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This Issue in Brief

Optical Character Readers for Automatic Document Handling in Banking Applications—The character readers discussed are limited to the 10 digits and to 4 arbitrary symbols used in bookkeeping.

In the reader described in detail, use is made of specially shaped characters that have their vertical strokes arranged in such a way as to aid machine identification without interfering with human reading. An enlarged optical image of the characters to be read is drawn at right angles across a row of 20 photodiodes. Only about 7 photodiodes operate on a character, the others providing for misalignment of characters and tilting of the document. The vertical strokes in the upper and lower halves of the characters are scanned in 5 columns to produce signals that identify each individual character.

By using both visible and infrared wavelengths, full response occurs for letterpress, typewriter, and black lead pencil. Other markings, such as from fountain and ball-point pens, stamp pads, and color pencils do not interfere with the machine.

Extensive tests were made by the German post office of 6 systems, 4 of which have been discontinued to permit future testing to be concentrated on this optical method and a magnetic system.

Automatic Postal Check Handling in Germany—The Deutsche Bundespost placed an order with several firms for a trial installation capable of mechanizing the handling of 20 000 accounts in the postal check system, which is limited to the deposit, transfer, and withdrawal of funds.

The characteristic feature of the trial installation is its capability to make on-line entries for all debit and credit notes regardless of their sequence. Therefore the *ER 56* Computer is equipped with 4 magnetic drum stores, which serve as account stores with an average access time for every account of 10 milliseconds.

The Deutsche Bundespost has developed a new document for all transactions. At the bottom of this document there may be encoded as many as 42 characters that can be read either mechanically or visually. The reader-sorter with 17 pockets is connected to the electronic computer and can read the encoded documents with a maximum speed of 45 000 documents per hour.

For printing the statements of account and enclosing these statements with the credit notes in a window envelope there has been developed a special machine, the envelope stuffer. This machine is the most-complicated electromechanical equipment of the test installation and is also linked to the *ER 56*.

Microwave Power Sources Using Solid-State Devices—Performance requirements are considered including power output, frequency, bandwidth, efficiency, operating temperature range, and spurious output levels of discrete tones and of noise. These requirements depend on the application of the source (for example, local oscillator of a radio relay link, frequency-modulated radio altimeter, radio relay up-converter, or directly modulated source).

The simple reverse-bias theory of varactor frequency multiplication is discussed, followed by consideration of the effects of positive drive on power and efficiency. Practical doubler circuits are described, and results of typical operation are given. The use of a varactor for up-conversion depends on radio-frequency input and intermediate-frequency drive and matching conditions; some typical results are given.

Triplers have the best efficiency; doublers and quadruplers have equal but lower efficiencies; quintuplers are even lower than doublers. If doublers and/or quadruplers are used in a chain with triplers, the triplers should follow them. Doublers and quadruplers may be cascaded in any order. Relative performance figures are given for chains multiplying up to 32 times.

The generation of spurious tones and noise in multipliers is examined, and methods of measurement are described. Tunnel-diode sources can also be applied to low-power local oscillators, and an account of their uses and limitations is given.

Future prospects are in the areas of increased power output, efficiency, and frequency, and in the possible development of gallium-arsenide varactor diodes.

Aerial Branching System Using Interdigital Filters—A microwave-antenna branching filter is described that uses coupled-transmission-line 3-decibel couplers and interdigital filters. Details are given of the performance of these components and of a complete 4-section branching filter that is suitable for use in a radio relay system in the 2-gigahertz band.

Otto Scheller and the Invention and Applications of the Radio-Range Principle—Two German patents issued in 1907 and 1916 disclosed the principles of the four-course radio range and of the goniometer method of coupling power to the two directive antenna arrays to permit easy adjustment of the azimuth bearing of the course without the need to modify the antennas themselves. They included the interlocking of the keying of the two radiators to give a constant equisignal indication when on course and, by noting whether dot keying or dash keying was dominant when off course, to determine to which side the course would be found. These principles are used in many radio navigation systems such as radio ranges, instrument landing or low-approach systems, and Consol.

Dewline After A Decade of Field Operation and Maintenance—The Dewline consists of an integrated chain of radar and communication systems extending about 6000 miles (9600 kilometers) from the Aleutian Islands to Iceland. From a standing start in December, 1954, an operational line was made available by the summer of 1957, despite the short summer construction seasons.

Because of the crash nature of the program, most of the equipment did not enjoy a normal development period before installation and use. Also, the Arctic presented an unfavorable environment to the outside plant and equipment. Finally, faulty logistics extended the length of failure times because parts were not available.

Complete redundancy of the equipment enabled the Dewline to operate satisfactorily despite the initial rash of equipment outages. With time, the outages were sharply reduced through equipment modifications, receipt of adequate instruction manuals, use of higher-quality parts, improved preventive-maintenance schedules, and computer-controlled procurement of spare parts.

The effects on system performance of adding the Dewdrop and Deweast links are included. The amount of maintenance required by each of the major electronic equipments used on the Dewline is also given.

Estimating Voltage Surges on Buried Coaxial Cables Struck by Lightning—General equations are given for estimating the peak values of surges that are liable to damage the insulation of coaxial cables. It is shown that at the points where the peaks are highest the surges may be expressed by products of three functions, involving, respectively, the parameters of the cable under consideration, the resistivity of the soil in which the cable is embedded, and the time and characteristics of the lightning stroke. A set of curves representing typical conditions indicates the order of the peak values to be expected. The surges inside the coaxial pairs are relatively small provided that the dielectric outside the pairs remains intact. However, if this dielectric fails, the surges inside the pairs leap in value by a factor of 10 or more.

Characteristics and Applications of Reed Contacts—Reed contacts have two long thin tongues of magnetic material arranged in line with a slight separation between them at a small overlap area. When subjected to a magnetic field, the tongues attract each other, closing the gap and providing electrical contact through the overlapped area. Mounted in a glass tube filled with protective gas, the contact unit slips into the operating coil. The small mass and short travel of the contacts permit rapid operation.

Tests in the laboratory and experience with over 10^5 contacts in field installations since 1959 show that representative designs operate for several million contact closures before any failures occur. The protective gas prevents corrosion, arcing, and burning of the contact areas. The contact resistance is low and unvarying even for long periods of inactivity, either with contacts closed and representative values of current flowing through them, or with contacts open. The insulation resistance for open contacts is that of the glass enclosure and drops to a low of 100 megohms for 90-percent relative humidity and 40 degrees Celsius.

Recent Achievements

***ESRO 1* Satellite Under Development**—The European Space Research Organization has assigned prime responsibility for its *ESRO 1* satellite (Figure 1) to Laboratoire Central de Télécommunications, which will handle design, development, testing, and launch support. Contraves AG of Switzerland will be a subcontractor and is well known for its experience in missile manufacture. Bell Telephone Manufacturing Company will also serve as a subcontractor on tracking and guidance systems.

The satellite will be launched in 1967 into a polar orbit having an apogee and a perigee of 1500 and 275 kilometers (932 and 171 statute miles), respectively. It will be magnetically stabilized by passive means. Its purpose will be to collect data for about 6 months on ionosphere conditions in the north polar region.

Laboratoire Central de Télécommunications
France
Bell Telephone Manufacturing Company
Belgium

Satellite Sequence Programers—At the request of the Société pour l'Étude et la Réalisation d'Engins Balistiques, two program control systems have been developed for the French space program based on the "Diamant" launching vehicle.

The type-*A* programer shown in Figure 2 controls precisely the operations of the rocket that launches the satellite.

Figure 1—Model of the *ESRO 1* satellite being inspected by Derek Oldroyd (left) and Roger Pacault (center) of the European Space Research Organization and Georges Phelizon (right) of Laboratoire Central de Télécommunications.

The type-*C* programer controls the equipments in the experimental orbiting payload used for checking the Diamant launcher.

Laboratoire Central de Télécommunications
France

Geodetic Satellites—The United States Army Corps of Engineers has ordered three more geodetic satellites to follow the original satellite that has been operating in orbit beyond its planned life of 6 months. It is used to establish the precise locations of widely separated places on the surface of the earth. This program, known as SECOR for Sequential Collation of Range, is helping to determine the exact size and shape of the earth.

The 40-pound (18-kilogram) satellite shown in Figure 3 carries a transponder that repeats measurement signals to ground terminals. With the exact positions of three terminals established, the location of an unknown fourth terminal can be calculated. This rectangular satellite circles the earth at an altitude of 600 miles (965 kilometers) in about a hundred minutes.

ITT Federal Laboratories
United States of America

Two New Exchanges Cut Over in Paris—Mr. Jacques Marette, Minister of Post and Telecommunications, officiated twice in one day in cutting over two new telephone exchanges in Paris. Accompanied by the Prefect of Val de l'Oise and high officials of his services and of Le Matériel Téléphonique, he first inaugurated the new 6000-line Pentaconta crossbar exchange in the north of Paris at Eaubonne (Figure 4). This regional center serves Eaubonne, Ermont, Franconville, Le Plessis Bouchard, Margenay, and Montlignon. It also works both ways with the 4000-line subcenter at St. Leu.

Accompanied by high-ranking civil personalities and representatives of the Paris "Intra-Muros" Administration, Mr. Marette later inaugurated Villette 2 in the eastern suburb of Paris. This 4000-line Pentaconta crossbar exchange serves Pantin, Les Lilas, Noisy-le-Sec, Romainville, Pré St. Gervais, and Bobigny. It shares a building with an existing 10 000-line rotary office.

The 10 000 lines connected to these two new central offices bring the Paris urban and suburban network to over 900 000 lines.

Le Matériel Téléphonique
France

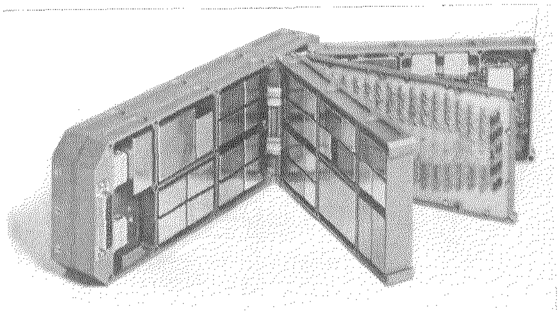


Figure 2—Module construction of the type-*A* programer, which controls the operation of the "Diamant" vehicle for launching satellites.

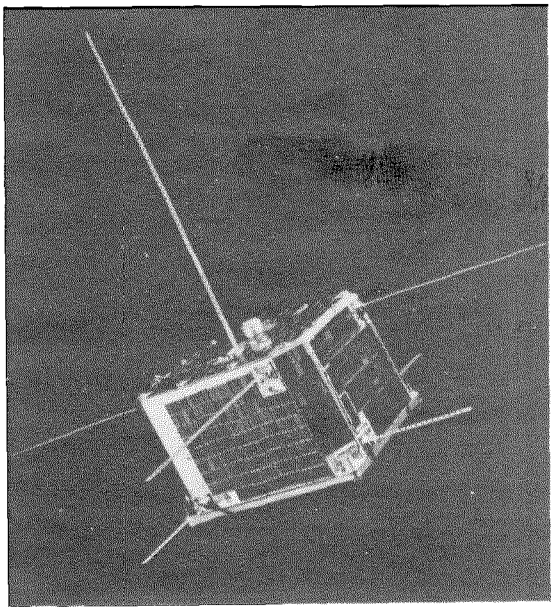


Figure 3—Geodetic satellite, still operating beyond its planned life in orbit, is used in an earth-mapping program.

Pentaconta Exchange Works With Rotary in Spain—A recently inaugurated Pentaconta telephone exchange in Toledo, Spain, interworks with an existing *7B* rotary central office with no modification of the latter. The new exchange has a final capacity of 10 000 lines and is initially equipped for 1000, while the rotary exchange serves 1900 subscribers.

Standard Eléctrica
Spain

Crossbar *48 HK 800* Exchange Cut Over—A public telephone exchange using a new crossbar system designated *48 HK 800* has been cut over in Matzen, Lower Austria, by Otto Probst, Minister of Telecommunication and Transportation, in the presence of Dr. Benno Schaginger, Director General of the Austrian posts and telecommunication administration, other high officials, and a delegation of Standard Telephon und Telegraphen headed by F. W. Mayer, General Manager.

Developed in cooperation with the Austrian Administration, this new system, through simplification and combining of switching stages, can accommodate twice the number of subscribers in the same space used by previous designs. It can be expanded to meet future needs.

Standard Telephon und Telegraphen
Austria

Flying Telephone Switchboard—An airborne electronic telephone switchboard used by the United States Air Force provides 4-wire toll quality with push-button dialing. Used for air-to-air and air-to-ground service, it provides for four classes of priority that are indicated by two prefix digits dialed from any subscriber's set. Provision is made for conference networks, intercommunication, and direct connections to radio and multiplex equipment. Operation is from the aircraft power source, supplemented by a self-contained standby battery.

ITT Kellogg Communications Systems
United States of America

Korea Radio Network Completed—A network of radio stations employing line-of-sight and tropospheric-scatter transmission to span some of the most-rugged terrain in the world has been completed in the Republic of Korea. The project included construction of buildings, prime power sources, radio equipment, antennas, voice-frequency and telegraph multiplex apparatus, telephones, cables, and instruction manuals in both English and Korean.

The complex will serve as a separate military communication network and will tie existing Air Force radar centers into an effective warning system.

ITT Federal Laboratories
Federal Electric Corporation
United States of America

Figure 4—Mr. Jacques Marette at the inauguration of the new Eaubonne telephone office in Paris.

Cathodic Protection of Oil Storage Tanks—To lessen the danger of contaminating drinking water by oil leakage, government attention has been directed to the cathodic protection of all new oil tanks and pipe lines buried in the earth. A first step is to electrically insulate these structures from earth and thus reduce the electrolytic action that causes corrosion.

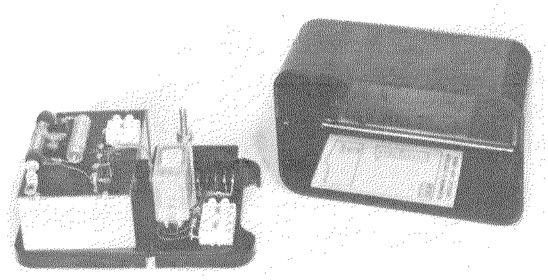


Figure 5—Rectifier for cathodic protection of oil tanks.

In Figure 5 is a small rectifier, providing up to 30 milliamperes and 3 volts, to be connected permanently for protecting tanks large enough to store 100 000 liters (26 420 United States gallons) of oil.

Two measuring sets have been developed for analyzing the requirements of each installation. The instrument shown in Figure 6 permits measurement of the potential developed electrolytically between the tank and a reference electrode of copper sulphate and copper buried in the earth near the tank, to determine the extent of protection needed. The second instrument, shown in Figure 7, is a power supply that can be adjusted to indicate the voltage and current needs of the installation. Both instruments are equipped with transistor amplifiers to minimize their effects on the circuits being tested.

Standard Téléphone et Radio
Switzerland

Figure 6—Measuring set for analyzing the electrical needs for cathodic protection.

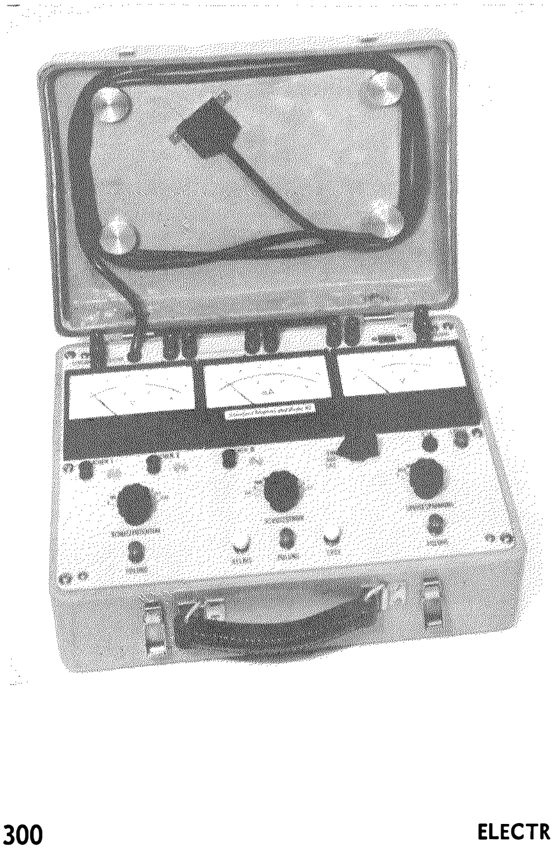
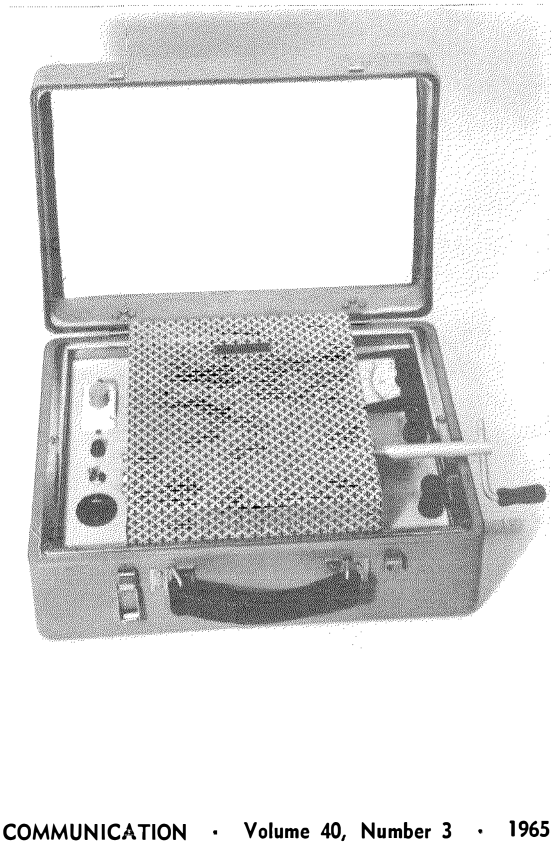


Figure 7—The voltage and current output of this power supply are adjustable to determine the electrical limits for cathodic protection of oil tanks.



Very-High-Frequency Radiotelephone Transceiver—The *P6* radiotelephone transceiver shown in Figure 8 was designed for civilian, maritime, and military service. It provides for up to 10 channels in the very-high-frequency band with channel widths of 20, 25, or 50 kilohertz.

Either a microphone-and-telephone handset or a combined loudspeaker and microphone may be had. The transistors operate from nickel-cadmium batteries and two sizes give either 10 or 20 hours of operation before recharging. Both radio-frequency and audio-frequency outputs are 0.5 watt. Temperature range is from −40 to +60 degrees Celsius. An adjustable squelch circuit and one or two calling tones are provided.

The transceiver is fully waterproof and weighs less than 1 kilogram (2.2 pounds). Its dimensions are 225 by 85 by 38 millimeters (8.9 by 3.3 by 1.5 inches).

Standard Electric
Denmark

Videx Image Converter—The Videx system transmits a television-type picture over a conventional telephone channel on a slow-scan basis for reproduction on a 5-inch (127-millimeter) display tube. The picture may be retained for long periods of time or erased at will.

A Videx image converter now enables several standard television monitors with screens up to 27 inches (686 millimeters) to reproduce these pictures. This increase in display area makes Videx useful for large photographs, weather maps, advertisements, and printed material.

A further development permits picture signals at radar weather stations to be sent over telephone lines for similar reproduction on large television monitors. Transmission is continuous and the received picture follows changes as they occur. If the receiver, who may be in the local weather station, wishes to discuss the display with the originating radar operator, the display will automatically be frozen for as long as 15 minutes at the time their telephone conversation begins.

ITT Industrial Laboratories
United States of America

Television Channel-Translator Transmitter—To extend the coverage of a television transmitter, its signal may be received and translated for transmission on another channel so as not to interfere with the original signal.

The prototype unit of Figure 9 was demonstrated to British broadcasting authorities on signals in Band 3 (179 to 215 megahertz) using British standards. The 405-line picture was

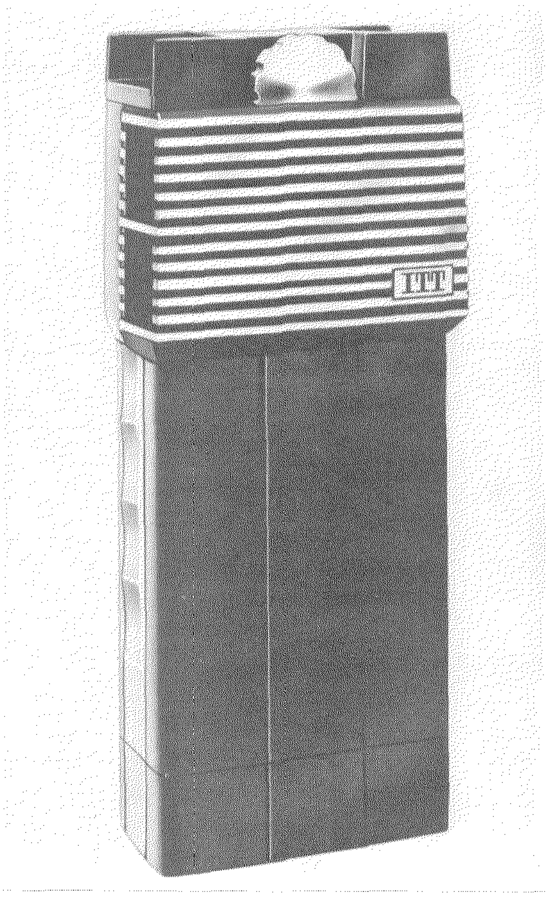


Figure 8—Very-high-frequency radiotelephone transceiver for civilian, maritime, and military service.

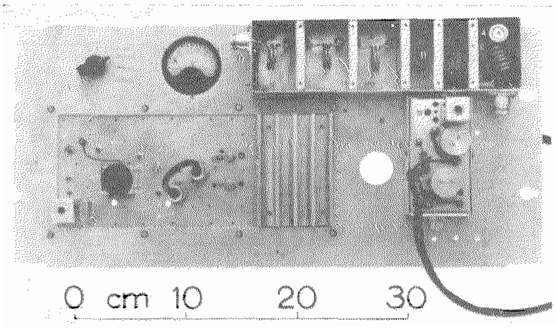


Figure 9—Laboratory model of solid-state transmitter section of a television signal translator.

transmitted with positive modulation, and the sound used amplitude modulation on a carrier level 6 decibels below the peak vision level.

The composite sound-and-vision modulation was supplied to the transmitter at the receiver intermediate frequency in the 30-to-40-megahertz range with a peak vision signal level of 6 milliwatts. After amplification to 750 milliwatts the signal was translated to the new channel in an up-converter consisting of a varactor diode pumped at a level of 16 watts from a crystal-controlled local oscillator. The upper sideband for the new channel was selected by a 4-section lumped-constant filter that suitably attenuated the intermediate, pump, and

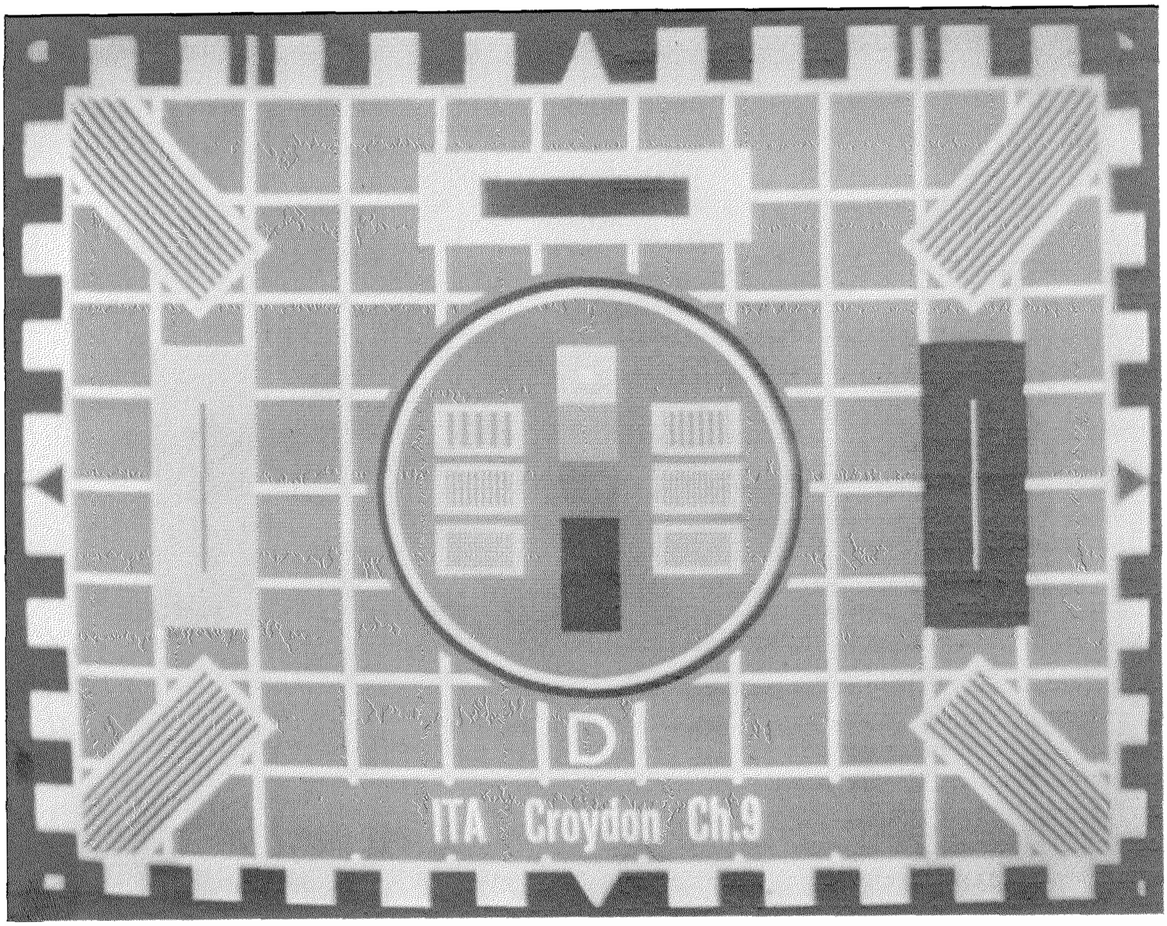


Figure 10—Test chart of signal translated from channel 9 to channel 12.

lower-sideband outputs. The peak vision output power was 2 watts with response within 0.5 decibel over the 5-megahertz bandwidth.

In the demonstration a normal test pattern in channel 9 (193 megahertz) was translated to channel 12 (208 megahertz) and produced the display given in Figure 10.

Power consumption of the transmitter was 40 watts at 28 direct volts.

Standard Telecommunication Laboratories
United Kingdom

Capacitor and Ribbon Microphones—The *4126* capacitor microphone in Figure 11 includes an integral amplifier using a field-effect transistor. Just over 2 inches (50 millimeters) long, it is particularly suited to in-shot television work. It can have either a cardioid or circular directivity pattern. With the cardioid pattern and maximum pick-up in line with the main axis, the microphone is ideal for an individual performer.

The *4119* ribbon microphone, tubular in shape, has a narrow-cardioid directivity pattern and is intended to be held close to the mouth of the performer. A spherical woven wire wind shield is provided. Its tubular bass chamber serves also as a convenient handle.

Figure 11—This miniature capacitor microphone, containing a transistor amplifier in the case, is designed for television broadcasting.

Standard Telephones and Cables
United Kingdom

Data Communication System *GH-201*—The *GH-201* shown in Figure 12 is a flexible data system for operation between various kinds of data sources and sinks such as paper tape, punched cards, magnetic tape, printed copy, and other media. It will handle characters of 8 bits at speeds as high as 200 characters per second. It may operate on-line with computers. The *GH-201A* can use communication-type paper tape with 4, 5, 6, 7, or 8 channels at speeds up to 133⅓ characters per second.

A 2-wire line is required for either switched telephone networks or private lines. The terminals can be arranged for 1-way or reversible 1-way transmission.

Error detection takes place at the receive end and a correction is made by retransmission. To ensure clean output, only characters found free of error are released from the receiver. The send terminal can make a continuous parity check if the input data includes parity bits.

The system conforms mechanically to the standard equipment practice for ITT Europe and

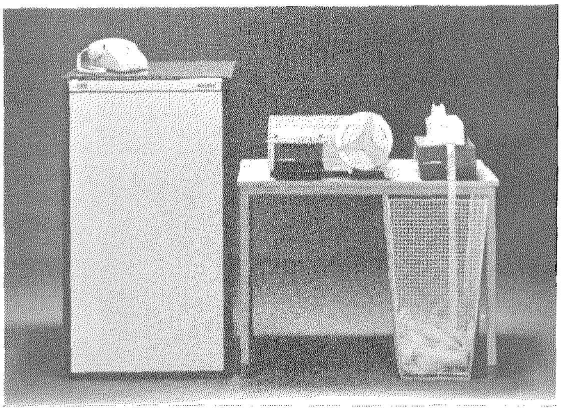


Figure 12—Data communication system type *GH-201*.

electrically to the recommendations of the Comité Consultatif International Télégraphique et Téléphonique.

Standard Radio & Telefon
Sweden

Data Modem *GH-2002*—The *GH-2002* is a frequency-modulated modem for data transmission in the serial mode over telephone channels. Asynchronous operation may be at any speed up to 1200 bits per second. Synchronous operation is crystal controlled at either 600 or 1200 bits per second. A supervisory channel at 75 bits per second facilitates transmission of supervisory signals in the backward direction.

Three versions are available. The *GH-2002A* is for reversible 1-way transmission over switched telephone networks or 2-wire private lines. The *GH-2002B* provides for simultaneous 2-way working over 4-wire lines and reversible 1-way transmission over 2-wire lines. The *GH-2002C* is for way stations multipled over a 4-wire private line. Way stations can transmit to the master station one at a time and all way stations receive simultaneously from the master station.

Remotely controlled equalizers to compensate for envelope delay are available for use with error-detecting systems. The modem can be mounted in a desk-top cabinet as shown in Figure 13 or in a 19-inch (483-millimeter) rack conforming mechanically to the standard equipment practice for ITT Europe and electrically to recommendations of the Comité Consultatif International Télégraphique et Téléphonique.

