passed. The peak amplitude of the current pulse is at least 1 ampere, and may be up to 10 amperes if the discharge capacitance is high.

The duration at half-peak amplitude $t_{\frac{1}{2}}$ is a useful criterion of pulse duration. Pulse duration varies with the gas pressure P, the discharge capacitance C, and the voltage across it V, according to the following general relationships :—

$t_{\frac{1}{2}}$ increases with C (See Figure 10)

$t_{\frac{1}{2}}$ increases linearly with $1/P$ (See Figure 11)

$t_{\frac{1}{2}}$ decreases linearly with V^2 for xenon (See Figure 12)

$t_{\frac{1}{2}}$ remains approximately constant for change of V^2 for hydrogen.

The shortest pulse durations are obtained with hydrogen as a gas filling. The duration at the base of a pulse is about twice $t_{\frac{1}{2}}$.

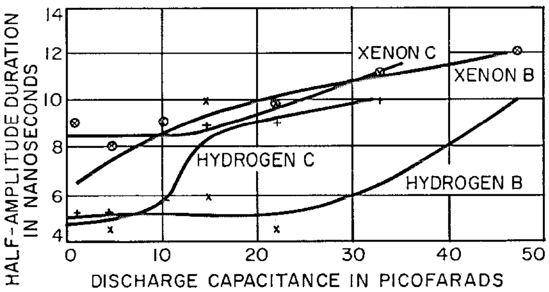


Figure 10—Half-amplitude pulse duration as a function of discharge capacitance for tubes filled with xenon and hydrogen tested in circuits *B* and *C* as indicated.

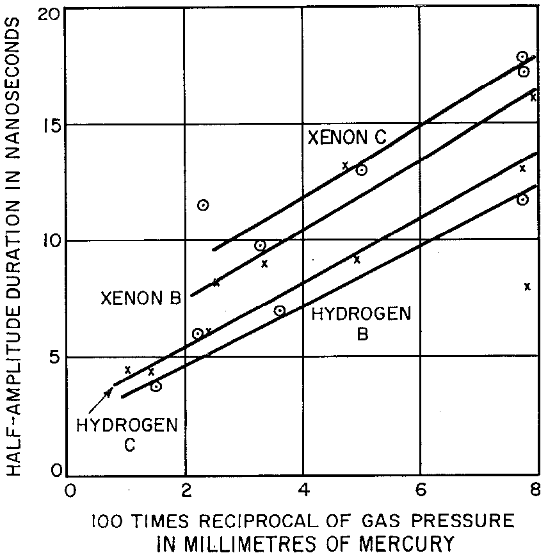


Figure 11—Half-amplitude pulse duration plotted against 100 times the reciprocal of the gas pressure for the gases and test circuits indicated.

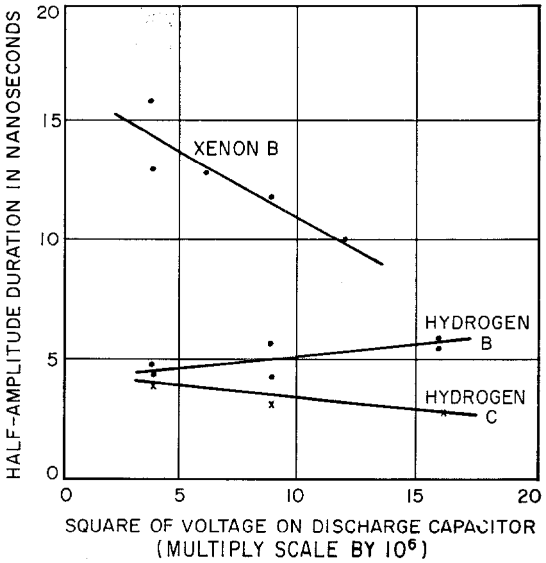


Figure 12—Half-amplitude pulse duration versus square of voltage across discharge capacitor.

4.5 Peak Light Output

The variation of peak light output with capacitance C, pressure P, and voltage V is shown in Figures 13, 14, and 15, respectively. The relationships are not simple. The peak pulse amplitude rises rapidly at first with increase in capacitance of the discharge capacitor (Figure 13), but the rate of increase slows down above 10 picofarads, and becomes appreciably constant above 30 picofarads in three of the four cases considered. The fact that Figure 10 shows $t_{\frac{1}{2}}$ to be approximately constant against capacitance below 10 picofarads explains the initial rapid increase in pulse amplitude because, as already noted, the product of pulse amplitude and $t_{\frac{1}{2}}$ is proportional to the energy stored in the discharge capacitor.

Figure 14 shows the variation of peak pulse amplitude against gas pressure. In general, the amplitude decreases as pressure increases, the change being much greater for xenon than for hydrogen. In circuit C, however, there is a maximum around 20 to 30 millimetres of mercury of pressure, this maximum being most pronounced in the case of xenon. These low-pressure results may be anomalous due to the glow discharge not remaining within the hollow cathode under pulse conditions, particularly since in circuit C the direct-current discharge increases the current density at the cathode surface.

The variation of peak pulse amplitude against the square of the discharge voltage shows an increase of pulse amplitude as the voltage increases, the change again being more marked in the case of xenon than for hydrogen. Since $t_{\frac{1}{2}}$ decreases with increase of voltage in the case of xenon, and changes only slowly with voltage for hydrogen, one would expect an increase of pulse amplitude as voltage increases because of the general energy relationship already stated.

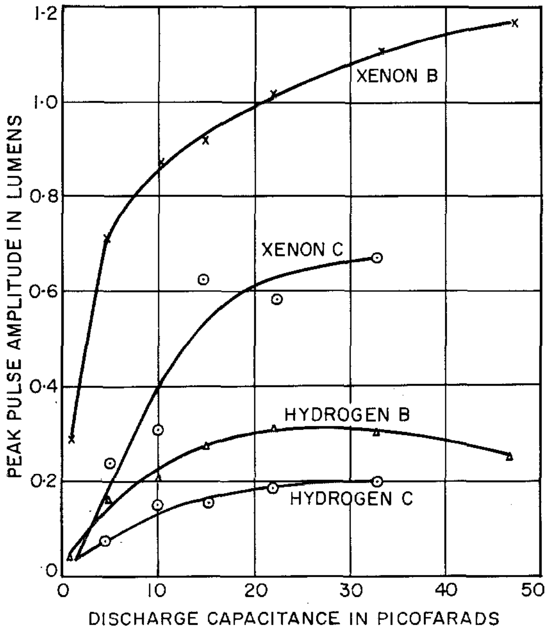


Figure 13—Peak amplitude of pulse as affected by the capacitance of the discharge capacitor.

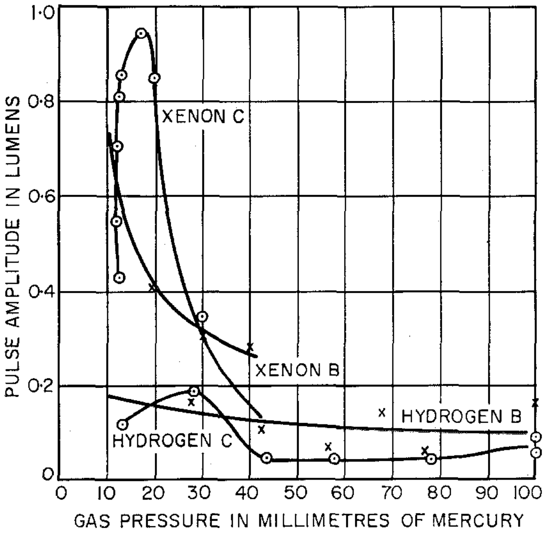
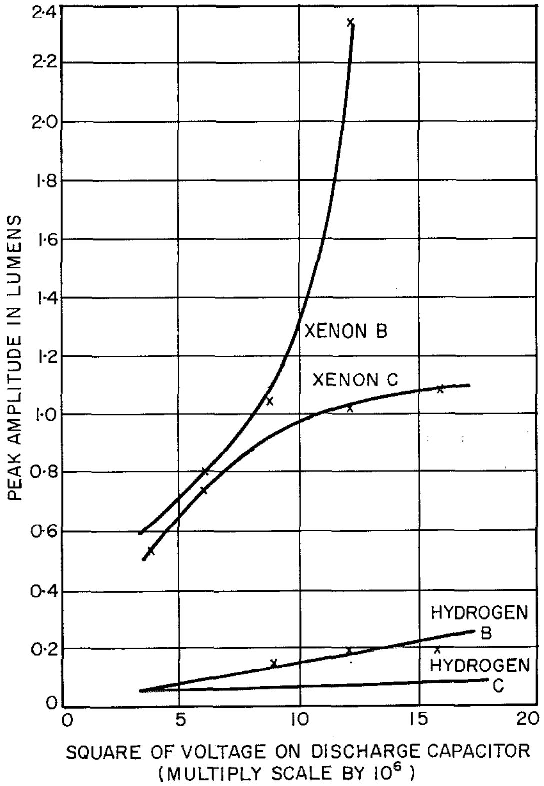


Figure 14—Effect of gas pressure on peak amplitude of pulse.

Figure 15—Effect of voltage across discharge capacitor on peak amplitude of pulse.



4.6 Time Jitter

The time jitter of the pulse depends on a number of factors, some of which are tube characteristics and others of which are circuit considerations. The nature of the gas filling and its pressure are important, and so are circuit parameters such as the amplitude of the triggering pulse, bias on the thyratron grid, and discharge voltage. In some high-pressure tubes, jitter from 10 to 200 nanoseconds has been observed. However, under optimum circuit conditions, the time jitter of xenon and hydrogen tubes in both *B* and *C* circuits is less than 5 nanoseconds and may be as low as 1 nanosecond. Circuit *C* produces the lesser jitter in general. It is also true that increase of discharge voltage always reduces time jitter.

4.7 Particular Results Illustrating Limiting Performances

The best results illustrating (A) the maximum modulating frequency for a discharge tube alone, (B) the minimum pulse duration at half peak amplitude, and (C) the maximum peak light amplitude of the pulse were obtained using different circuits. The data are below.

Circuit Type A

New hollow-cathode discharge tube filled with xenon to 13 millimetres of mercury

Direct current = 1 milliampere

Maximum frequency = 5 megacycles per second

Peak light output at this frequency = 10^{-4} lumen

Ratio of peak light output to background level = 10

Ratio of peak light output to photomultiplier noise = 1.

Circuit Type B

Discharge capacitor = 10 picofarads

High-tension supply voltage = 4 kilovolts

New hollow-cathode discharge tube filled with hydrogen to 100 millimetres of mercury

Pulse duration at half peak amplitude = 3·2 nanoseconds

Peak light output = 0·204 ± 0·034 lumen

Peak brightness = 140 stilbs *

Estimated rise time = less than 2 nanoseconds

Time jitter = 3 nanoseconds

Signal-to-noise ratio = 10^4:1

Maximum frequency before some pulses disappear = 30 kilocycles per second

Peak intensity at this frequency = $3{\cdot}5 \times 10^{-2}$ lumen.

Circuit Type C

Discharge capacitor = 47 picofarads

High-tension voltage = 3·5 kilovolts

New hollow-cathode discharge tube filled with xenon to 13 millimetres of mercury

Direct current = 1 milliampere

Peak light output = 2·6 ± 0·2 lumens

Peak brightness = 1800 stilbs *

Duration at half peak amplitude = 14 nanoseconds

Estimated rise time = 2 nanoseconds

Time jitter = less than 5 nanoseconds

Maximum frequency before some pulses disappear = 17 kilocycles per second

Ratio of peak light output to background level = 5×10^4:1.

4.8 HOLLOW CATHODES OF DIFFERENT DIAMETERS

Gas discharge tubes having several diameters of hollow cathodes were tested for differences in light output or intensity. The gas fillings were of xenon at 18 millimetres and of hydrogen at 100 millimetres of mercury, the cathode internal diameters for each being 0·020, 0·030, and 0·040 inch (0·51, 0·76, and 1·02 millimetres).

All were tested under the same circuit conditions for different values of discharge capacitor. The larger-diameter hollow cathodes showed larger peak light outputs, these being about 1·5 times that of the 0·020-inch (0·51-millimetre) cathode. However the peak brightness of the 0·020-inch cathodes was about twice that of those with larger-diameter cathodes.

5. Discussion

Despite the large current (greater than 1 ampere) passing between the electrodes during the electrical pulse, visual inspection of the light source shows no sign of an electrical arc being present during the pulse. The gas discharge must therefore be operating well into abnormal cathode fall-of-potential condition of a glow discharge, and this explains why a high voltage is required to sustain the pulsed glow. The peak power dissipation is of the order of kilowatts.

---

* Light collected within a cone of vertical semi-angle of 2·5 degrees to the axis of the hollow cathode.

If the pulse repetition frequency is to be increased appreciably, two difficulties are immediately apparent: (*A*) the power dissipation at the electrodes and (*B*) the problem of producing high-voltage high-power pulses in the nanosecond range at high repetition frequencies. Water cooling the cathode is a possible solution to the power dissipation problem, but (*B*) is a nice problem to tax the ingenuity of the circuit engineer. The circuit problem is complicated by the fact that valves capable of dissipating large power normally have large self capacitances. If the circuit problem can be solved, pulse repetition frequencies of tens of megacycles per second may be practicable. Sputtering and gas clean-up, however, may limit the life of tubes used under such conditions.

The hollow-cathode discharge has been operated with a sine-wave input of approximately 50 volts peak to peak up to frequencies of 5 megacycles per second, and this is not the upper limit of frequency. The alternating-current signal was applied to a direct-current glow discharge operating at a current of 1 milliampere. The average power input was 0·25 watt and peak light signals of the order of 10^{-4} lumen were obtained. Under direct-current conditions, the cathode glowed red at 2 watts dissipation. With a water-cooled cathode and a high-voltage high-power oscillator, higher frequencies of operation than 5 megacycles per second may be possible, and the signal-to-noise ratio, which is poor at low voltages, should be considerably improved. Radio-frequency excitation of ionisation in the whole volume of the gas may set an upper limit of a few tens of megacycles per second to the frequency at which high-power continuous-wave operation is possible.