Figure 13—Data transmission modem *GH-2002*.

Standard Radio & Telefon
Sweden

Data Modem *GH-4002*—The *GH-4002* modem of Figure 14 is intended for data transmission over switched telephone networks. Parallel-mode transmission permits the design of a relatively inexpensive send terminal so that the system is particularly suitable if a large number of send terminals are transmitting sequentially to a central receive terminal.

The modem will transmit 75 characters per second, each of 8 bits. Timing information is normally transmitted simultaneously with the data over a specially designed timing channel. A supervisory channel enables the receive terminal to send amplitude- or frequency-modulated answer-back signals to the transmit terminal.

Frequency coding is of the 4-out-of-16 type. The modulators generate 4 tones simultaneously, one from each of 4 groups of 4 frequencies.

The receive terminal provides for binary-coded output and can be adapted for other codes by replacing subunits. Return-to-zero coding with an at-rest condition between characters is particularly interesting for transmission rates not exceeding 20 characters per second. The timing

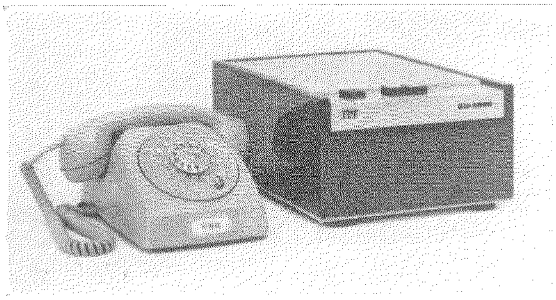


Figure 14—Data transmission modem *GH-4002*.

information can then be extracted from the received data, making the timing channel unnecessary.

A variety of input and output media may be used. The modem can be adapted to manual keyboard operation and to punched-tape and punched-card machines using character-by-character operation.

The modems are normally housed in desk-type cabinets but can be mounted on 19-inch (483-millimeter) racks. Mechanical construction is in accord with the standard equipment practice for ITT Europe.

Standard Radio & Telefon
Sweden

Tacan Computer for Off-Track Navigation—The normal bearing information derived from the *AN/ARN-21* Tacan equipment is often used to actuate a left-right indicator for homing on the beacon transmitter.

The computer in the rectangular case in Figure 15 permits not only the simple homing operation, but by using both bearing and distance information provides for lateral straight courses with the beacon transmitter to the left or to the right of the course and for circular paths orbiting the beacon either clockwise or counterclockwise. Flight tests have shown accuracy of course to be within 1 nautical mile (1.85 kilometers) out to distances of 80 nautical miles (148 kilometers) from the beacon. The computer weighs less than 0.9 kilogram (2 pounds) and is 125 by 55 by 75 millimeters (5 by 2.2 by 3 inches) in size.

Le Matériel Téléphonique
France

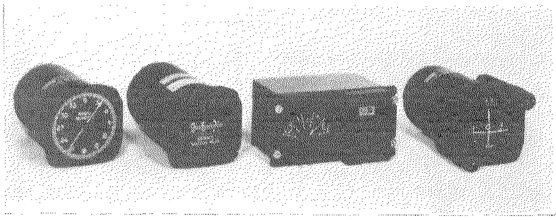


Figure 15—The computer in the rectangular case operates on the bearing and distance information provided by Tacan navigation equipment. It permits straight courses past the beacon or orbits around the beacon by observing the left-right deviation indication on the instrument at the right.

Inorganic Film Deposition—Glassy and amorphous film may be deposited on glass, plastic, and metal by a vapor-phase process using a glow discharge induced by a radio-frequency field. Heat has normally been used to energize the gas molecules to produce this kind of chemical reaction.

As shown in Figure 16, the gases are separately metered into a quartz reaction tube, which is continuously evacuated to a pressure of about 0.1 torr. The radio-frequency generator can be coupled to the gas stream by either inductance or capacitance. Deposition occurs on the substrate in the glow discharge at a rate of 2 to 10 microns per hour. As the reaction vessel remains cold and contains only the substrate and active gases, contamination is avoided.

Amorphous layers of silicon nitride have been deposited from mixtures of silane and anhydrous ammonia. If deposited at room temperature these layers are hard and electrically insulating. If deposited at or subsequently heated to 400 degrees Celsius, they become

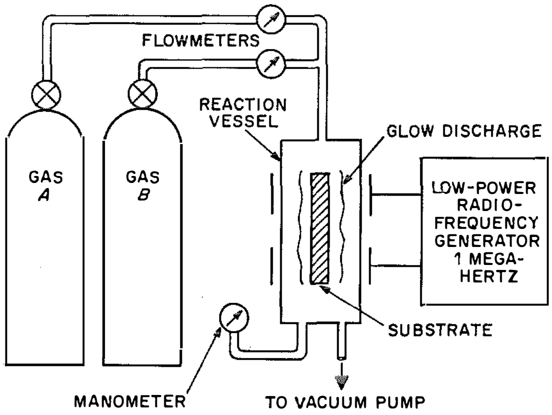


Figure 16—Apparatus for vapor deposition of glassy layers using radio-frequency glow discharge.

extremely hard, scratch resistant, and chemically inert, with a dielectric constant between 8.6 and 9.4 and a dielectric strength in excess of 5×10^6 volts per centimeter. The refractive index is 2.1.

Adherent amorphous layers of silicon, silicon dioxide, silicon carbide, and metallic molybdenum have also been formed by the same technique. The large range of possible vapor-phase reactions offers an alternative to the conventional vacuum evaporation, and possible applications include a wide field of surface protection as well as the obvious electrical uses for capacitor dielectrics, insulating glassy layers, and metallic conducting paths.

Standard Telecommunication Laboratories
United Kingdom

Centralized Control of Protection Switching for Television Networks—As shown in Figure 17, a central control station is connected via 4-wire voice-frequency channels to the television broadcast stations in a network that handles, in this example, three different programs simultaneously. Each program is distributed to the desired broadcast stations by one or more radio links having only one common standby equipment for emergency service associated with all branches of the regular channels in the whole television network.

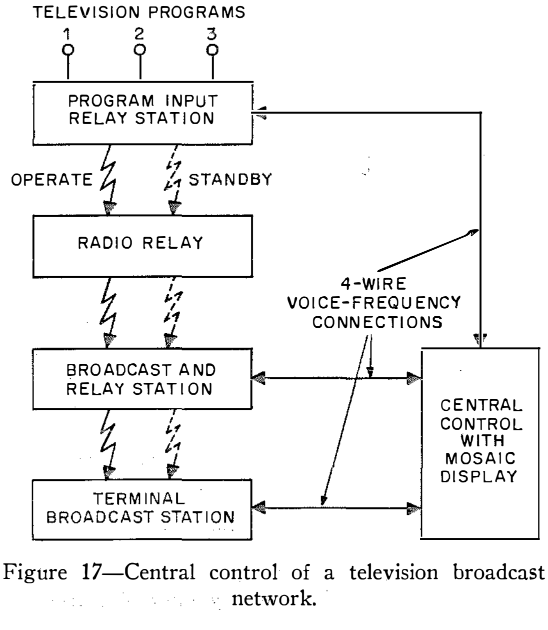


Figure 17—Central control of a television broadcast network.

The operating conditions for receiver input, intermediate-frequency output, pilot, and sound carrier levels are checked at each terminal broadcast station and are reported to the switching logic of the station. Failure indications are automatically identified as either equipment or transmission faults and are indicated to the central control station in a 2-out-of-*n* frequency code.

The control station first checks to see if the standby channel is available, commands the input terminal to transmit over the free standby in parallel to the regular channel, and on confirmation from the terminal station that the standby channel is providing the signal, then institutes the full changeover to the standby system. If more different program channels need standby facilities than exist, a decision as to which will be given preference is made by the central-control operator.

When a fault condition disappears, the return from standby to normal operation is made automatically by the terminal station. By a mosaic mimic display, central control always is informed of all operating conditions in the whole network.

Standard Elektrik Lorenz
Germany

Gallium-Arsenide Laser Operates Continuously at 77 Degrees Kelvin—Lasers with and without end-cavity reflectors have been produced that will operate continuously at the temperature of liquid nitrogen (77 degrees Kelvin). The dimensions of the laser die are 0.5 millimeter by either 0.2 or 0.1 millimeter.

It was found necessary to clamp the laser die in a heat sink in the form of a copper pincer as shown in Figure 18. Coatings of indium between the die and the copper ensure good thermal contact.

A typical continuous-laser threshold value is 900 milliamperes, corresponding to a current density of 900 amperes per square centimeter, but it has been found possible to increase the current density above threshold by factors of 3 or 4, giving power outputs in excess of 500 milliwatts.

Standard Telecommunication Laboratories
United Kingdom

Transportable Microwave Radio Terminal, *AN/TRC-112*—Transportable terminals or repeaters shown in Figure 19 for tropospheric-scatter and line-of-sight operation in the 2-, 5-, or 8-megahertz bands have been delivered to the United States Army Electronics Command. Transmitting and receiving equipment, two demountable paraboloidal antennas, and a shelter are transported in two light trucks each towing a small trailer containing the primary power sources. The station can be on the air 30 minutes after arrival at a site.

Except for a 1-kilowatt klystron power tube, solid-state active components are used throughout. A frequency synthesizer provides output frequencies at 1-megahertz intervals through each band. Provision is made for 300 frequency-division telephone channels and for teleprinter and data transmission from standard military and commercial sources. The system will also work with tactical pulse-code-modulation equipment.

In the receiver, a tunnel-diode amplifier gives a noise figure of 4.5 decibels, which increases to 9.5 decibels if the amplifier is bypassed.

The two demountable paraboloidal antennas are 10 feet (3 meters) in diameter and may be used for either angle or space diversity with predetection combining in a squelched linear adder. Beam broadening and increased receiver sensitivity may be employed for rapid signal acquisition.

ITT Federal Laboratories
United States of America

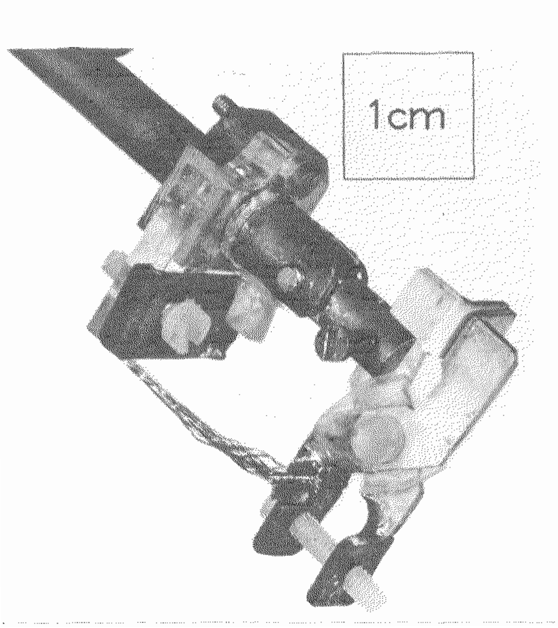


Figure 18—Copper pincer heat sink for gallium-arsenide die used as a laser.

Figure 19—The *AN/TRC-112* may be set up for operation within a half hour after reaching a site. The entire equipment is stowed in the two trucks for transportation and two small trailers (not shown) carry the primary power source.

Digital Motors—Bidirectional pulse-operated magnetically detented motors suitable for control systems, data processing, and computer interface applications have recently become available. A wide range of torque, speed, and accuracy requirements can be met. They feature controlled speed, immediate reversal, no brushes, no drift, and minimum overshoot. Compensation networks or feedback are not required.

The motor and its plug-in printed-circuit controller are shown in Figure 20.

Automatic Development Corporation,
a division of Barton Instrument Corporation
United States of America

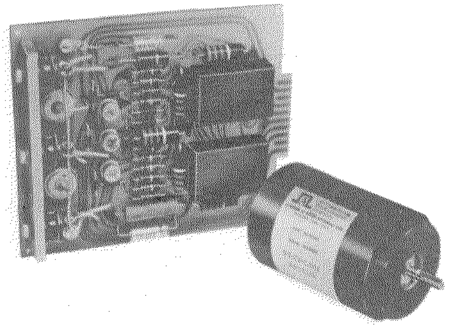


Figure 20—Bidirectional pulse-operated magnetically detented control motor.

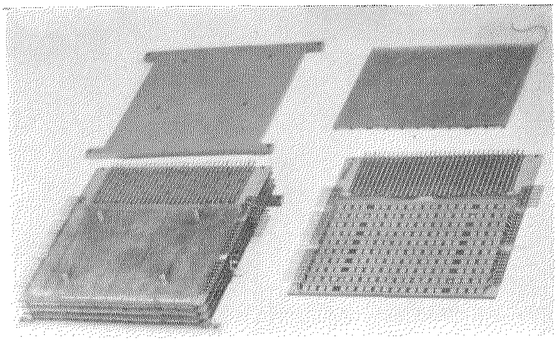


Figure 21—Semipermanent store using capacitance coupling at the crosspoints.

Semipermanent Store—The device shown in Figure 21 is basically an array of printed-circuit row and column wires. Binary information is stored at those crosspoints the capacitance of which has been increased by the insertion of plates. A read pulse applied to a given row will produce output at all capacitance-coupled columns. The active crosspoints for a given row can be changed simply by withdrawing its 20-bit code strip for replacement by another.

A maximum capacity of 5000 words of 60 bits each equals 300 000 bits. The volume is 1.35 cubic centimeters (0.08 cubic inch) per bit including the access selector. A reading speed of 250 kilohertz or 4 microseconds per reading with random access makes the store useful for class-of-line and line-number translation in telephone switching systems, for program storage in data processing, and for price lists in mail-order or similar businesses.

Bell Telephone Manufacturing Company
Belgium

Carbathene, a New Copolymer—Ziegler catalysis has been used in a low-cost process to prepare a new copolymer of ethylene and *N*-vinyl carbazole. The material is a high-molecular-weight linear thermoplastic. Compared with present high-density polythene, this low-density polythene shows slightly better unoriented tensile strength, greatly reduced stress cracking in solvents, greater stability of form at elevated temperature, enhanced resistance to repeated flexing, and lower coefficient of friction.

Moulding and extrusion are possible only above 180 degrees Celsius, as carbathene is still form stable above the phase transition temperature of 140 degrees Celsius. For this reason, its melt flow index cannot be determined with a conventional polythene grader. Crosslinking by chemicals or irradiation is also possible, although consequent changes in properties have not yet been evaluated.

Electrical properties are similar to conventional polythene. The pure polymer resists oxidation sufficiently to obviate the need for antioxidants, which tend to degrade electrical performance.

As shown in Figure 22, carbathene may be substituted for crosslinked polythene to insulate electrical conductors. The heat of soldering such conductors does not cause run-back of the insulation. Its high resistivity and low losses make it suitable for many electrical applications. Its temperature stability and resistance to stress cracking and fatigue recommend it for chemical and other pipework.

Standard Telecommunication Laboratories
United Kingdom

Remote Control and Indication for Augsburg Power Plant—Installation of Telepuls *10* remote control and indication equipment* has completed the first stage in centralizing operation of the Augsburg city power system.

Two transformer stations are each connected by 3 voice-frequency telegraph channels through *ZM 5* time-division-multiplex equipment, which permits simultaneous transmission of 5 metering indications over each channel. Transmission is protected by 2 standby channels. Each station may receive 100 different commands and transmit 130 indications to the central control office.

Standard Elektrik Lorenz
Germany

Thyristor Control Units—The single-phase and 3-phase control units shown in Figure 23 provide firing pulses under controlled delay to the gates of thyristors in power supplies to control output current and voltage.

The units have self-contained power supplies, fast time response, and will control thyristors down to 2 percent of maximum output voltage. A square-wave firing signal gives full control for inductive circuits and the pulse height is unaffected by mains voltage changes from +20 to −50 percent.

Standard Telephones and Cables
United Kingdom

Submarine Cable Between Hong Kong and Australia—The second stage of Seacom, the South-east-Asia section of the round-the-world telephone cable, is now under way. Nearly 200 undersea repeaters and equalizers, 1800 nautical miles (3350 kilometers) of submarine coaxial cable, and large quantities of shore-based power supplies and other equipment are being manufactured. The cable will link Hong Kong, Guam, Madang in New Guinea, and Cairns in Australia. At Guam it will connect with the cable between Japan and the United States, which was placed in service in 1964.

Standard Telephones and Cables
United Kingdom

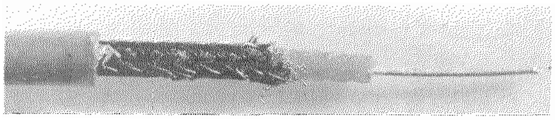


Figure 22—Miniature coaxial cable insulated with carbathene. On soldering the conductors there is no run-back of the insulation.

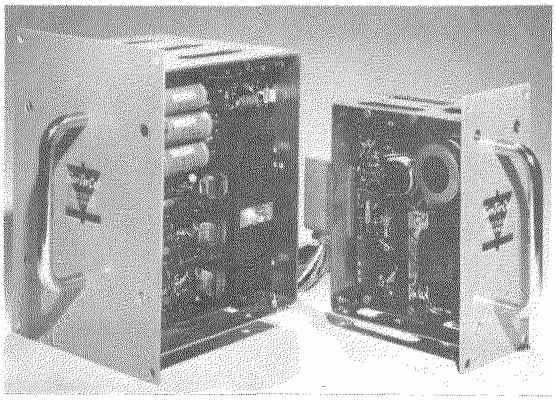


Figure 23—Single-phase and 3-phase thyristor control units.

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* K. Bartels, "Telepuls and FMX Modular Electromechanical and Electronic Remote Control," *Electrical Communication,* volume 38, number 4, pages 487–494; 1963.

Fast Analog-to-Digital Encoder—A laboratory model of the encoder shown in Figure 24 will sample analog signals between 0 and 4 volts at a rate of 1.25 megahertz and distinguish among 512 amplitude levels to produce a 9-bit output for each sample. This is more than 10 megabits per second. The sampling time is 70 nanoseconds and the total encoding time per sample is 0.8 microsecond.

The binary output of each sample is available in either series form or in parallel for 0.8 microsecond. A complementary decoder operates in 0.2 microsecond per sample and the overall accuracy is within ±0.5 level. The encoder uses 140 transistors and 250 diodes. It weighs 5 kilograms (11 pounds).

Laboratoire Central de Télécommunications
France

Data System for Aerial Photography—Data systems are being furnished to the United States Navy for use in its aerial reconnaissance photography to electronically imprint on each photograph such significant factors as the time and altitude at the moment the picture was taken.

ITT Federal Laboratories
United States of America

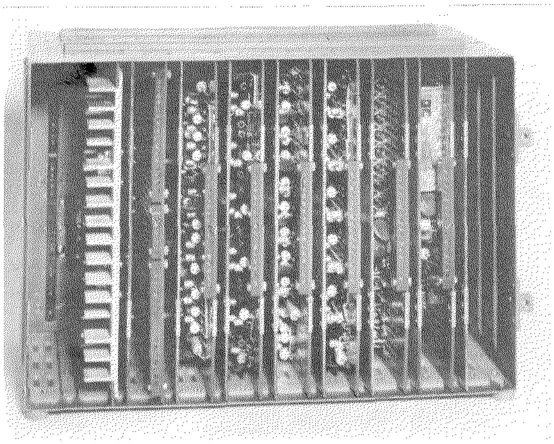


Figure 24—Analog-to-digital encoder, which samples at a 1.25-megahertz rate for 512 levels and produces 9-bit codes.

"British Admiral" Radio Installation—The main radio installation on the new 100 000-ton tanker, "British Admiral," recently launched at the Vickers-Armstrong yard in Barrow-in-Furness, includes the latest *ST 1200* marine radio transmitter, which is suitable for telegraph, telephone, and data transmission in the medium- and high-frequency bands.

Standard Telephones and Cables
United Kingdom

Double-Ended Noise Generator—A double-ended noise generator for the 90-to-140-gigahertz range employs a neon gas-discharge tube in *RG-138/U* waveguide with *TRG-714* connectors. The tube fires at 1200 volts and operates at 200 volts and 50 milliamperes. The noise figure is 18 ±0.5 decibels.

ITT Electron Tube Division
United States of America

High-Repetition-Rate Laser—The laser head shown in Figure 25 was demonstrated at the 1964 Paris exhibition of the Société Française de Physique. A useful repetition rate higher than 1 pulse per second provides burst outputs of 10 joules or peak power of 10 megawatts in Q-switched mode of operation accomplished by use of a rotating prism.

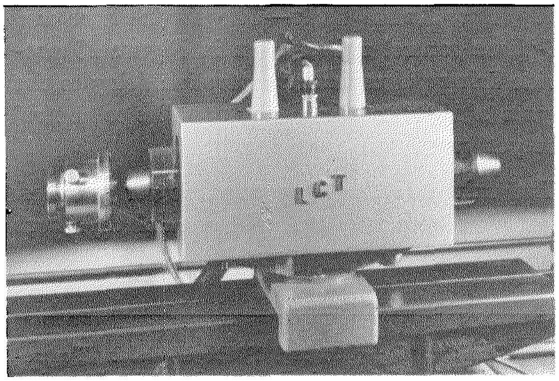


Figure 25—Ruby laser giving peak power bursts of 10 megawatts at 1-second intervals.

A ruby crystal 125 millimeters (5 inches) long by 10 millimeters (0.4 inch) in diameter was pumped optically. Both the crystal and helicoidal pump tube were water cooled to extend the life of the ruby.

The beam divergence of less than 5 milliradians and high peak power make the unit particularly adaptable to optical ranging, tracking, welding, metal removal, photochemical reactions, et cetera.

Laboratoire Central de Télécommunications
France

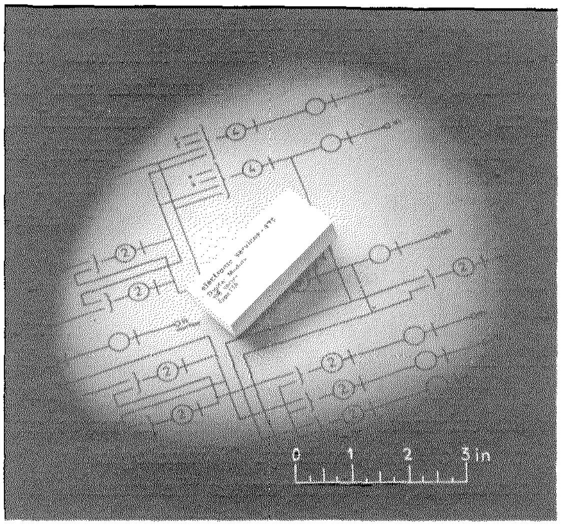
London Airport Telephone Switchboard—A private automatic branch telephone exchange cut over at London Airport has 120 lines to the local central office and 140 lines to the various airlines, other airports, and the Ministry of Aviation. A special cordless manual switchboard, independent of the automatic installation, provides service lines in the event of an emergency.

Standard Telephones and Cables
United Kingdom

Power Unit for Logic Systems—A power-supply unit for operating digital logic systems provides two output voltages. A positive output adjustable between 20.6 and 27.6 volts supplies 1 ampere and a negative output between 5.0 and 7.0 volts supplies 0.5 ampere.

The maximum ripple at full load is 1 millivolt. Up to the full load and with an input voltage variation of 20 percent, the nominal 24- and 6-volt outputs are maintained within 250 and 60 millivolts, respectively.

Figure 26—Digital circuit module in potted form.



Input may be between 210 and 250 volts at 50 or 60 hertz. Under operating conditions the permissible variation is ±25 volts. Maximum input is 75 volt-amperes. The units meet the mechanical equipment practices of ITT Europe.

Standard Telephones and Cables
United Kingdom

Digital Circuit Modules—In a new series of digital modules, the *10A* are open and the *10B* (Figure 26) are potted. They are suitable for decision logic in control systems and arithmetic logic in data-handling equipment, including the peripheral circuits. Intended for operations up to 10 kilohertz, they have high immunity to noise and a designed life of not less than 20 years. Ambient temperature may be between −10 and +70 degrees Celsius.

Standard Telephones and Cables
United Kingdom

Optical Character Readers for Automatic Document Handling in Banking Applications

W. DIETRICH

Standard Elektrik Lorenz AG; Stuttgart, Germany

Character readers are machines that recognize characters, primarily printed numerals and letters. A description of the methods and devices used for reading code combinations (punched-card and punched-tape equipment) or sensing stroke markings is beyond the scope of this paper. Compared with code readers, character readers offer the advantage of being able to read the same characters man reads.

Developments beyond the stage of fundamental research and directed at producing marketable equipment started about 10 years ago. They were enhanced by technological advances and growth of the economy. Technologically, the character reader incorporates the essential features of both electronic computers and code readers. Like the electronic computer, its realization became feasible only after the invention of the transistor. Underlying the demand for character readers are economic considerations. First, these machines allow automatic handling of original documents without requiring these documents to be duplicated or punched. Second, the number of documents to be processed has increased with economic growth to such an extent that manual processing has become problematic. Last but not least, character readers have processing speeds closer to those of electronic computers than other conventional input machines achieve, and consequently allow better use of computer time.

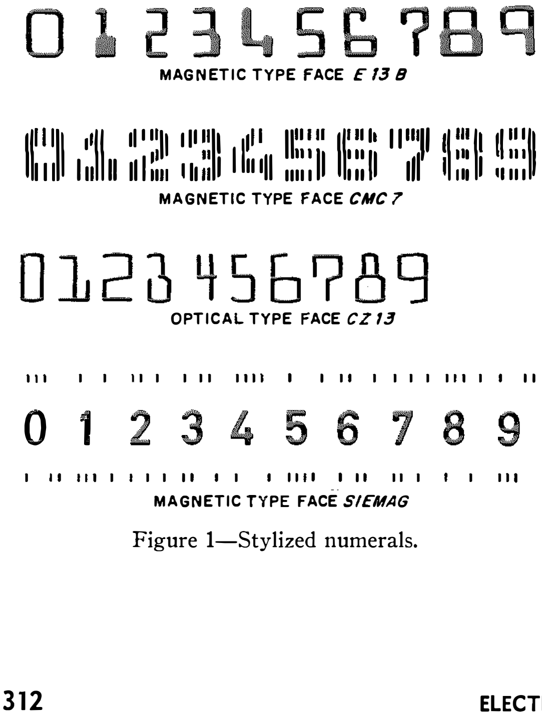


Figure 1—Stylized numerals.

While these considerations apply to many applications of character readers, there are two additional factors in their favor, particularly in banking systems: Daily accounting is desired if possible and the number of characters can be limited to 10 numerals and a few symbols. This limitation means lower equipment cost and higher reliability compared with systems that also require recognition of letters. It is therefore not surprising that the manufacturers of character-recognition equipment concentrated their efforts primarily on meeting the requirements in banking applications. As a result of these efforts, there are now available a variety of character readers that operate on very-different principles.

1. Comparison of Man and Machine

Before discussing character readers and their features, it appears advisable to outline the limits of their abilities and to draw some conclusions therefrom.

Anyone seeing a machine in operation for the first time will be disappointed by its "stupidity." The machine will often reject as unreadable characters that man reads easily without noticing any irregularity. Such incapability is inherent in all machines substituting for parts of the human organism, but we usually are not aware of it in machines we use in everyday life. (Whoever would want to cross a potato field in a car—which substitutes for our legs—or expect it to climb stairs?) The relatively low recognition capability of the character reader becomes understandable if we consider man's "expenditure" for the reading process. Brain-cell functions are sufficiently well known today for us to simulate them electronically. Science is further able to approximate the number of cells. A rough calculation shows that man's expenditure for storing and recognizing characters is 10^5 to 10^6 times greater than that of the machine.

Since nature has been generous to man, though not lavish, the large difference must result in a very-much-smaller recognition capability of the machine, especially since the machine is also required to read much faster and more reliably than man.

2. Reading Methods

For an appraisal of the various reading methods known, the following characteristics must be investigated.

Type face
Number of characters
Reading speed
Printing specifications
Reliability
Legibility to man
Sensitivity to interference
Expense
Protection from forgery

Taking into account the difficulties described earlier, the following compromise has been worked out: To attain high reliability and reading speed at tolerable cost, a special type face must be used as well as a limited number of characters and close printing tolerances. This compromise on requirements holds true primarily for banking applications. In other fields, the factors are to be accentuated slightly differently.

Four reading methods designed on this concept, but distinctively different in some ways, are being offered to the user. Other character-recognition methods developed for similar applications can only be referenced here, for example those used for reading and carrying over balances on Zeiss-Ikon account cards [1, 2], or the various document readers produced by Farrington for application to fields other than banking. These readers are used for accounting in public utilities, insurance companies, and commercial organizations [3, 4].

2.1 Type Faces

Figure 1 shows only the numerals of four type faces drawn to the same scale, while Table 1 contains further specifications of the reading methods. It is typical of the present trend in industry that the four reading methods are based on fundamentally different approaches, having in common merely the objective to provide in the characters some coding that will facilitate reading by machine.

The Siemag type face uses external coding, that is, the machine reads a bar code provided above and below Arabic numerals. The bar code is placed on the same printing hammer with the corresponding Arabic numeral. The other three type faces have internal coding (the code to be recognized by the machine is contained in the shape of the numerals).

Using the numeral *8* as an example, Figure 2 illustrates how humans and machines "see" the same character. It further shows the typical voltage waveform produced during scanning and passed to the recognition circuits. It is noteworthy that an analog waveform is obtained in the case of the type face *E 13 B,* while the

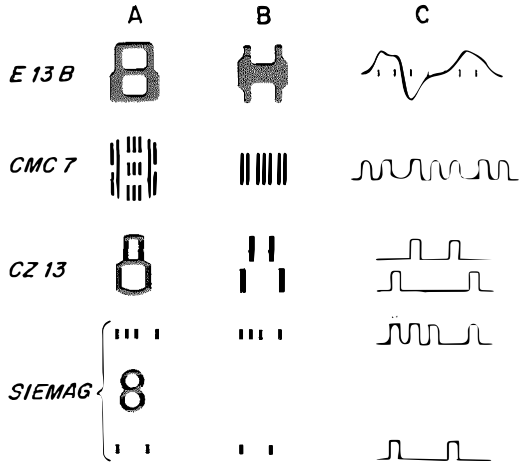


Figure 2—Using the numeral *8* as an example, *A* and *B* show how it looks to the man and to the machine, respectively. Column *C* shows the voltage waveforms derived from the numeral.

square-wave pulses of the other methods indicate digital evaluation. For analog evaluation, the vertical stroke length is decisive. A good printing quality is therefore required to ensure reliable distinction of stroke lengths. The digital methods test merely whether or not there is a stroke in the respective position. Such yes-or-no information is easier to detect and process.

Note that none of the four methods makes use of all information contained in the shape of the characters (column *B* of Figure 2). Of the many character readers developed for type face *E 13 B,* only the one produced by International Business Machines works on the basis of area resolution (not shown here), registering—though only in rough outline—the entire shape of the character. This capability increases the equipment cost, however.

The stylized characters may raise the question why no method based on conventional type faces has been mentioned here. This question is justified, especially since readers for conventional characters are available and many laboratories and organizations are working to improve them. However, even considering the inevitable higher equipment cost, these readers are unable to meet banking-application requirements with respect to reliability and reading speed. For this application, only the four type faces shown in Figure 1 are being considered. The situation may change in the future, but we may assume that character readers for stylized type faces will continue to be more advantageous in banking applications since they will also be improved.

A similar situation is encountered in handwriting readers, models of which have already been demonstrated in the United States. These machines are not suited for banking application despite their use of numerals and symbols that must meet certain requirements with regard to shape. Their reliability and reading speed are insufficient and, although able to read some handwriting, they cannot recognize printed characters.

2.2 NUMBER OF CHARACTERS

All reading methods have been developed for the ten numerals and for four symbols. Two of the type faces (*CMC 7* and Siemag) may be expanded to include printed letters.

2.3 READING SPEED

Referring to Table 1, Siemag is the only slow system. Having a processing speed as low as 320 characters per second and simple document conveying facilities with only a few pockets, this equipment is especially suited for small-scale banking automation.

The other methods shown in Table 1 are applied only in conjunction with high-capacity sorting machines provided with 12 or 13 sorting pockets and especially developed for large-scale banking automation. The difference in achievable speed is due to the fact that Siemag characters allow very-little vertical misalignment (refer to Table 1), which causes difficulties with fast document transport. In addition, the sorting machines used by the other companies are obtained from the United States where the huge volume of banking documents handled creates the need for high-capacity systems.

On the European continent, organizations branch out so widely and their document volume differs so much that both small and large processing systems must be offered. A large system denotes a sorter with about 12 pockets and a speed of 10 or more documents per second. The price, which ranges up to $100 000, is too expensive for small institutions. Cost can be essentially reduced, however, by using a document conveying system having only 2 or 3 sorting pockets and a speed of 1 to 3 documents per second.

Type faces *CMC 7* and *CZ 13* presently seem equally well suited for low and high reading speeds.

2.4 PRINTING SPECIFICATIONS

Table 1 contains some important printing specifications for the various type faces, as well as worst-case tolerances. Since the complete specifications are considerably more extensive and parts of them have been disclosed merely as provisional data, it is recommended to contact the respective manufacturers concerning particular questions. It should be noted further that the data given apply only to the image of the characters printed on the document. The reading equipment must therefore allow greater tolerances (particularly in vertical misalignment and skew), which depend on the type of conveying facility used.

Compared with the others, the Siemag type face has very-high characters but at the same time narrow vertical-misalignment limits. This is

TABLE 1
STYLIZED TYPE FACES FOR MACHINE READING OF DOCUMENTS

	Type Faces			
	E 13 B	*CMC 7*	Siemag	*CZ 13*
Detection	magnetic	magnetic	magnetic	optical
Manufacturer	International Business Machines, Burroughs, National Cash Register, and International Computers and Tabulators	Compagnie des Machines Bull	Siemag	Standard Elektrik Lorenz
Number of characters	10 numerals and 4 symbols (control signs)			
		letters possible	letters possible	
Reading speed:				
Documents per second	12.5 to 25	≈25	≈3	12.5
Characters per second	1250 to 3200	≈3200	≈320	1500, up to 3000 possible
Printing specifications:				
Character height in millimeters (inches)	2.97 (0.12)	3.17 (0.13)	6.50 (0.26)	3.10 (0.12)
Stroke width in millimeters (inches)	0.33 (0.013); 0.66 (0.026); 1.32 (0.05)	0.15 (0.006)	0.15 (0.006)	0.30 (0.012)
Stroke width tolerance in millimeters (inches)	±0.08 (0.003)	±0.02 (0.001)	±0.05 (0.002)	±0.10 (0.004)
Vertical misalignment of characters in millimeters (inches)	±0.18 (0.007) for adjacent characters; ±1.50 (0.06) for printing fields	±1.6 (0.07)	±0.6 (0.02)	±1.5 (0.06)
Admissible character skew in degrees	±1.5	±1.5	±2	±2
Pitch in characters per millimeter (per inch)	0.31 (8)	0.31 (8)	0.31 (8)	0.39 (10)
Reliability (according to tests by Posts, Telegraphs, and Telephones Administrations):				
Rejects per 1000 characters	0.51 to 0.72	0.26	—	0.056
Reading errors per 1 million characters	2.2 to 51.5	0.65	—	0.25

due to the external coding that permits, on the other hand, a simple and reliable reading method to be used. Concerning stroke width and admissible tolerances, *CZ 13* is closest to conventional office machines. Moreover, it is the only one of these four type faces allowing a pitch of as many as 10 characters per inch (4 per centimeter). This is significant because most typewriters have this pitch and a larger number of characters can be printed on a document of given size. For example, on a document 6 × 4 inches (15 by 10 centimeters) in size (*DIN A 6*), approximately 53 characters can be printed on one line, compared with only 42 characters with a pitch of 8 characters per inch.

2.5 Reliability

In banking, the most-important criterion for appraising a reading method is its reliability. Normally, it is difficult to obtain dependable information since realistic experiments are costly and time consuming. Moreover, the causes for errors are so manifold that, for example, the results obtained in the United States for *E 13 B* and in France for *CMC 7* cannot be used to compare these two type faces, as interesting as these results might be for the organizations concerned.

Section 5 discusses in detail the only experiments carried out thus far that are suitable for comparison and the results of which have been made public.

2.6 Legibility to Man

More or less, all stylized characters disturb man's artistic sense. Since all judgements in this direction are subjective, every reader must form his own opinion.

However, there is also a realistic aspect to legibility for humans. In the course of further automation, they will have to recognize stylized characters as quickly and reliably as conventional characters, if possible. In this respect differences may exist between the type faces shown. Comparison tests, which are very difficult since they involve human factors, are being carried out in Europe but results are not yet available.

2.7 Sensitivity Against Interferences

One of the advantages claimed for magnetic reading methods is their insensitivity to interferences (color of paper, nonmagnetic printing inks, signatures, smudges, et cetera). This argument induced the banking institutions in the United States to decide in favor of a magnetic type face about 9 years ago.

Although this argument was correct, it did not consider all the facts. Because of abrasion of the paper-manufacturing machines, for example, the paper contains small iron particles that normally cannot be detected by humans but are large enough to disturb the magnetic reader. On the other hand, a photoelectric reading method for type face *CZ 13* that uses infrared in addition to the visible light waves has been demonstrated to be insensitive to a fairly good extent to the above-mentioned interferences. For details refer to Section 3.

2.8 Expense

A further important aspect to be considered in comparing magnetic and optical reading methods is the question of fixed and operating expense.

Manufacturers thus far have not quoted definite prices for character readers but the following estimate is valid on the basis of the reading method used: The Standard Elektrik Lorenz reader for *CZ 13* is more expensive than the readers for the other methods indicated in Figure 2, but less expensive than the International Business Machines reader for *E 13 B*, which works on the principle of area resolution.

With respect to printing, the cost factor tends to favor the optical method. The keyboard printers recommended by *E 13 B* manufacturers are special designs that cost more than the equipment used for the other methods.

With regard to the sorting machines, costs of the three high-speed methods do not differ.

An estimate of variable expense has been prepared for a large postal check office [5]. A comparison of carbon-tape expense for 500 000 documents showed a saving of $200 for the optical method over the magnetic methods. Estimates of the Swiss Postal Department led to similar results.

Variable cost depends also on the reliability of the system, since documents not correctly processed by the machine require additional handling by skilled personnel.

2.9 Protection from Forgery

The danger of a character being altered so that man sees a different character than does the machine is least when the machine sees the character in the same way that man sees it. None of the four methods discussed is fully able to meet this requirement, but the optical one comes closest. An investigation of forgery protection offered by the various type faces has been made public recently [6]. The reference mentions a single case of forgery of the type face *CMC 7*. However, no practical and comparable experiences with forgery have been accumulated thus far. These studies are more or less theoretical considerations, since the people professionally interested in this question shun publicity. Compared with other problems, however, forgery is of minor importance.

3. Character Reader of Standard Elektrik Lorenz

The reading method we have developed illustrates how the stringent requirements of character recognition can be satisfied with the aid of stylized characters and a suitably designed reader.

3.1 Type Face *CZ 13*

The main consideration in the choice of type face and degree of character stylization is that the characters should allow simple and reliable machine scanning and recognition. Economical printing methods and legibility to humans are additional conditions to be met.

In addition to the ten numerals of *CZ 13,* three special symbols used as control signs for bookkeeping purposes are shown on the upper document in Figure 3. Figure 4 shows a construction grid consisting of ten vertical stroke

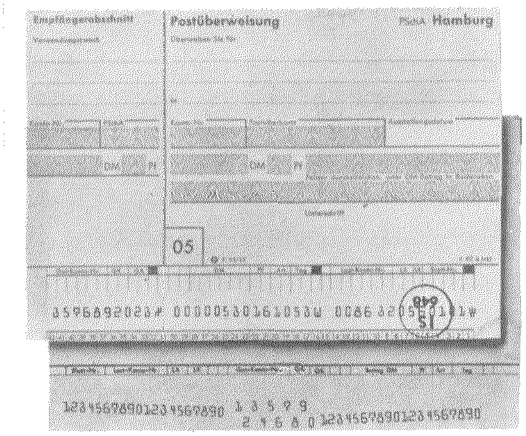


Figure 3—The upper document is typical of those used in the postal check system; the lower document has skewed and misaligned characters.

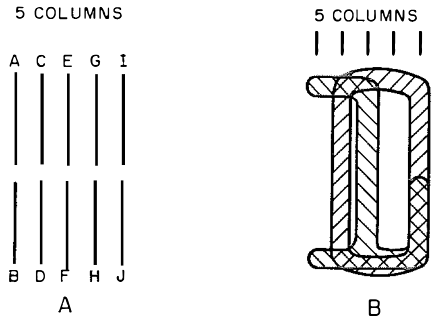


Figure 4—Coding of *CZ 13* characters. *A* shows the construction grid, which contains 10 vertical lines. *B* shows numerals *0* and *1* superimposed on the grid.

elements *A* through *J*. All characters are constructed into this grid in the manner shown in Figure 4*B* for numerals *0* and *1*. Table 2 contains the coding scheme for the numerals.

The code has been so chosen that the characters differ from each other by as many stroke elements as possible. The differentiation or Hamming distance between any pair of numerals can be easily determined by placing the respective numerals one atop the other and counting the stroke elements they do not have in common. In the case of the numerals *0* and *1* shown in Figure 4, the difference is 5 elements. From the ten numerals, 45 such pairs can be formed that will differ by four stroke elements on the average and by two stroke elements in the worst case. This represents a satisfactory safety margin, since at least two stroke elements must be wrong in a particular way before the machine will mistake one character for another.

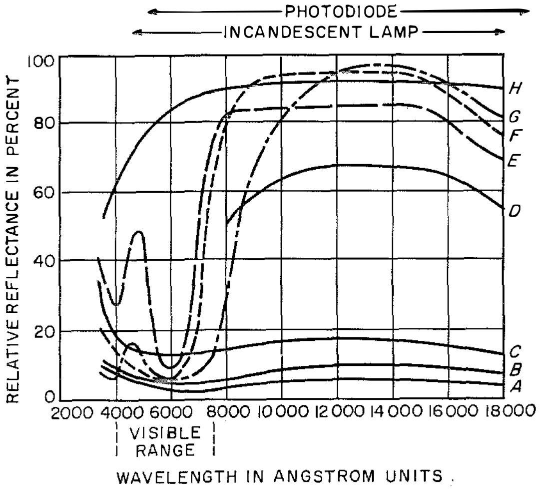


Figure 5—Spectral reflectance of various elements referred to white Bristol board as 100 percent.

A = black printing ink and typewriter with (carbon) paper ribbon
B = typewriter with black fabric ribbon
C = black lead pencil
D = spirit copy "Ormig," dark
E = green lead pencil
F = dark-blue office stamp
G = ball point and fountain pens
H = gray paper

3.2 Optical Scanning

The physical basis and the advantages of a scanning method using infrared as well as visible light waves are indicated in Figure 5. The relative reflectance of some printing inks and colors is plotted as a function of the wavelength of the radiation. White Bristol board is used as 100-percent-white reference; thus the curves illustrate operating conditions. It is obvious that if in addition to the visible range (4000 to 7500 angstrom units) the infrared range of waves up to 17 000 angstrom units is used, the character reader will distinguish much easier between interference produced by elements of curves *E* through *H* and those characters having a reflectance similar to curves *A* and *B*. It is evident that in the infrared range these interferences reflect almost as much light as does white paper, while printing inks remain black.

The application of this method requires that the light source and detector both be capable of operating in the visible and infrared ranges—a requirement satisfactorily met by the incandescent lamp and the germanium photodiode. The spectral range of the light of an incandescent lamp and the sensitivity range of the germanium photodiode are indicated at the top of Figure 5. Compared with the alternative of using a cathode-ray tube as light source and a photomultiplier as transducer, the incandes-

TABLE 2

Coding of *CZ 13* Numerals in a Grid Consisting of Ten Stroke Elements *A* to *J* (1 = black, 0 = white)

Numeral	Stroke Elements									
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*
0	0	0	1	1	0	0	0	0	1	1
1	0	0	0	0	1	1	0	0	0	1
2	0	1	0	0	0	0	0	0	1	0
3	0	0	0	1	0	0	1	0	0	1
4	0	0	0	0	1	0	0	0	1	1
5	0	0	1	0	0	0	0	0	0	1
6	1	1	0	0	0	0	0	0	0	1
7	1	0	0	0	0	1	0	0	1	0
8	0	1	1	0	0	0	1	0	0	1
9	1	0	0	0	0	0	0	0	1	1

cent lamp and the germanium photodiode have the virtues of simplicity and economy.

Gray paper (curve *H*) shows characteristics typical of bad paper. Its gray color causes a decrease of reflectance in the visible range, yet in the infrared range it is almost as bright as white paper. Thus, a wide variety of light colors of paper can be tolerated.

On the other hand, Figure 5 also shows some limitations of the scanning method. Curve *C* (graphite pencil) is too close to those of the printing inks. Heavy black pencil lines, therefore, will interfere with the scanning operation. Spirit copies are not sufficiently black to be clearly distinguished from interferences. However, the first carbon copies of documents as well as xerographic copies are sufficiently black for machine reading. This opens fields of application unsuitable for magnetic methods.

In general, use of the infrared range makes interferences from fountain and ball-point pens, colored pencils, office stamps, colored paper, and finger smudges tolerable, while materials containing carbon or graphite have a reflectance similar to printing inks and thus cause trouble. The quantitative influence of interferences is explained in Section 3.4.3 with the aid of an example.

3.3 Basic Reading Method

The documents are mechanically drawn from a stack and move past the reading station horizontally, parallel to the printed line. An optical system projects the image of the character from the illuminated character field onto photodiodes. While passing the reading station, the character is scanned from right to left. The photodiodes of the scanning device (Figure 6) deliver pulses the time sequence of which depends on the position of the stroke elements within the construction grid. The association of these pulses with the corresponding black or white values of the stroke elements is ensured by the clock, which counts the 5 columns of the character field. Black information is supplied to two shift registers that shift under the control of the clock pulses. In the case of the numeral *1*, for example, register stages *E*, *F*, and *J* are marked black (refer to Table 2). Subsequent AND gates identify the character on the basis of the information stored in the registers.

This simple system operates reliably and fast as long as printing quality is good and only small vertical misalignment of characters is encountered, as is the case with accounting machines provided with automatic account card feeders. Scanning of the characters in only two traces is insufficient, however, if there are voids, spots, or smudges in the character image, or if the characters are so misaligned that any of the horizontal strokes of the numeral *1*, for instance, is detected by either photodiode of Figure 6.

Normal documents are printed by several distinctively different printing devices and are transported and sorted by high-speed sorters. As a consequence, it is not possible to hold the characters within narrow printing and misalignment tolerances. For this reason, a vertical row of photodiodes is used.

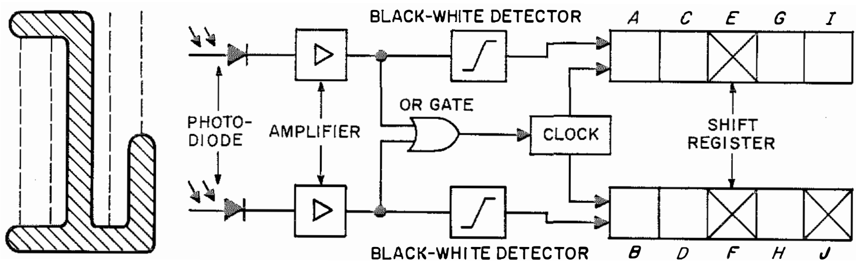


Figure 6—Basic reading method.

3.4 TECHNICAL DESIGN

3.4.1 *Scanning*

The photodiodes are arranged in a vertical row, parallel to the vertical stroke elements (Figure 7). The character to be read is magnified by an optical system so that one vertical stroke element is projected onto, say, three adjacent photodiodes. A horizontal element of maximum stroke width will then cover not more than one photodiode. Three adjacent photodiodes are connected via three resistors to point *D*. The voltage at *D* is then proportional to the photodiode surface covered by black stroke elements and it is at least three times as large for a vertical stroke element (for example, column 1 of the numeral *0*) as for a horizontal element (columns 2 and 3). The worst-case voltage ratio is 3:1, large enough to be quantized reliably as black or white at the following threshold detector even if interferences of the described types (for example, a white void in a black stroke element or a black spot in a white element) are present.

The length of the photodiode bank shown in Figure 7 can be adapted to operational requirements based on the vertical misalignment of characters met in service. The character reader contains a sufficient number of photodiodes to accommodate a vertical printing misalignment of ±1.5 millimeters (±0.06 inch), and in addition +2 millimeters (+0.08 inch) for the document transport. The cost of the scanning device increases in proportion to the number of photodiodes. However, the expenditure for digital circuits to store and recognize the scanned character represents a major part of equipment cost and in this design is independent of the number of photodiodes.

Since in the *CZ 13* characters the essential information is contained in the vertical strokes, the scanning method accentuates the vertical and suppresses the horizontal stroke elements. Neglecting the horizontal elements reduces the number of circuits, for to detect horizontal strokes in addition to the vertical strokes would require considerably higher resolution, that is, a

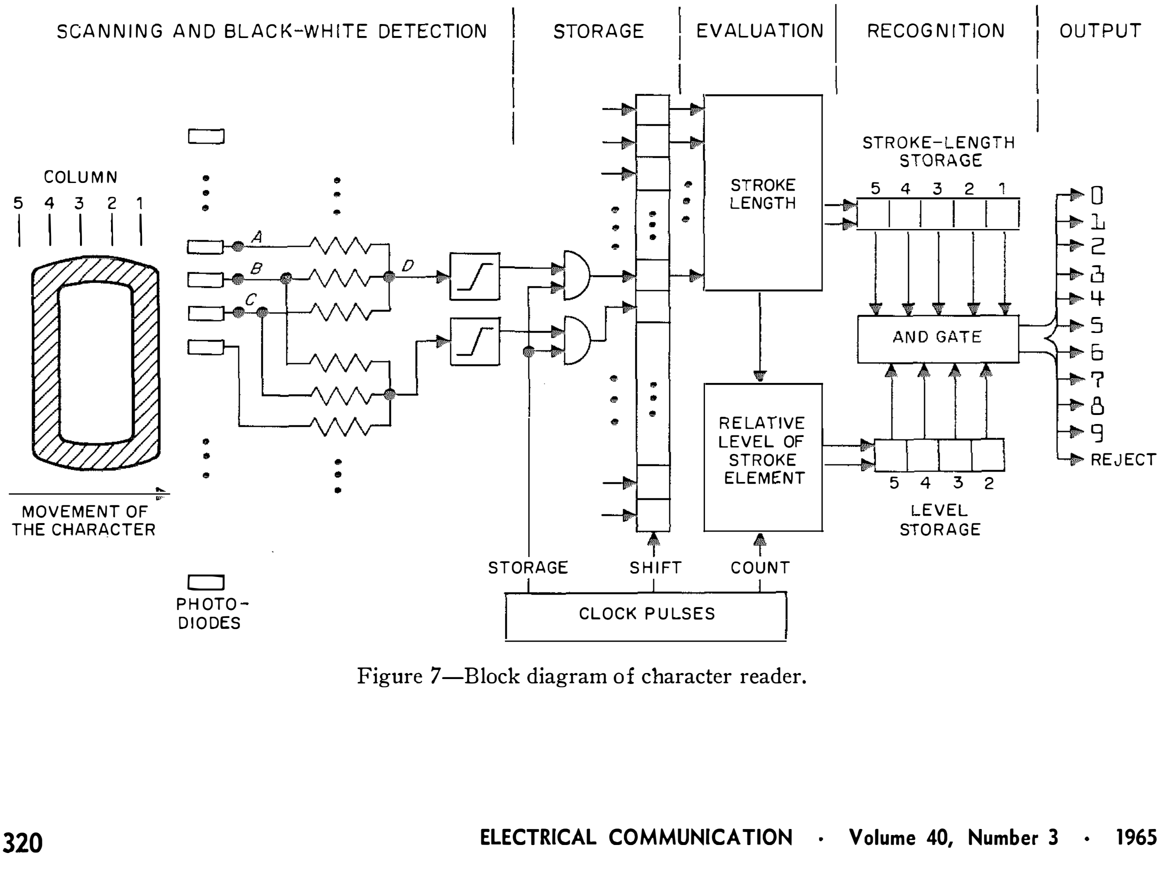


Figure 7—Block diagram of character reader.

larger number of scanning tracks with corresponding digital circuits.

3.4.2 *Storage and Evaluation*

The scanning device is followed by the digital circuits that store and recognize the characters (Figure 7). The store consists of only one shift register, which accepts and centers the black-white information a column at a time. During centering, all scanned information is shifted to a prescribed section of the register, independent of the vertical location of the character. The stroke length evaluation circuits are connected to this part of the shift register to analyze each column for long stroke, short stroke, no stroke, or not recognized (reject). For the 5 columns stored in binary form, this information consists of 10 bits.

The level or vertical position of the stroke element in the first column is registered relative to a suitably chosen reference level, and the levels of the other columns are then compared to it. This comparison tells whether the stroke elements in columns 2, 3, 4, or 5 are higher, lower, or equal in level to the stroke element of each preceding column. This indicates whether the short strokes are in the upper or lower halves of the character. For four comparisons, this information consists of 8 bits. The information "no stroke" is evaluated as equal level.

The $10 + 8 = 18$ bits clearly define all characters. This compares favorably with the 100 bits required for area storage of a character, with 7 photodiodes assumed for a character height and 20 diodes in the row. This substantial data reduction not only justifies the expense for the shift register and the control circuits, but also allows extremely simple logic decision circuits to be used for recognizing a character from evaluation of the strokes and the levels.

3.4.3 *Optical Scanning Results*

The following example illustrates the advantages of optical scanning in the infrared spectral range. The scanning signals have been recorded for the numeral *0* beneath the stamp on the right-hand side of the upper document in Figure 3. Oscillograms *A, B,* and *C* in Figure 8 indicate the output voltages of photodiodes *A, B,* and *C* of Figure 7. The wide pulse from diode *A* is caused by the upper horizontal stroke of the *0*. Curve *D* of Figure 8 shows the summing voltage, measured at point *D* of Figure 7, while curve *E* shows the timing pulses that associate the voltage response with the 5 coding columns.

The dark-blue stamp causes only the small interference marked by arrows and in no way prevents correct recognition of the character. If only visible light were used for scanning, the signal effected by this stamp would be almost as strong as the character signals.

The reading machine accepts wide tolerances of the printing and transport equipment, as illustrated by the lower document in Figure 3,

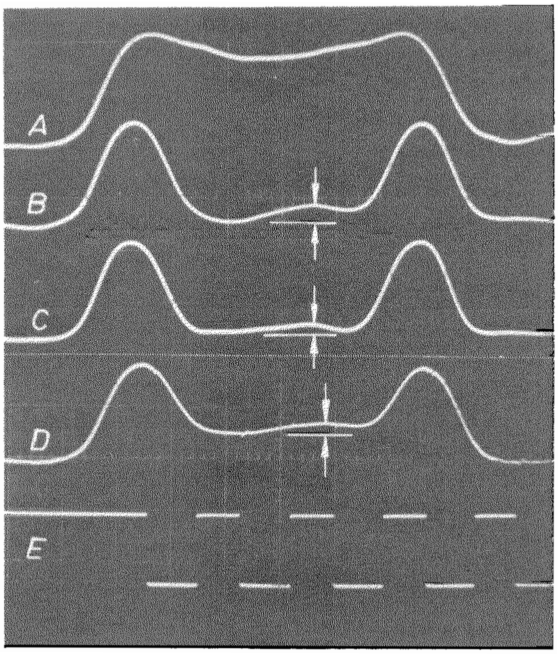


Figure 8—Scanning oscillograms. Curves *A* through *C* indicate the output voltages of 3 photodiodes, curve *D* indicates the summing voltage, and curve *E* the timing pulses for the 5 scanning columns.

which contains skewed and vertically misaligned characters.

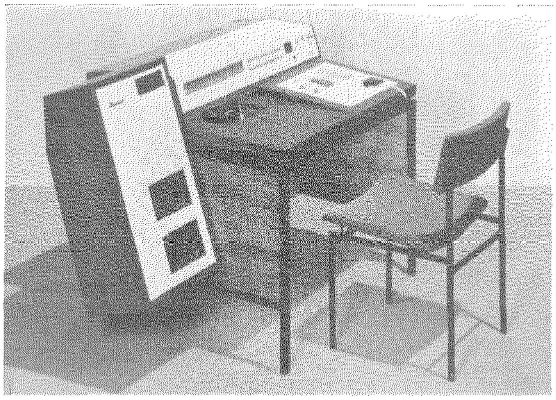


Figure 9—Standard Elektrik Lorenz document encoder.

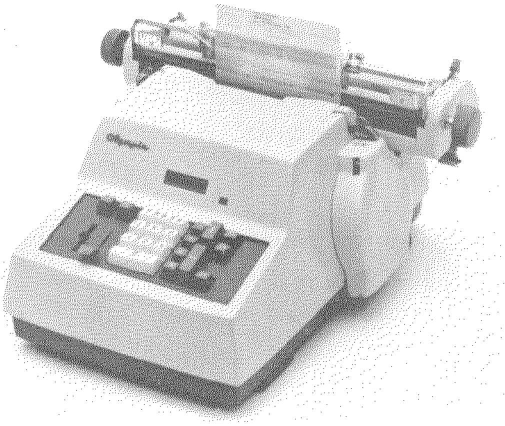


Figure 10—Olympia accounting machine.

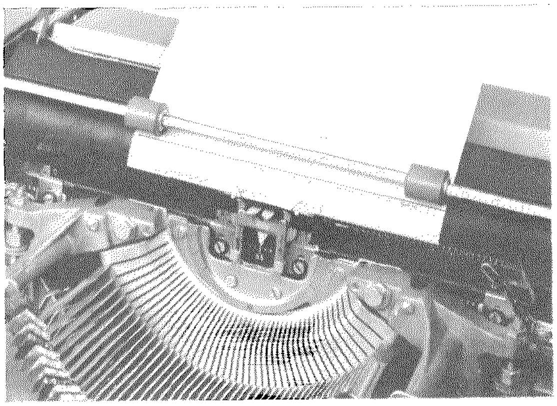


Figure 11—International Business Machines electric typewriter with *CZ 13* characters.

4. Machine Concept

To use the character reader, printing machines as well as machines for transporting, sorting, and stacking the documents must be provided. A selection of printers for type face *CZ 13* is described in the following section. The printers have been tested in field operation. The encoder shown in Figure 9 has been developed for the German postal check system. It permits extensive programs for automatic printing of fixed and preselected data and is equipped with automatic document input and output facilities, a list printer, and punched-tape verification of the data keyed in [7]. Figure 10 shows an accounting machine with carbon-tape transport and insertion pocket. The electric typewriter shown in Figure 11 is a standard design. While the accounting machine allows some programing with the aid of special bars, the relatively inexpensive typewriter can be used advantageously as a general code printer for special purposes or in small installations.

A sorter unit used for the transportation of documents is shown in Figure 12. It is equipped with 12 pockets, 10 of them being used for the individual numerals, one for special purposes, and one for rejects. The machine feeds documents at a rate of 12.5 documents per second with a conveyor speed of 3.8 meters per second.

The box on the rear left side in Figure 12 accommodates the lamp and the scanning device for the optical reader. Since the machine was originally designed for magnetic scanning, the lamp and scanning device were fitted to it later. The unit may also be attached to sorting machines of other manufacture. Figure 13 shows part of the character-reader rack.

The machines just described have been supplied to the Deutsche Bundespost in 1963 and 1964 as part of the Standard Elektrik Lorenz pilot system for automatic postal check handling. The system includes five encoding sets (Figure 9), two sorters with *CZ 13* character readers, the *ER 56* electronic computer with magnetic drums to store the data of 20 000 postal check accounts, a high-speed printer for producing the daily statements, a special-inquiry set, and machinery for stuffing documents into envelopes [7, 8].

5. Test Results

To confirm the suitability of the reading method and machine design, the character reader has been subjected to extensive tests. It is very difficult, as mentioned earlier, to obtain dependable data on the most-important property of the machine, namely its reliability. In addition to technical properties of the reader, test results also reflect the printing quality, the paper quality, and the mechanical reliability of the sorting machine. For this reason, the tests must be conducted in compliance with precisely defined specifications, and all faults must be carefully analyzed to obtain usable results.