6. Conclusions

A light pulse with the following characteristics can be generated in a hydrogen hollow-cathode discharge operated in a type *B* circuit:—

Rise time = less than 2 nanoseconds

Pulse duration at half peak amplitude = 3·2 nanoseconds

Peak light output = 0·204 ± 0·034 lumen

Peak brightness = 140 stilbs

Maximum repetition frequency = 30 kilocycles per second

The diameter of the light source is 0·030 inch (0·76 millimetre), so that the requirement of small physical size is met. The pulse can also be generated under single-shot pulse operation with a time jitter of less than 5 nanoseconds. The specification given in Section 1 is therefore met except that the pulse shape is not square, although it approximates to this shape, and the repetition frequency of 30 kilocycles per second is not very high.

The above characteristics should be compared with results given by Malmberg for a light pulse generator, using a similar circuit [10] but with an arc discharge in hydrogen.

Measured rise time = 1 nanosecond

Measured duration at half-peak amplitude = 2 nanoseconds

Repetition frequency = 10 kilocycles per second as an estimated possibility.

As can be seen, his results show a shorter pulse than those reported here. However, his results could not be reproduced by repeating his tube design. Moreover, pulse generators made to his design do not give a fixed light source since the arc discharge varies in position for successive pulses. The best results in these repeated experiments are:—

Measured rise time = 7 nanoseconds
(Calculated rise time = 5·7 nanoseconds)

Duration at half peak amplitude = 4 nanoseconds

Peak light output = $7 \cdot 3 \times 10^{-2}$ lumen.

The present detecting and measuring apparatus is not the same as that used by Malmberg and since time measurements in the range from 0 to 5 nanoseconds are difficult to carry out and corrections have to be applied for time constants in the circuit, some discrepancy is to be expected. Too much significance should not, therefore, be attached to the differences in the two sets of results. Indeed, since the pulse-producing circuit was identical in both cases and since the results with the Malmberg type tube were worse than those obtained with the proposed new tube in the measuring circuit used to take measurements for this report, it may be that the new design produces the shorter light pulse.

An extension of the work already done would be to redesign the device to include a water-cooled cathode to investigate the possibility of increasing the frequency at which the device will work.

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Lasers

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The word laser is derived from the word maser, the latter having been made up by the inventors, Townes and his associates, from the first letters of the expression Microwave Amplifier by Stimulated Emission of Radiation. *Light* has replaced *microwave* to form *laser*. Some purists say *optical maser* to pay hommage to Professor Townes, but the use of a special word to designate this device is more convenient because the properties of the laser present notable differences from those of the maser. Consequently, the word laser will be used here.

It can be seen from the etymology given above that the properties of the laser basically depend on the interaction between electromagnetic waves and matter. It is interesting to note, in this regard, that the greatest part of the knowledge necessary to conceive this device was acquired more than 40 years ago. Nevertheless, the prodigious development of microwaves since the beginning of the war was necessary for the scientists to concentrate their interest on the identity of the nature of light waves and radio waves. In particular, the work of Professor Kastler and his associates on optical pumping since 1950, literally paved the way to these new developments.

1. Interactions Between Electromagnetic Radiation and Matter

To study the interactions between electromagnetic radiation and matter, it is necessary to refer briefly to the basic theories. In fact, the concepts used in the explanations are not at all intuitive and it seems appropriate to show the logical sequence that led to their formation. The first important concept is that of the photon. This appears indispensable in understanding the photoelectric effect. When a metallic surface is illuminated by light of short wavelength, electrons are emitted by the metal. Their number per unit of time is proportional to the intensity of the incident radiation, but their kinetic energy is a linear function of frequency according to the law $E_c = h(\nu - \nu_o)$. The simplest interpretation of this result is that the incident radiation is made up of energy packets of photons each having the amount $h\nu$. If this value exceeds the value $h\nu_o$ necessary for an electron to cross the potential barrier at the surface of the metal, this electron is then emitted with a kinetic energy which corresponds to the excess $h(\nu - \nu_o)$.

Next, Compton observed that when X-rays hit various surfaces the resulting scattered radiation contains frequencies that are lower than those of the incident radiation, according to a well-defined function of the angle between incident and scattered X-rays.

The explanation of this phenomenon requires that not only an energy $h\nu$ be attributed to the X-ray photons, but also a momentum of value $h\nu/c = h/\lambda$, where c is the velocity of light and λ is the wavelength.

Moreover, the photon concept justifies the black-body radiation law called Planck's law. Take a cavity the walls of which are at the absolute temperature T. These walls will radiate electromagnetic energy to each other. Consequently, they will absorb and emit electromagnetic energy and a radiation field will exist inside the cavity. In the equilibrium state, there will be no more energy transfer and the energy density u will be the same at any point. Write $u_\nu = \partial u/\partial \nu$. Planck's law is then

$$u_\nu = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{h\nu/kT} - 1}$$

where h = action constant of Planck
$= 6.62 \times 10^{-34}$ joule·second
k = Boltzmann's constant
$= 1.38 \times 10^{-23}$ joule per degree
c = velocity of light in vacuum
$= 3 \times 10^8$ meters per second.

This formula has been demonstrated starting from the photon concept by Bose and Einstein. Nevertheless, they were obliged to complete it to obtain this result. Indeed, one thinks immediately of the preceding cavity as containing a photon gas and of applying to it the classical method of Boltzmann's statistics. In this manner, a law in $e^{-h\nu/kT}$ is obtained instead of a law in $(e^{h\nu/kT} - 1)^{-1}$. It is thus necessary to add supplementary conditions to the definition of the photon. It is first necessary to mention that the space phase of the photon is also quantified and that its momentum varies in a discontinuous fashion. In fact, if the above cavity is considered in the state of thermal equilibrium, to say that its walls emit as much energy as they receive is the same as saying that its walls are perfect conductors, taking into account the electromagnetic nature of the radiation. In this case, a stationary wave will be associated with each photon.

Assume, to simplify, that this cavity is a cube of side a. It is known that any system of stationary waves in this cavity can be broken down into a system of plane waves reflecting from the sides. The condition for the number of reflections to be finite is that the projection of one side into the propagation direction of any wave be an integer of 1/2 wavelength.

Then

$$\frac{2a}{\lambda}\alpha = n_1, \qquad \frac{2a}{\lambda}\beta = n_2, \qquad \frac{2a}{\lambda}\gamma = n_3$$

α, β, and γ being the direction cosines of the perpendicular to the wave plane and n_1, n_2, n_3 being integers.

The components of the momentum of the associated photon are given by

$$p_x = \frac{h}{\lambda}\alpha, \qquad p_y = \frac{h}{\lambda}\beta, \qquad p_z = \frac{h}{\lambda}\gamma.$$

It can be deduced from this that the only photons that can exist inside the cavity are those whose momentum components satisfy

$$p_x = \frac{h}{2a}n_1, \qquad p_y = \frac{h}{2a}n_2, \qquad p_z = \frac{h}{2a}n_3$$

and, consequently

$$p = \frac{h}{2a}(n_1^2 + n_2^2 + n_3^2)^{1/2} = \frac{h}{\lambda}.$$

If we wish to evaluate the number ΔN of possible values of the momentum comprised between p and $p + \Delta p$, we are led to represent each value represented by n_1, n_2, n_3 by a point in space where the n_1 would be plotted along Ox, n_2 on Oy, and n_3 on Oz. It is seen that the points having the same p are found at the surface of a sphere of radius

$$\frac{2ap}{h}(n_1^2 + n_2^2 + n_3^2)^{1/2}.$$

Each state is at the apex of a cube whose side is equal to 1 and the number of states having a momentum lower than p is equal to the volume of the sphere quadrant of radius $2ap/h$ or

$$\frac{1}{8}\cdot\frac{4\pi}{3}\left(\frac{2ap}{h}\right)^3 = \frac{4\pi}{3}\frac{V^{\varphi}}{h^3}p^3$$

letting $V = a^3$.

It is necessary, moreover, to double the number of states to take into account the existence of 2 possible polarization directions. We then get the formula

$$\Delta N = \frac{8\pi V p^2 \Delta p}{h^3}.$$

It is also the number of proper vibrations (or modes) of the cavity that have a wavelength comprised between λ and $\lambda + \Delta\lambda$. By using $p = h/\lambda$ we find

$$\Delta N = -\frac{8\pi\Delta\lambda}{\lambda^4}.$$

To compute ΔN as a function of ν, it is sufficient to use the relations

$$v_g = \frac{1}{\frac{d}{d\nu}\left(\frac{1}{\lambda}\right)}$$

and $v_p = \lambda\nu$, v_g and v_p being, respectively, the group velocity and the phase velocity of the light in a material medium. We then find $\Delta N = \frac{8\pi V\nu^2\Delta\nu}{v_p^2 v_g}$, which can be reduced to $\Delta N = \frac{8\pi V\nu^2\Delta\nu}{c^3}$ in the vacuum. The important point in the above reasoning is that the momentum of the photon is perfectly determined if we know the mode it occupies and that, consequently, according to the uncertainty principle, we can have no information on its position, since precision on the latter is inversely proportional to precision on momentum.

We therefore know all there is to know about the photon in a cavity, when we know in what mode it is found. Moreover, these modes constitute a discontinuous sequence of states. To find the distribution of the photons between these different states, it is necessary to enumerate the different configurations possible. It is here that Bose and Einstein introduced a supplementary hypothesis: the indistinguishability of the photons. Let us assume, for example, that we had given a number to the photons. If photon 1 is in mode a and photon 2 in mode b, this distribution represents the same physical state as when, all else being equal, photon 1 would be in mode b and photon 2 in mode a. In the enumeration, these 2 configurations would only be counted for 1 and the problem would not be to know which photons are in which modes, but how many photons would be in one given mode. In other words, the enumeration would concern only the states of occupation of the modes. With this supplementary hypothesis, we get a distribution in $(e^{h\nu/kT} - 1)^{-1}$ and not in $e^{-h\nu/kT}$ by applying the same processes as in Boltzmann's statistics.

Summarizing, the properties of the photons are

Energy: $h\nu$

Momentum h/λ

Impossibility of distinguishing one particular photon. It is only possible to specify that there are so many photons in a given state.

2. Absorption, Stimulated and Spontaneous Emission

Let us assume that this cavity is now filled with material systems able to be in different electric or magnetic states of different energies. Call 1 and 2 two of these states. Let E_1 and E_2 be their energies (with $E_2 > E_1$) and N_1 and N_2 the number of the systems, respectively, in these states. These systems will pass from one state to the other, absorbing or emitting a quantity of electromagnetic energy $E_2 - E_1$ as a photon of frequency $\nu = (E_2 - E_1)/h$. At thermal equilibrium, the distribution of populations in the different states will be made according to Boltzmann's law

$$\frac{N_2}{N_1} = e^{-(E_2-E_1)/kT}$$

the high energy state being obviously the least populated. This is however only a statistical equilibrium and the systems will continually undergo transitions from one state to the other. There will therefore be a certain density u of electromagnetic energy inside the cavity, which will naturally obey Planck's law, and will have a frequency $(E_2 - E_1)/h$. It is tempting to picture this ensemble of systems as an electromagnetic oscillator interacting with a radiation of the same frequency but of random phase. If it were left to itself, the oscillator would dampen with its own time constant. According to whether or not the phase of the radiation is in phase with that of the oscillator, a transfer of energy from one to the other and vice versa will occur. This transfer will of course be quantified by photons $h\nu$. At equilibrium, we should have

$$\frac{dN_2}{dt} = -\frac{dN_1}{dt}.$$

Now dN_2/dt = the self damping of the oscillator plus the loss of energy of the oscillator

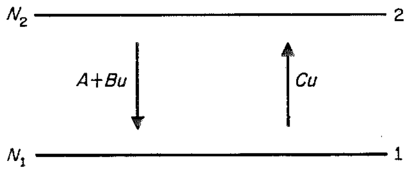

Figure 1—Two systems N_1 and N_2 in energy states 1 and 2.

in the out-of-phase part of the radiation. dN_1/dt = increase of energy of the oscillator from the in-phase part of the radiation.

With respect to Figure 1, we can then write

$$\frac{dN_2}{dt} = (A + Bu)N_2 \quad \text{and} \quad \frac{dN_1}{dt} = CuN_1.$$

The above reasoning suggests that $B = C$ since it is assumed that the distribution of the phases of the radiation is perfectly random. Moreover, the following thermodynamic reasoning absolutely proves it. In fact, we have

$$(A + Bu)N_2 = CuN_1 \quad \text{and} \quad \frac{N_2}{N_1} = e^{-(E_2 - E_1)/kT}.$$

Replacing u by its value drawn from Planck's law, we get

$$\frac{A}{C}\,\frac{c^3}{8\pi h\nu^3}\,(e^{h\nu/kT} - 1) + \frac{B}{C} = e^{h\nu/kT}.$$

This equality should be true for any T. In particular, for $T = 0$ and for $T = \infty$. We get $B = C$ and $A = \dfrac{8\pi h\nu^3}{c^3}B$. The coefficient A is the probability of spontaneous emission. It can be considered as the inverse of the damping time of the oscillator or the average duration of the excited states; B is the probability of absorption or of induced emission. There are therefore 3 distinct effects: production or radiation by spontaneous emission, amplification by induced emission, and attenuation by absorption. At equilibrium we have $B(N_1 - N_2)u = AN_2$; as $N_1 > N_2$, the attenuation is greater than the amplification and the equilibrium can be maintained only by the generation of new radiation by spontaneous emission. It would be different if, by any artificial means whatever, it were possible to make N_2 greater than N_1, which is known as inverting the populations. An incident radiation crossing the cavity would come out more intense than when it had entered. We would then have an amplifier, for example, of light. The principle of the laser is completely contained in this remark. The problem consists in making a population inversion sufficient to surmount the losses inherent to any physical system. It is necessary to point out that the spontaneous emission constitutes an unfavorable factor since it tends to depopulate the upper level and therefore to decrease the amplification. Now, the importance of the spontaneous emission increases very rapidly with the transition frequency. The preceding relations give in fact

$$\frac{A}{Bu} = e^{h\nu/kT} - 1.$$

This is normal, since at constant temperature, according to Boltzmann, the upper levels should be less and less populated as the energy increases.