The Deutche Bundespost deserves credit for being the first neutral and independent organization to carry out large-scale tests on type faces *E 13 B, CMC 7,* and *CZ 13* under the same conditions. The test results permit a comparison of these methods as well as conclusions regarding their future application in postal check service. The tests included printers, sorters, and character readers, that is, a machine configuration that may be used also for other banking organizations. For the type face *E 13 B,* equipment from four different manufacturers was tested; for both *CMC 7* and *CZ 13,* one reader and one sorter were tested.

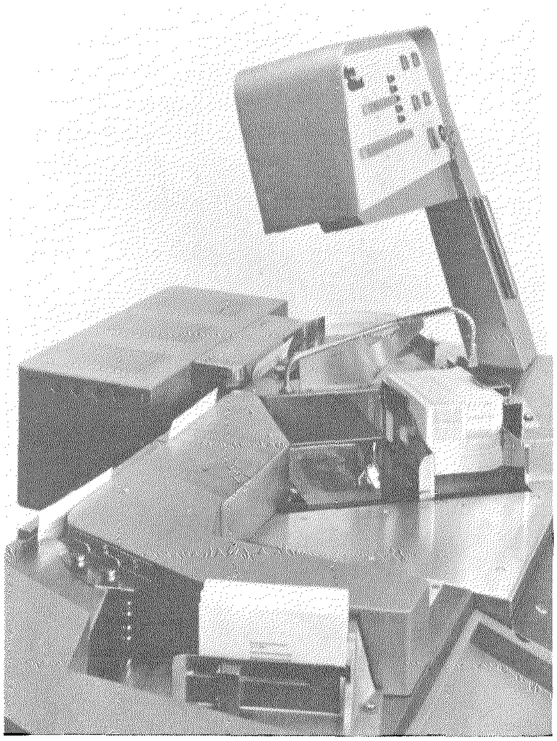


Figure 12—National Cash Register sorter with control panel, document feeder (right), first stacker (front), and some documents being processed.

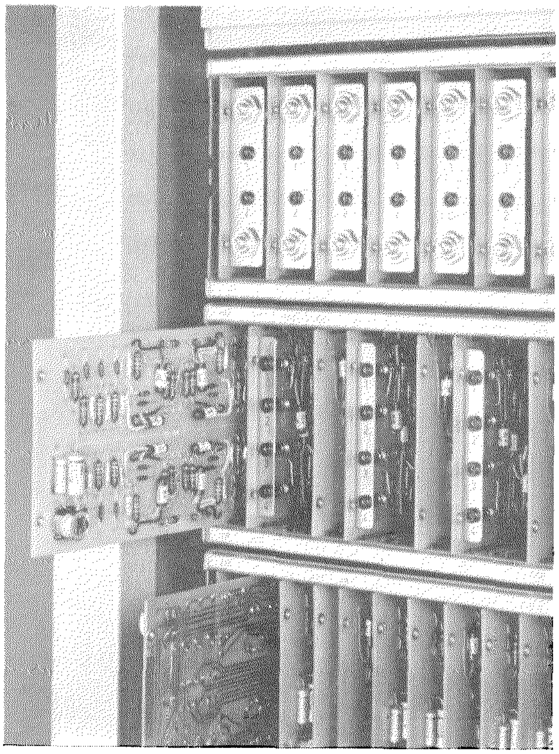


Figure 13—Printed cards partly withdrawn from character reader.

A first report of the Deutsche Bundespost has been published on the conditions and the execution of the test [9]. A second report describes and analyzes the results obtained for magnetic type faces *E 13 B* and *CMC 7* as well as for optical type face *CZ 13*. This report serves as a basis for the following data. Further details are given in the literature [10, 11].

The test results are broken down by rejects and reading (substitution) errors, the former denoting that the character reader was able to detect information but failed to identify it as a numeral or special symbol. In these cases, the document is rejected by the machine and passed automatically to the reject pocket, from which it is removed for manual processing. A reading error (substitution error or wrong recognition) means that the character reader mistook one character for another. The document then passes to the wrong sorting pocket, and in most cases an incorrect entry is made, which is particularly troublesome in banking applications. Therefore, reading errors should not occur at all, if possible, or at least be considerably rarer than rejects. Organizational procedures beyond the scope of character recognition may be used to discover reading errors in time. For example, a check digit could be formed from the account number or amount and printed on the document. The computer checks the digit sum total and rejects the document if a mistake is detected.

5.1 Rejects

Similar to the procedure practiced in some places in the United States, documents rejected during the first reading were processed by the sorter twice more to exclude accidents, such as documents in skewed position or wrong side up. The final rejects after the third pass (18 700 documents rejected out of 1 769 000) were then checked for causes of rejection [9]. The reject rates for letterpress and keyboard printing are given in Tables 3 and 4, broken down by the main causes. The sums of these two tables are charted in Figure 14, which also shows the average for letterpress and keyboard printing.

While Figure 14 shows all rejects, Figure 15 indicates merely the reject rates significant for comparing reading methods, that is, the data in Tables 3 and 4 after we subtract the errors attributed to "sorter mechanism" and "operator mistakes," which obviously have no bearing on the accuracy of the reading method. The aver-

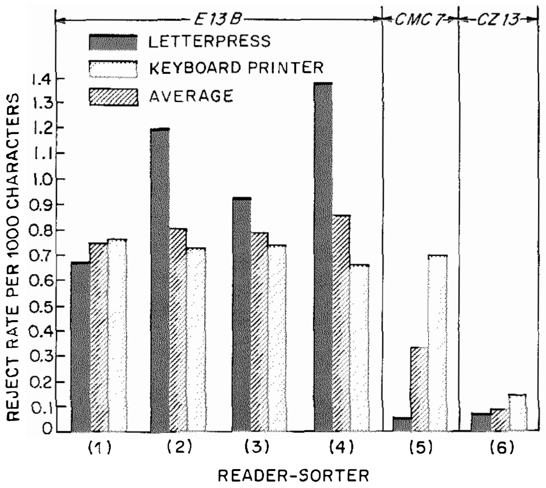


Figure 14—Reject rates per 1000 characters read, for six reader-sorters. Refer to Tables 3 and 4.

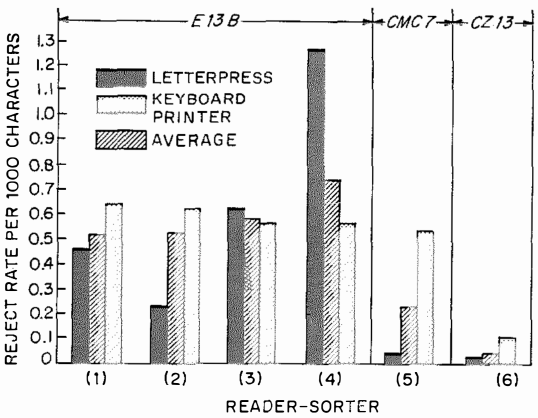


Figure 15—Reject rates per 1000 characters read, for six reader-sorters. The data in the bar graphs include only those rejects that are significant for comparing readers.

age rates shown as bar graphs in Figure 15 are given numerically under "Reliability" in Table 1.

5.2 READING ERRORS

The significance of reading errors has already been discussed. Table 5 shows the test results for the six different reading and sorting machines tested.

5.3 DISCUSSION OF TEST RESULTS

The test results for the *CZ 13* reading method were definitely better than those obtained for the other methods. In field operation higher

TABLE 3
REJECT RATES IN PERCENT FOR LETTERPRESS PER 1000 CHARACTERS READ

	Type Faces					
	E 13 B				*CMC 7*	*CZ 13*
Reader-sorter	(1)	(2)	(3)	(4)	(5)	(6)
Reject causes:						
Letterpress	0.419	0.140	0.432	0.741	0.018	0.012
Sorter mechanism	0.223	0.854	0.267	0.029	0.008	0.014
Character reader	0.016	0.014	0.133	0.307	0.002	0.002
Paper	0.014	0.087	0.052	0.212	0.021	0.001
Operator mistakes	0.003	0.024	0.024	0.068	0.004	0.043
Totals	0.675	1.119	0.908	1.357	0.053	0.072

TABLE 4
REJECT RATES IN PERCENT FOR KEYBOARD-CONTROLLED PRINTERS PER 1000 CHARACTERS READ

	Type Faces					
	E 13 B				*CMC 7*	*CZ 13*
Reader-sorter	(1)	(2)	(3)	(4)	(5)	(6)
Reject causes:						
Keyboard printer	0.602	0.554	0.390	0.411	0.499	0.103
Sorter mechanism	0.061	0.034	0.103	0.014	0.035	0.025
Character reader	0.022	0.011	0.095	0.082	0.004	0.001
Paper	0.017	0.057	0.076	0.091	0.035	0.003
Operator mistakes	0.050	0.067	0.052	0.050	0.124	0.042
Totals	0.752	0.723	0.716	0.648	0.697	0.174

TABLE 5
READING ERRORS PER 1 MILLION CHARACTERS

	Type Faces					
	E 13 B				*CMC 7*	*CZ 13*
Reader-sorter	(1)	(2)	(3)	(4)	(5)	(6)
Reading errors	2.20	14.12	11.58	51.46	0.65	1.25

reject and error rates must be expected than obtained in these tests, within which only clean documents not handled by the public were processed and only a limited number of machines were used, under control of qualified postal personnel. On the other hand, the restricted but well-defined test conditions of the Deutsche Bundespost allow a more-critical comparison of the reading methods.

After evaluating the results, the Bundespost discontinued tests on type face *E 13 B,* while further tests are scheduled for *CMC 7* and *CZ 13.*

Results have been received from the United States on type face *E 13 B* in field operation. In part, these results are substantially worse than those obtained during the Bundespost tests. However, it is not certain that similar results would be obtained during practical operation in the German postal check system, for conditions are quite different in the United States and in many cases less favorable.

6. Conclusions

The present state of the art can make optical character readers largely insensitive to interferences on the document. Parallel scanning of the characters further permits such high reading speed that the character reader may be used in conjunction with fast sorting equipment, which thus far has been reserved for magnetic character recognition. With respect to economy and choice of printing methods, optical character recognition has always been superior to magnetic methods. A number of conventional printing methods have proved suitable.

The objective is an optical reading method that can process documents printed with ordinary inks. Stylized characters may be included to achieve high reliability and overall economy. In this respect, some users tend to consider magnetic-ink systems as an intermediate state. The future will show whether they are right.

7. References

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Walter Dietrich was born in Hamburg, Germany, on 22 June 1915. He studied telecommunications at the Technische Hochschule in Stuttgart. After serving as a faculty assistant from 1946 to 1951, he then received the Dr.-Ing. degree.

Dr. Dietrich joined Standard Elektrik Lorenz in 1951, where he developed electrical measuring and test equipment. Since 1957 he has been in charge of the development of optical character readers.

Automatic Postal Check Handling in Germany

K.-H. KLÖNNE

Standard Elektrik Lorenz AG; Stuttgart, Germany

As in most European countries, financial transactions in Germany are mainly carried out by ordinary banks, savings and clearing (endorsement) banks, and postal check offices.

The German postal check service is limited to the transfer of money, whereas credit allowance and other banking transactions are carried out by ordinary banks as well as by savings banks and clearinghouses. Despite these limitations, transactions within the German postal check service have grown to a considerable extent since its beginning in 1909.

The widespread network of more than 30 000 post offices and paying-in and paying-out offices contributed considerably to this volume. At present the Deutsche Bundespost has 13 postal check offices of various sizes with 2 million accounts and more than 4 million entries per day.

The main operations within the postal check service are: transfer from one account to another, cash payments to and from postal check accounts, and execution of permanent orders. These operations are so well coordinated that it is almost impossible to overdraw a postal check account.

In view of the large volume of business, the Deutsche Bundespost decided to mechanize the postal check service, which heretofore depended mainly on manual operations. Before all 13 postal check offices could be reorganized, new equipment and techniques had to be tested thoroughly. This is why Standard Elektrik Lorenz, among other firms, received an order from the Deutsche Bundespost for a complete postal check trial installation for 20 000 accounts. This system, installed in Nuremberg and turned over to the Bundespost in September 1964, is described in the following sections.

1. Requirements

The Bundespost required automatic handling of the original documents from account entries through stuffing envelopes for mailing to the customer. Electronic data processing was required, but punched cards and tape could not be used as booking elements.

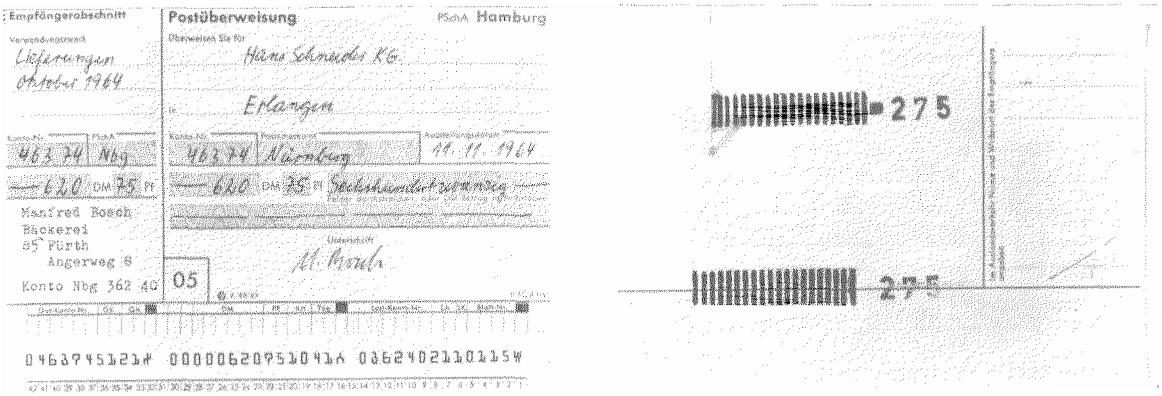
1.1 Documents

In the present system, each transaction uses a document divided into the three following parts:

(A) The main slip, which is kept at the postal check office after processing;

(B) The debit slip, which goes to the debited customer; and

(C) The credit slip, which goes to the credited customer.



Empfängerabschnitt

Verwendungszweck

Lieferungen
Oktober 1964

Konto-Nr. 463 74 PSchA Nbg

620 DM 75 Pf

Manfred Bosch
Bäckerei
85 Fürth
Angerweg 8
Konto Nbg 362 40

Postüberweisung PSchA Hamburg

Überweisen Sie für Hans Schneider KG

in Erlangen

Konto-Nr. 463 74 Postscheckamt Nürnberg Ausstellungsdatum 11. 11. 1964

620 DM 75 Pf Sechshundertzwanzig

Unterschrift M. Bosch

05

0463745121 00000620751041 0362402110115

Figure 1—New postal check document. The front is encoded with *CZ 13* type face and the back with machine-readable endorsement stamp as a receipt for crediting as well as debiting.

For the new system, the single document shown in Figure 1 has been developed. It is 148 by 102 millimeters (5.8 by 4 inches) in size. The debit slip is replaced by a notation on the statement of account, similar to present bank transactions. In the future it is planned to use microfilms to record all transactions. This will permit the original document to be given to the credited customer.

At the bottom of the new document there may be encoded as many as 42 characters, which can be read either mechanically or visually. In principle, all known type faces can be used. For the present trial operation, however, the Bundespost has chosen *CMC 7* as a magnetic type face and *CZ 13* as an optical type face. The final choice will be made after all the test results have been evaluated.

1.2 OPERATION

The operation of the trial installation required thorough study of the present postal check service as well as evaluation of data systems presently available.

In the present service, all incoming documents are first sorted manually according to debit account numbers. These accounts are then debited using simple accounting machines. At the same time, the debit is charged against the balance of the last statement of each account to produce a new statement of account.

The documents are again sorted manually according to credit account numbers. These accounts are then credited and new statements of account are prepared for them. Each accounting unit works with certain customers and maintains an account file covering address, account balance, blocking notes, list of signatories, et cetera. Every entry is reviewed by a second person. Finally, the statements of account as well as the respective documents are manually stuffed in preaddressed envelopes.

For customers who frequently receive credit or debit notes, special lists are prepared by adding machines. Only the total is indicated in the statement of account.

For check cashing and counter service at individual postal check offices and their distant branch offices, the checks presented for acceptance must be forwarded as soon as possible to the respective accounting unit to avoid any impermissible cash disbursements. This procedure, however, causes some delay in check cashing and counter service.

In reorganizing the service, the following operations are to be mechanized: entry of credits and debits; account information for check cashing and counter service; sorting of documents and data; compiling and printing of special lists; printing of statements of account and attaching the respective documents as well as stuffing both into envelopes; and computing of balances.

In addition to the above requirements, it is imperative that all operations necessary for 20 000 postal check accounts be carried out daily between 6 in the morning and 6 at night. All orders must also be processed without first being sorted by account numbers. This on-line processing is one of the most-important features.

2. Equipment of Trial Installation

2.1 ELECTRONIC COMPUTER *ER 56*

The *ER 56* electronic computer shown in Figure 2 includes operating and extra stores as well as periphery devices.

A core store with a capacity of 25 200 digits serves as an operating store. Four magnetic-drum stores, each having a capacity of 84 000 digits, supplement the core store and also serve as account stores.

The average access time for each of the magnetic-drum stores is 10 milliseconds. Additional storage is provided by 8 magnetic tapes, which are also connected to the core store. They process data at a speed of 2.5 milliseconds per bit and a density of approximately 10 characters per millimeter (254 per inch).

A punched-tape input device with a speed of 400 characters per second has been linked to the computer. In addition, a punched-card input has been connected to the core store and processes up to 400 cards per minute. This machine mainly processes alphanumeric data. An extremely fast printer is used that can process up to 63 thousand 80-digit lines per hour.

The data stored in the computer is accessible by means of a special inquiry device.

2.2 READER-SORTER

A reader-sorter with 17 pockets, an endorsing device, and an endorsing-stamp recognition device is provided for processing the new documents. This reader-sorter, which is connected to the electronic computer, can read the encoded *CZ 13* optical characters on the documents with a maximum speed of 45 000 documents per hour. The computer controls the distribution to the 17 pockets after electronically processing all read-in document data in less than 80 milliseconds.

The endorsing-stamp device puts on the back of each document a stamp that is legible to the machine. This stamp device is also controlled by the computer. The stamp consists of a bar pattern that is distinguishable from other stamps or contamination.

2.3 DOCUMENT SORTER

The document sorter is composed of the same units as the reader-sorter but contains only 12 pockets and no endorsing-stamp device. This machine ordinarily sorts the documents independently of the electronic computer. If the reader-sorter breaks down, however, the document sorter can be connected to the *ER 56* as a substitute.

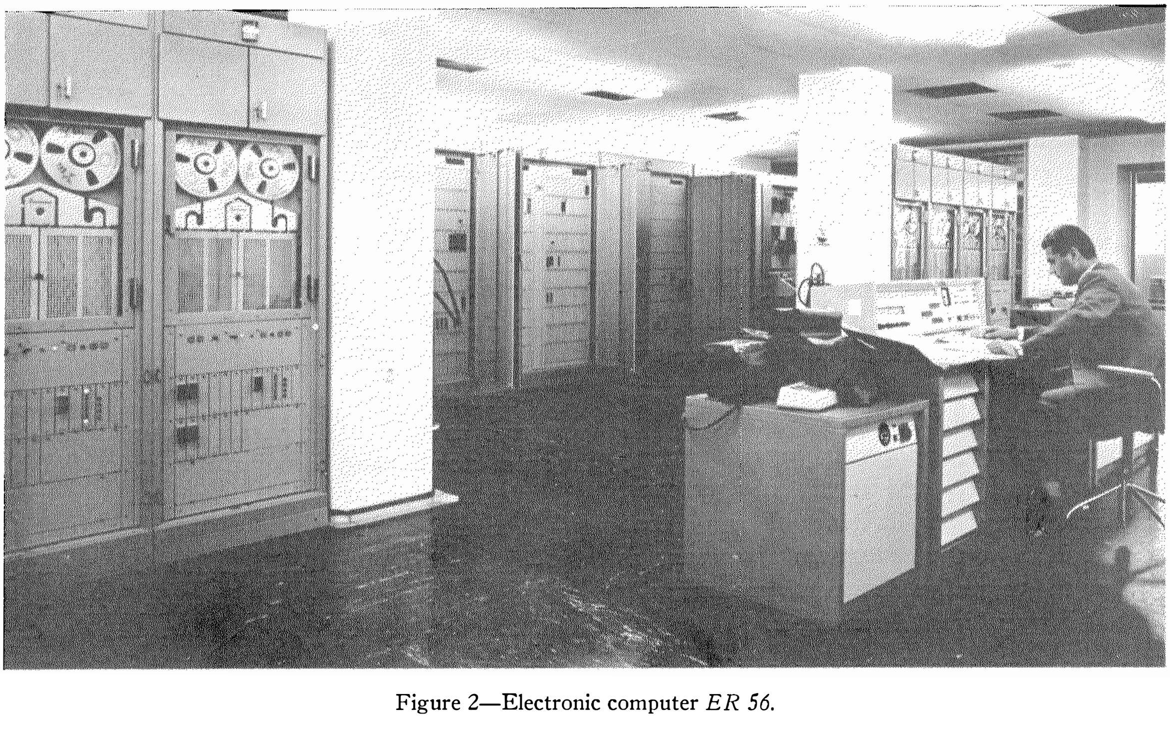


Figure 2—Electronic computer *ER 56*.

2.4 Envelope Stuffer

The envelope stuffer is the most-complicated electromechanical equipment of the test installation. Like the reader-sorter, it is also connected to the *ER 56* and includes a document reader as well as a document feeder in the input. The document feeder is linked with a document stacker that can stack up to 10 documents, which are transported to the envelope stuffer. At the same time this machine receives the statements of account from the high-speed printer. The statements are cut away from the paper roll, turned and folded to proper size, and joined with their respective document stacks. The statements of account and the document stacks are then stuffed in window envelopes. The envelopes are sealed and stacked in one of the 5 pockets of the machine.

The main problem in developing the envelope stuffer was the variable number of credit notes as well as the variable printing time per statement of account. The envelopes must be stuffed in conformance with these 2 parameters with the additional guarantee that documents are always properly inserted with their respective statements of account. This problem has been satisfactorily solved by an electronic control system that synchronizes the mechanical operation. The calculated efficiency of the envelope stuffer mainly depends on the speed of the printer, which varies from 0.9 to 1.3 seconds per statement of account.

2.5 Preparation Stations

Documents are encoded mechanically as well as visually at the preparation stations. Two stations comprise an encoding unit. At one station the document information to be encoded is keyed in and punched on a tape that is read at the encoding station, shown in Figure 3. The characters are printed only if the keyed-in and the punched data correspond. The document is printed automatically by putting it into the opening provided.

The encoding station also contains a printer that can be set manually for encoding fixed data. Without keying-in, the operator initiates the automatic encoding of data that are the same for a large number of documents (for example, the date of entry and the kind of document). The encoded documents are automatically transported to a special stacker pocket. The encoding station also includes an accounting device that adds and records all keyed-in amounts.

3. Trial Installation

Figure 4 depicts the total operation in a German postal check service trial installation.

3.1 Document Encoding

For security, the individual documents are encoded in 2 steps at 2 different preparation stations. To simplify the encoding, data that are known when the documents are issued are printed in advance using a type face legible to the machine. Examples of such data are: account check digit, account number and postal check office number of the customer, as well as the sheet number and serial number of the form being used. Tapes punched at the first preparation station are attached to their respective documents and then transported to the encoding station. After confirmation of the encoded documents by means of the control list, which was

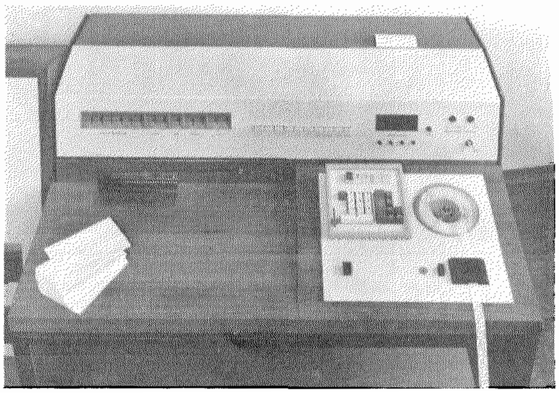


Figure 3—Postal check encoding station.

prepared at the same time as the punched tape, the documents are ready for further processing.

3.2 On-Line Entry of Accounts

3.2.1 *Entries via Documents*

A characteristic feature of the trial installation is its capability to make on-line entries for all debit and credit notes regardless of their sequence.

For transfer orders that require a debit as well as a credit entry in the accounts of the trial installation, the entries may be made on line.

The reader-sorter reads the document information into the computer. The sequence of operations is shown in Figure 5. The entire process is completed within 80 milliseconds. Data such as the account number, account check digit, credit balance, and possibly blocking notes necessary for accounting purposes, are stored

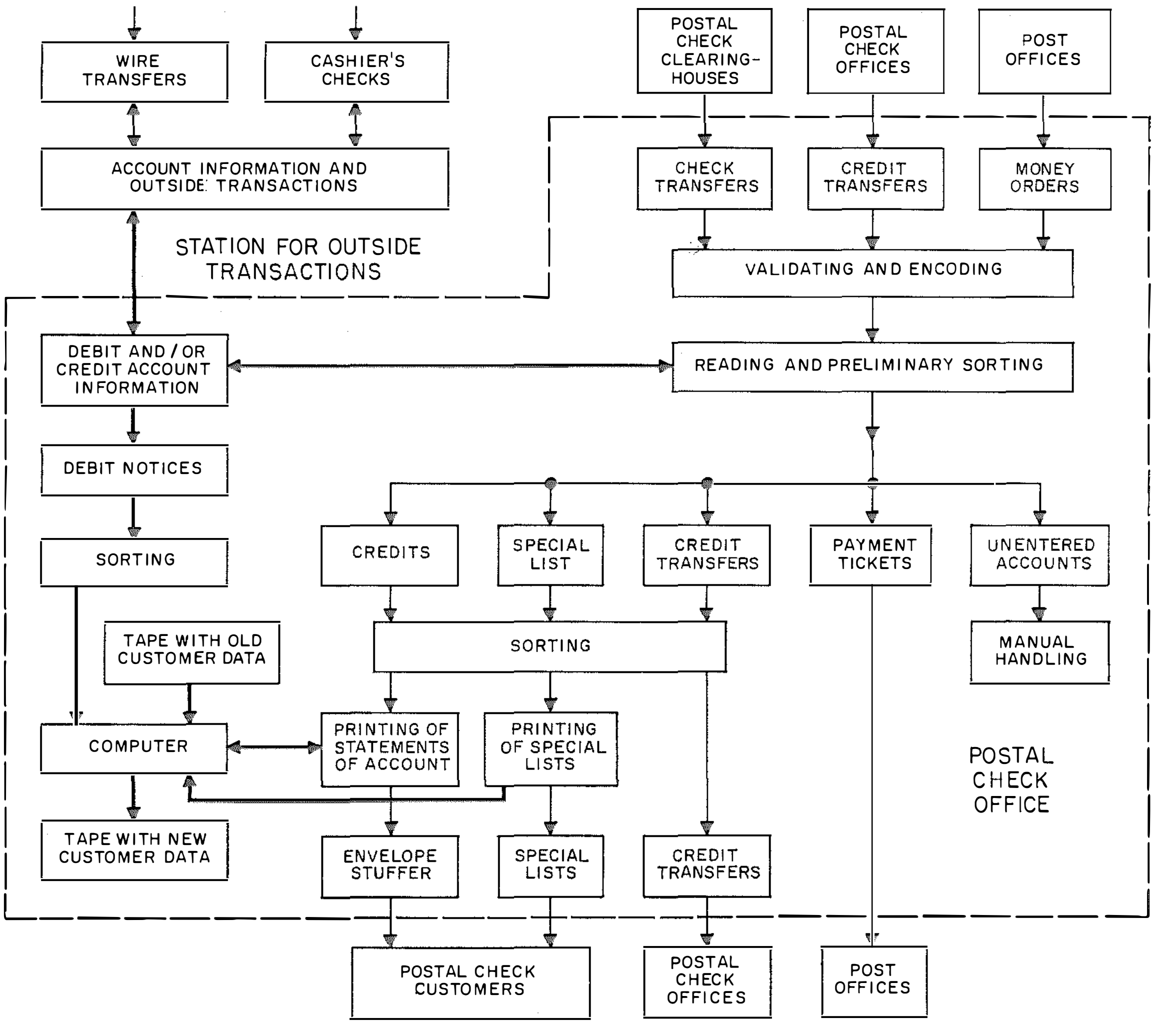


Figure 4—Total operation of the German Postal Check Service trial installation. The heavy lines represent signal data flow, while the others represent document flow.

in the magnetic drums. At the end of the entire entry process the magnetic drums cover the latest balances of account. These are used for control before being printed on the statements of account and are therefore transferred to magnetic tape.

After the reading and entry processes are finished, the reader-sorter stacks the documents into 16 of the 17 pockets as follows.

(1) documents without credit

(1) documents not in proper form

(4) credit notes of the 4 largest postal check customers for whose transactions special lists must be prepared

(1) credit notes of the other big postal check customers who also receive special lists

(4) credit notes for dispatch of statements of account

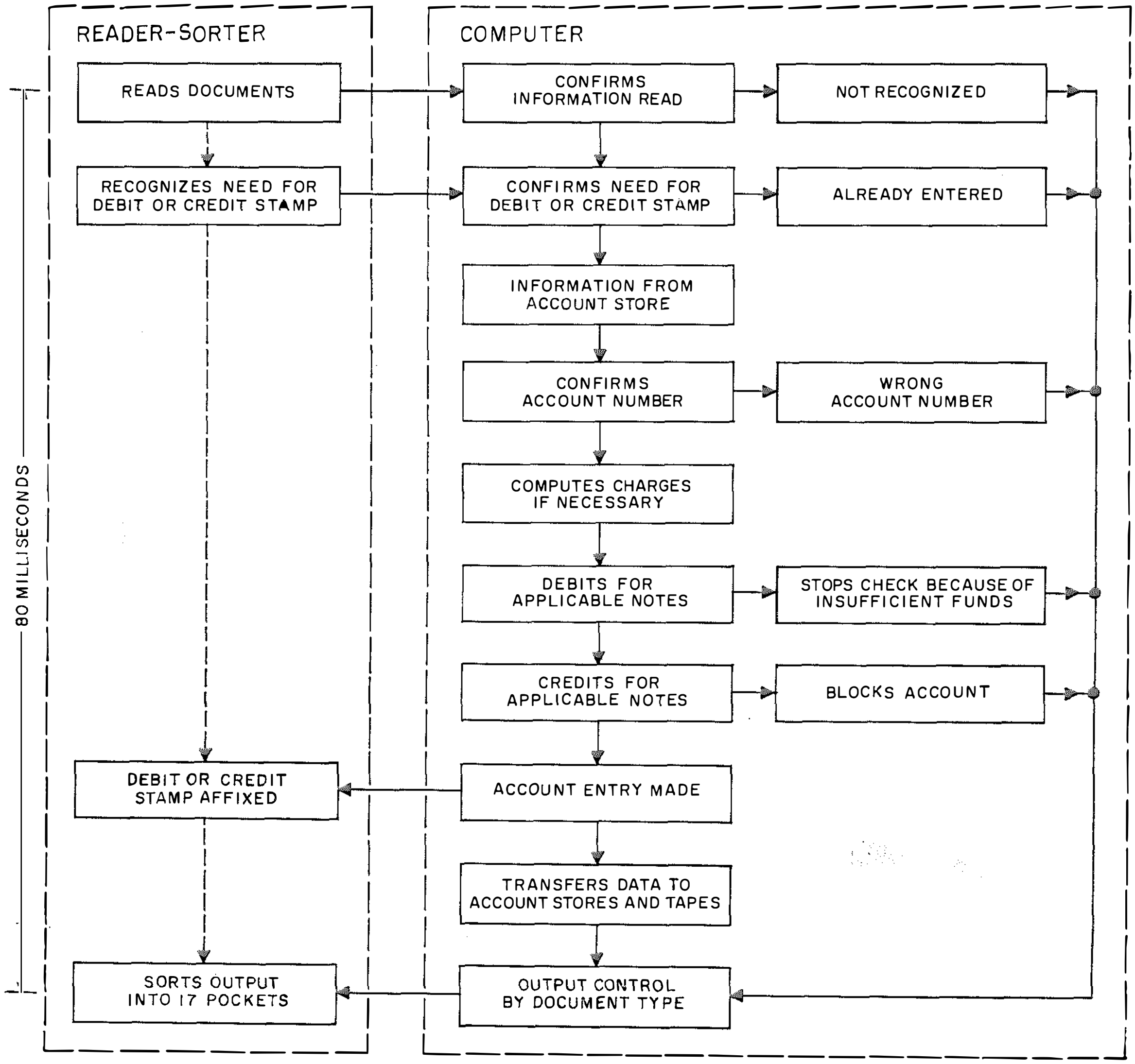


Figure 5—Sequence of operations in reader-sorter and computer for making entries to accounts.

(1) documents to be sent to other post offices

(1) documents with erroneously encoded account check digit

(1) documents that need manual handling

(1) documents with blocking notes

(1) documents rejected for technical reasons.

All data received by the computer during the electronic entry of accounts are converted to the following magnetic tapes.

(1) for all processes (program tape)

(1) for all received credits

(1) for all received debits

(1) for all unsettled documents (cases)

(1) for all special-list data.

3.2.2 *Entries and Information via Inquiry Unit*

The inquiry unit is used for entering accounts of cashier's checks and wire transfers of credits without documents as well as for account information and modification of blocking notes. After keying in the respective account number and operating a programing key, the new balance of the requested account is printed out. A second keying in of the amount and a corresponding account-entry key correct the account store.

As a receipt for the account entry, the request data are printed out by the inquiry unit. These entries and information are automatically handled on line with other operations.

3.3 SORTING

3.3.1 *Credit Notes*

Credit notes that must be sent to the credit receiver together with special lists and statements of account must be sorted according to credit account numbers. Only after the documents are sorted can the special lists and statements of account be printed. The sorting machine is used for these processes also, operating independently of the computer and in parallel with the electronic sorting of magnetic-tape data.

3.3.2 *B-Documents*

All debit processes or *B*-documents (documents to be credited to the other 12 postal check offices) must be sorted. This operation may be performed by the reader-sorter in one sorting process or by the sorter in two processes. In the trial installation this process can only be simulated, as no exchange of documents with other postal check offices is planned at present and for the near future.

3.3.3 *Magnetic-Tape Data*

Before compiling the data of statements of account, the debit data converted to the magnetic tapes during entry of accounts must be sorted according to debit account numbers. As already mentioned, the computer can sort these data in parallel with the document sorting.

3.4 PROCESSING STATEMENTS OF ACCOUNT

The documents sorted by debit account numbers and credit account numbers are necessary for preparing statements of account. Further, with this operation the addresses of postal check customers and balances of their latest statements of account must be added. The last-mentioned data are stored on the so-called customer tape.

At the beginning of this process the sorted documents go to the envelope stuffer (see Figure 6). The high-speed line printer connected to the computer is now prepared for coordinated operation with the envelope stuffer. This is automatically controlled by the computer.

Figure 7 shows the individual steps. The sorting machine takes the sorted credit notes from the stack and reads the data from the notes into the computer. All documents necessary for the statements of account are collected in the stacker. In addition, the computer receives the latest credit balances of the respective accounts from the magnetic drum, the credit balances of the day before from the customer old tape, and all the day's debits from the debit tape. By means of the new credit data and the credit balance of the day before, the computer ascertains the new credit balance and compares it with the drum credit balance converted by on-line entry. If both agree the statement of account is presented via the high-speed line printer; at the same time the new credit balance is converted to the customer new tape. The program tape supplies postal data necessary for dispatch, mainly the name and address of the customer.

The printed statement of account is separated from the paper roll, turned, and folded, the respective credit notes are attached, and all are automatically stuffed into a window envelope. The sealed envelope is then conveyed to one of the five pockets of the stacker. One pocket receives all statements of account rejected for errors; these are handled manually.

4. Conclusions

The on-line concept of entering accounts and the automatic stuffing of statements of account into envelopes are especially important to the future mechanization of the automatic postal check service. The on-line entry of all documents by their sequence of arrival in the postal check office is advantageous because the transfer documents may be credited and debited in one operation without re-sorting. Furthermore, encoding and entry are carried out in parallel

Figure 6—View of trial installation. The envelope stuffer and line printer are at left foreground and the stamping device for sealed letters is at right foreground. The document sorter equipped with 12 pockets and the reader-sorter equipped with 17 pockets are in the background.

and more time is thus available for encoding. This results in a considerable reduction of encoding units and personnel.

Before the advantages in techniques and organization could be proved by this trial installation, considerable planning plus programing of approximately 30 000 instructions were necessary. The Deutsche Bundespost shared in this work, which lasted more than 3 years and was completed in September 1964.

The Bundespost now is in a position to evaluate and improve the new processes and to carry out capability and reliability tests. Furthermore, the ease of programing the system will be very valuable in preparing statistical material as a basis for planning further mechanization of all postal check offices.

To provide for future integration of a mechanized postal check service into the overall automation of the entire postal service, it is planned to equip the envelope-stuffing system with extra units. An additional function will be to print the mail area code number on the envelopes in a machine-readable way. This will result in faster mail distribution. Furthermore, a dated postage stamp (franking notice) will be automatically printed on each envelope.

To fully mechanize postal check operations, which are now done mainly by hand, much time will be required to complete the preparatory

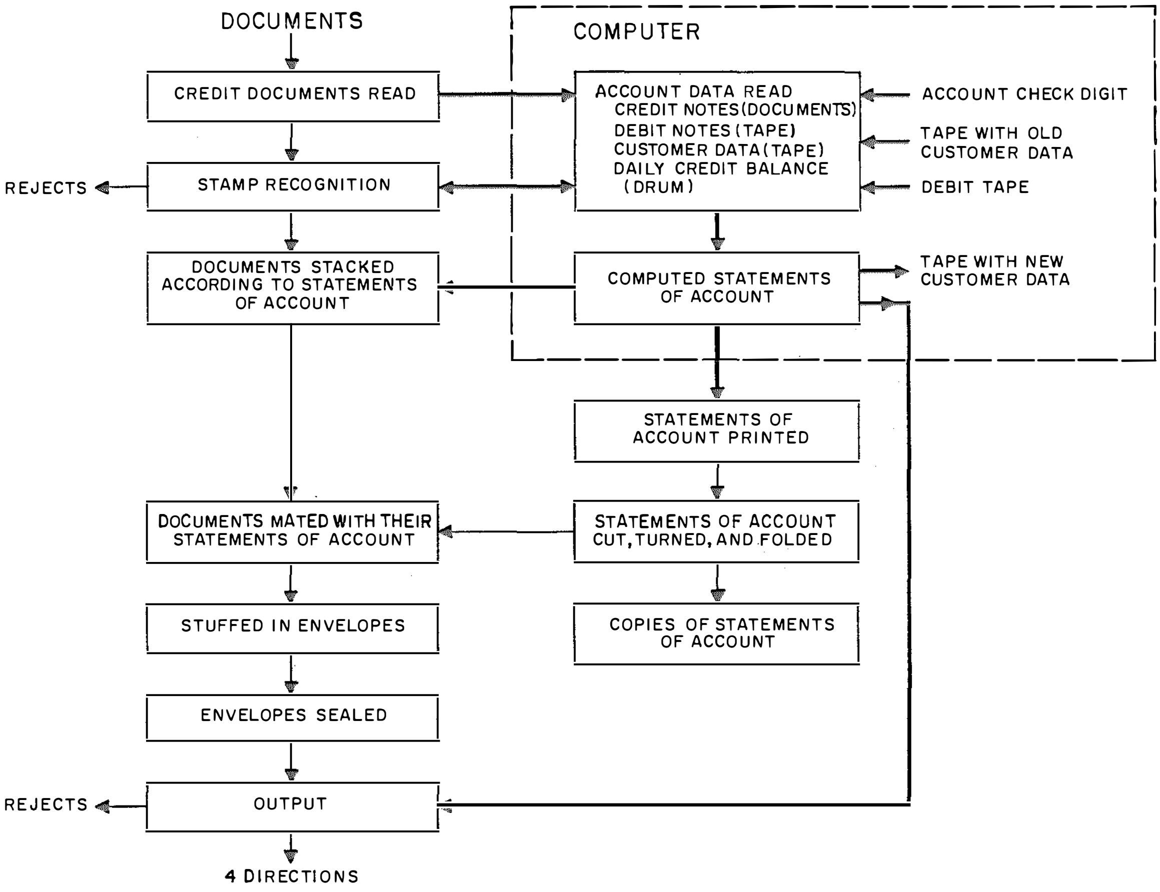


Figure 7—Handling of documents after they are validated and encoded. The heavy lines represent signal data flow, while the others represent document flow.

phase. This trial installation is one step along the path to completion.

Since this paper was prepared, the Deutsche Bundespost has decided that later it will modify the optical readers in the Nuremberg test installation for the *OCR-A* type face. This is an international standard [12] and, being very similar to the *CZ 13,* the same performance features are shared by the two faces.

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Microwave Power Sources Using Solid-State Devices *

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Introduction

The past few years have seen the replacement of valves of low to medium power by solid-state sources, either varactor chains or tunnel-diode oscillators. The requirements for these sources depend very much on their proposed use and on their power, noise, bandwidth, and other properties.

1. Examples of Specifications

In the baseband and intermediate-frequency circuits of radio-link equipments, the use of transistors permits a reduction in equipment volume, maintenance costs, and power consumption, plus an increase in reliability. To carry this trend further and replace the valves in the radio equipment by solid-state devices requires the development of microwave power sources of appropriate performance, together with some changes in equipment design to avoid the need for a direct relationship between the solid-state source and the valve source it replaces. For example, the introduction of an input radio-frequency parametric or tunnel-diode amplifier of lower noise figure eases the transmitted power requirement.

The local-oscillator power in a heterodyne microwave repeater for 1800-channel capability, in which a traveling-wave tube is retained to provide the output power of 10 watts, is required to be from 2 to 3 milliwatts for the input mixer and about 40 milliwatts for the output mixer, at fixed frequencies within the International Radio Consultative Committee bands from 3·8 to 4·2 and from 5·9 to 6·4 gigahertz, with a stability of ±100 kilohertz. It is also required that any incidental frequency modulation produce no more than 10 picowatts of psophometrically weighted noise power in any of the baseband channels between 300 kilohertz and 8·2 megahertz after demodulation. If this is considered to be due to a spectrum of white noise, uncorrelated on either side of the local-oscillator frequency, of power density N per 4-kilohertz bandwidth, the carrier-power-to-noise-ratio requirement in decibels can be written

$$\frac{P}{N} = 80 - W + (FM)$$

where

W = psophometric weighting allowance
= 3·6 decibels

(FM) = frequency-modulation disadvantage factor

$$= 20 \log \left(\frac{\text{baseband frequency}}{\text{root-mean-square deviation}} \right)$$

where the deviation corresponds to 1 milliwatt referred to a point of zero reference level at this baseband frequency.

Hence

$$\begin{aligned} (P/N) &> 107 \cdot 7 \text{ decibels at } 8 \cdot 2 \text{ megahertz} \\ &> 107 \cdot 4 \text{ decibels at } 5 \cdot 0 \text{ megahertz} \\ &> 102 \cdot 6 \text{ decibels at } 2 \cdot 0 \text{ megahertz} \\ &> 97 \cdot 2 \text{ decibels at } 1 \cdot 0 \text{ megahertz} \\ &> 86 \cdot 9 \text{ decibels at } 0 \cdot 3 \text{ megahertz.} \end{aligned}$$

Since the effective frequency deviation is directly proportional to the multiplication factor M, these noise-margin requirements become more severe by $20 \log M$ decibels if referred to preceding points in a multiplier chain.

For a 960-channel system it becomes feasible to replace the traveling-wave tube by a varactor-multiplier chain that supplies an up-converter producing a sideband output power of 1 watt. In this case a local-oscillator power of 2·5 watts is required and the corresponding noise margins, allowing for a 0 decibels relative 1 milliwatt referred to a point of zero reference level deviation of 200 kilohertz root-mean-

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* Presented at 11th International Congress on Electronics, Rome, Italy; 22–26 June 1964.

square and the appropriate International Radio Consultative Committee pre-emphasis characteristic, become

$$
\begin{aligned}
(P/N) &> 98\cdot 7 \text{ decibels at } 4\cdot 188 \text{ megahertz}\\
&> 97\cdot 8 \text{ decibels at } 2\cdot 0 \text{ megahertz}\\
&> 93\cdot 7 \text{ decibels at } 1\cdot 0 \text{ megahertz}\\
&> 83\cdot 8 \text{ decibels at } 0\cdot 3 \text{ megahertz.}
\end{aligned}
$$

To ease the selectivity requirements on the multiplier circuits and on any subsequent filters used to suppress spurious output frequencies, the crystal-oscillator frequency and overall multiplication factor should be chosen so that the unwanted sideband tones do not fall at spacings simply related to the intermediate frequency. Thus for a range of local-oscillator frequencies from 5·87 to 6·47 gigahertz, a multiplication factor of 128 requires a crystal-frequency (f_c) range of 45·9 to 50·6 megahertz, which is suitably spaced from 70 and 35 megahertz. This permits the spurious margin of $f_{lo} \pm f_c$ to be about 50 decibels less severe than if f_c had fallen in the range from 62 to 78 megahertz.

The transfer characteristic curve, from the input of the intermediate-frequency driver amplifier to the sideband output of the up-converter, is required to have a 0·25-decibel-down bandwidth of not less than 20 megahertz.

Another possible application of solid-state microwave power sources is in a transmitter unit for a frequency-modulated radio altimeter. In this case an output power of about 0·5 to 1 watt at 4 gigahertz is adequate, but provision must be made to sweep the transmitter frequency over a band of 100 megahertz at a frequency of a few hundred hertz. This requires that the multiplier chain have a dynamic bandwidth of the order of at least 3 per cent.

Radio-link equipments are often required to operate over a room ambient temperature range of 0 to 50 degrees Celsius and relative humidity of up to 85 per cent. The corresponding figures for an altimeter transmitter may be −55 to +70 degrees Celsius. Usually the higher limit is more significant because of overheating of transistors and varactors, with consequent loss of power and failure.

2. Basic Theory of Varactor Circuits

Most solid-state microwave sources that develop more than a few milliwatts depend for their operation on the voltage-variable capacitor or varactor diode, for which the capacitance C_v at reverse bias voltage V is related to the zero bias capacitance C_0 by

$$C_v = C_0/(V - \phi)^{1/n} \qquad (1)$$

where ϕ is the contact potential of the diode, which is usually of the order of 0·5 to 1·0 volt, and n is a constant that depends on the diode construction. Thus $n = 2$ for an abrupt junction and $n = 3$ for the graded type.

The varactor diode is generally used in a circuit of the type shown in Figure 1. Here the varactor current is provided by a number of branch circuits, each containing filters that have zero loss at the angular frequencies indicated and infinite loss at all other frequencies.

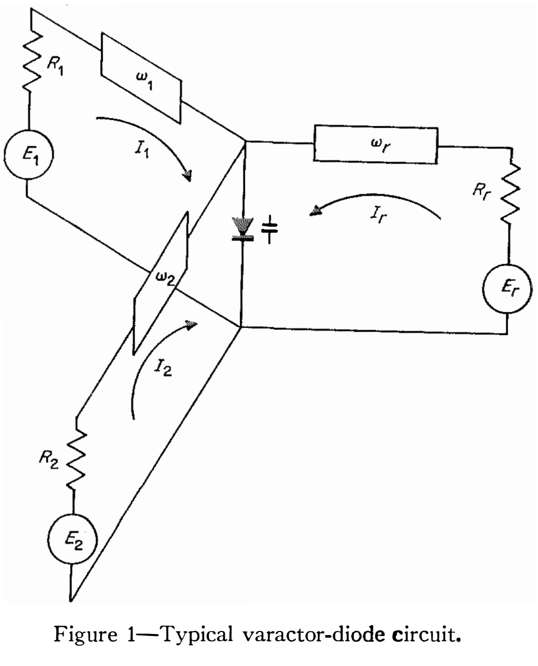

Figure 1—Typical varactor-diode circuit.

The varactor current is therefore

$$i = \sum_{1}^{m} I_r \sin(\omega_r t + \theta_r) \qquad (2)$$

and the charge q is given by

$$q = \int i\mathrm{d}t = \bar{q} - \sum_{1}^{m} \frac{I_r}{\omega_r} \cos(\omega_r t + \theta_r) \qquad (3)$$

where $\bar{q}$ is the mean charge.

If we consider the abrupt-junction varactor, (1) may be written

$$C_v \cong C_0 V^{-\frac{1}{2}} \qquad (4)$$

if $V \gg \phi$, and hence the charge is

$$q = \int C_v \mathrm{d}V = 2C_0 V^{\frac{1}{2}}. \qquad (5)$$

It follows that $\bar{q} = 2C_0\bar{V}^{\frac{1}{2}}$ where $\bar{V}$ is the voltage across the varactor corresponding to the mean charge.

From (3) and (5) the varactor voltage is

$$V = \frac{1}{4C_0^2} \times \left\{2C_0\bar{V}^{\frac{1}{2}} - \sum_{1}^{m} \frac{I_r}{\omega_r} \cos(\omega_r t + \theta_r)\right\}^2. \qquad (6)$$

The power input P_r to the varactor due to the flow of current I_r at an angular frequency ω_r is therefore

$$P_r = \frac{\omega}{2\pi} \int_0^{2\pi/\omega} V I_r \sin(\omega_r t + \theta_r)\mathrm{d}t \qquad (7)$$

where $\omega/2\pi$ is the fundamental frequency of the system.

2.1 Frequency Doubler

If we put $m = 2$, then $\omega_2 = 2\omega_1$. If $E_2 = 0$, Figure 1 reduces to the doubler circuit.

In this case, (7) gives P_1, the input power to the doubler, as

$$P_1 = \frac{I_1^2 I_2}{16 C_0^2 \omega_1^2} \sin(2\theta_1 - \theta_2).$$

If we set $\theta_1 = 0$, P_1 is a maximum if $\theta_2 = -\pi/2$. That is

$$P_1 = \frac{I_1^2 I_2}{16 C_0^2 \omega_1^2}.$$

The power input P_2 to the doubler at $2\omega_1$ is

$$P_2 = \frac{I_1^2 I_2}{16 C_0^2 \omega_1^2} \sin(\theta_2 - 2\theta_1) = -P_1. \qquad (8)$$

Thus, the varactor diode behaves as a power source P_2 at $2\omega_1$.

Examination of (6) shows that the varactor has a mean input capacitance $C = C_0\bar{V}^{-\frac{1}{2}}$. If the varactor is driven over the entire reverse-bias region, $\bar{V} = V_b/4$ as the charge waveform is symmetrical about $\bar{q}$ and the mean capacitance is then

$$C = 2C_b. \qquad (9)$$

The results obtained above are for operation of a loss-free varactor; however, the practical varactor is not loss-free but has a series resistance R_s. The quality of a varactor is frequently expressed in terms of the cut-off frequency $\omega_c/2\pi$, defined as the frequency at which the $Q = 1$ for a stated reverse voltage.

Thus, at the breakdown voltage V_b, the series resistance $R_s = \dfrac{1}{\omega_c C_b}$.

The efficiency η of a doubler circuit having a conversion resistance R_c and a load resistor R_2 is

$$\eta = \frac{R_c}{R_c + R_s} \cdot \frac{R_2}{R_2 + R_s} \qquad (10)$$

and for high efficiency

$$\eta \simeq \frac{1}{1 + R_s(1/R_c + 1/R_2)}.$$

From (8), the power delivered to the load circuit comprising $R_2 + R_s$ is

$$P_2 = \frac{I_1^2 I_2}{16 C_0^2 \omega_1^2} \cong \frac{I_2^2 R_2}{2}$$

for $R_2 \gg R_s$. Hence

$$I_2 = \frac{2I_1^2}{16C_0^2\omega_1^2R_2}$$

and

$$P_2 = \frac{2I_1^4}{(16C_0^2\omega_1^2)^2R_2}\,.$$

But

$$\begin{aligned} R_c &= \frac{2P_2}{I_1^2} \\ &= \frac{2(2)^{1/2}}{16C_0^2\omega_1^2}\cdot\left(\frac{P_2}{R_2}\right)^{1/2}. \end{aligned}$$

Therefore

$$\eta = \frac{1}{1 + R_s\{4C_0^2\omega_1^2(2R_2/P_2)^{1/2} + 1/R_2\}} \qquad (11)$$

which is maximized when $R_2 = 2R_c$.

This result corresponds to

$$I_2 = I_1(R_c/R_2)^{1/2} = I_1 2^{-1/2}.$$

Substituting for I_2 in (3), and for the condition $\bar{V} = V_b/4$ gives

$$\begin{aligned} q_{\max} &= 2C_0V_b^{1/2} \\ &= C_0V_b^{1/2} - \frac{I_1}{\omega_1} \\ &\quad \times \left(\cos\omega_1 t + \frac{1}{2 \times 2^{1/2}}\sin 2\omega_1 t\right). \end{aligned}$$

Solving for I_1 gives

$$I_1 = \omega_1C_0V_b^{1/2}/1{\cdot}177. \qquad (12)$$

From (8)

$$R_c = \frac{2P_1}{I_1^2} = \frac{2^{1/2}I_1}{16C_0^2\omega_1^2}\,.$$

Thus

$$R_c = \frac{1}{(13{\cdot}3\omega_1C_b)}\,. \qquad (13)$$

Substituting $R_2 = 2R_c$ and (13) into (10) gives

$$\eta = \frac{1}{1 + 20(\omega_1/\omega_c) + 88{\cdot}8(\omega_1/\omega_c)^2}\,.$$

This is plotted in Figure 2.

From (12) and (8) the power-handling capacity is

$$P_1 = \frac{\omega_1C_bV_b^2}{16 \times 2^{1/2}(1{\cdot}177)^3} = 0{\cdot}17f_1C_bV_b^2. \qquad (14)$$

2.2 TRIPLERS AND QUADRUPLERS

If we impose the conditions $m = 3$, $\omega_2 = 2\omega_1$, $\omega_3 = 3\omega_1$, and $E_2 = E_3 = R_2 = 0$, then Figure 1 corresponds to a frequency tripler. Equation (7) then gives

$$P_1 = \frac{I_1I_2}{16C_0^2\omega_1^2}\cdot(I_1 + I_3/3)$$

for $\theta_2 = -\pi/2$ and $\theta_3 = -\pi$.

$$P_2 = -\frac{I_1^2I_2}{16C_0^2\omega_1^2} + \frac{I_1I_2I_3}{24C_0^2\omega_1^2} = 0$$

or $3I_1 = 2I_3$.

$$P_3 = -\frac{I_1I_2I_3}{16C_0^2\omega_1^2} = -\frac{3I_1^2I_2}{32C_0^2\omega_1^2} = -P_1. \qquad (15)$$

From (15) it is evident that a current I_2 must be permitted to flow through the varactor to

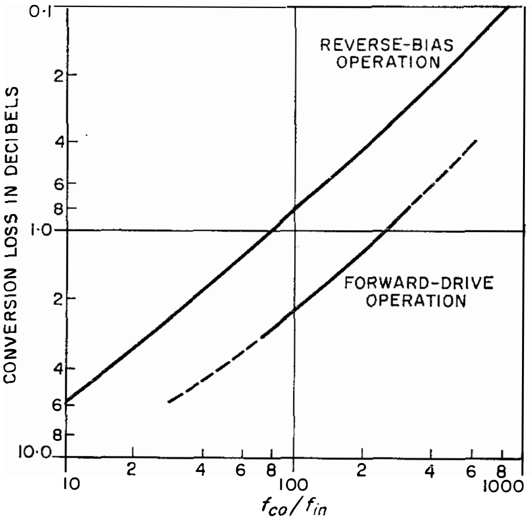

Figure 2—Conversion loss in varactor frequency doubler. f_{co} = cut-off frequency and f_{in} = input frequency to doubler.

obtain an output at $3\omega_1$. An idler circuit is therefore necessary to provide a suitable path for I_2.

If $\omega_3 = 4\omega_1$, the circuit will operate as a quadrupler without requiring additional idler circuits.

3. Practical Performance of Varactor Multiplier Chains

3.1 Transistor Power Sources

The power sources used to drive frequency-multiplier chains usually comprise low-power oscillators, buffer stages, and power output amplifiers to provide the appropriate output level. Research is directed toward generating higher output powers at the highest possible frequency, to reduce the multiplication factors required in multiplier chains and also the problems of spurious outputs at unwanted harmonics.

The present situation is summarized in Figure 3, which illustrates manufacturer's claims regarding the power output characteristics of a number of transistors, together with some experimental results.

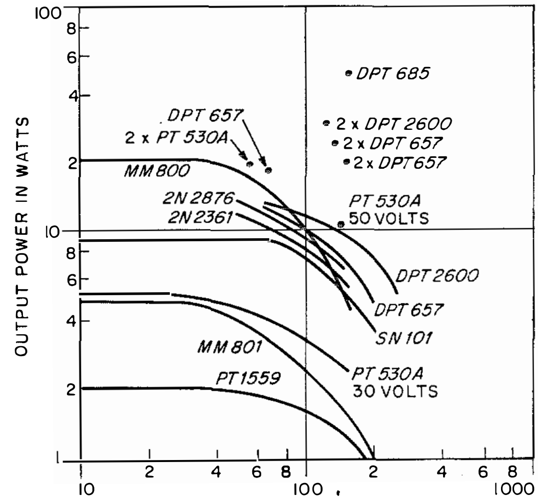

Figure 3—Rated power output of various transistors as a function of frequency.

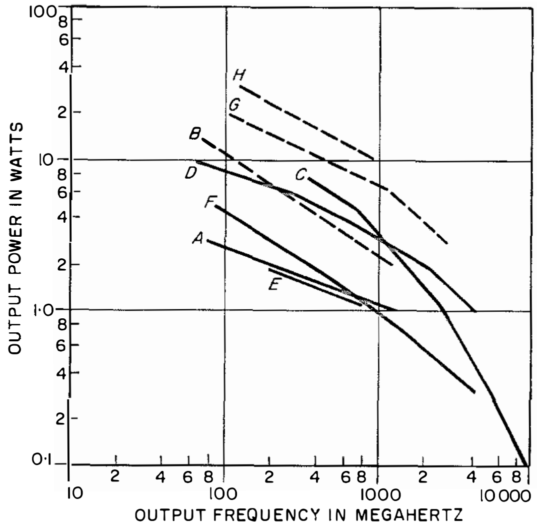

Figure 4—Performance of varactor multiplier chains. $A = 4 \times 4$, $B = 2 \times 3 \times 3$, $C =$ doublers, $D =$ doublers, $E =$ quadrupler, $F = 3 \times 4 \times 4$, $G = 3 \times 2 \times 2 \times 2$, $H =$ doublers.

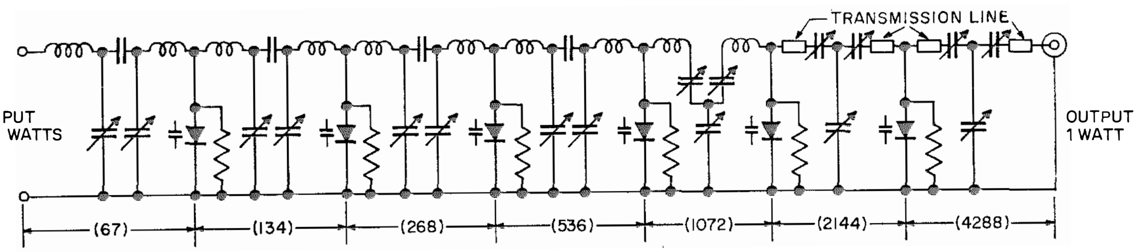

Figure 5—Varactor multiplier chain of doublers represented by curve D of Figure 4. Frequencies in megahertz are in parentheses.