The computation of A and of B can be made from A. Assume an oscillating electrical system of moment P constituted, for example, by a negative electrical mass m oscillating, according to the law $x = a \cos 2\pi\nu t$ around an equal positive mass. This is the Hertz dipole of moment $P_o = am$. We will assume that in an element of dimensions that are small with respect to the wavelength of the radiation envisaged, there is a great number of these dipoles with random phase and orientation. Let n be this number. The energy stored is $W = nh\nu$ and the energy radiated per second dW/dt is equal to $Anh\nu$. If the energy radiated by a dipole of moment P_o is computed, $\dfrac{16\pi^4\nu^4}{3c^3}P_o^2$ is classically found, therefore we find $A = \dfrac{16\pi^4\nu^3}{3hc^3}P_o^2$. In the case of transition between state 2 and state 1, we can identify P_o^2 with $4|\mu_{12}|^2$, μ_{12} being the element of the matrix of the transition under consideration.

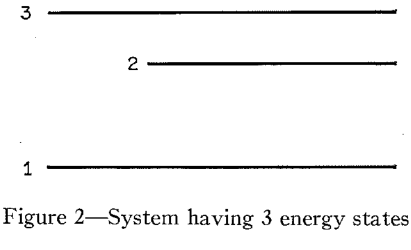

Figure 2—System having 3 energy states.

The value of μ_{12} must be computed from quantum-mechanics methods. It may indeed be extremely different from the value one would obtain by use of a classical analogy in the case for example of forbidden transitions (metastable states).

The magnitude of A gives directly the transition bandwidth $2\Delta\nu$ for we know that in an oscillating circuit

$$2\Delta\nu = \frac{1}{2\pi W}\cdot\frac{dW}{dt} = \frac{A}{2\pi}.$$

The formulas then become

$$A = \frac{64\pi^4\nu^3}{3hc^3}|\mu|^2, \quad \text{for spontaneous emission}$$

$$B = \frac{8\pi^3}{3h^2}|\mu|^2, \quad \text{for induced emission.}$$

3. Population Inversion

It has been seen that the inversion of population was the condition necessary for the appearance in matter of the property for amplifying radiation. A certain number of processes have been invented for this purpose. We shall only describe the process using 3 or 4 energy levels, which was invented by Professor N. Bloembergen in 1956, because it has been the only one used in lasers up to the present time.

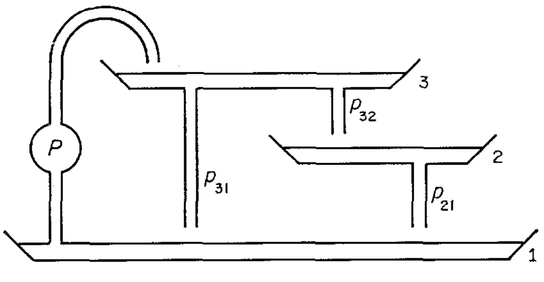

Figure 3—Hydraulic analogy of system having 3 energy states.

3.1 THREE LEVELS

Take a set of systems having 3 energy levels 1, 2, and 3. If we illuminate very strongly with a radiation of frequency $(E_2 - E_1)/h$, the equality of the absorption and induced emission coefficients show that we can at best hope to equalize the populations in the 2 levels. If, on the other hand, we illuminate with a radiation of frequency $(E_3 - E_1)/h$, we can invert the populations between the levels 2 and 1 or between the levels 3 and 2. To be specific, let us assume that the probability of transition from 2 to 1 is much smaller than that from 3 to 2 and from 3 to 1. We then see that the states will have a tendency to accumulate in level 2 and we can thus hope to invert the population of 2 with respect to 1. If, on the contrary, the probability of transition from 3 to 2 is smaller than the others, we will have a chance of being able to invert the population of 3 with respect to 2. A simple hydraulic analogy is in Figure 3: the energy levels are basins placed at different heights. A pump brings up the water from 1 to 3. It comes back down from 3 to 1 and from 2 to 1 by leakages, which are the probabilities of transition. The flow from the pump (absorption—induced emission) is proportional to the difference of the volumes of the 2 basins. The leakage rates are proportional to the volume of water in the basins because we can neglect the possibility of re-excitation by absorption. The equations of the system are then simple. We have, at the equilibrium

$$P(N_1 - N_3) = (p_{31} + p_{32})N_3$$

$$N_2 = \frac{p_{32}}{p_{21}}N_3.$$

We get

$$\frac{N_2}{N_1} = \frac{p_{32}}{p_{21} + \dfrac{p_{21}(p_{31} + p_{32})}{P}}.$$

It is seen that for any P, the condition necessary for the inversion is $p_{32} > p_{21}$. It should be pointed out that the probabilities that are

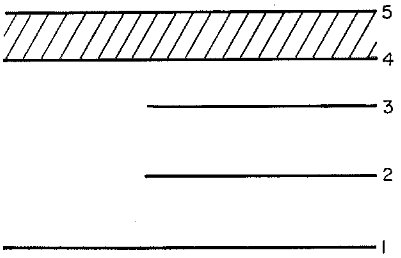

Figure 4—System having supplementary energy level above the 3 states.

to be considered here are not necessarily equal to the coefficient A computed above. In fact, the above computation applies only to the de-energizations that produce radiation. But there can be some that lead to other products such as, for example, increase of the mechanical energy of the molecules in case of collisions in the gas or else heating of a crystal lattice in the case of a solid. Therefore the radiative and nonradiative transitions can be distinguished. In the latter case, we always have $p_{mn} > A_{mn}h\nu_{mn}$. The transition bandwidth is then $2\Delta\nu_{mn} = p_{mn}/2\pi h\nu_{mn}$.

3.2 Four Levels

In the case of the laser, it is necessary for the pumping to be very intense, because of the predominance of the spontaneous emission. It is never easy to obtain a high power in a narrow frequency band and conditions where the upper level is widened so as to form an absorption band instead of a line are looked for. This widening can, for example, be produced by the interaction of a crystal electric field. The useful transition above considered is the transition 2 to 1; and the population inversion requires that the level 1 be considerably depopulated, therefore that it has been pumped very intensely. This disadvantage can be decreased by introducing a supplementary level above the basic level as shown in Figure 4. If the probability of transition from 2 to 1 is very high, it is seen that the population of 3 will be easily inverted with respect to 2. In fact, a computation that is analogous to the preceding one shows that

$$\frac{N_3}{N_2} = \frac{p_{21}p_{43}}{p_{43}p_{32} + p_{32}p_{42} + p_{31}p_{42}}$$

or that this ratio is still inverted and does not depend on the rate of pumping. Only the quantity $N_3 - N_2$, which determines the amplifying power, depends on it. This result that may look paradoxical comes from the fact that the possibility of re-excitation from absorption was neglected, which is permitted as soon as pumping is no longer small. However this reasoning shows the main interest of the above device.

4. Self Oscillations of a Laser

Let us assume that we have enclosed in a cavity a substance composed of systems with 2 energy levels, that the population of these systems is inverted, and that we have what is called a negative temperature (since $(N_2/N_1) > 1$). This population tends to return to the state of thermal equilibrium and the systems will be de-energized by spontaneous emission of photons of frequency $(E_2 - E_1)/h$.

To understand what follows, we are obliged to attribute imperfections to the cavity: it dissipates a fraction of the energy that it stores. We can thus define a Q factor for each mode of the cavity equal to 2π times the ratio of the energy stored in the mode to the energy dissipated during one period. We know that we have the following relations

$$Q = \frac{\nu_o}{2\Delta\nu} = 2\pi\nu_o T,$$

$\Delta\nu$ being the half bandwidth of the cavity and T being the time at the end of which the energy stored in the cavity left to itself has dropped to $1/e$ of its value. If we go on to orders of magnitude, we immediately see a very important phenomenon that again differentiates the lasers from the masers. Whereas in microwaves the bandwidth of the transition is much smaller than the bandwidth of the cavity, here the contrary occurs: the cavity resonance is much narrower than the transition. In fact, the finest lines known have a relative width of 10^{-8} and the transitions used are wider by several orders of magnitude. On the other hand, we will see that the cavities used can actually be as fine as 10^{-8}.

The consequence of this is that the photons emitted spontaneously are going to have the possibility, with variable probabilities of course, of energizing all those modes of the cavity the frequencies of which are inside the transition band. If the population inversion is sufficiently great to compensate for the losses of the mode, the latter will be more and more reinforced by induced emission. Under these conditions, it will de-energize a fraction of the upper energy level and starve the other modes. It is then a case of competition between the different modes possible and those that will be the most reinforced will tend to be those that present the least losses and whose frequency is near the center of the bandwidth of the transition.

In certain cases, it is possible to let only one mode develop, or at least only a group of modes having very close characteristics. If we let a fraction of this mode radiate to the outside, we could thus obtain a radiation that would be coherent since it would have simultaneously the space and time coherence of the mode existing inside the cavity. It is thus seen that the Q factor of the cavity is the determining factor of this coherence because, on one hand, it gives a measurement of the geometric definition of the mode by indicating, for example, the depth of penetration of the electric field into the conductive walls and, on the other hand, it gives a measurement of the stability of oscillation in the cavity. The oscillation conditions can be determined. The gain of a mode by induced emission should be greater than its losses in the cavity with volume V.

Let us assume that at a given moment there are n photons in the mode under consideration. This mode has a frequency ν_o and a width $2\delta\nu$. The energy stored in the mode is $nh\nu_o$. Its spectral density is $nh\nu_o/V\delta\nu$ and the energy losses per oscillation cycle are $(2n/Q)nh\nu_o$, which corresponds to a number of photons disappearing per time unit $2\pi n\nu_o/Q$ or $4\pi n\delta\nu$. It is necessary for the number of photons created by induced emission to be larger than the number of those that disappear.

$$B(N_2 - N_1)\cdot\frac{nh\nu_o}{2V\delta\nu} \geqslant 4\pi n\delta\nu.$$

Therefore

$$N_2 - N_1 \geqslant \frac{2\pi(2\delta\nu)^2 V}{Bh\nu_o}.$$

It should be mentioned that in the case of microwaves where the bandwidth $\Delta\nu$ of the transition is much smaller than $\delta\nu$, we then find

$$N_2 - N_1 \geqslant \frac{2\pi(2\delta\nu\cdot 2\Delta\nu)V}{Bh\nu_o}$$

and if its width is due to a process that is only radiative $4\pi\Delta\nu = A$. Therefore

$$N_2 - N_1 \geqslant \frac{8\pi 2\delta\nu V}{\lambda^3\nu_o}.$$

5. Fabry-Perot Type Interferometer Optical Cavities

5.1 PRINCIPLES

The cavities used in radioelectricity have dimensions that are comparable to the wavelength. One of the basic differences between the maser and the laser is that in the latter, on the contrary, the cavity used has dimensions that are extremely large with respect to the wavelength (of the order of $10^5\lambda$ to $10^6\lambda$).

Figure 5 is the simplest type of cavity that can be studied. It is constituted by 2 infinite parallel planes. The imprisoned volume being infinite, the number of modes of this cavity will be equally infinite for a given frequency. In fact, we will always find an angle of the propagation direction of the waves such that the distance from one wall to the other will be an integer of half wavelength. However, if the perpendicular to the wave plane is at an angle, we have a lateral flow of energy. For certain values of the frequency, corresponding to the case when the distance L between the walls is $n\lambda/2$, it is seen that we have a system of stationary waves. If the lateral dimensions of the walls are not infinite, we see however the possibility of storing electromagnetic energy there. Another possibility is to constitute the cavity by 2 confocal spherical mirrors, that is, the center of curvature of one is on the apex of the other. In this case, we have stationary waves obtained by superposition of spherical wave systems instead of plane wave systems. The introduction of optical cavities analogous to Perot and Fabry interferometers was suggested and studied in the prophetic article of Schawlow and Townes [1]. The use of confocal reflectors in the place of plane reflectors in interferometry is due to P. Connes [2].

In fact, this type of cavity will not store the energy indefinitely for two reasons:

(A) The reflective power of the end mirrors is lower than 1.

(B) There will be energy losses by diffraction during the travel from one mirror to the other.

Fox and Li [3] and Boyd and Gordon [4] showed the existence of nonplanar propagation modes in which diffraction losses were zero. These modes correspond to various field distributions as in a waveguide and can have degrees of dissymetry that are quite important. We can then compute the energy stored in each mode. We verify that the mode TEM_{00}, which is the closest to the plane distribution, is the best. It is also found that a confocal mirror cavity is much better in this respect than a plane mirror cavity.

6. Electric Analog of the Interferometric Cavities

The properties of the interferometric cavities, as we have just seen, depend on the propagation conditions of the waves they contain. It is consequently tempting to consider them as transmission lines. Therefore, consider a resonance mode of a cavity in which the laser effect takes place.

We may consider that its analog is represented by the following scheme shown in Figure 6. A transmission line of length $n\lambda/2$ supplied by a generator of voltage E situated at a voltage antinode and ended by 2 impedances Z. These impedances, being in the voltage nodes, are certainly represented by impedances that are low with respect to the characteristic impedance of the line, which we will take as unity for simplification.

We can determine the normalized impedance z from the reflective power. In fact $r = (z-1)^2/(z+1)^2$ gives for small value of z: $z = (1-r)/4$. Let us show that we have, indeed, a resonant cavity. It is known that the impedance of a line is $\frac{z + j \operatorname{tg} \theta}{1 + jz \operatorname{tg} \theta}$, θ being the electric length of the line.