3.2 VARACTOR MULTIPLIER CHAINS

The performance of a number of multiplier chains is indicated in Figure 4. It is seen that doublers and triplers are usually employed for the high-power applications, as the dissipation per varactor is then minimized, whilst quadruplers are used for lower-power generation.

The power-handling capacity of the varactor diode is frequently limited by the need to restrict the voltage swing to the reverse-bias region rather than by dissipation in the series resistance R_s. It has been found experimentally, however, that the power-handling capacity is considerably improved by taking advantage of the charge storage effects obtained by driving the varactor voltage into the conducting region for part of the input cycle. The main result of operation in the forward-bias region is a reduction in the input impedance of the varactor; both the conversion resistance and the mean series reactance are considerably reduced.

The conversion resistance R_c of a varactor operating as a doubler under conditions of forward drive is approximately equal to R_2, and is usually of the order of $1/(30\omega_1 C_b)$. Substituting these values into (10) gives the curve labeled Forward-Drive Operation in Figure 2. Although the efficiency is lower than for reverse-bias operation, the power-handling capacity may be increased by up to 30 times. The conversion resistance is sensibly independent of input power level, whilst the mean input capacitance is a function of power level and is usually much higher than the zero-bias capacitance.

3.3 BANDWIDTH AND METHODS OF CASCADING MULTIPLIERS

The varactors in a multiplier chain are usually coupled by 8 double-tuned transformers to provide a reasonable compromise between bandwidth and the suppression of unwanted harmonics. The double-tuned transformers, which may employ inductance or capacitance coupling, also provide the impedance transformation required to couple the various stages.

The circuit arrangement of the multiplier chain of the unit labeled D in Figure 4 is shown in Figure 5. Figure 6 is a photograph of the

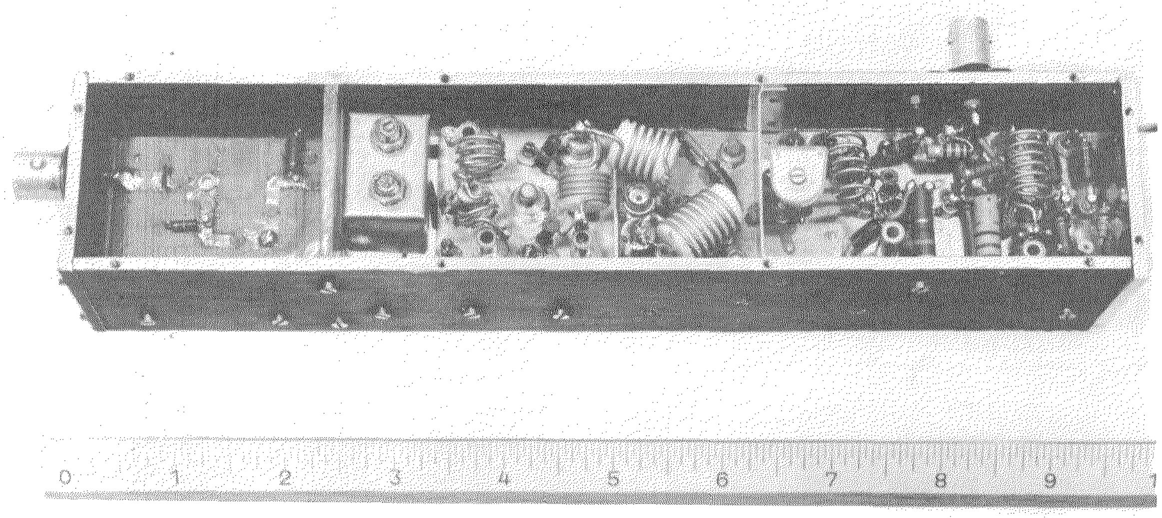

Figure 6—Varactor multiplier chain. The scale is in inches.

same unit, which requires a direct-current input of about 20 watts. If the efficiency per stage is high, a multiplier chain behaves substantially as if composed of pure reactances, and the overall bandwidth is only slightly smaller than that of any one stage. The bandwidth of the coupling network depends on the loaded Q of the circuits, but the range of loaded Q values that may be used is limited by the varactor itself to a minimum of 1 to 3 (depending on power level).

There is no upper limit to the loaded Q factors of the coupling networks, provided that the circuit loss can be tolerated and that the pass band is stable with respect to temperature fluctuations, ageing, et cetera.

3.4 TEMPERATURE AND STABILITY

The efficiency of the varactor falls as the operating temperature increases. The loss of a typical chain may increase by as much as 0·5 to 1·0 decibel for a rise of 50 degrees Celsius above normal operating temperature.

It will be seen from Figure 5 that all the varactors are self-biased. The bias resistors stabilize the input-level-to-output-level characteristic of the varactor and alleviate the hysteresis effects that otherwise occur.

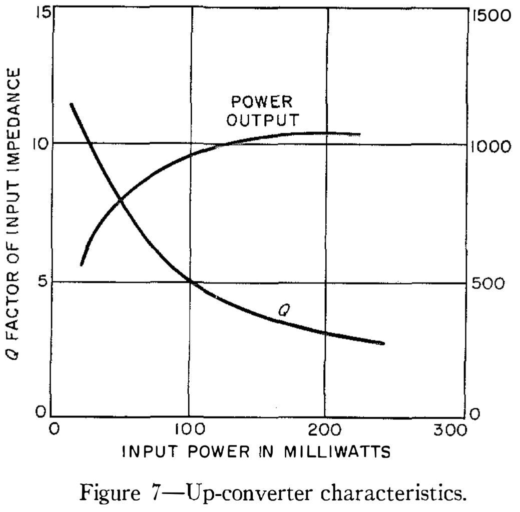

Figure 7—Up-converter characteristics.

4. Up-Converter

The up-converter is essentially a variable-capacitance mixer that provides an amplified upper-sideband output.

Thus if we put $m = 3$, $\omega_3 = \omega_1 + \omega_2$, and $E_3 = 0$ in Figure 1, the circuit corresponds to a shunt-connected up-converter. Equation (7) then gives

$$P_1 = \frac{I_1 I_2 I_3}{8C_0^2 \omega_2(\omega_1 + \omega_2)}$$

$$P_2 = \frac{I_1 I_2 I_3}{8C_0^2 \omega_1(\omega_1 + \omega_2)}$$

$$P_3 = -\frac{I_1 I_2 I_3}{8C_0^2 \omega_1 \omega_2}$$

if $\theta_2 - \theta_3 = \pi/2$.

From the above equations, it is seen that

$$P_1 + P_2 + P_3 = 0. \tag{16}$$

Also

$$\frac{P_1}{\omega_1} = \frac{P_2}{\omega_2} = -\frac{P_3}{\omega_3} = \frac{I_1 I_2 I_3}{8C_0^2 \omega_1 \omega_2 \omega_3}. \tag{17}$$

Equation (17) is the Manley-Rowe equation and shows that

$$\frac{P_3}{P_1} = -\left(1 + \frac{P_2}{P_1}\right) = -\frac{\omega_3}{\omega_1}. \tag{18}$$

Thus if P_1 is a low-level angle-modulated signal input, if P_2 is a "pump" supply, and if P_3 is the upper-sideband output, then P_3 is an angle-modulated signal that has the same modulation index as P_1 but is changed in frequency from ω_1 to $\omega_1 + \omega_2$ and amplified by a factor ω_3/ω_1, the increased output power being supplied by the pump source.

As in frequency multipliers, the series resistance of the varactor reduces the overall efficiency; the performance of an experimental unit is shown in Figure 7. This unit translates a signal input at 70 megahertz up to 4 gigahertz. The input impedance is also a function of power level, the variation of Q with input power being indicated in Figure 7.

5. Multipliers Using Higher Multiplication Ratios

If multiplying from a frequency f_{in} to f_{out} (integrally related), one has in principle the choice of using a single high harmonic or of using a chain of doublers, triplers, or other multipliers including mixed chains.

Sometimes the form will be decided by the integers involved, but since the usual problem is to achieve a given frequency f_{out} with a certain range of f_{in}, there will be some choice of multipliers to meet the conditions. From the point of view of efficiency, what is the best form of multiplier to use?

The efficiency of a single stage can be written approximately as

$$\eta = \eta_0 (1 - \alpha_n f_{\text{in}}/f_{co}) \qquad (19)$$

where η_0 depends on circuit losses, f_{co} is the varactor cut-off frequency, n is the multiplication ratio, and α is an empirical coefficient. This equation only holds for $f_{co}/f_{\text{in}} > 100$, but a modified form has a wider range of validity.

$$\eta = \eta_0 \exp(-\alpha_n f_{\text{in}}/f_{co}). \qquad (20)$$

Circuit losses are often negligible. In what follows we shall ignore the factor η_0 and concentrate on the effect of the diode.

The effect of two multipliers in tandem is easily calculated. Thus a doubler followed by a tripler will have an exponent in the efficiency equation of $(\alpha_2 + 2\alpha_3) f_{\text{in}}/f_{co}$, whilst a tripler followed by a doubler has an exponent $(\alpha_3 + 3\alpha_2) f_{\text{in}}/f_{co}$. (This assumes that diodes with the same cut-off frequency are used.) It can be seen that though they constitute a ×6 multiplier in both cases, the efficiencies are not the same.

The α factor multiplying f_{in}/f_{co} determines the total efficiency. For a range of multipliers this coefficient (deduced from Radio Corporation of America figures) is as follows. (It is plotted against n in Figure 8.)

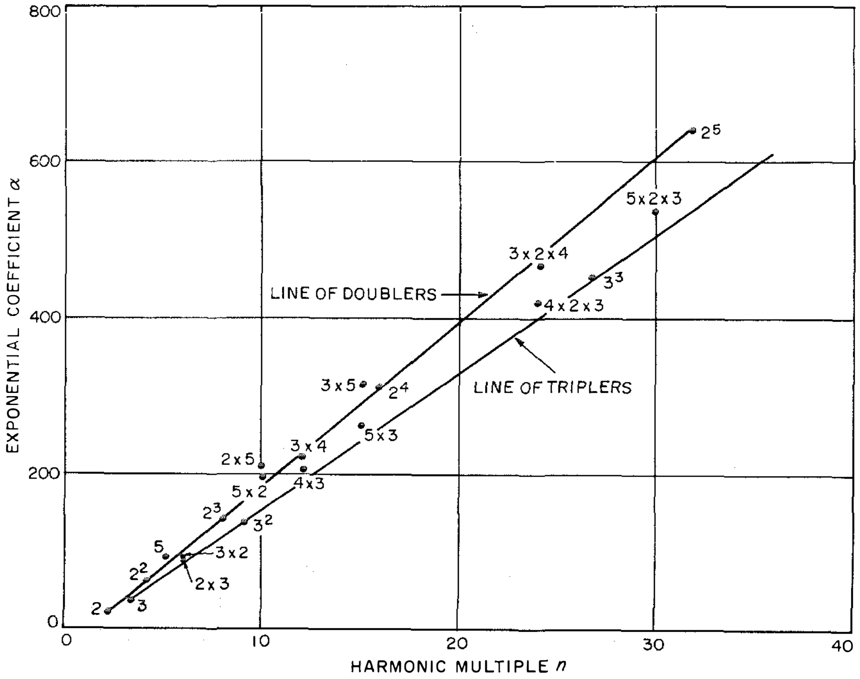

Figure 8—Efficiency coefficient as a function of harmonic multiple.

Multipliers					
Stages			Total	Coefficient α	Figure of Merit
×2			2	20·8	1
×3			3	34·8	0·836
×4			4	62·5	1
×2	×2		4	62·4	1
×5			5	92·9	1·12
×2	×3		6	90·4	0·87
×3	×2		6	97·2	0·935
×4	×2		8	146	1
×3	×3		9	139	0·836
×2	×5		10	207	1·103
×5	×2		10	197	1·052
×4	×3		12	202	0·88
×3	×4		12	222	0·971
×3	×5		15	316	1·072
×5	×3		15	267	0·916
×4	×4		16	312	1
×2	×4	×3	24	424	0·887
×3	×2	×4	24	472	0·99
×3	×3	×3	27	452	0·836
×5	×2	×3	30	545	0·904
×2	×4	×4	32	645	1

A figure of merit can be arrived at as follows: If m doublers are used in tandem, the combined efficiency for a common varactor cut-off frequency is

$$\begin{aligned}\eta_m &= \exp\{-\alpha_2 f_{\text{in}}(1+2+2^2\cdots+2^{m-1})/f_{co}\}\\ &= \exp\{-\alpha_2 f_{\text{in}}(2^m-1)/f_{co}\}\\ &= \exp\{-\alpha_2(f_{\text{out}}-f_{\text{in}})/f_{co}\}\end{aligned}$$

a form not dependent explicitly on m.

If the same output frequency is achieved by some other multiplication process, a figure of merit can be defined by dividing the second exponent by $\alpha_2(f_{\text{out}}-f_{\text{in}})/f_{co}$. The smaller this figure of merit, the more efficient the device.

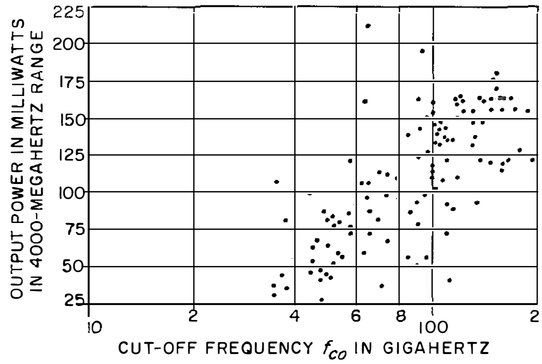

Figure 9—Power output at 4000 megahertz as a function of cut-off frequency for a quintupler. The input was 500 milliwatts at 800 megahertz.

Since the efficiency of a quadrupler and two doublers is seen to be (fortuitously) the same, the figure of merit of doublers and/or quadruplers in tandem is always unity. The figure of merit of a tripler is 0·836, the best of any combination, and hence a string of triplers is potentially the most-efficient way of reaching a given high frequency. Since the deleterious effect of a finite cut-off frequency is always most severe on the last stage, combinations involving triplers are always more efficient if the triplers come last. Experimental evidence to date is not sufficient to indicate whether the circuit losses associated with triplers outweigh this advantage in comparison with doublers or quadruplers.

In practice, diode parameters other than cut-off frequency can affect the efficiency, such as capacitance or the index in the voltage-capacitance law. Variations in output, for a fixed circuit, of up to 4 times can be met by changing diodes of the same cut-off frequency. Figure 9 shows the results obtained with a quintupler circuit in which two tuning elements were adjusted for each new diode. The form of circuit is shown in Figure 10, which is an octupler multiplier. The input of approximately 800 megahertz passes through a coaxial low-pass filter with a cut-off frequency of 1200 megahertz to a coaxial member that mounts the varactor. The varactor is probe coupled to the appropriate size of waveguide in which the wanted harmonic is selected by a band-pass filter. For fifth-harmonic outputs in the 4-gigahertz range, the waveguide has internal dimensions of 2·000 × 0·667 inches (5·080 × 1·694 centimetres); for eighth-harmonic outputs in the 6-gigahertz range, the internal dimensions are 1·372 × 0·622 inches (3·485 × 1·580 centimetres). The performance is optimized by choosing the spacing of the filters and the varactor from the coaxial junction. One set of these spacings is sufficient to cover the 4-gigahertz range for the fifth harmonic, but five sets are required to cover the 6-gigahertz range at the eighth harmonic.

Using the same type of varactor to generate the eighth harmonic gives a trend rather more than twice as steep with respect to cut-off frequency, with a mean value of 12 decibels of conversion loss for a cut-off frequency of 100 gigahertz.

For high harmonic numbers the step-recovery diode, with an empirical loss law of $1/n$, seems efficient for low powers. For example, a Hewlett-Packard device multiplies from 100 megahertz to 2000 megahertz with a 4-milliwatt output and a 10-decibel loss, of which 3 decibels is estimated to be circuit loss.

6. Noise

The frequency-modulated-noise performance of local-oscillator sources for an 1800-channel system in the 6-gigahertz band was measured using a super-high-frequency receiver with a noise figure of 9 decibels, a demodulator, and a selective baseband-level meter with a bandwidth of 4 kilohertz. The residual noise was first determined with the two microwave frequencies supplied from *H*-wave valve oscillators *V265A/1M*. This residual noise was demonstrated to be due to the demodulator by adding an invar wavemeter-type filter of ±0·8-megahertz bandwidth to each of the oscillators and finding no change in the baseband noise. One valve oscillator was then replaced by the solid-state source and the noise contribution of the latter was calculated from the change in baseband noise level.

For greater resolution, as for example when examining the noise contributed by the output octupler alone, the frequency-modulated noise was enhanced by using a double-heterodyne receiver including a ×64 multiplier chain. As shown in Figure 11, the octupler under test was driven from a crystal oscillator followed by a ×18 valve multiplier to obtain about 800 megahertz. After being multiplied 8 times in the octupler under test, the output frequency was mixed to about 67 megahertz. A similar multiplier and octupler were used for the mixing and were followed by a narrow-band 3-section invar microwave filter to remove their noise contribution above 0·5 megahertz. The 4-gigahertz output from the ×64 multiplier in the receiver was mixed to 70 megahertz

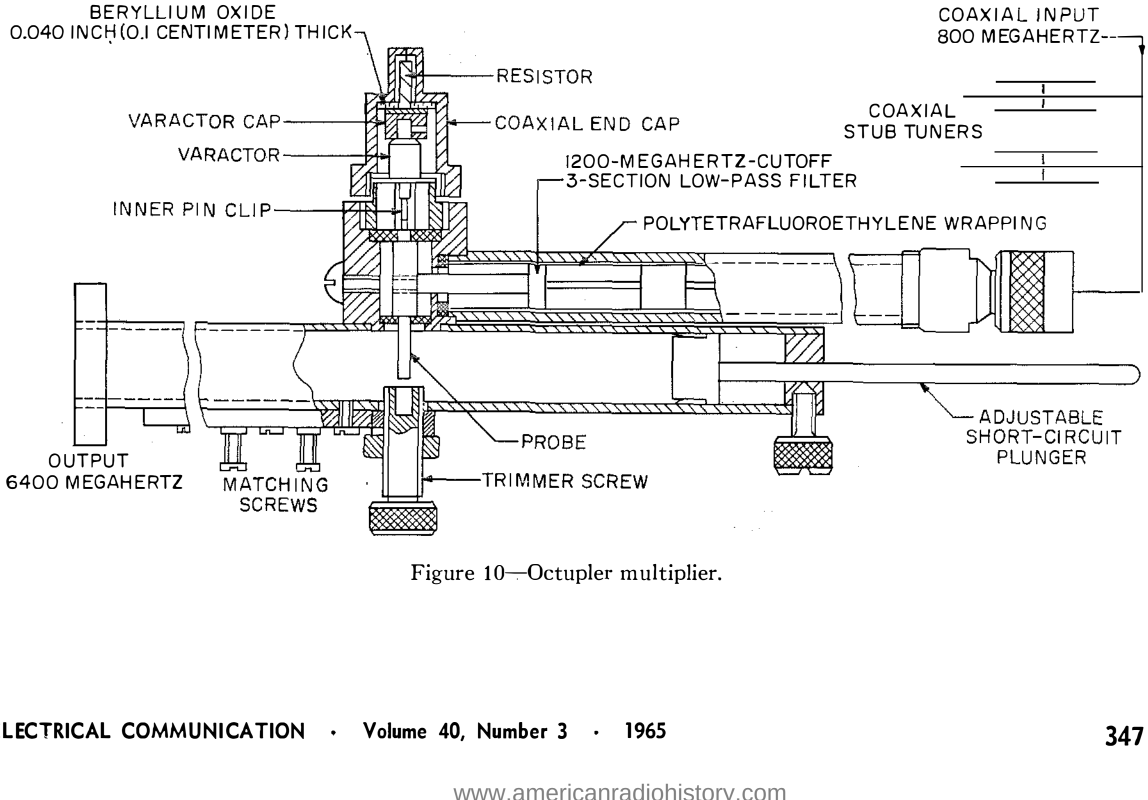

Figure 10—Octupler multiplier.

using a *CV2190* valve oscillator and then demodulated. The frequency-modulated response of the double-heterodyne receiver was calibrated by a radio-link modulator and transmitter substituted for the octupler under test, and although restricted by the bandwidth of the ×64 multiplier, the receiver gave increased resolution up to 4 megahertz. This arrangement proved most useful for examining the effect of circuit changes since most trouble was experienced with noise at around 2·0 megahertz.

Figure 12 shows the block diagram and noise performance of a radio-link transmitter comprising four units: an oscillator unit delivering 50 milliwatts at 50 megahertz, a driver unit including a varactor doubler and filter with output of 3·5 watts at 100 megahertz, a multiplier unit consisting of a quadrupler and doubler, and an octupler delivering 40 milliwatts at 6·4 gigahertz.

7. Tunnel-Diode Generators

A recent paper [1] describes the present and expected performance from tunnel-diode oscillators in which the diode constitutes the negative-resistance element of a simple tuned circuit in the form of a microwave cavity. Table 1 gives the best performance of present devices. It is seen that powers suitable for local-oscillator use are obtainable up to about 10 gigahertz. Although not given in the table, the powers obtainable below 1 gigahertz begin to be suitable for low-power radio transmitters.

An upper limit on future performance is estimated as 5 milliwatts at 30 gigahertz, with perhaps 70 microwatts at 140 gigahertz; peak junction currents are required of about 10^5 amperes per square centimetre and a line characteristic impedance of 1 ohm.

TABLE 1

PRESENT PERFORMANCE OF TUNNEL-DIODE GENERATORS

Frequency in Gigahertz	Power in Microwatts	Wafer Material
2·8	700	Germanium
10	200	Germanium
1·6	15 000	Gallium-arsenide
6	4 000	Gallium-arsenide
17	50	*p*-type gallium-arsenide
50	25	*n*-type gallium-arsenide
90	2	*n*-type gallium-arsenide

8. Future Prospects

Improvements can be foreseen in the directions of higher power, higher frequency, broader bandwidths, and simpler construction. The improvements will come from (*A*) improved circuits, (*B*) improved devices, and (*C*) new devices.

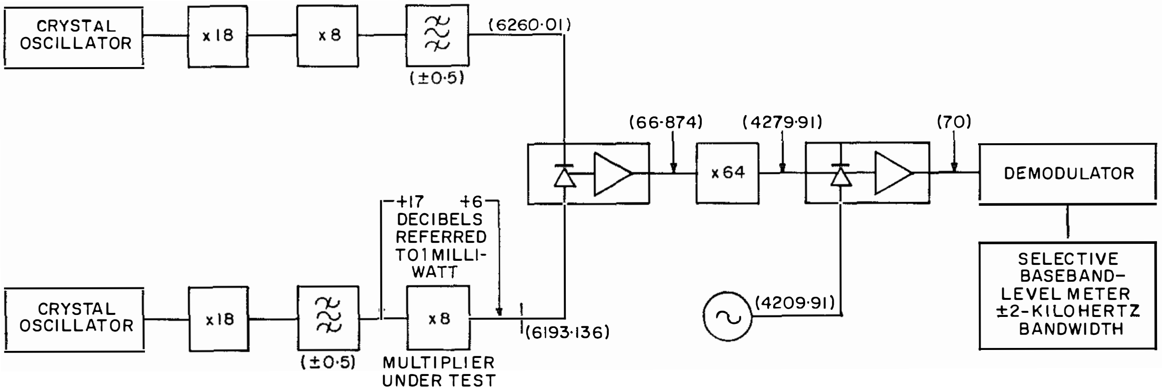

Figure 11—Circuit for measuring baseband noise in the octupler. The numbers within parentheses are in megahertz.

In the now-conventional doubler chains, the circuit loss is small compared with the diode loss and not much improvement is anticipated at the lower frequencies, though the microwave doublers have a little in hand. In going from 2 to 4 gigahertz, a loss of some 2·5 decibels is encountered; about 0·5 decibel of this is circuit loss in strip line. This loss is halved for a good coaxial or waveguide design. Rafuse [2] describes a quadrupler from 5·5 to 22 gigahertz with an output of 50 milliwatts, in which the use of waveguide and coaxial circuits and balanced gallium-arsenide varactors results in a conversion loss of 7·3 decibels, of which about 2 decibels is circuit loss.

The use of triplers instead of doublers promises a potential saving of 16 per cent, and circuit designs that benefit from this can be expected.

The use of higher multiplication numbers, either with varactor diodes or with step-recovery diodes, promises useful local-oscillator powers up to 30 gigahertz. If accurate control of the frequency is not important, a similar power can be foreseen for tunnel-diode sources. These may also give powers in hundreds of milliwatts in the very-high-frequency and lower super-high-frequency bands.

Transistor development is proceeding in two directions. Four watts at 500 megahertz is now possible, permitting the initiation of chains at this frequency with a consequent reduction of multiplier phase noise. Within a year or two 1·5 watts at 1·5 gigahertz is expected. On the other hand, high-power transistors giving up to 50 watts at 100 megahertz are now feasible, and 100 watts can be expected in a year or two. Collector efficiencies of 70 to 80 per cent are possible, and still-higher efficiencies have been achieved on single samples. Thus simplified circuits that start at high frequencies can be anticipated, or alternatively, high-power circuits that use triplers or quadruplers in tandem. At 4 gigahertz, 3 to 4 watts is now feasible, and perhaps 10 watts may be expected within a year.

Still-further improvement can be expected after the full potentialities of gallium-arsenide are realized. Figure 13 shows the resistivity of gallium-arsenide and of silicon as a function of carrier concentration. Much the same diode

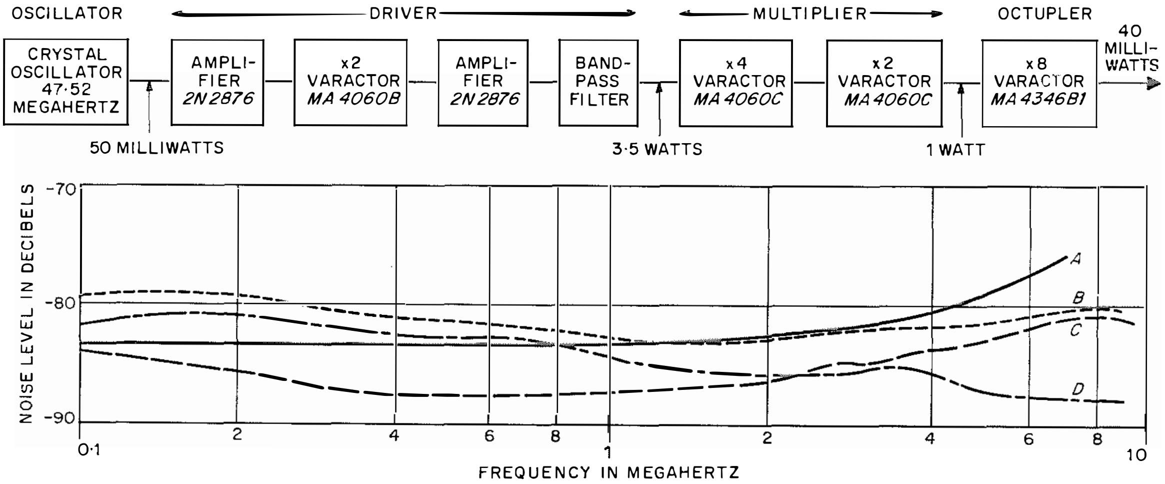

Figure 12—Block diagram of multiplier chain plus curves of baseband noise in decibels referred to a deviation of 200 kilohertz root-mean-square. Curve *A* represents the noise spectrum that will produce 10 picowatts of noise in an 1800-channel system. Curve *B* shows the measured noise of the multiplier chain plus the measuring circuit, curve *C* the noise of the measuring circuit, and curve *D* the noise of the multiplier chain.

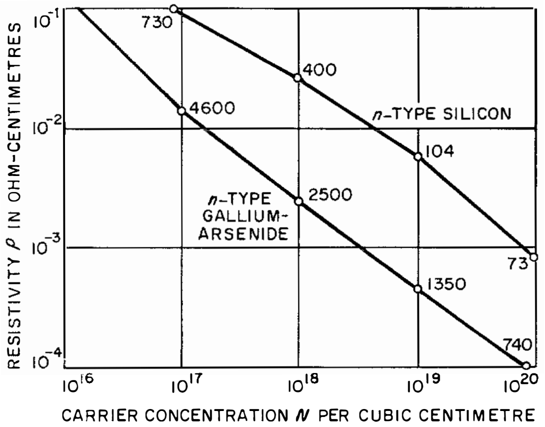

Figure 13—Resistivity of gallium-arsenide and silicon diodes. The numbers on the curves show electron mobilities.

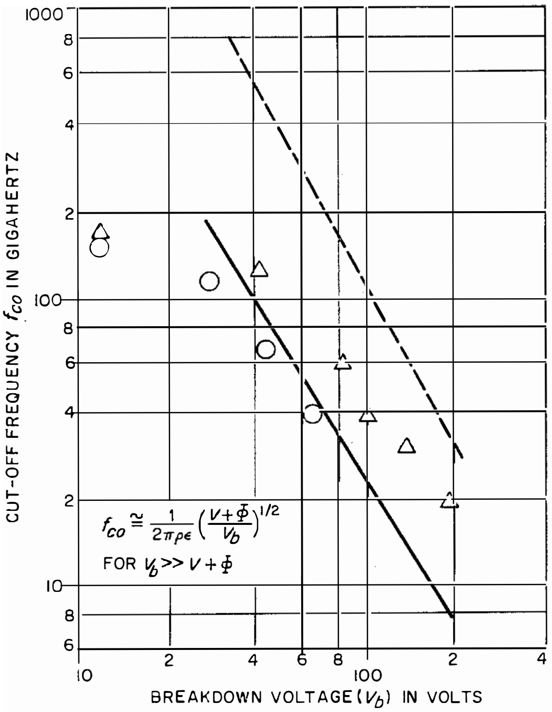

Figure 14—Theoretical maximum cut-off frequency as a function of breakdown voltage for gallium-arsenide (broken curve) and for silicon (solid curve) diodes. Experimental points for gallium-arsenide diodes (triangles) and for silicon diodes (circles) are also given.

capacitance and breakdown voltage can be expected, whilst the higher mobility of gallium-arsenide (about 5 to 10 times) should permit much-lower series resistance or higher cut-off frequencies if techniques can be developed to control the contact resistance at a sufficiently low level. Figure 14 shows the theoretical curves and experimental points for silicon and gallium-arsenide diodes. It is seen that the latter material has exceeded the capability of silicon, although there is still a factor of about 3 to be gained before it reaches its theoretical limit.

A further improvement with gallium-arsenide comes from its increased energy gap, permitting operation at higher temperatures. A maximum junction temperature of 175 degrees Celsius for silicon compares with 300 degrees Celsius for gallium-arsenide, although low-melting-point solders limit this at the moment to 220 degrees Celsius. An improvement in operating temperature of 1·3 to 1·5 can be expected, and with an improvement of 5 times in cut-off frequency, a power-handling capacity of 7·5 times can be expected compared with current silicon devices. The performance of an existing doubler chain and a possible chain using gallium-arsenide diodes is shown in Table 2.

With the full development of these devices, powers of 50 to 100 watts at 4 gigahertz may be foreseen.

TABLE 2

COMPARISON IN PERFORMANCE BETWEEN EXISTING DOUBLER CHAIN AND POSSIBLE GALLIUM-ARSENIDE CHAIN

Multiplying Factor	Input—Output Frequencies in Megahertz	Existing-Chain Loss Per Stage in Decibels	Gallium-Arsenide-Chain Loss Per Stage in Decibels
2	100—200	0·8	0·35
2	200—400	1·2	0·5
2	400—800	1·5	0·65
2	800—1600	1·7	0·7
2	1600—3200	2·2	0·9
32	100—3200	7·4	3·1

At these power levels modulation may be a problem, since an up-converter would need up to several watts of drive power. For a broadband signal the requirements of intermediate-frequency amplifiers in terms of signal linearity, amplitude-to-phase conversion, temperature response, et cetera, can be very severe, and it is not clear whether the necessary powers will always be forthcoming. Moreover, a good varactor diode and its circuit do not isolate one frequency from another and this could be an embarrassment, with mismatches and other impedance variations thrown back into the intermediate-frequency circuit. We can therefore anticipate efforts to effect direct modulation and also wider bandwidths. Currently bandwidths of 10 to 20 per cent can be achieved and up to an octave have been recorded. Beyond this, difficulty may be expected with leak-through of unwanted frequencies, although possibly triplers may be able to overcome this.

Finally, we would mention the solid-state source investigated by Gunn [3] and others. A thin semiconductor disc has ohmic contacts on its sides, and a high-intensity pulse is applied. The material breaks into oscillation in the microwave band. Powers up to hundreds of milliwatts and frequencies up to 10 gigahertz are considered possible. The mechanism is not now fully understood, but the frequency is connected with the inverse thickness of the sample via the electron transit time. If it can be controlled this promises to be a useful device for medium power levels.

9. References

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3. J. B. Gunn, "Microwave Oscillations of Current in III-V Semiconductors," *Solid State Communications*, volume 1, pages 88–91, Pergamon Press, Oxford, England; September 1963.

L. Lewin was born in 1919 at Southend-on-Sea, England. He joined Standard Telecommunication Laboratories in 1946 and in 1962 became assistant manager of the Transmission Systems Division, being in charge of development of microwave systems.

Mr. Lewin is an Associate Member of the Institution of Electrical Engineers. He has received 33 patents, and has published more than 60 technical papers, mainly on microwaves and antennas, in addition to two technical books. In 1961 he received two awards for a paper published in the Institute of Radio Engineers Transactions on Microwave Theory and Techniques, one of which, the W. R. G. Baker prize, was for the best paper published that year in all the transactions of the professional groups of the Institute.

Joseph Paine was born on 26 August 1916 in Oldham, England. In 1938, he received a B.Sc., Honours Physics, from Manchester University.

In 1938, he joined Standard Telephones and Cables and engaged in development work on multichannel carrier systems and test gear. Since 1950 he has worked on microwave radio links and is now in charge of design of waveguide components and aerials.

Mr. Paine is an Associate of the Institute of Physics.

Aerial Branching System Using Interdigital Filters

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1. Introduction

In multi-channel microwave radio relay systems, several transmitters and receivers frequently share the same aerial for reasons of economy, and the various signals are separated by a branching filter or multiplexer. A simple branching filter for two radio-frequency channels (diplexer) consists of two band-pass filters connected to a Y junction by short sections of transmission line, the lengths of which are chosen to give a good impedance match at the frequencies involved. Similar arrangements for four or more radio-frequency channels are unwieldy and difficult to set up, however, and branching filters using hybrid junctions have been widely used in such cases.

Several waveguide filters of this type have been described previously, and these have proved very satisfactory for the 4- and 7-gigahertz bands, but at lower frequencies their large size is a disadvantage. The 2-gigahertz branching filter described in this paper uses coupled-transmission-line 3-decibel hybrids and interdigital filters, and these permit a design that is much-more compact than would have been possible in waveguide, yet had comparable performance.

2. Operation of Branching Filter

The manner in which the branching filter separates the radio-frequency signals may be understood by reference to Figure 1, which shows one section of the filter. Signals from the aerial entering the left-hand hybrid at port 1 divide into two equal parts, which pass through the band-pass filters F and recombine in the right-hand hybrid if they fall within the filter pass band. Otherwise they are reflected and emerge at port 2 of the left-hand hybrid, to which is connected a chain of similar sections.

In the same way, the signal from a transmitter, connected to port 3 of one of the filter sections, emerges at port 1 and propagates up the aerial feeder after reflection in any intervening filter sections. A desirable feature of this type of filter is that transmitter breakthrough to the receivers, which occurs along a path like that between ports 2 and 3, is governed by the hybrid directivity as well as the insertion loss of the filters F at the transmitter frequency, and so is typically about 30 decibels below the level obtained in Y-junction diplexers using similar band-pass filters.

Figure 1A shows a branching-filter section using in-phase hybrids such as the magic-T, in which equality of power division is guaranteed by the symmetry of the junction. It is necessary to insert an additional quarter-wavelength of line as shown to obtain the correct phase relationship between the reflected waves, and this is frequency-sensitive. Furthermore, both coaxial [1] and waveguide in-phase hybrids are difficult to match over a broad band.

In Figure 1B the phase-quadrature hybrid, typified by the waveguide short-slot junction [2] and the coupled strip-transmission-line 3-decibel couplers [3], provides outputs that are in quadrature at all frequencies, and broad-band matching is readily achieved. Although the power-division ratio (coupling coefficient) changes with frequency, it can be kept within close limits over a fairly broad band.

It is well known that multiple reflections in the aerial feeder give rise to phase distortion in multi-channel frequency-modulated signals. Consequently it was necessary to design the branching filter to have a low reflection, and a voltage standing-wave ratio averaging better than $1 \cdot 1$ over the band from $1 \cdot 7$ to $2 \cdot 3$ gigahertz was desirable, and this has been achieved for a 4-section branching filter.

The overall voltage standing-wave ratio of the branching filter depends mainly on that of the hybrids, since residual reflections of the band-pass-filter pairs, if they are identical and identically tuned, cancel at the hybrid input port, and the reflected wave emerging at the conjugate port can be absorbed by a resistive termination at the end of the chain of branching-filter sections.

3. Theory of 3-Decibel Coupler

In this section we investigate the performance of an imperfect 3-decibel coupler, using the scattering-matrix formalism [4]. The amplitudes a_r and b_r of the incident and outgoing waves at an n-port junction satisfy a linear relationship

$$\mathbf{b} = \mathbf{S}\mathbf{a}. \tag{1}$$

If the junction is reciprocal, the scattering matrix $\mathbf{S}$ is symmetric, and if it is lossless, $\mathbf{S}$ is unitary.

$$\tilde{\mathbf{S}}^*\mathbf{S} = \mathbf{I}. \tag{2}$$

The scattering matrix of an ideal directional coupler

$$\mathbf{S} = \begin{bmatrix} 0 & 0 & \alpha & j\beta \\ 0 & 0 & j\beta & \alpha \\ \alpha & j\beta & 0 & 0 \\ j\beta & \alpha & 0 & 0 \end{bmatrix} \tag{3}$$

where $\beta = (1 - \alpha^2)^{1/2}$ is the coupling coefficient, and the zero elements indicate the perfect match and directivity. An imperfect coupler has the scattering matrix

$$\mathbf{S} = \begin{bmatrix} \gamma & -j\delta & \alpha & j\beta \\ -j\delta & \gamma & j\beta & \alpha \\ \alpha & j\beta & \gamma & -j\delta \\ j\beta & \alpha & -j\delta & \gamma \end{bmatrix} \tag{4}$$

in which, by suitable choice of reference planes, α and β can be made real and positive. Expansion of the unitary condition (2) gives $\alpha\gamma - \beta\delta = 0$; in particular, for a 3-decibel coupler (hybrid), $\gamma = \delta$, and so the return loss equals the coupling between conjugate ports.

Now suppose that ports 3 and 4, which we represent by subscript b, are connected to a 2-port network with scattering matrix $\mathbf{S}_1$. We can partition (4) so that (1) becomes

$$\begin{pmatrix} \mathbf{b}_a \\ \mathbf{b}_b \end{pmatrix} = \left(\begin{array}{c|c} \mathbf{S}_{aa} & \mathbf{S}_{ab} \\ \mathbf{S}_{ba} & \mathbf{S}_{bb} \end{array}\right) \cdot \begin{pmatrix} \mathbf{a}_a \\ \mathbf{a}_b \end{pmatrix} \tag{5}$$

and, since the waves incident on $\mathbf{S}_1$ are outgoing from $\mathbf{S}$ and vice versa, we have

$$\mathbf{a}_b = \mathbf{S}_1\mathbf{b}_b. \tag{6}$$

Eliminating $\mathbf{b}_b$ from (5) and (6) we find that

$$\begin{aligned} \mathbf{b}_a &= \{\mathbf{S}_{aa} + \mathbf{S}_{ab}\mathbf{S}_1(\mathbf{I} - \mathbf{S}_{bb}\mathbf{S}_1)^{-1}\mathbf{S}_{ba}\}\mathbf{a}_a \\ &= \mathbf{S}_2\mathbf{a}_a, \text{ say.} \end{aligned} \tag{7}$$

If ports 3 and 4 are terminated by open-circuited lines of electrical length θ (representing detuned filters), we have

$$\mathbf{S}_1 = e^{-2j\theta}\mathbf{I}.$$

Substituting this in (7), and neglecting squares and products of the small quantities γ, δ, and $\alpha - \beta$, we obtain after some manipulation

$$\begin{aligned} \mathbf{S}_2 = &\begin{pmatrix} \gamma & -j\delta \\ -j\delta & \gamma \end{pmatrix} + e^{-2j\theta} \\ &\times \begin{pmatrix} \alpha^2 - \beta^2 + \gamma e^{-2j\theta} & 2j\alpha\beta + j\gamma e^{-2j\theta} \\ 2j\alpha\beta + j\gamma e^{-2j\theta} & \alpha^2 - \beta^2 + \gamma e^{-2j\theta} \end{pmatrix} \end{aligned} \tag{8}$$

so that the reflection coefficient is a maximum when $\theta = n\pi$ or $\{n + (1/2)\}\pi$, according as $\alpha^2 - \beta^2$ and γ have the same or opposite signs, and equals $|\alpha^2 - \beta^2| + 2\gamma$.

Thus to ensure, for instance, a reflection coefficient for one filter section not exceeding 0·04 (voltage standing-wave ratio = 1·08),

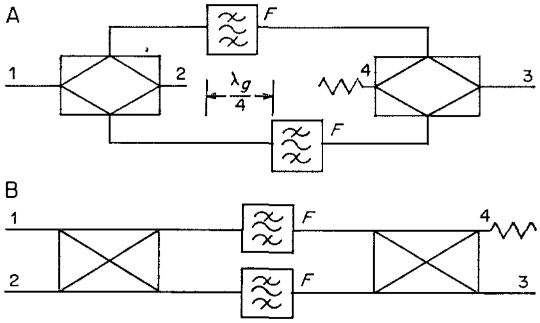

Figure 1—Diagrams of branching-filter sections. *A* uses in-phase hybrids and *B* uses phase-quadrature hybrids.

we may make $|\gamma| \leq 0{\cdot}01$; $|\alpha^2 - \beta^2| \leq 0{\cdot}02$; then the coupling must be between 2·92 and 3·10 decibels.

The coupled-transmission-line directional coupler has scattering-matrix elements [5]

$$\alpha = \frac{(1-k^2)^{1/2}}{(1-k^2)^{1/2}\cos\theta + j\sin\theta} \tag{9}$$

$$j\beta = \frac{jk\sin\theta}{(1-k^2)^{1/2}\cos\theta + j\sin\theta} \tag{10}$$

where θ is the electrical length of the coupled region and k the coupling coefficient at the design centre frequency at which $\theta = (1/2)\pi$. Putting $k^2 = 0{\cdot}51$ we find that $|\beta|^2 = 0{\cdot}49$ for $\theta = 73{\cdot}5$ and $105{\cdot}5$ degrees, so that the coupling can be kept between the above limits over a 0·7-gigahertz bandwidth centred on 2·0 gigahertz.

4. Design of 3-Decibel Coupler

Since the mismatch of strip-transmission-line directional couplers and other components is normally too great for the application envisaged, it was decided to use a double-ground-plane slab-line construction, with conductors in the form of rectangular or round bars. These can be fabricated more accurately than strip-transmission-line couplers, and the reflections at discontinuities are smaller and more-easily compensated.

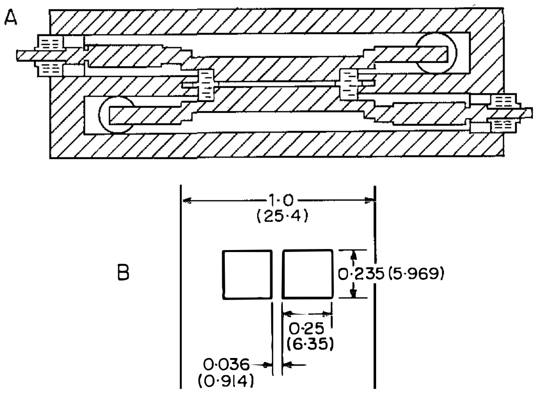

Figure 2—*A* is the cross-section of a 3-decibel coupler; *B* shows the dimensions in inches (millimetres) of the coupled transmission lines.

The configuration adopted is shown in Figure 2. The mid-band coupling coefficient and the characteristic impedance of the coupler may be expressed in terms of the even- and odd-mode characteristic impedances, Z_{0e} and Z_{0o}, of the coupled region [5].

$$k = (Z_{0e} - Z_{0o})/(Z_{0e} + Z_{0o}) \tag{11}$$

$$Z_0 = (Z_{0c}Z_{0o})^{1/2}. \tag{12}$$

In particular, for a 50-ohm 3-decibel coupler, $Z_{0e} = 120{\cdot}71$ ohms, and $Z_{0o} = 20{\cdot}71$ ohms. Z_{0c} is half the characteristic impedance of the two bars connected in parallel, which can be determined accurately from the formulae given by Bates [6], since the gap between the bars has a negligible effect on Z_{0e}. The gap appropriate to the chosen Z_{0o} was estimated from Cohn's results [7, 8], but some empirical adjustment was necessary since the ground-plane spacing is of the same order of magnitude as the length of the coupled region, and the distortion of the fields near the ends affects the coupling appreciably.

The spacing between the bars is accurately maintained by Rexolite spacers at the ends, through which pass nylon screws. These spacers also locate the bars centrally between the ground planes. The dimensions of the steps at the ends of the bars and of the gap between

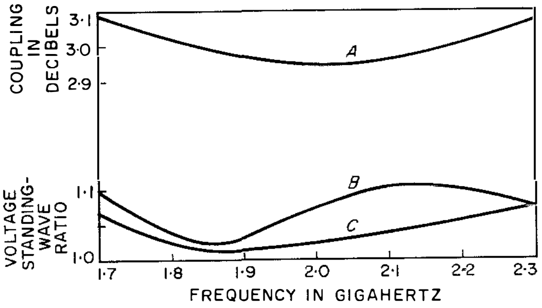

Figure 3—Measured performance of a 3-decibel coupler. The voltage standing-wave ratio is shown in curve *B* with detuned filters on two ports and in curve *C* with three ports terminated in matched loads.

them were adjusted until a good match and the correct coupling were obtained. The measured performance of one of these couplers is shown in Figure 3.

The most-critical dimension of the 3-decibel coupler is of course the spacing s between the bars, and the effect of small errors can be estimated from (11) and (12). If w is the width of the bars, we evidently have

$$Z_{0o} = \frac{188\cdot 3}{w/s + 2C/\epsilon_0}$$

where C is that part of the capacitance between the bars associated with the field exterior to the gap. Hence

$$\frac{dZ_{0o}}{ds} = \frac{188\cdot 3w/s^2}{(w/s + 2C/\epsilon_0)^2} = \frac{Z_{0o}{}^2 w}{188\cdot 3s^2}$$

and from (11) and (12)

$$\frac{dk}{ds} = -\frac{2Z_{0e}}{(Z_{0e} + Z_{0o})^2}\frac{dZ_{0o}}{ds}$$

$$= -\frac{2Z_0{}^2 Z_{0o} w}{188\cdot 3(Z_{0e} + Z_{0o})^2 s^2}$$

$$\frac{dZ_0}{ds} = -\left(\frac{Z_{0e}}{Z_{0o}}\right)^{1/2}\frac{dZ_{0o}}{ds} = -\frac{Z_0 Z_{0o} w}{188\cdot 3s^2}$$

since dZ_{0e}/ds may be neglected.

Substituting $k^2 = 1/2$ and the values of w and s (Figure 2) we obtain

$$\frac{dk}{ds} = 5\cdot 0; \quad \frac{dZ_0}{ds} = 1000$$

and an error of 0·001 inch (0·025 millimetre) in s causes an error of 1 ohm in Z_0 (voltage standing-wave ratio 1·02) and 0·005 in k (0·06 decibel).

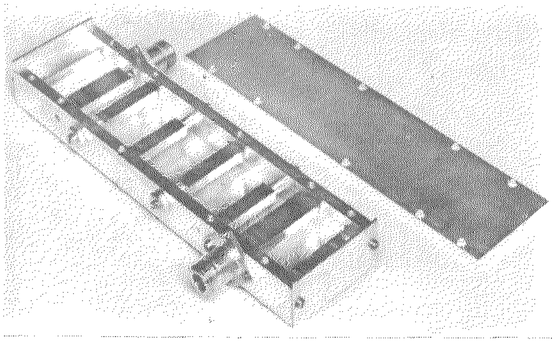

Figure 4—Interdigital filter.

5. Interdigital Filters

The band-pass filters are 4-resonator interdigital structures (Figure 4) between parallel ground planes spaced $\frac{3}{4}$ inch (19·05 millimetres) apart. This type of construction is more compact and gives more-reproducible results than does a conventional loop- or iris-coupled coaxial-resonator design, though of course accurate machining of the filter parts is necessary to obtain the required performance.

The filters were designed, using the procedure described by Matthaei [9], to have a Chebishev response with 0·01-decibel pass-band tolerance (maximum voltage standing-wave ratio 1·1) and a half-power bandwidth of 2 per cent. A tuning range of 0·2 gigahertz was obtained by adjusting the loading capacitances at the ends of the resonator bars with tuning screws. To cover the whole band from 1·7 to 2·3 gigahertz, three types of filter were made, with side-wall spacing of one quarter-wavelength at 1·8, 2·0, and 2·2 gigahertz.

The measured voltage standing-wave ratio and insertion-loss characteristics of these filters were in good agreement with the

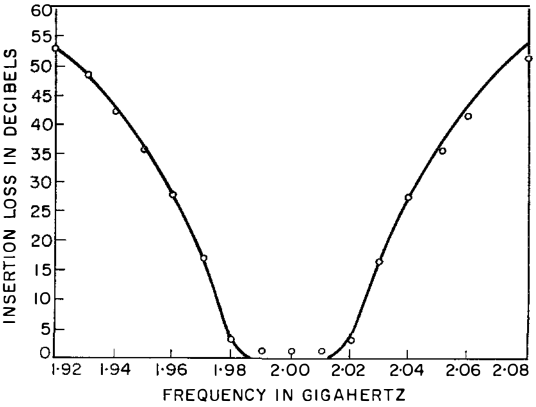

Figure 5—Measured and calculated insertion loss as a function of frequency. The mid-pass-band loss is about 0·4 decibel.

theoretical values; some typical results are shown in Figure 5. The mid-pass-band insertion loss was about 0·4 decibel.

6. Branching-Filter Performance

The 3-decibel couplers and interdigital filters were designed so that they could be bolted together without intervening connectors and cables, which would of course have considerably increased the overall voltage standing-wave ratio. One section of the branching filter is shown in Figure 6, and it will be seen that further sections can be bolted directly to it after removal of the connectors.

A 4-section filter was built up in this way; it was found that the reflections from individual sections were in phase at the input near 1·9 gigahertz, but the resulting mismatch (voltage standing-wave ratio) was reduced to below 1·15 over the whole band by introducing compensating discontinuities at the junctions between sections (Figure 7).

6.1 Tuning Procedure

Another 3-decibel coupler of the type described was modified by adding matching screws so that a very-high directivity could be obtained, and this served as a reflectometer for tuning purposes. The tuning procedure used is a modification of that described by Alstadter and Houseman [10] and depends on the fact that, as each successive resonator of a

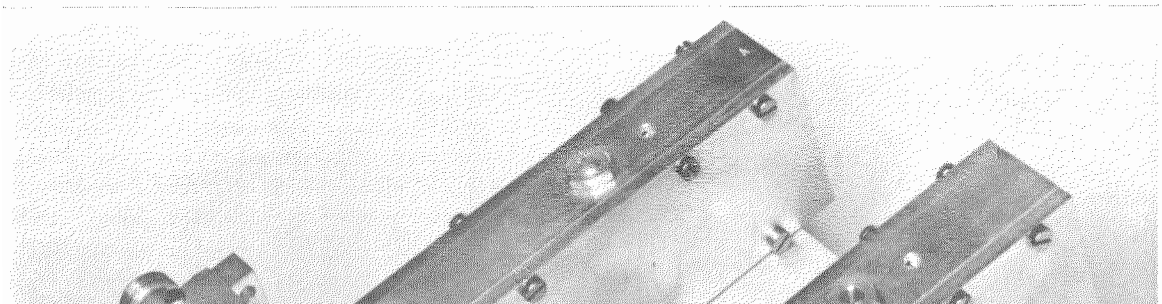

Figure 6—Section of branching filter.

band-pass filter is tuned, the phase of the reflection changes by π. With an input signal at one of the required tune frequencies, the reflectometer is first adjusted for maximum directivity with matched terminations on two ports and then one of these ports is connected to the branching-filter input. Commencing with all filters detuned, the first resonator of one of the filters is tuned to resonance by adjusting the tuning screw for maximum reflectometer output, and then the first resonator of the other filter of the pair is tuned for minimum reflectometer output. The other resonators of the filter pair are tuned in the same manner, and then the procedure is repeated for the other sections of the branching filter.

The voltage standing-wave ratio of the 4-section filter, with all sections aligned by this method, is shown in Figure 7. The oscillations in the pass-band regions represent the Chebishev ripple of the interdigital filters and indicate that the filter pairs are not tuned to precisely the same frequencies. Further improvement in the voltage standing-wave ratio could probably be achieved by using a sweep generator for alignment.

7. Conclusion

An aerial branching system has been developed for the band from 1·7 to 2·3 gigahertz using interdigital band-pass filters and coupled-transmission-line hybrids. Despite its much-smaller size, performance is equal to that of similar waveguide systems and is adequate for large-capacity radio relay links.

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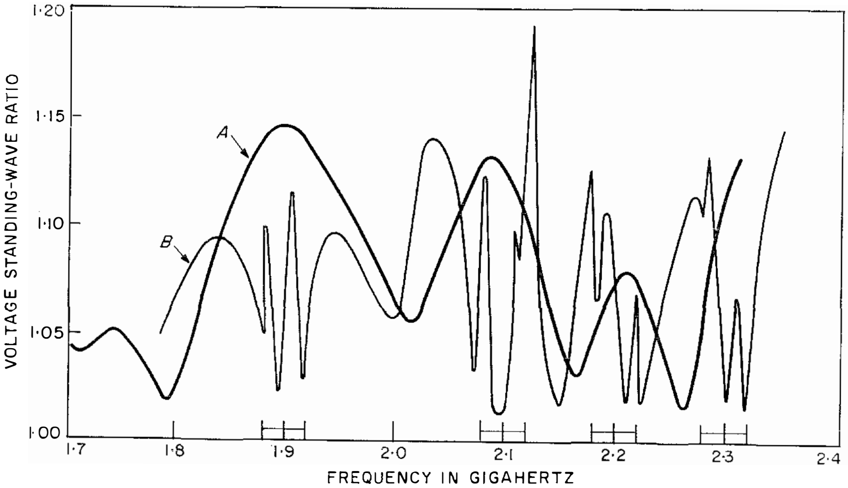

Figure 7—Measured voltage standing-wave ratio of 4-section branching filter with all sections detuned (curve *A*), and tuned to 1·9, 2·1, 2·2, and 2·3 gigahertz (curve *B*).

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S. W. Conning was born in Portsmouth, England, in 1923. He received the B. Sc. degree in 1945 and the M.Sc. degree in mathematics in 1952 from the University of London.

Until 1949 he worked at the Admiralty Signal and Radar Establishment, mostly in the infrared field, and subsequently joined the Ministry of Fuel and Power in London.

In 1954 Mr. Conning joined the Radio Transmission Division of Standard Telephones and Cables Pty., in Australia, where he has been engaged mainly in the development of microwave components and aerials.

Mr. Conning is an Associate of the Institute of Physics and of the Australian Institute of Physics, and a Member of the Institution of Radio Engineers Australia.

Otto Scheller and the Invention and Applications of the Radio-Range Principle

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Otto Scheller, born in 1876 in Germany, was a pioneer in aeronautic navigational electronics long before there was such a thing as aeronautic navigational electronics. The explanation of that paradoxical statement is a story overdue to be told.

Among the tens of thousands of patents issued all over the world in any one year, only a few, if any, represent contributions of the highest order in respect to novelty and usefulness. As a further generality, one is on quite-safe ground in estimating that the originality and technical value of a patent is in inverse proportion to the bulk of the patent document. A very-long patent with complex diagrams and with text that is difficult to translate into plain English by one not versed in patent language is apt to consist of minor embroidery or improvement on old ideas. The inventor and his patent attorney are trying to wring every possible claim out of something that just gets by the legal definition of what is patentable. On the other hand, a truly great and novel idea is apt to be describable in brief and clear text and simple diagrams.

The subject of this article, Otto Scheller and his first-rank contributions to the art of radio navigation, could serve as a classic example of the (perhaps risky!) generalities mentioned above. The story illustrates another aspect that may characterize a great invention or discovery. That is, a major invention may go unrecognized initially because it was made far in advance of its time. The legal patent validity may expire before the idea is put to practical application, and by that time the world may have forgotten who the inventor was. It is an object of this article to draw attention to that lapse in the case of Otto Scheller and his original conception of the radio-range principle, a basic principle that has found extensive application to radio navigation systems from 1930 to the present time.

The principle in question is that of delineating one or more fixed paths in space for the nonvisual guidance of vehicles by radio means, by the following technique: A simple on-course equisignal indication is created by suitable modulation of two or more antenna arrays that produce radiation lobes intersecting along the desired course direction. This principle will be recognized as exactly that of the four-course radio range, the first systematic air navigation aid installed on a wide scale; it is a basic principle of later variants such as the visual-aural range, the localizer and glide-slope portions of instrument landing systems, and Sonne or Consol. It is also a principle that has been extensively applied to radio compasses, direction finders, and radar.

Otto Scheller presented his idea to the world in 1907. That was only a short time after the birth of the airplane; for that matter, it was not long after the birth of wireless. Commercial air transport was then a thing of the future (around the 1920's); hence the need for air navigation aids, and the practical application of Scheller's idea to fulfill that need, awaited the passage of many years. But that time did come. Before discussing Scheller's inventions, however, a brief biographical sketch follows [1].

Otto Scheller was born on 6 June 1876 in Blankenstein in the province of Thuringia, Germany. His education in mechanical and electrical engineering began in 1896 at the Berlin Technische Hochschule. A well-known scientist in early wireless, Professor Slaby, steered young Scheller into the then-new field of radio. Radio became Scheller's principal and intensive field of activity throughout his life. He began his professional career as an engineer with the Allgemeine Elektricitäts-Gesellschaft (AEG), working on the design and construction of the earliest commercial radio stations in Germany. He traveled on behalf of AEG-Telefunken to Mexico and the United States to install a number of radio stations.

In 1906 Scheller became technical manager of the Amalgamated Radio Telegraph Company of London. Here he worked on the practical exploitation of Poulsen's invention of an improved process to generate continuous-wave radio oscillations by means of the electric arc.

At about that time the Poulsen patent rights were acquired in Germany by the firm of C. Lorenz (presently known as Standard Elektrik Lorenz, principal German member of the International Telephone and Telegraph Corporation).* Scheller joined the Lorenz organization, remaining with it for the major part of his professional career. At Lorenz, Scheller initially continued his work on the Poulsen arc with W. Hahnemann, who later became well-known for his contributions to radio direction finders and instrument landing systems. Scheller patented an important technique for improving Poulsen arc operation, involving the operation of the arc in a hydrogen atmosphere obtained by the use of alcohol.

In 1911 Scheller became technical manager of the radio division of Lorenz. In that capacity for many years he was prolific in important contributions ranging over the whole field of radio. He worked in such areas as the Goldschmidt mechanical high-frequency continuous-wave generator, radio-frequency measurement techniques, antenna design, electroacoustics, and even television. He was also responsible for inspiring and guiding a future generation of engineers who contributed greatly to the new art of radio and to the commercial successes of Lorenz.

Scheller retired from the Lorenz organization in 1924 but continued his active interest and contributions to radio. In his later years he developed a technical interest in exploitation of wind power and obtained a number of patents in that field. From 1907 to 1940 Scheller accumulated over 110 patents, most of them in the field of radio. He acquired the status of a "grand old man of radio" in Germany, and died in Berlin on 14 April 1948 at the age of 71 years.