For small z, we will have the maximum impedance seen from the generator, therefore the minimum of power dissipated for $\operatorname{tg} \theta = \pm \infty$, that is, $\theta = (n_1\pi + \pi/2)$. In other words, for the generator, the line must have an odd number of $\lambda/4$, that is, its length must be an integer of $\lambda/2$, since the generator is at an antinode. This impedance is then

$$\frac{1}{z} \cdot \frac{1}{1 - j\dfrac{(2n_1+1)\pi}{2z} \cdot \dfrac{\Delta\nu}{\nu}}$$

making a limited development of the impedance around the tuning position. $Q = n\pi/(1-r)$ is deduced from this and we again find here the equation for the resolution of an interferometer $R = \frac{2\pi L (r)^{1/2}}{\lambda(1-r)}$ if r is around 1.

In the case of the helium-neon gas laser of Javan and others [4], $L = 1m$, $\lambda = 10^{-6}m$, and $r = 0.99$. Q is then $\pi \cdot 10^8$.

7. Sharpness of Line of A Laser

Experience has proved [5] that the sharpness of line of the radiation emitted by the laser can be far superior to the sharpness of line of the cavity itself. This is a phenomenon that is well-known by all electronicians who know that the frequency spectrum emitted by an oscillator can be much purer than the sharpness of the resonance curve of the tuned circuit that drives it. This can be seen in the following manner: Assume that the laser works in steady state. Under these conditions, we can write that during one time unit, and at a determined frequency ν, the variation of the spectral density of the energy supplied by the amplification of the system and of that supplied by the noise source are exactly compensated for by the losses of the system.

Let b^2 = spectral density of the noise source
u^2 = energy stored in the cavity
g = amplification coefficient of the system
α = coefficient of losses dependent on frequency
β = coefficient of losses independent of frequency.

Write $b^2 = b_o^2 f_1$, $u^2 = u_o^2 f_2$, and $\alpha = \alpha_o f_3$. b_o, u_o, and α_o being the values corresponding to $\nu = \nu_o$ the resonance frequency of the cavity; f_1 and f_2 are functions of the $(\nu - \nu_o)^2/\nu_o^2$, the maximum of which is equal to 1 for $\nu = \nu_o$; f_3 is also a function of $(\nu - \nu_o)^2/\nu_o^2$, but for $\nu = \nu_o$, it has a minimum equal to 1. We then have at any frequency

$$b^2 f_1 + g u^2 f_2 = \alpha u^2 f_2 f_3 + \beta u^2 f_2$$

and for $\nu = \nu_o$

$$b_o^2 + g u_o^2 = (\alpha + \beta) u_o^2.$$

We then get, eliminating u^2/b^2

$$f_2 = \frac{(\alpha + \beta - g) f_1}{\alpha f_3 + \beta - g}$$

which gives the curve of the spectral density of u^2.

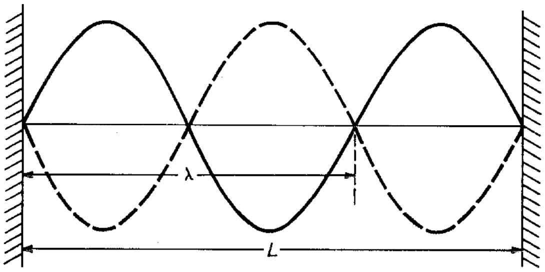

Figure 5—Cavity of 2 infinite parallel planes.

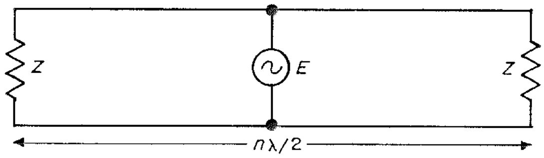

Figure 6—Transmission-line analogy.

In the case that interests us, $b_o^2 = AN_2(\Delta\Omega/4\pi)$ and $g = B(N_2 - N_1)$ $\Delta\Omega$ being the solid angular spread of the beam of the laser. αf_3 corresponds to the selectivity curve of the cavity due to the losses by reflection.

If we write $(\nu - \nu_o)/\nu_o = x$, we find $\alpha = \nu_o/Q$ and $f_3 = (1 + 4Q^2x^2)^{1/2}$. β corresponds to the losses by divergence.

In general, as we have already pointed out, the line width of the spontaneous emission is much greater than the one of the cavity. Moreover, if we assume that there are no losses by divergence as in the case of the modes computed by Fox and Li, we can write $f_1 = 1$ and $\beta = 0$. We then get

$$f_2 = \frac{\alpha - g}{\alpha(1 + 4Q^2x^2 - g)^{1/2}}.$$

Assuming $4Q^2x^2 \leqslant 1$, which is permissible since the line of the laser is sharper than that of the cavity, we then get

$$f_2 = \frac{1}{1 + \dfrac{\alpha}{\alpha - g} \cdot 2Q^2x^2}.$$

It can then be seen that the line obtained has its width reduced in the ratio $(\alpha - g)/\alpha$.

Summarizing, to obtain a very sharp line, it is necessary

(A) To have a cavity with very low losses to have a high Q.

(B) To make the amplification compensate for the losses as much as possible, which means that the stimulated emission must be as great as possible since $\alpha - g = b_o^2/u_o^2$.

8. Conclusions

We have concentrated on trying to point out the most outstanding characteristics of the lasers, such as they may appear to the radio-electrician. It may be said that, in the devices experimented with up to the present time, their main advantages, that is, the space and time coherences of the emitted radiation, are basically determined by the properties of the cavity used. The reason for this is the greater sharpness of this cavity compared to the width of the transition used. As long as this remains true, it is reasonable to say: the laser is as good as the cavity.

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Tunnel-Diode Memory

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1. General Considerations

1.1 Tunnel Diode

Since its appearance in 1958, the tunnel diode [1] has raised many hopes for its applications in digital circuits.

The static characteristic of a tunnel diode as will be seen in Figure 1, includes in the forward direction a region of negative resistance $-R_d$ between the peak voltage V_p at which the current reaches a maximum I_p and the valley voltage V_v corresponding to the minimum I_v of current. For voltages that are lower than V_v, the current is mainly due to the tunnel effect. For sufficiently high voltages, the diffusion process of the minority carriers starts, and the current continually increases reaching again the value I_p for the voltage V_{fp}. In the region around V_v, an excess current is observed that can be attributed neither to the tunnel current nor to the diffusion current.

A tunnel diode in series with a resistance $R > |-R_d|$ and a direct-current bias source $U > V_v$ constitutes the simplest form of a bistable element: the load line R cuts the tunnel-diode characteristic at 3 points, 2 of which correspond to the 2 stable states of operation $A(I_A, V_A)$ and $B(I_B, V_B)$.

Let the bistable element be in state A. The increase of U changes the position of the load line and, for voltage U_1, the tunnel diode switches. Another switching takes place if the voltage is then decreased to value U_2. The change of state of the bistable element can also be ensured by supplying a positive current $I^+ > I_p - I_A$ or a negative current $|I^-| > I_B - I_v$.

The ease with which bistable circuits can be obtained is all the more interesting because their switching speed is very great. Setting aside the parameters of the circuits excluding the tunnel diode, its working speed is determined by the time constant $|-R_d|C$ or by the ratio C/I_p where C is the PN junction capacitance. The values of these parameters can be made very small without excessive difficulty, which ensures very-short switching times (a fraction of a nanosecond). The manufacturing technology seems less costly for a very-fast tunnel diode than for a fast transistor.

The very-low power dissipated in the circuits using low-peak-current diodes give the possibility of extreme minification. The resistance to nuclear radiation is good, and the temperature characteristics are satisfactory. Another quality of the tunnel diode that distinguishes it from other semiconductor devices is the close tolerances that can be maintained in manufacture. At least one parameter, the peak current, can be very accurately controlled, to within better than ±10 percent and even to ±1 percent.

Aside from these advantages, the development of tunnel-diode circuits presents some particular problems. The tunnel diode is a 2-terminal device and effective separation must be provided between the driving circuit and the output circuit. The characteristic voltages are determined by the semiconductor material used for its manufacture. Tunnel-diode circuits produce low output voltages. In numerous types of tunnel-diode digital circuits, the tolerances on the elements and on the voltages are very strict [2].

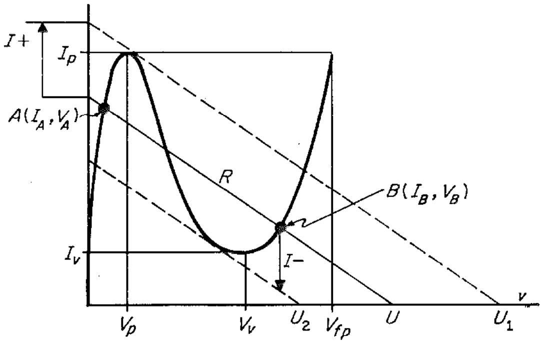

Figure 1—Negative-resistance region of tunnel-diode characteristic.

1.2 Tunnel-Diode Memories

The construction of fast memories or stores seems to constitute one of the most interesting applications of tunnel diodes.

The negative resistance region of its static characteristic makes it easy to devise a memory point: it is sufficient to choose a suitable bias voltage and value of the load resistance or, in the case of a nonlinear load the shape of its characteristic, to obtain 2 points of intersection corresponding to 2 stable states of operation.

However, the practical design of memories presents problems that are not always easy to solve.

(A) Certain circuits require very strict tolerances on the tunnel-diode characteristics and on the passive elements [3] to the point of being impractical.

(B) The search for larger tolerances sometimes leads to rather-complex circuits having a great number of elements [4].

(C) The construction of sensing amplifiers is very critical because of high speed operation; the low level of the output signal, especially in the case of nondestructive reading; and the low signal-to-noise ratio, sometimes caused by stray signals produced by the memory itself.

(D) The use of nonlinear load. A point-contact diode in a memory point can reduce the number of elements, but the nonlinear element can limit the operating speed, increase the price, or both. Moreover, accurate computation of tolerances and of optimal values seems difficult.

(E) In circuits that are based on the precise control of the peak current I_p, the driving signals are current signals rather than voltage signals. The use of driving stages with tunnel diodes necessitates the series connection of several tunnel diodes with a high peak current [5]. This can be avoided by using transistor drivers, but they can limit the speed.

The problem of tunnel-diode memories is largely that of the associated circuits. The choice of the memory point should be guided by the possibility of obtaining a practical design, operational reliability, and simplicity of both driving circuits and sensing amplifiers.

2. Proposed Memory Point

2.1 Operation

The operating principle of a memory point in the proposed circuit is that of threshold logic. The threshold is constituted by the peak current I_p, the most precisely defined parameter of a tunnel diode. A diode that is biased so as to obtain two stable operating states, as shown in Figure 1, constitutes the essential element of a memory point. The value of the bias resistance is high and the load line is practically horizontal. The switching of the tunnel diode between the two points of stable operation is made by the application of current pulses.

The writing of a 1, that is, the passage from A (0) to B (1) is obtained by the coincidence of two positive current pulses that together exceed the threshold I_p. Either one of these pulses is not sufficient to cause the switching. The parallel destructive reading is made by applying a negative current pulse. At the end of the operation, the diode is in the A state, whatever its previous state was. It is seen that the voltage variation at its terminals is very

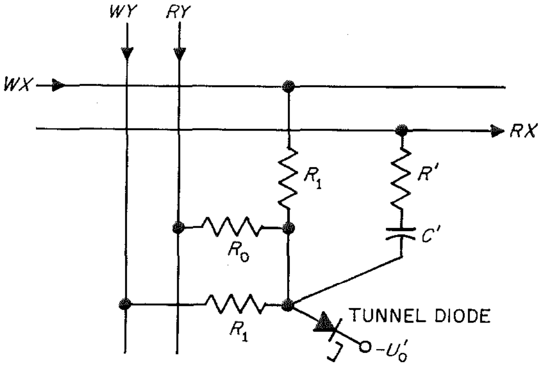

Figure 2—Memory point.

different depending on whether a 0 or a 1 is read.

Figure 2 represents a memory point. The connection of this point in an assembly and the manner of obtaining the different signals for bias, reading, and writing will be described. The 3 inputs RY, WY, WX are direct-current coupled with the collectors of the 3 fast PNP transistors in the grounded-emitter configuration. The transistor connected to RY is normally saturated and brings this input to the saturation voltage $-V_{CE\ sat}$. The transistors WY and WX are normally cut off and set the corresponding inputs at the supply voltage of the collectors $-U_{CC}$.

In static operation, no signal is supplied to the inputs of the memory point. The direct-current bias is set by the resistance R_0 and the tunnel diode, which are shunted by the 2 resistances $R_1 \gg V_{fp}/I_p$. The bias voltage is

$$U_0 = U_0' - V_{CE\ sat}. \tag{1}$$

The values of the elements are chosen to fulfil the condition

$$\frac{U_0 - V_v}{R_0} > I_{v\ max} + \frac{(U_{CC} - U_0) + V_v}{R_1/2} \tag{2}$$

that ensures the existence of the 2 points of stable operation

$$0 = (V_0, I_0) \qquad \text{and} \qquad 1 = (V_1, I_1)$$

shown in Figure 3. These points correspond to the 2 stable states of a memory point in static operation. For

$$\left.\begin{aligned} U_0' &\gg V_{fp} \\ R_0 &\gg V_{fp}/I_p \end{aligned}\right\} \tag{3}$$

we can write

$$I_1 \cong I_0 \cong U_0/R_0.$$

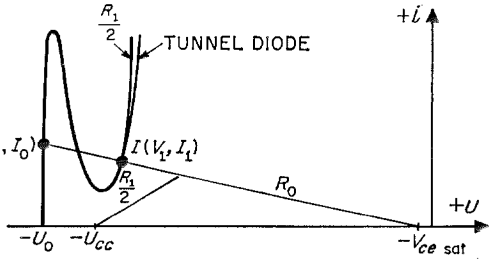

Figure 3—The 0 and 1 points of stable operation.

In dynamic operation, it is necessary to ensure both writing and reading at the desired moments. Figure 4*A* shows the approximate shape of the voltages at the inputs RY, WY, and WX for the 1 state of a memory point put into dynamic operation, and Figure 4*B* is the 0 state. The writing occurs at the point of intersection of lines WY and WX, on which the positive writing pulses appear.

$$V_W = U_{CC} - V_{CE\ sat} \gg V_{fp}. \tag{4}$$

The amplitude V_W is chosen to fulfil the conditions

$$\frac{U_0}{R_0} + \frac{V_W}{R_1} < I_p \tag{5}$$

$$\frac{U_0}{R_0} + 2\frac{V_W}{R_1} > I_p. \tag{6}$$

It is necessary to apply 2 pulses in coincidence to switch the tunnel diode from 0 to 1. Note that if the term

$$\frac{U_{CC} - U_0' + V_p}{R_1/2} = \frac{V_E - U_0 + V_p}{R_1/2} \tag{7}$$

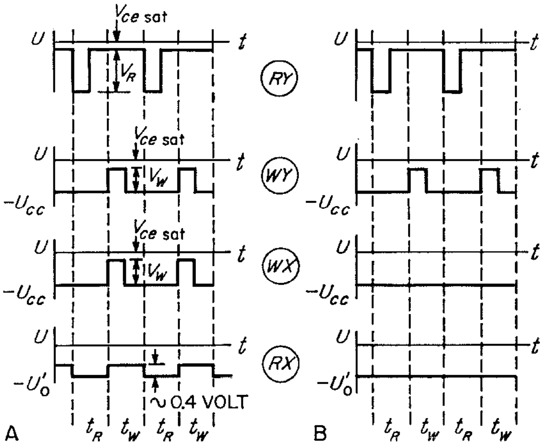

Figure 4—*A* is the voltages on RY, WY, and WX for the 1 state and *B* is for the 0 state.

is not negligible with respect to I_p, it should be introduced into expressions (5) and (6) to take into account the supplementary direct-current bias.

The working cycle is divided into 2 time intervals, reading time t_R and writing time t_W. If at the beginning of the reading time, the tunnel diode is in the 1 state, the negative reading pulse applied to RY, of amplitude V_R such that

$$\frac{V_R}{R_0} > I_1 - I_v \tag{8}$$

will switch it from 1 to 0 and will deliver an output signal, RX of Figure 4A, of amplitude ~0.4 volt for germanium tunnel diodes. This pulse will not change the state of a tunnel diode in the 0 condition. The differential resistance of the tunnel diode for voltages lower than V_0, including the tunnel diode biasing in the reverse direction, is very small, and the output signal is negligible being lower than 20 millivolts for germanium tunnel diodes.

The purpose of C' and R' is to separate the different memory points connected to the same sensing line RX.

In the proposed circuit, the destructive read-out ensures a large read-out signal, producing a high ratio between the 1 signal and any stray 0 signal. Read-out by only one V_R pulse in the Y direction makes it possible to obtain large tolerances and to apply a high reading pulse to increase the switching speed from 1 to 0. Moreover, the useful-to-stray-signal ratio during the read-out time t_R does not depend on the dimensions of the matrix. The associated circuits are both very simple and very reliable. The driving stages are direct-current connected to the inputs RY, WY, WX, the voltages on these inputs are accurately established, and the load is essentially resistive, R_0, R_1 being very high with respect to the impedance of the tunnel diode. This permits a simple and exact computation of the tolerances and of the optimum values of the elements.

2.2 Computation of Tolerances

To establish the tolerances of the elements, let

$$\left.\begin{aligned} U_0 &\pm \Delta U_0 = U_0(1 \pm u_0)\\ V_R &\pm \Delta V_R = V_R(1 \pm v_R)\\ V_W &\pm \Delta V_W = V_W(1 \pm v_W)\\ I_p &\pm \Delta I_p = I_p(1 \pm i_p)\\ R_0 &\pm \Delta R_0 = R_0(1 \pm r_0)\\ R_1 &\pm \Delta R_1 = R_1(1 \pm r_1). \end{aligned}\right\} \tag{9}$$

These are the limits within which the voltages, parameters of the tunnel diodes, I_p, and resistances can vary in the inequalities (5) and (6).

Under practical conditions, it can be assumed that

$$\begin{aligned} u_0 &= v_R = v_W = u\\ r_0 &= r_1 = r. \end{aligned} \tag{10}$$

The inequalities (5) and (6) and the tolerances of (9) and (10), give in the worst case

$$\frac{U_0(1+u)}{R_0(1-r)} + \frac{V_W(1+u)}{R_1(1-r)} < I_p(1-i_p) \tag{11}$$

$$\frac{U_0(1-u)}{R_0(1+r)} + 2\frac{V_W(1-u)}{R_1(1+r)} > I_p(1+i_p). \tag{12}$$

The solution of (11) and (12) in terms of u gives

$$u < u' = \frac{I_pR_0R_1(1-i_p)(1-r)}{U_0R_1 + V_WR_0} - 1 \tag{13}$$

$$u < u'' = 1 - \frac{I_pR_0R_1(1+i_p)(1+r)}{U_0R_1 + 2V_WR_0}. \tag{14}$$

Solving (11) and (12) in terms of r, we obtain

$$r < r' = 1 - \frac{(U_0R_1 + V_WR_0)}{I_pR_0R_1}\frac{(1+u)}{(1-i_p)} \tag{15}$$

$$r < r'' = \frac{(U_0R_1 + 2V_WR_0)}{I_pR_0R_1}\frac{(1-u)}{(1+i_p)} - 1. \tag{16}$$

Equations (13) and (14) make it possible to determine the tolerances on the voltages u, and (15) and (16) give the tolerances on the resistances. From (15) and (16) for $r' = r''$, we can draw the optimum value of R_1

$$R_{1\,opt} = \frac{3V_W \dfrac{1 + ui_p - \frac{1}{3}(u + i_p)}{1 - i_p^2}}{2\left[I_p - \dfrac{U_0\,(1 + ui_p)}{R_0\,(1 - i_p^2)}\right]}. \tag{17}$$

Let us consider a particular case

$$\begin{aligned} U_0 &= V_W = U \\ R_0 &= R_1 = R. \end{aligned} \tag{18}$$

This means the use of the same supply voltage $U_0' = U_{CC}$ for the matrix and for the driving generators (writing), as well as the resistances of a single value R. The expressions (13) to (16) give

$$u < u' = \frac{I_pR}{2U}(1 - i_p)(1 - r) - 1 \tag{19}$$

$$u < u'' = 1 - \frac{I_pR}{3U}(1 + i_p)(1 + r) \tag{20}$$

$$r < r' = 1 - \frac{2U}{I_pR}\frac{(1 + u)}{(1 - r)} \tag{21}$$

$$r < r'' = \frac{3U}{I_pR}\frac{(1 - u)}{(1 + r)} - 1. \tag{22}$$

The condition $u' = u''$ carried into (19) and (20) gives the optimum value of U

$$U_{opt} = \frac{I_pR}{12}[5(1 + i_pr) - (i_p + r)]. \tag{23}$$

This is equivalent to the choice of the optimum value of I_0 for a given tunnel diode (I_p, i_p) and tolerances on the resistances r.

$$I_{0\,opt} = \frac{U_{opt}}{R} = \frac{I_p}{12}[5(1 + i_pr) - (i_p + r)]. \tag{24}$$

We can also compute the optimum value of R for a particular tunnel diode (I_p, i_p) and supply voltage (U, u) by making $r' = r''$ in (21) and (22).

$$R_{opt} = \frac{U}{I_p}\left[\frac{3\,(1 - u)}{2\,(1 + i_p)} + \frac{(1 + u)}{(1 - i_p)}\right]. \tag{25}$$

In the particular case (18), it is easy to determine the relation between the tolerances u, i_p, and r. From (19) and (20) for $u' = u''$, we find

$$u + i_p + r = \tfrac{1}{5} + \tfrac{1}{5}(ui_p + i_pr + ru) - ui_pr. \tag{26}$$

It is seen that the tolerances on the voltages u, resistances r, and on the peak current of the tunnel diodes i_p have the same importance. Neglecting the second-order terms, the sum of these three tolerances in the particular case (18) is

$$u + i_p + r \cong 0.2 \tag{27}$$

that is, ±20 percent. Figure 5 shows the curves $u = f(r)$ for different values of i_p.

In the general case $(U_0 \neq V_W, R_0 \neq R_1)$, the sum of the tolerances can be higher than ±20 percent. By making $u' = u''$ in (13) and (14), we obtain, neglecting the second-order terms

$$u + i_p + r \cong \frac{1}{3 + 2(I_0/I_W)} \tag{28}$$

where $I_0 = U_0/R_0$ is defined in Figure 3. $I_W = V_W/R_1$ is the writing half-current.

Figure 6 gives the graphic representation of (28).

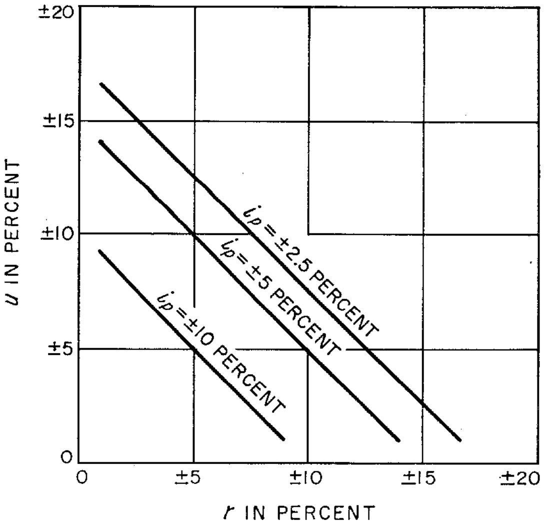

Figure 5—Effect of the tolerance on peak current i_p of the tunnel diode on the tolerances on voltages and resistances.

The ratio I_0/I_W is determined by expressions (11) and (12). The minimum admissible value of I_0 depends on the ratio I_p/I_v of the tunnel diode (see condition (2)), and on the security margin $I_1 - I_v > 0$ chosen for eventual parasitic signals, for the shunt effect of the 2 resistances R_1 also set by (2), and for the increase of I_v with temperature.

We find these results to be very satisfactory: the memory point proposed can easily be made with presently available components. It must be pointed out that, in technical publications, one can find the description of tunnel-diode circuits that are practically unrealizable, requiring tolerances on the fast pulse currents or voltages of the order of ±3 percent, a great accuracy of the valley current I_v, et cetera.

Computation of the tolerances permits making a precise assessment of the optimal values of the components. Here, we will restrict ourselves to making a few remarks concerning the choice of the tunnel diodes and to giving a numerical example.

The maximum power dissipated by a memory cell, including the resistances, is at the most equal to

$$P_D = \frac{U_0^2}{R_0}(1 - F) + \frac{(V_R - U_0)^2}{R_0} F + 2\frac{V_W^2}{R_1} F \qquad (29)$$

where F is the duty factor of the reading and writing pulses.

The choice of tunnel diodes with low peak current I_p decreases the power dissipation and necessitates only low values of the writing and reading currents. A single transistor is sufficient to drive a greater number of tunnel diodes. A strict tolerance on I_p widens the tolerances admissible on the voltages and resistances of Figure 5. A high I_p/I_v ratio is advantageous for obtaining condition (2), gives a better security margin, and can permit widening the tolerances on the components as indicated in Figure 6, and on the temperature.

A small junction capacitance C, or more exactly a low C/I_p ratio, increases the switching speed of the tunnel diode. The germanium tunnel diodes seem more advantageous than the gallium arsenide diodes: the stability of I_p with time is better, the voltages and dissipated power are lower, the price is lower, and the I_p/I_v ratio is sufficient in the commercially available diodes.

2.3 NUMERICAL EXAMPLE

For the tunnel diode *T1975* produced by Philco (USA), $I_p = 1$ milliampere, $i_p = 0.025 \pm 2.5$ percent, $I_p/I_v \geqslant 8$, and for the ±10 percent resistances ($r = 0.10$), we have found $u = 0.075 \pm 7.5$ percent, $I_{0\,opt} = 0.402$ milliampere, $R_0 = R_1 = 4.7$ kilohms, $U_0 = V_W = U_{0\,opt} = 1.9$ volts, $V_W = 3$ volts, and $P_D \leqslant 0.97$ milliwatt.

3. Design of Memory

Figure 7 is a diagram of the experimental memory.

The matrix comprises 192 memory elements such as the one shown in Figure 2, arranged in

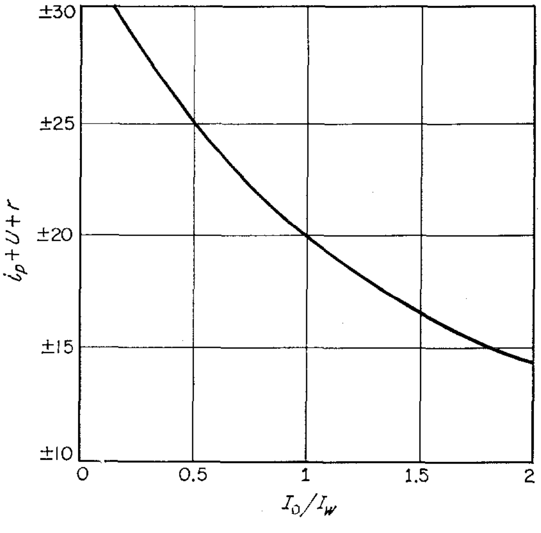

Figure 6—Effect of writing current on the tolerances of the peak current, voltages, and resistances.

8 words (rows) of 24 binary digits (columns). There are as many RY and WY wires as rows and as many WX and RX wires as columns. Each of the 24 memory cells of the same row is connected to the RY wire and the WY wire corresponding to this row, and each of the 8 points of the same column to the WX wire and the RX wire corresponding to this column. The transistor-operated clock sends square pulses of duty factor 0.2 in 2 phases shifted by a half-period with respect to one another as shown in Figure 4.

The address registers store the chosen address. They are followed by a decoder that switches the reading pulses and a writing half-current onto 1 of the 8 rows. The change of address is made between the end of the writing pulse and the beginning of the reading pulse.

We have provided in both binary and decimal versions for the possibility of a manual choice of the address with switches and for identifying the chosen address by light indicators.

The 8 points of the same column are connected through separation circuits, C' and R' of Figure 2, to the same read-out wire at the input of one of the 24 read-out amplifiers. Three-position switches ensure the manual writing of the information, 0 or 1, on the selected row. This information is presented on information indicators.

The reading and writing pulse drivers are preceded by AND gates. The AND gates of the 8 row drivers of V_R (RY) and the 8 row drivers of V_W (WY) are controlled by the state of the address registers. The 24 read-out amplifiers control the AND gates at the inputs of the 24 column drivers of V_W (WX): they open these gates if the information read in the preceding cycle is 1.

We thus obtain the work cycle in which the destructive reading is followed by a re-writing. This cycle is repeated at the clock frequency. This permits an easy observation of the recurrent signals with an oscilloscope and is a reliability test of the memory.

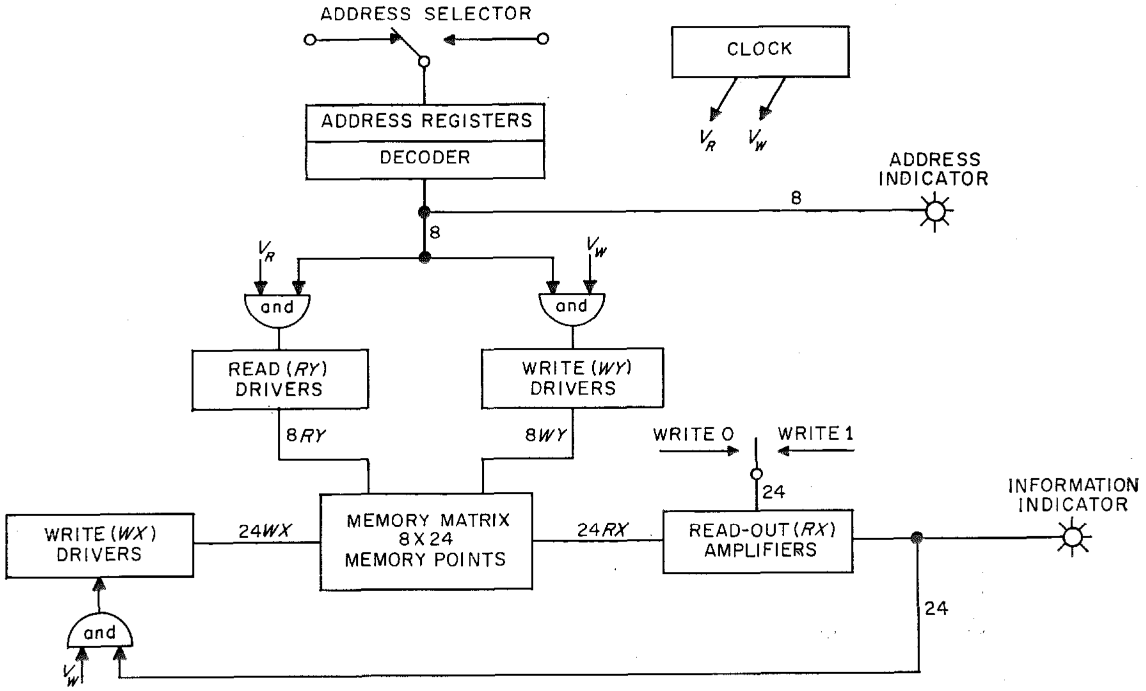

Figure 7—Experimental memory.

4. Associated Circuits

We will describe only the associated circuits that are used to produce the driving signals and to amplify the useful signals of the memory matrix.

4.1 Drivers

Transistor pulse amplifiers in the common-emitter configuration, preceded by 2 input AND gates act as drivers for the memory matrix. Figure 8 gives the diagram of one of these generators. Consider the case of the V_W driving (WY) that supplies the pulses of the first row. The negative clock pulses in t_W phase are supplied to input 1, and input 2 is connected to the decoder. The transistor is normally saturated. The choice of the first row corresponds to the application of a negative voltage to input 2: the AND gate opens and the pulses V_W appear at the output.

The same circuit is used as V_W, driver of line (WX), and V_R, driver of row (RY).

One transistor stage can act as driver for a large number of tunnel-diode memory elements in the proposed circuit. Setting aside the question of an excessive stray capacitance, a transistor with $I_{C\,max} = 50$ milliamperes (for example, 2N1500) can supply the writing pulses for at least 125 memory cells using diodes with $I_p = 1$ milliampere (for example, *T1975*) under typical working conditions.

4.2 Read-Out Amplifier

The detection of the state of a memory point constitutes one of the greatest problems of tunnel-diode memories. The level of the read-out signal is low and this necessitates the use of read-out amplifiers. The working speed is high and the gain-bandwidth product of the amplifier is great. One read-out amplifier should serve a large number of memory cells to decrease the complexity and price of the circuits. An effective separation must be provided between the different points connected to the same read-out line.

In the system adopted, the destructive reading of a 1 corresponds to a rapid decrease in voltage at the terminals of the tunnel diode, and ensures a useful read-out signal that is relatively strong. The reading of a 0 gives a very small voltage change and as R_0 is very large with respect to the differential resistance of the tunnel diode the resulting stray signal is negligible. On the other hand, the re-writing of a 1, which follows the destructive read-out, corresponds to a rapid increase in the voltage on the tunnel diode. There results a signal with an amplitude comparable to that of the useful read-out signal of opposite sign and shifted in phase by a half period, hence the possibility of its elimination by clipping and/or by time selection. It is, nevertheless, necessary to be sure that this signal does not paralyze the read-out amplifier during the following reading.

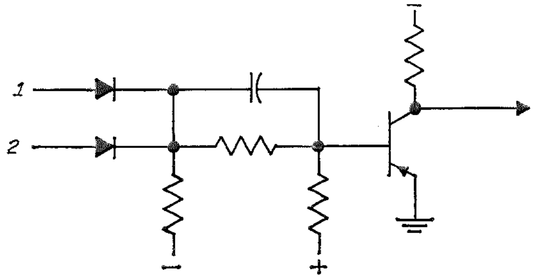

Figure 8—Transistor pulse amplifier used for driving the tunnel diode bistable element.

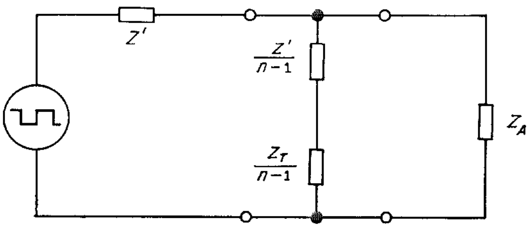

Figure 9—Voltage divider from which read-out amplifier operates.

In the proposed circuit shown in Figure 2, the capacitor C' and the resistor R' are used to separate the n different memory points connected to the same read-out line RX at the input of the same read-out amplifier. Only one of these points is in dynamic operation: in state 1, it supplies the read-out signal of Figure 4, RX. This signal is differentiated and supplied in part to the input of the read-out amplifier, according to the divider of the equivalent diagram of Figure 9, in which Z_T represents the impedance of the tunnel diode, Z' the impedance of the separation circuit, Z_A the input impedance of the amplifier. A fraction of the input signal determined by the ratio Z_T/Z', goes to the other diodes of the same column, which are in static operation.

An exact analysis should take into account the nonlinearity of the Z_T and Z_A as well as the existence of the stray elements (series inductance and parallel capacitance). A simplified reasoning indicates that (A) Z' high with respect to Z_T assures a good separation. (B) For the negative signals (therefore the useful signal) and in the case $Z_A \gg Z'/(n-1) \gg Z_T/(n-1)$, the useful signal is divided n times. This can constitute a limitation for the number of words n according to the noise level at the input of the read-out amplifier.

Two examples of read-out amplifiers are shown in Figures 10 and 11. A silicon diode placed between the base and the collector of the first common-emitter stage assures the automatic bias of the transistor in the active region, determines the direct-voltage on the collector in the absence of signals, and slips the positive pulses.

The read-out amplifier output state can be replaced by an information register. We have successfully used a bistable circuit comprising a transistor and a tunnel diode in parallel on the emitter-base junction.

5. Construction

The most-important elements of the memory were mounted on 3 double-faced plug-in printed circuits with dimensions of 185 by 135 millimeters (7.3 by 5.3 inches). Each contains 8 × 8 memory points, 8 reading amplifiers, and 8 column drivers (WX), that is, 64 tunnel diodes, 32 transistors, and the associated passive components. A much-more-advanced minification is possible because of the extremely low power dissipated per memory point.

The principal components used for the construction of the memory are

Philco (USA) *T1975* tunnel diodes

Philco (USA) MADT *2N1500* and *2N769* transistors.

Compagnie Française Thompson Houston (France) *19P1* point-contact diodes.

Dralowid (Germany) 1/50-watt ± 10-percent carbon film resistors.

No selection of the matrix components has been made.

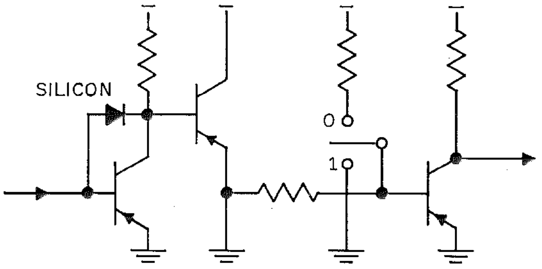

Figure 10—Read-out amplifier.

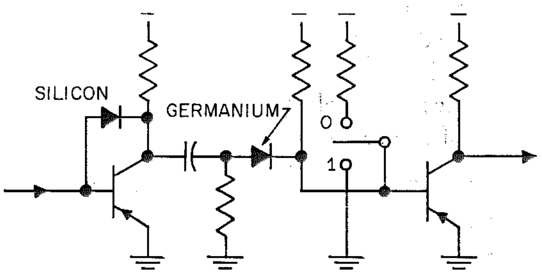

Figure 11—Read-out amplifier.

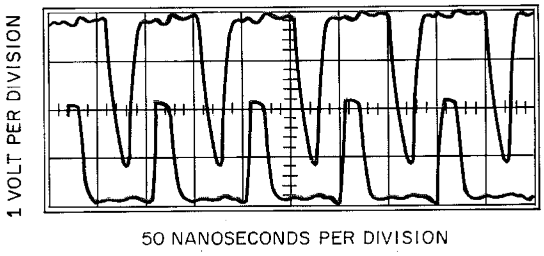

Figure 12—Upper trace is of the reading signal V_R and lower trace is of the writing signal V_W.

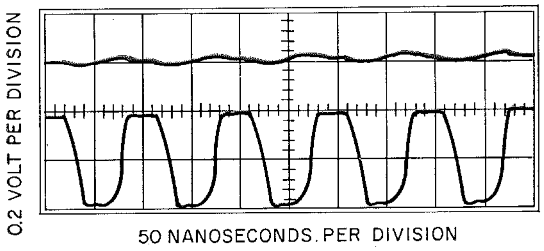

Figure 13—The 0 state of the tunnel diode is shown in the upper trace and the 1 state in the lower trace.

Very careful decouplings and much attention to ground connections were found to be indispensable to a stable design.

6. Results

The memory has been working without interruption for several months at the clock frequency of 10 megacycles per second. The complete read-write cycle occurs in 100 nanoseconds. This cycle time includes the access times for reading and for writing the memory matrix, as well as those of the different associated circuits, and notably: the address change time (switching of the address register, decoding), the delay of the drivers, and the delay of the read-out amplifier.

The reading and writing pulses have a width of $\sim$20 nanoseconds and rise and fall times of $\sim$5 nanoseconds as shown in Figure 12. The tunnel diodes in dynamic operation deliver, in the 1 state, a square signal of $\sim$0.4 volt, the switching time is 10 nanoseconds in the 0 state, there is practically no signal (<20 millivolts) at the terminals of the tunnel diodes as will be seen in Figure 13.

According to Figure 5, the admissible tolerance on the voltages is ±7.5 percent. This figure includes the tolerances on the direct voltage $-U_0' = -U_{CC}$, the overshooting of the writing pulses, as well as the nonuniformity of $-V_{CE\ sat}$ for the different transistors used as writing drivers. In reality, the memory permits a variation of ±10 percent of only the direct voltage.

The memory model (power supply included) was put into an oven and brought up to a temperature of 50 degrees centigrade. The operation was normal at this temperature, even though no compensation was provided in the circuits.

7. Conclusions

The memory shown in Figure 14 offers the following advantages and indicates that the tunnel diode has great application for small-capacity subminiature high-speed memories.

High working speed

Small power dissipation per memory point

Simplicity and low price of the access circuits

Practical tolerances on the components

Large ratio of useful signal to stray signal

Good temperature behaviour.

The working speed can be increased by using faster access circuits. The *T1975* tunnel diodes in the present circuit should make possible a memory with an access time of 20 nanoseconds. Even faster tunnel diodes might be employed.

The small power dissipation permits further reduction in the matrix through the use of micromodules and integrated circuits. It is easy to conceive of a micromodule comprising 1 tunnel diode and 2 or 3 resistors of the same value as well as integrated circuits composed as several micromodules made in a single block. The sum of the tolerances on the resistors and on the peak current of the tunnel diode need be only ±10 percent.

The capacity of the memory can be considerably increased. However, regarding cost per element, the tunnel-diode memory is most competitive in the smaller capacities because the associated circuits are simple and inexpensive. The price of the diode itself is still rather high.

It is obvious that the future of the tunnel-diode memory is related to the price of the diodes. It should be noted that the speed of digital computers is limited by the speed of the memories rather than by the speed of the logic circuits. There is a tendency to remedy this by using a very-high-speed buffer memory of small capacity with a slower memory having a much-larger capacity (ferrite-core memory, for example). The speed of the tunnel diode could make it very important in this domain.

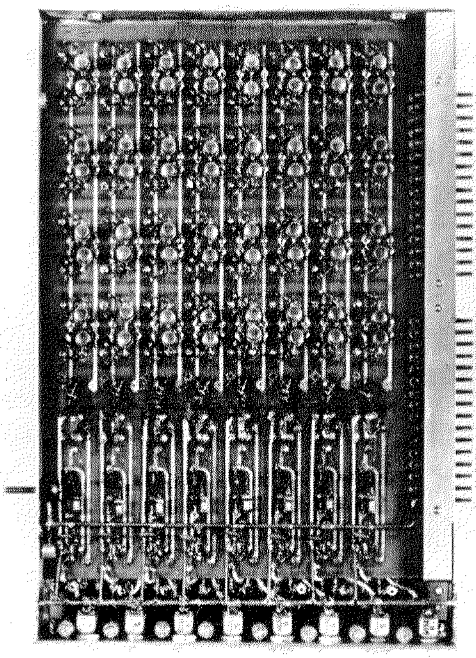

Figure 14—Tunnel-diode memory.

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Note on Tunnel Diodes for Majority Logic Circuits

A. JUDEINSTEIN
J. BEZAGUET
Laboratoire Central de Télécommunications; Paris, France

The high operating speed of the tunnel diode and its two stable states of operation suggest its use for logic circuits. The extremely simple arrangement of Figure 1 and the operating characteristics of the tunnel diode were considered for threshold logic. Unfortunately, the design computations indicate that the tolerances on the elements and voltages will be too close for commercial application.

An investigation was then made for majority logic operation of the balanced circuit shown in Figure 2 together with the characteristic curves of the diodes. A binary adder for 2 words of 8 bits each was built. The basic circuit is given in Figure 3. Addition is particularly simple, the carry and sum being expressed by

$$R_n = \text{Maj}\ (a_n,\ b_n,\ R_{n-1})$$
$$S_n = \text{Maj}\ [a_n,\ \text{Maj}\ (\bar{a}_n,\ b_n,\ R_{n-1}), \overline{R_n}].$$

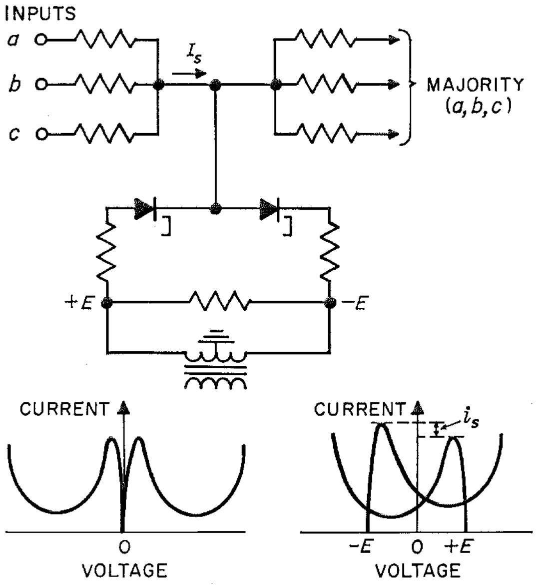

Figure 2—Balanced circuit for majority logic.

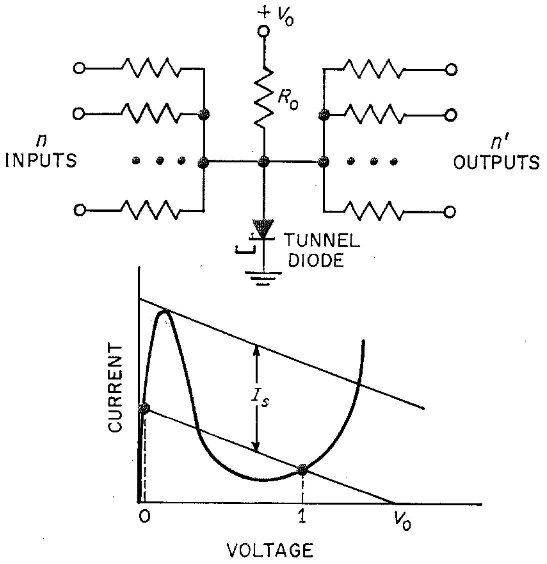

Figure 1—Threshold logic circuit and operating characteristic curve of a tunnel diode. As an AND gate, $(n-1)\ i < I_S$ and $ni > I_S$.

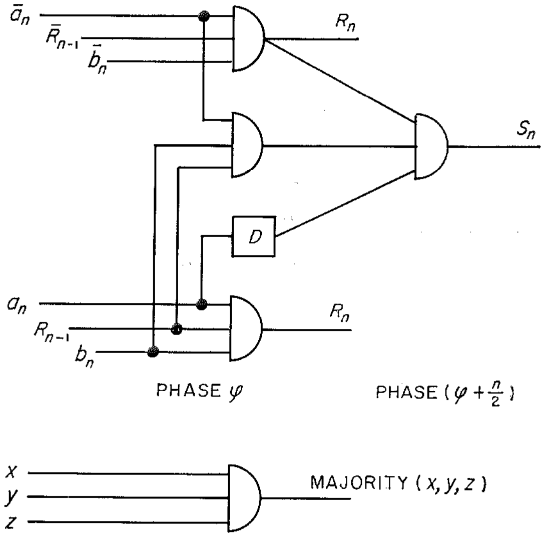

Figure 3—Binary adder.

A multiphase supply voltage is required for the balanced circuit to insure unilateral flow of information. Computation indicated that a 3-phase clock would not separate the stages satisfactorily. A 4-phase clock was selected and is easier to build. An elementary addition is performed in not over 25 nanoseconds.

With 3 inputs and a maximum of 3 outputs, the following tolerances were computed.

Peak Current ±2.5 percent
Clock Voltage ±5 percent
Resistances ±5 percent.

These close tolerances are considered to be an important handicap in view of the limited capacity of the circuit.

The working speed is limited by the variations in the diode junction capacitance, which can be as high as 15 picofarads per milliampere of peak current for commercial tunnel diodes. The speed does not exceed that obtainable from conventional diode and transistor circuits. The higher cost of the tunnel diode must also be considered but may change with increased use and manufacturing experience.

Although failure rate has not been specifically evaluated, it should not be greater than for resistors and other circuit components, particularly with surface passivation of the semiconductors.

At this time, there appear to be no definite advantages in this use of tunnel diodes over conventional systems. There are, however, good prospects of commercial production of higher-speed tunnel diodes approaching picosecond operation. For certain uses, their continued effectiveness in the presence of nuclear radiation can be of great significance.

United States Patents Issued to International Telephone and Telegraph System; May–October 1961

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C. E. Anderson, ITT Federal Laboratories, Radio-Frequency Impedance-Matching Section, 2 987 644.

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Electrical Sorting System

2 987 705

G. Van Mechelen

This patent covers an electrical sorting system for collating numbers, in which the documents are applied from two random stacks to a comparator and directed to two output stacks as a result of the comparison. The numbers are compared digit by digit. A simple reliable circuit including shift registers is provided to effect the comparisons.

Data-Sensing Routing-Control Arrangement

2 997 253

F. Mittag and J. Lindner

A pneumatic carrier routing system using a fixed permanent magnet on the carrier as a reference, and providing other permanent magnets adjustable about the carrier to provide a destination code. A sensing station is provided to pick up signals as the carrier passes the station. These signals then serve to operate switches to open a path for the carrier to the desired destination.

Producing Silicon of High Purity

2 989 378

H. F. Sterling

In a decomposition chamber, having transparent walls, in which silane is decomposed thermally to deposit silicon on a seed crystal in the form of a rod, an arrangement is provided within the chamber to wipe a circular area around the chamber. The wiper is mounted to rotate with the seed crystal support, but is provided with a mechanism to keep it at a fixed height as the rod formed on the seed crystal is withdrawn from the decomposition zone.

Electromagnetic Coordinate Switch

2 999 140

C. R. J. Dumousseau and E. Touraton

A coordinate reed-relay switch in which the operating magnetic windings are located at the ends of the operating magnetic vertical and horizontal bars. Individual operating windings are used on each bar, and a common holding winding is provided for each of the vertical and horizontal sets of bars.

Gyroscope Systems

2 986 943

J. J. B. Lair and J. E. Metzger

This is a system for maintaining the axis of rotation of a gyroscope substantially at a constant angle with respect to the supporting platform by the use of control pulses generated by the gyroscope rotation, in which greater accuracy of control is achieved by circuits that provide the same energy quantity in each control pulse.

Method of Mechanically Detecting a Mark Affixed to a Document

2 999 166

J. Schunack

A photoelectric stamp-detecting system, in which there is provided a circuit that will pass only signals above a predetermined amplitude, corresponding, for example, to the bright background of the envelope. Another circuit is provided that responds only to signals within a predetermined range, corresponding to the stamp or to a dark envelope. Stamps may thus be detected whether the background is lighter or darker than the stamp.

Television Receiver with Ultra-High-Frequency Cavity Tuner Inside Very-High-Frequency Turret Tuner

2 989 627

J. O. Silvey

This tuner for television receivers is operative in both the very-high-frequency and ultra-high-frequency bands. The very-high-frequency tuner is in the form of a turret with individual contact strips for the channels in this band. The ultra-high-frequency tuner is positioned within the cylinder forming the turret tuner and has connections to a strip of the turret for connecting it to the other receiver circuit elements.

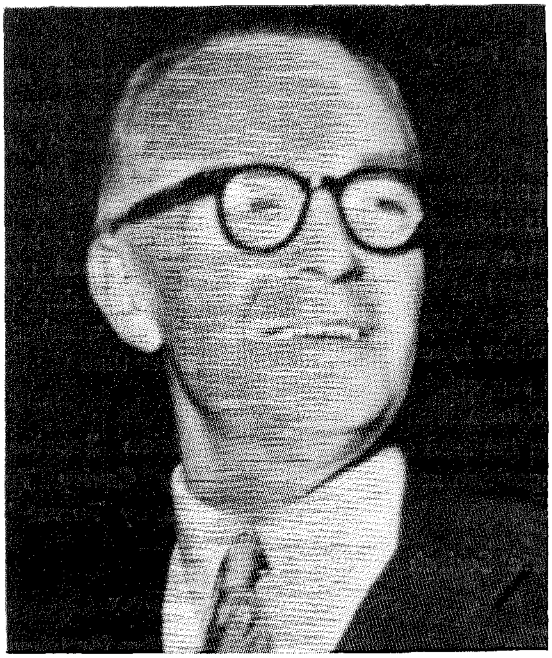
Semiconductor Devices

2 985 807

A. C. Sim

A point-contact semiconductor device produced by an electrical forming process, in which the wire used as the point-contact element is made of an alloy of tin and silver, the proportions being such that its melting point is between 400 and 500 degrees centigrade. Thus, thermal conversion of the semiconductor during forming may be avoided.

In Memoriam



GEORGE WITHEY

Cuthbert George Garland Withey was born in Arlsford, Hampshire, England, on 27 October 1906.

In 1925, he joined the Cunard Line as a radio officer and served on several of its well-known ships, including the Berengaria, Aquitania, and Queen Mary, which was his last sea appointment. He was transferred to the International Marine Radio Company in 1932, when it contracted to operate the radio services on Cunard vessels. In 1939 he was transferred to the shore staff.

Mr. Withey was appointed technical manager in 1944. He was responsible for the design and development of a complete range of marine radio equipment that had to comply with the requirements of the Atlantic City Conference of the International Telecommunications Union. He also handled many special developments and engineering projects.

Over the years, he represented the company and the marine radio industry on many advisory committees. He was an Associate of the Institution of Electrical Engineers and a Member of the Institute of Navigation.

Mr. Withey died on 28 April 1962, at the age of 56, after a short illness. Held in the highest esteem by his colleagues, he will be remembered for his selfless dedication to his duties.

Contributors to This Issue

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Eric Baguley was born in Lancashire, England, in 1905. He graduated in electrical engineering from Manchester University in 1924.

On graduation, he joined Western Electric Company in London and was soon assigned to the engineering of communication cables. Since then, he has been concerned with all types of communication cables.

From 1927 to 1932, he was with ITT Laboratories at Hendon. He was then transferred to Standard Telephones and Cables and in 1940 was placed in charge of the telephone cable development laboratories at North Woolwich. In 1955, he was transferred to the newly formed submarine cable division at Southampton, where he is now chief cable engineer.

Mr. Baguley is a Member of the Institution of Electrical Engineers.

JANINE BÉZAGUET

Janine Bézaguet was born in Carthage, Tunisia, on 5 December 1937. Licenciée es Sciences in physics and mathematics in 1958, she received her degree from the Ecole Supérieure d'Electricité in 1960.

In 1960 she joined Laboratoire Central de Télécommunications, where she is an engineer in the department on ultrafast electronics.

Miss Bézaguet is a member of the Société Française des Electroniciens et des Radioélectriciens.

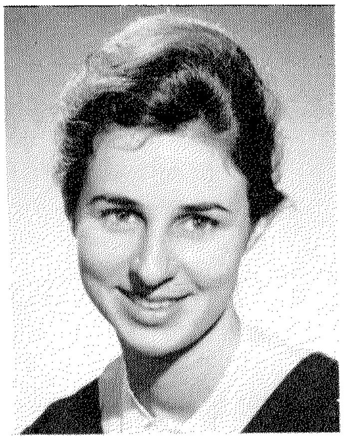
HENRI BOSC

Henri Bosc was born in Paris, France, on 23 June 1920. He graduated as a physicist engineer from the Ecole de Physique et Chimie of Paris and received the Licence es Sciences Physiques from the University of Paris in 1942.

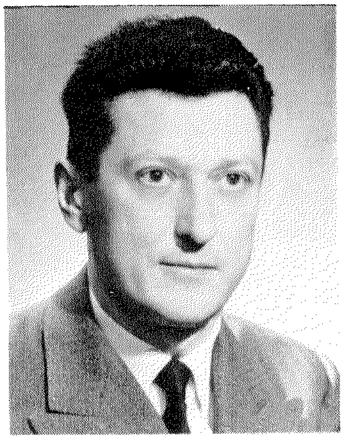
After World War II, he went to work for Compagnie Française Thomson Houston. In 1954, he joined Laboratoire Central de Télécommunications, where he is the head of a department in charge of military radars and applications of lasers.

ERIC BAGULEY

JANINE BÉZAGUET



HENRI BOSC



Henri de Lanouvelle

Henri de Lanouvelle was born in Marseilles, France, on 6 January 1921. He graduated as a regular naval officer in 1941 and as a Certified Radio Engineer in 1943 from the Ecole Supérieure d'Electricité.

The French navy assigned him to Laboratoire Central de Télécommunications for a year of training in electronics and to England for half a year of training in radar. He then served as a radar officer until 1947.

In 1948, he joined Le Matériel Téléphonique and spent half of that year at ITT Federal Laboratories working on the ILS-2 instrument landing system. Returning to France, he supervised evaluation trials and the installation of ten instrument-landing-system runways. He lectured on navigation electronics for four years at Ecole Nationale de l'Aviation Civile. Since 1955, he has been engaged in the introduction of tacan to the French forces.

M. de Lanouvelle is an Associate Member of Société Française des Electroniciens et des Radioélectriciens.

C. Della Giovanna

C. Della Giovanna was born in Potenza, Italy, on 23 December 1916. He received a degree in electrical engineering from Genoa University in 1938.

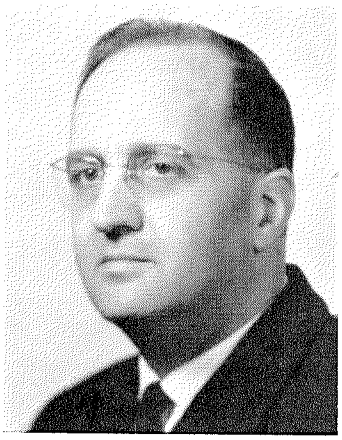
He then spent some time with Societa Italiana Telecomunicazioni Siemens in Milan and from 1939 to 1950, he worked for Societa Anonima Fabbricazione Apparecchi Radiofonici, advancing to technical director.

In 1950, he joined Fabbrica Apparecchiature per Comunicazioni Elettriche Standard, where he is now assistant to the managing director.

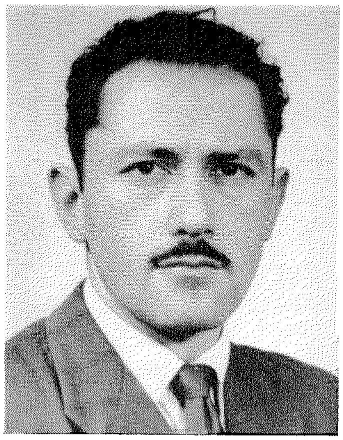
Mr. Della Giovanna teaches telegraphy and data transmission at Milan Polytechnic University. He is a delegate of the Compañia de Telefonos de Chile to the Comité Consultatif International Télégraphique et Téléphonique. He is a Member of the Associazione Elettrotecnica Italiana and a Senior Member of the Institute of Radio Engineers.

Henri de Lanouvelle

C. Della Giovanna



Lucien R. Gillon



C. W. Earp

C. W. Earp. A photograph and biography of Mr. Earp will be found on page 166 of volume 37, number 2, 1961.

Lucien R. Gillon

Lucien R. Gillon was born in Saint-Maur-des-Fossés, France, on 21 February 1920. He graduated in 1940 as an engineer from the Ecole Nationale d'Arts et Métiers of Paris.

He joined the Compagnie Générale de Constructions Téléphoniques in 1941 and was assigned to the remote-control division of the technical department. He is now in the research division and is concerned with development of industrial products.

F. Gliubich

F. Gliubich was born in Turin, Italy, in 1929. He received a doctorate in electrotechnical engineering from the University of Milan in 1955. He joined the sales department of Fabbrica Apparecchiature per Comunicazioni Elettriche Standard in 1957 in charge of remote control and telemetering. He is especially concerned with railway application of these techniques.

Andre Judeinstein

Andre Judeinstein was born in Paris, France, on 2 January 1931. In 1955, he received his engineering degree from the Ecole de Physique et Chimie Industrielles de la Ville de Paris.

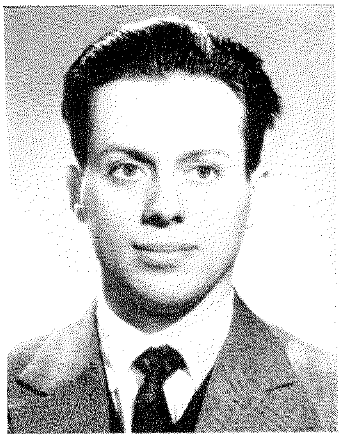
In 1958, he joined Compagnie Française Thomson Houston to work on microwave tubes. In 1959, he entered the switching research department of Laboratoire Central de Télécommunications, where he is now the head of the department on ultrafast electronics.

R. W. Lomax

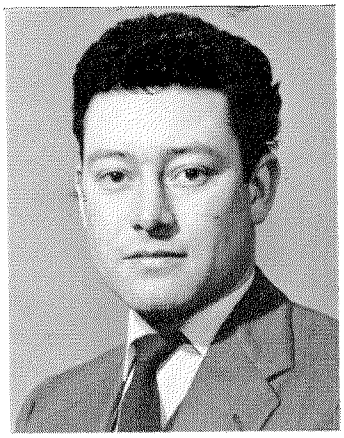
R. W. Lomax was born in London on 21 October 1935. He served a five-year apprenticeship as a lamp engineer with Associated Electrical Industries, during which he obtained a

F. Gliubich

Andre Judeinstein



R. W. Lomax



Higher National Certificate in electrical engineering. He received a degree in physics from the University of London in 1960.

In 1960, he joined Standard Telecommunication Laboratories, where he has been working on electro-optical devices.

Mr. Lomax is a graduate Member of both the Institute of Physics and the Institution of Electrical Engineers.

J. Lytollis

J. Lytollis was born in Skegness, Lincolnshire in 1924. He was educated at Worcester College, Oxford, and received a bachelor of arts degree in physics from the Honour School of Natural Science in 1945.

He spent two years with the Philips group of companies and three years as Instructor Officer in the Royal Navy.

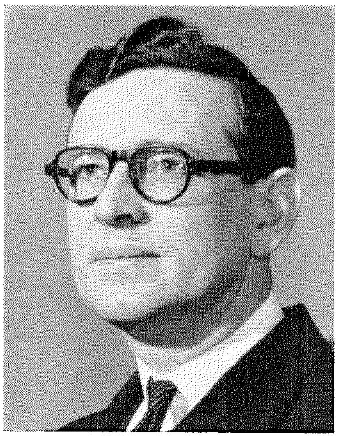
In 1951, he joined the Enfield valve laboratory of Standard Telephones and Cables and within the year was transferred to the valve division of Standard Telecommunication Laboratories. In 1959, he went to the electro-optics department where he is working on generators for pulsing light in the nanosecond range and methods of modulating light at high frequencies.

Marcel Pauthier

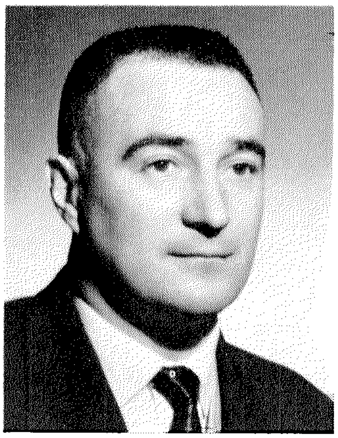
Marcel Pauthier was born in Paris, France, 3 November 1923. In 1946, he received his engineering degree from the Ecole de Physique et Chimie Industrielles de la Ville de Paris.

From 1946 to 1950, he was in the aviation laboratories of Société Nationale d'Etudes et de Constructions de Moteurs d'Aviation. In 1950, he joined Laboratoire Central de Télécommunications, working on solid ultrasonic delay lines. He was on loan to the French atomic energy commission to participate in the development of the Saturn proton synchrotron. On his return to Laboratoire Central de Télé-

J. Lytollis



Marcel Pauthier



communications, he was engaged in the development of the fully electronic 240-line automatic telephone exchange. Since 1959, he has been in charge of advanced research.

F. H. STEINER

F. H. Steiner was born in Villach, Austria, on 2 June 1913. The Technical University in Vienna conferred on him a diploma in 1938 and a Dr. Ing. degree in 1946. Since 1938, he has been with companies associated with the International Telephone and Telegraph Corporation. He was with C. Lorenz until 1945 and with Standard Telephon und Telegraphen in Vienna from 1946 to 1954. He joined Standard Elektrik Lorenz in 1954 in Pforzheim and Stuttgart and is in charge of cybernetics, including the development of direction finders, remote control, telemetering, and radar data handling. He has been engaged for many years in the planning of navigation and air-traffic-control systems.

J. M. TYSZKA

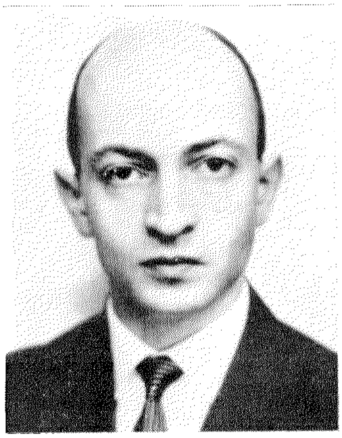
J. M. Tyszka was born in Lodz, Poland, on 23 May 1931. He received a bachelor of science degree in engineering in 1954 and a master of science degree three years later from Politechnika Warszawska, where he also served as a faculty assistant.

In 1956–1957, he was an engineer at the Institute of Mathematical Instruments of the Polish Academy of Sciences. He then joined the Laboratoire de Physique de l'Ecole Normale Supérieure in Paris to work toward a doctorate.

Since 1960, Mr. Tyszka has been with Laboratoire Central de Télécommunications, working on tunnel-diode memories.

F. H. STEINER

J. M. TYSZKA



Principal ITT System Products

Telecommunication Equipment and Systems

- Automatic telephone and telegraph central office switching systems
- Private telephone and telegraph exchanges—PABX and PAX, electromechanical and electronic
- Carrier systems: telephone, telegraph, power-line
- Long-distance dialing and signaling equipment
- Automatic message accounting and ticketing equipment
- Switchboards: manual, central office, toll
- Telephones: desk, wall, pay-station
- Automatic answering and recording equipment
- Microwave radio systems: line-of-sight, over-the-horizon
- Radio multiplex equipment
- Coaxial cable systems
- Submarine cable systems, including repeaters
- Data-transmission systems
- Teleprinters and facsimile equipment

Military/Space Equipment and Systems

- Aircraft weapon systems
- Missile fuzing, launching, guidance, tracking, recording, and control systems
- Missile-range control and instrumentation
- Electronic countermeasures
- Electronic navigation
- Power systems: ground-support, aircraft, spacecraft, missile
- Radar
- Simulators: missile, aircraft, radar
- Ground and environmental test equipment
- Programmers, automatic
- Infrared detection and guidance equipment
- Global and space communication, control, and data systems
- Nuclear instrumentation
- Antisubmarine warfare systems
- System management: worldwide, local

Industrial/Commercial Equipment and Systems

- Distance-measuring and bearing systems: Tacan, DMET, Vortac, Loran
- Instrument Landing Systems (ILS)
- Air-traffic control systems
- Direction finders: aircraft and marine
- Ground and airborne communication
- Data-link systems
- Inverters: static, high-power
- Power-supply systems
- Altimeters
- Flight systems
- Railway and power control and signaling systems
- Information-processing and document-handling systems
- Analog-digital converters
- Mail-handling systems
- Pneumatic tube systems
- Broadcast transmitters: AM, FM, TV
- Studio equipment
- Point-to-point radio communication
- Marine radio
- Mobile communication: air, ground, marine, portable
- Closed-circuit television: industrial, aircraft, and nuclear radiation
- Slow-scan television
- Instruments: test, measuring
- Oscilloscopes: large-screen, bar-graph
- Vibration test equipment
- Magnetic amplifiers and systems
- Alarm and signaling systems
- Telemetering
- Intercommunication, paging, and public-address systems

Consumer Products

- Television and radio receivers
- High-fidelity phonographs and equipment
- Tape recorders
- Microphones and loudspeakers
- Refrigerators, freezers
- Air conditioners
- Hearing aids
- Incandescent lamps
- Home intercommunication equipment
- Electrical housewares

Cable and Wire Products

- Multiconductor telephone cable
- Telephone wire: bridle, distribution, drop
- Switchboard and terminating cable
- Telephone cords
- Sumarine cable
- Coaxial cable, air and solid dielectric
- Waveguides
- Aircraft cable
- Power cable
- Domestic cord sets
- Fuses and wiring devices
- Wire, general-purpose

Components and Materials

- Power rectifiers: selenium, silicon
- Parametric amplifiers
- Transistors
- Diodes: tunnel, zener, parametric
- Semiconductor materials: selenium, germanium, silicon
- Capacitors: wet, dry, ceramic
- Ferrites
- Tubes: power, transmitting, traveling-wave, rectifier, receiving, thyratron
- Picture tubes
- Relays and switches: telephone, industrial
- Magnetic counters
- Resistors
- Varistors
- Fluorescent starters
- Transformers
- Quartz crystals
- Crystal filters
- Printed circuits
- Hermetic seals
- Magnetic cores

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