Among Scheller's multitudinous patents are two, dating to 1907 and 1916, respectively, that represent outstanding contributions to the art of radio navigation and are the main subject of this article.

Reproduced herewith as Figure 1 is the complete German patent 201 496 issued to Otto Scheller on 17 March 1907. A present-day engineer, studying that patent, might well bear in mind the rudimentary state of the art of radio and especially of the art of radio navigation at that time. The patent consists of one small page of text and two simple diagrams. On inspection, one quickly recognizes not only the heart but even many of the details of the four-course radio range as it exists today. A translation into English of the text follows.

Wireless Course Indicator and Telegraph

In all prior systems of directed wireless telegraphy using interference effects among a plurality of transmitters, it has always been the case that in no direction is a sharply pronounced line produced that could be used by some distant mobile receiving station as a position marker.

And yet, the production of such sharply determined lines, which could be easily located even in poor weather or visibility, would be very desirable for the marking off of ships' tracks.

This invention produces such lines in this manner: two directional transmitters of equal intensity and wavelength A^1-A^2 and B^1-B^2, (Figure 1) are oriented at an angle to each other, and transmit signals alternately.

If the angle is chosen properly, the line of equal intensity for mobile stations is easy to recognize

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* It is interesting to note that the acquisition of the same Poulsen arc patent rights in the United States by C. F. Elwell in 1909 led to the founding in Palo Alto, California, of the Federal Telegraph Company, ancestor of the present ITT Federal Laboratories, which is the principal United States member of the International Telephone and Telegraph Corporation. Another historic link between ITT Federal Laboratories and Lorenz arose much later, around 1937, when the former became a principal developer and manufacturer of instrument landing systems, an outgrowth of the Scheller invention to be described.

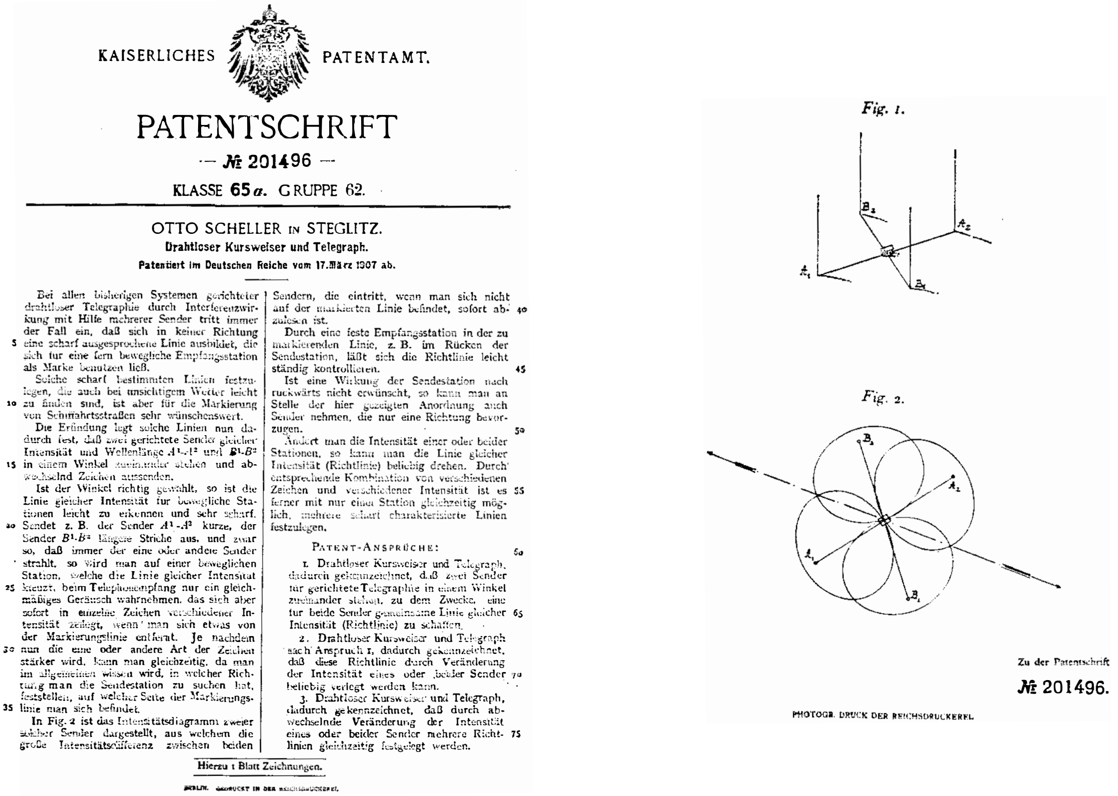
and is very sharp. Suppose, for example, the transmitter A^1-A^2 sends out short dashes and the transmitter B^1-B^2 sends out longer dashes, and specifically in a manner such that always one or the other transmitter is radiating, then the following effect results: A mobile receiving station that happens to cross the line of equal intensity will detect in its telephone receiver a steady sound; but as soon as the mobile receiver moves away even slightly from the marked line, the telephone reception changes immediately into separate signals of varying intensity. According to whether the one or the other kind of signal is stronger, one can determine on which side of the marked line one happens to be located, since one will know the general direction of the transmitting station.

Figure 2 represents the intensity diagram of two such transmitters, from which one can directly read off the great difference in intensity between the two transmissions that arises if the receiver is not on the marked line.

By means of a fixed receiving station located on the line to be marked, for example at the rear of the transmitting station, it is easy to monitor the direction of the marked line constantly.

If it is not desired to have any rearward effect of the transmitters, then one can, in place of the illustrated arrangement, set up transmitters that have a single direction of radiation.

If one adjusts the intensity of one or both transmitters, one can in this manner shift at will the direction of the equisignal (course direction) line. By means of corresponding combinations of different signals and different intensities, it is possible, moreover, with only one



KAISERLICHES PATENTAMT.

PATENTSCHRIFT

— № 201496 —

KLASSE 65*a*. GRUPPE 62.

OTTO SCHELLER IN STEGLITZ.

Drahtloser Kursweiser und Telegraph.

Patentiert im Deutschen Reiche vom 17. März 1907 ab.

Bei allen bisherigen Systemen gerichteter drahtloser Telegraphie durch Interferenzwirkung mit Hilfe mehrerer Sender tritt immer der Fall ein, daß sich in keiner Richtung eine scharf ausgesprochene Linie ausbildet, die sich für eine fern bewegliche Empfangsstation als Marke benutzen ließ.

Solche scharf bestimmten Linien festzulegen, die auch bei unsichtigem Wetter leicht zu finden sind, ist aber für die Markierung von Schiffahrtsstraßen sehr wünschenswert.

Die Erfindung legt solche Linien nun dadurch fest, daß zwei gerichtete Sender gleicher Intensität und Wellenlänge A^1-A^2 und B^1-B^2 in einem Winkel zueinander stehen und abwechselnd Zeichen aussenden.

Ist der Winkel richtig gewählt, so ist die Linie gleicher Intensität für bewegliche Stationen leicht zu erkennen und sehr scharf. Sendet z. B. der Sender A^1-A^3 kurze, der Sender B^1-B^2 längere Striche aus, und zwar so, daß immer der eine oder andere Sender strahlt, so wird man auf einer beweglichen Station, welche die Linie gleicher Intensität kreuzt, beim Telephonempfang nur ein gleichmäßiges Geräusch wahrnehmen, das sich aber sofort in einzelne Zeichen verschiedener Intensität zerlegt, wenn man sich etwas von der Markierungslinie entfernt. Je nachdem nun die eine oder andere Art der Zeichen stärker wird, kann man gleichzeitig, da man im allgemeinen wissen wird, in welcher Richtung man die Sendestation zu suchen hat, feststellen, auf welcher Seite der Markierungslinie man sich befindet.

In Fig. 2 ist das Intensitätsdiagramm zweier solcher Sender dargestellt, aus welchem die große Intensitätsdifferenz zwischen beiden Sendern, die eintritt, wenn man sich nicht auf der markierten Linie befindet, sofort abzulesen ist.

Durch eine feste Empfangsstation in der zu markierenden Linie, z. B. im Rücken der Sendestation, läßt sich die Richtlinie leicht ständig kontrollieren.

Ist eine Wirkung der Sendestation nach rückwärts nicht erwünscht, so kann man an Stelle der hier gezeigten Anordnung auch Sender nehmen, die nur eine Richtung bevorzugen.

Ändert man die Intensität einer oder beider Stationen, so kann man die Linie gleicher Intensität (Richtlinie) beliebig drehen. Durch entsprechende Kombination von verschiedenen Zeichen und verschiedener Intensität ist es ferner mit nur einer Station gleichzeitig möglich, mehrere scharf charakterisierte Linien festzulegen.

PATENT-ANSPRÜCHE:

1. Drahtloser Kursweiser und Telegraph, dadurch gekennzeichnet, daß zwei Sender für gerichtete Telegraphie in einem Winkel zueinander stehen, zu dem Zwecke, eine für beide Sender gemeinsame Linie gleicher Intensität (Richtlinie) zu schaffen.
2. Drahtloser Kursweiser und Telegraph nach Anspruch 1, dadurch gekennzeichnet, daß diese Richtlinie durch Veränderung der Intensität eines oder beider Sender beliebig verlegt werden kann.
3. Drahtloser Kursweiser und Telegraph, dadurch gekennzeichnet, daß durch abwechselnde Veränderung der Intensität eines oder beider Sender mehrere Richtlinien gleichzeitig festgelegt werden.

Hierzu 1 Blatt Zeichnungen.

BERLIN. GEDRUCKT IN DER REICHSDRUCKEREI.

Zu der Patentschrift
№ 201496.

PHOTOGR. DRUCK DER REICHSDRUCKEREI.

Figure 1—Copy of German patent 201 496 issued on 17 March 1907 describing equisignal radio range.

transmitting station, to set up a plurality of sharply characterized course lines.

Patent Claims:

1. Wireless course indicator and telegraph in which two transmitters for directional telegraphy stand at an angle to each other, for the purpose of producing a line of equal intensity from both transmitters in common.

2. Wireless course indicator and telegraph, according to claim 1, in which the equisignal line may be shifted at will by adjusting the intensity of one or both transmitters.

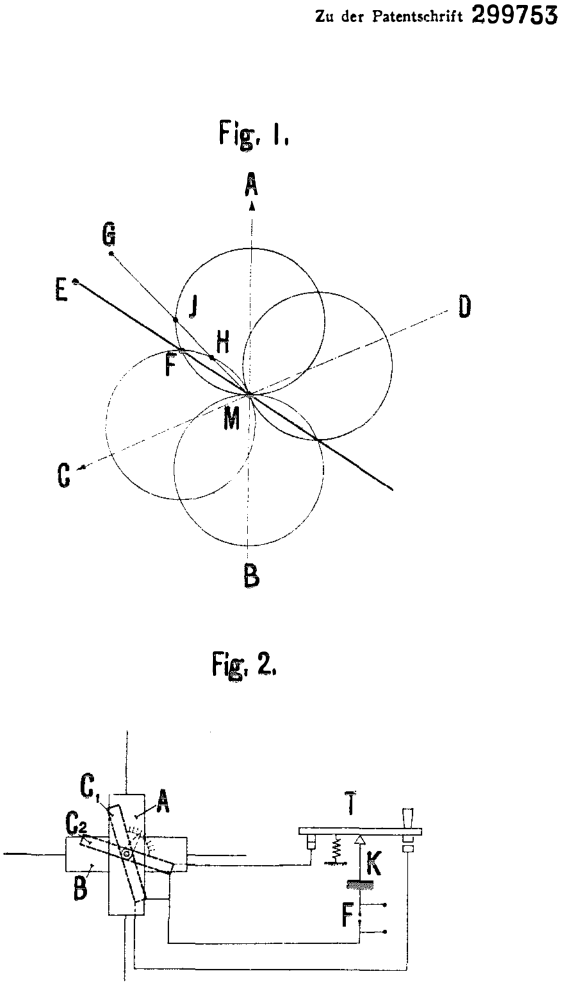


Figure 2—Drawing from German patent 299 753 issued on 9 January 1916 showing use of goniometer for coupling power to a pair of directive antennas.

3. Wireless course indicator and telegraph, in which by means of alternating variation in intensity of one or both transmitters, a plurality of equisignal position lines may be established at the same time.

The quoted text, which could not be improved on for clarity, conciseness, perspicuity, and completeness, is a classic. In discussing the potential use of his invention, Scheller of course refers to navigation of marine vessels, because in 1907 only science fiction could have entertained the notion of thousands of great superswift commercial airliners transporting passengers, mail, and freight between cities and across continents and oceans throughout the world. The 1907 Scheller patent clearly and specifically covers practically all of the basic features of the radio ranges that are in operation today.

(A) The fundamental principle of creating two intersecting radiation patterns by arranging two directive antenna arrays at an angle with respect to each other (a principle applied also to instrument landing systems and other systems).

(B) The fundamental principle of exciting the two directional radiations in rapid alternation, supplied from a common transmitter, so that the relative strengths of the received signals could be compared (a principle applied also to early types of instrument landing systems and to Consol).

(C) Keying the individual radiations with distinctive Morse code dots and dashes for simple aural recognition of the individual radiations at the receiving end.

(D) So interlocking the keying cycle that along the on-course line, where the lobes intersect and hence the two alternately radiated signals have equal strength, the signals merge into a continuous tone. This is the familiar aural equisignal indication.

(E) Position of the vehicle to the left or the right of the on-course line is revealed in a simple aural manner by recognition of the prevailing stronger dot or dash signals heard.

(F) Possibility of shifting the four equisignal courses by changing the relative amounts of power supplied alternately to the two antenna arrays. This shifts the direction along which the lobes intersect (a principle applied in present radio range stations).

(G) The possibility, even, of cyclically adjusting the power to the two antenna arrays to establish a larger number of available equisignal courses from one set of antenna arrays. (This technique is not applied to four-course ranges, but the idea uncannily foreshadows a technique used in the Sonne or Consol system, a multicourse radio range system developed by Lorenz during the second World War.)

(H) Provision for continuous monitoring of the stability of the on-course direction by setting up a receiver at a fixed location nearby. (Monitoring is considered a *sine qua non* in all ground-based radio navigation systems today.)

It is also worthy of note that the diagram in Scheller's 1907 patent indicates antennas that are in the form of vertical radiating elements. When the radio range was reborn in the 1920's in the United States and equipments were first installed along airways in the 1930's, huge loop antennas were used. Later the loops were superseded by vertical Adcock antennas, much as pictured in Scheller's 1907 diagram. Note also Scheller's remark that "If it is not desired to have any rearward effect of the transmitters, then one can, in place of the illustrated arrangement, set up transmitters that have a single direction of radiation." Such a principle is applied through the use of special antenna elements (reflectors and directors) in modern instrument landing systems and other systems, where only one (but a sharp) course is required.

All in all, a modern-day engineer cannot help marveling at the clarity, brilliance, completeness—and also the practicality and usefulness as subsequent history has proved—of Scheller's 1907 conception. Only two technical features of present-day four-course ranges are not covered in the 1907 patent. One is the simultaneous voice feature; but that is strictly speaking a communication adjunct to the basic navigation function. The other feature is the facility for convenient alignment of the equisignal directions without need to move the antennas, through introduction of a special means for coupling the transmitter to the antennas. With respect to that feature, however, Scheller also first showed the way in his patent of 1916.

German patent 299 753 was issued on 9 January 1916 to Otto Scheller and assigned to C. Lorenz. In that patent, the diagram of which is herewith reproduced as Figure 2, Scheller supplies radio-frequency energy to the antennas through an adjustable cross-coil inductive coupling arrangement. The device is now referred to as a "goniometer" or "radio goniometer" and has many applications in radio navigation. (Scheller did not invent the goniometer itself; that device had been proposed and used earlier in connection with radio direction finders [2]).

An English translation of only the "Claims" portion of Scheller's 1916 patent follows.

1. Wireless course indicator and telegraph with two directional transmitters at an angle, so arranged that coupling coils are applied, and these are alternately switched on and can be rotated with respect to each other.

2. Modification of the course indicator according to Claim 1, in such a manner that the two alternately switched coupling coils are arranged to be rotatable in common.

3. Wireless course indicator and telegraph according to Claims 1 and 2, arranged in such a manner that the two coupling coils may be rotated both with respect to each other as well as in common, to the end that both the sharpness and the direction of the equisignal courses may be adjusted.

The application of the goniometer to the radio-range system, in exactly the way proposed by Scheller in 1916, has been a feature of the existing four-course-range system since its inception before 1927. It makes possible a great practical convenience. Radio-range antennas are permanently installed because of their considerable size and spacing. Without moving the antennas, adjustment of the goniometer enables the equisignal courses to be aligned along operationally desired directions, or to be aligned later if the airway pattern is to be changed after initial installation of the station. Rotating the four courses bodily by the 1916 goniometer technique of Scheller, plus shifting the courses with respect to each other by the intensity-variation technique as Scheller proposed in 1907, together provide a great degree of flexibility in alignment of the four courses. This flexibility is widely used, as a glance at present-day air navigation charts of four-course-range airways in the United States will show.

Scheller also points out that the goniometer makes it possible to alter the sensitivity or "sharpness" of the equisignal indication, by shifting the point at which the lobes intersect to regions at which the "slope," or azimuth-rate-of-change of signal strength, is most suitable. These various possibilities foreshadow the techniques used in instrument landing systems and in other systems to adjust sensitivities, directions, minor lobes, et cetera.

It is understandable that Scheller's two basic patents did not initially arouse much excitement, being far in advance of their time. Ships did not have any pressing need for radio navigation facilities and aviation was in an early stage. However, some early tests of the Scheller proposal of 1907 were made by Lorenz and by the German Navy, and these demonstrated the practicality of the principle [3]. In 1911 Professor Kiebitz, at first not aware of Scheller's prior work, proposed a similar scheme. Before and during the early part of the first World War, experiments with the system were performed for marine guidance but no operational installations were made [3, 4]. Tests with airplanes in Germany first took place toward the end of the first World War, as before that time the German military appeared to show no interest in the possibilities of radio navigation for aircraft. In those tests, errors were found to be produced because of directional effects of the receiving antenna on the airplane [3]. (That troublesome effect was the subject of considerable research effort in the United States, beginning in the late 1920's, which were the early days of radio-range development in that country [5]).

After the first World War there began the spectacular rise in development of aviation, highlighted by headline-making long-distance flights and by the crude beginning of scheduled passenger and mail transport services. For such services to operate on a systematic basis, all-weather and all-visibility navigation aids were pressing needs. Hence, and especially in the United States where intercity distances are greater than in Europe, an intensive search began for suitable radio navigation aids for aircraft.

Rotatable-loop direction finders had been known since the early days of radio, and in fact were introduced for ship and shore use even at the time of the first World War. Experiments with the derivative airborne radio compass had also been made, but not until about 1940 did a practical equipment for airborne use become perfected in the form of the automatic radio direction finder [6]. Airborne direction-finder devices are very useful for "homing" flights; and together with the magnetic compass are usable also for position fixing. However, they indicate bearings relative to the momentary direction of the fore-and-aft axis of the airplane, hence they have the disadvantage that they do not establish fixed predetermined geographical paths that a vehicle can follow [7]. Technology had progressed sufficiently for the application of Scheller's 1907 proposal, but it still lay buried in the German patent office.

As sometimes happens, great new ideas can occur to different people independently. In 1920 P. D. Lowell of the United States Bureau of Standards conceived ideas similar to those of

Scheller. During 1921–1923 F. M. Engel and F. W. Dunmore of the Bureau staff first converted Lowell's suggestions to practice in work performed on behalf of the United States Army Air Service [8]. The work was then carried on for the Army Air Service by the Signal Corps Aircraft Radio Laboratory at McCook Field, Dayton, Ohio (predecessor of the present Wright-Patterson Air Force complex). Engel, of the Bureau staff, initiated that program of radio-range development. It was then carried forward by W. H. Murphy and E. J. Wolfe [9, 10]. Murphy reintroduced the idea of using a goniometer exactly as proposed in Scheller's 1916 patent. Development for the Air Service was advanced during 1924–1929 to the point of construction of operational equipment by C. C. Shangraw [11, 12].

During 1926–1934 the Bureau of Standards resumed its work on the radio range, this time for the Aeronautics Branch of the Department of Commerce (predecessor of the Civil Aeronautics Administration and the Federal Aviation Agency). Associated in these efforts were H. Pratt, J. H. Dellinger, and H. Diamond. The Bureau installed its first operational radio ranges on civil airways during 1926–1927, at College Park, Maryland, and Bellefonte, Pennsylvania [13–17].

A culmination of all the early efforts on radio-range development in the United States took place in 1927. In June of that year Hegenberger and Maitland of the United States Army made an epochal long-distance overwater flight. They flew from San Francisco to Hawaii, a destination that was not a huge continent but a small island 2400 miles distant in the middle of the ocean. Their perfect pinpoint navigation was made possible by the use of signals from two terminal-point radio-range stations built and installed for the purpose by C. C. Shangraw [18]. In July and August of the same year, additional flights made use of the same radio-range stations.

These successful demonstrations by the Army, together with the success of the initial civil range installations, provided the impetus that ushered in an era of wide-scale installation of four-course radio ranges for both civil and military use in the United States. This era began in the early 1930's and reached its peak in 1949. The civil ranges formed a system of city-to-city airways, which eventually formed links in a country-wide system of continental air routes. This was the first systematic radio navigation system for aviation installed on a wide scale. It contributed immeasurably to the emergence of instrument flying as a regular and indispensable procedure by United States civil airlines.

The radio-range system permitted flights in poor weather conditions and at night over long distances, and it was an important factor in the spectacular development of civil air transport in the United States between 1930 and 1950. The radio range (in contradistinction to airborne radio compasses and automatic direction finders) was the first system permitting establishment of fixed geographical paths that aircraft could follow in a positive and reliable manner. Because aircraft flying by radio range signals can be relied on to be on the assigned or reported paths (within the accuracy of the system), the radio ranges also made possible the beginning of systematic air-traffic control. The utility of the radio-range system for air navigation and traffic control was improved through the installation of marker beacons at selected points along airways. These markers permitted periodic position fixes to be made, by producing a simple airborne indication as the airplane passed directly overhead.

In 1949 a high-water mark of 390 operational civil radio ranges in the United States, serving over 60 000 miles (97 000 kilometers) of federal airways, was attained [19]. It has been estimated that more than 600 four-course radio ranges have been installed all over the world. Since about 1950, the United States medium-frequency aural four-course radio ranges have been supplemented with or replaced by more-modern types of radio navigation aids, such as the very-high-frequency omnidirectional range, Tacan, and Vortac. The latter two also establish fixed tracks and operate at very- or ultra-high frequencies that provide certain propagation advantages; they present indications visually on a meter and provide full 360-degree selection of tracks [19].

Yet some 300 four-course radio ranges are still in operation in the United States. Despite certain superiorities of the more-modern aids, the four-course range has a unique advantage. That is, no special airborne receiver or instrumentation is required. All that the airplane requires is a simple communication receiver and headphones—the minimum radio equipment that an airplane would carry anyway. This feature endears the radio-range system especially to operators of small aircraft, which are equipped with the minimum of radio apparatus to save weight, space, and expense. The existing four-course ranges also provide an emergency navigation facility to larger aircraft that carry modern radio equipments. Scheller himself had drawn attention to the outstanding feature of the aural radio range in the following words published in 1929 [3].

"The airplane carries no equipment that is difficult to service, takes up a lot of space, weighs a great deal, and is expensive; all heavy and complex equipment is exclusively at the beacon on solid ground, which eases the problem of servicing and maintenance. With respect to simplicity and operational reliability, the system described should be far superior to all existing systems; airways that are provided with this system should be flyable with safety even at night and in fog and under all weather conditions."

The words quoted (in translation) have a ring that is uncannily modern, being reminiscent of statements of requirements and reports of evaluations that have been issued in great numbers by committees and agencies concerned with planning navigation aids.

The fruits of Scheller's 1907 idea are not limited to the four-course range. In addition to airways navigation facilities, aviation requires an all-weather landing or approach facility. Only two on-course paths are required, one in azimuth and one in sloping elevation, but these must have very-great sharpness. The idea occurred both to workers at Lorenz and at the Bureau of Standards that the Scheller principle of a cross-lobe equisignal radio path might be used for instrument approach. Early experiments were performed at the Bureau, at first using medium frequencies as in the radio ranges. At Lorenz, Hahnemann and Kramar proposed that the instrument landing system (as it was later called) should operate at higher frequencies, in the very-high-frequency range. This permits greater course sharpness, smaller antenna size, and has several propagational advantages [4, 20, 21].

The Lorenz proposal led to development of equipment and to 40 installations of the so-called "Lorenz System" at airports throughout Europe by 1937. It also led to development and installations by the British affiliate of the International Telephone and Telegraph Corporation, Standard Telephones and Cables, of their system known as "Standard Beam Approach," in England during the second World War. In early instrument landing systems, the feature of aural indication of the equisignal localizer course was retained, much as in Scheller's 1907 patent.

In 1937, at the invitation of the Civil Aeronautics Administration, a complete Lorenz system was brought to Indianapolis, Indiana, for demonstration and evaluation. The Administration selected the basic principle of the Lorenz system for further refinement and development in the United States by the International Telephone and Telegraph Corporation. With the addition of an equisignal-type glide-slope, a number of civil installations were built for the Civil Aeronautics Administration, and were referred to initially as the "International Telephone System" or the "ITT Landing System." Mobile military models, known as the *SCS-51,* were also built by ITT Federal Laboratories, and saw service throughout the world during and after the second World War. The basic features of those systems led to the present specifications that were made international standards by the International Civil Aviation Organization in 1949 [21].

There are over 200 civil installations of instrument landing systems in the United States and approximately 500 military and civil installations in the world [19]. In present systems the indications to the pilot are presented visually on a cross-pointer meter. This meter is actuated by simultaneous but distinctive audio-frequency modulations imposed on the radio signals radiated by the ground antennas. However, the crossed-lobe equisignal principle first stated by Scheller in 1907 is still the basis of instrument landing systems and has been applied to both the localizer and the glide-slope portions of the system [21]. Thus Scheller's 1907 principle continues to find great application even to today's jet age.

Although the 1907 invention was far ahead of its time, Scheller's life span permitted him to witness some measure of the great practical use made of it by aviation, directly in the form of the radio range and indirectly in the form of instrument landing systems and other systems. After learning of the Hegenberger-Maitland flight in 1927, Scheller published an article in 1929 on the radio range [3]. In this, he recalled his early proposals of 1907 and 1916; he reviewed the earliest tests of the principle both in Germany and by the Bureau of Standards; and he described the striking use made of the system in the Hegenberger flight. Both Kiebitz in Germany and Lowell in the United States learned, after their own work had started, of the prior publications by Scheller. For that reason these men did not apply for patents on the radio range.

In the 1929 article, Scheller appraised the potentiality of the radio-range principle in the words quoted earlier in this paper. That appraisal, made in 1929, has been borne out by the history of aeronautical navigation electronics from 1930 to the present. Although the world at large may not be generally aware of the fact, the familiar beeps listened to by countless pilots along airways the world over and the familiar cross-pointer needle watched by pilots during instrument approaches, constitute aural and visual testimonials to the brilliance, foresight, and practical applicability of the principle conceived by Otto Scheller back in 1907.

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Robert I. Colin was born in Brooklyn, New York. He received an A.B. degree from Cornell University in 1928 and an M.S. degree in experimental physics in 1933 from New York University, where he also served as a teaching fellow. He then studied physics for a year at the University of Frankfurt in Germany as an exchange fellow.

He joined the faculty of the Hebrew Technical Institute in New York City in 1934 as instructor in physics and mathematics. In 1941 he became an instructor, then head, of the Aircraft Electrical Systems Department of the Air Force Technical School at Chanute Field that later became the Officers Maintenance Engineering School at Yale University.

In 1944, he joined ITT Federal Laboratories, where he worked for 10 years in the aerial navigation department. He is presently serving in the Publications Department.

As a participant in Special Committee 31 of the Radio Technical Commission for Aeronautics, Mr. Colin shared in the 1950 award of the Collier Trophy for its work on aerial navigation and traffic control. Since 1956 he has been active in research and writing on the history of radio navigation for the Awards Committee of the IEEE Group on Aerospace and Navigational Electronics.

Dewline After a Decade of Field Operation and Maintenance *

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1. Introduction

The name Dewline is simply a short way of saying "Distant Early-Warning Line." It is the land-based portion of the early-warning system controlled by the United States Air Force and consists of an integrated chain of radar and communication systems stretching about 6000 miles (9600 kilometers) from the Aleutian Islands to the west coast of Iceland. It is almost entirely within the Arctic Circle, except for the Aleutian portion. Two Dewline sites are located on the Greenland icecap with more than 1.5 miles (2.4 kilometers) of solid ice beneath them. The purpose of the Dewline is to provide the North American continent with the earliest possible warning of the approach of airborne objects over polar regions.

This paper discusses the construction and subsequent operation and maintenance of the most-northerly portions of the Dewline between the

Figure 1—Dewline is the northernmost of the warning lines shown.

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* Presented at the 8th International Convention on Military Electronics, Institute of Electrical and Electronics Engineers, Washington, District of Columbia; 14 September 1964.

northwest coast of Alaska (Dewmain) and Iceland (Deweast). The Aleutian portion (Dewwest) is not covered specifically although most of its parameters are similar.

2. History

The Dewline was conceived in 1952 by a group of our nation's foremost scientists. This group was called the Summer Study Group and was sponsored by the Massachusetts Institute of Technology Lincoln Laboratories. The group recommended the construction of a distant early-warning line much as it is now (Figure 1).

The Dewline was born in the cornfields of Illinois where the first prototype was installed in 1953. Since that time the Dewline has grown from a few trial sites built in 1954 near Barter Island, Alaska, to a very-complex system 6000 miles (9600 kilometers) long. Initial responsibility for the construction was assigned to the American Telephone and Telegraph Company, which turned management of the design and construction over to its Western Electric Company.

During the fall of 1952 and throughout 1953, prototype buildings and antennas multiplied around the radome at sites near Streator, Illinois (Figure 2), and at Barter Island, Alaska.

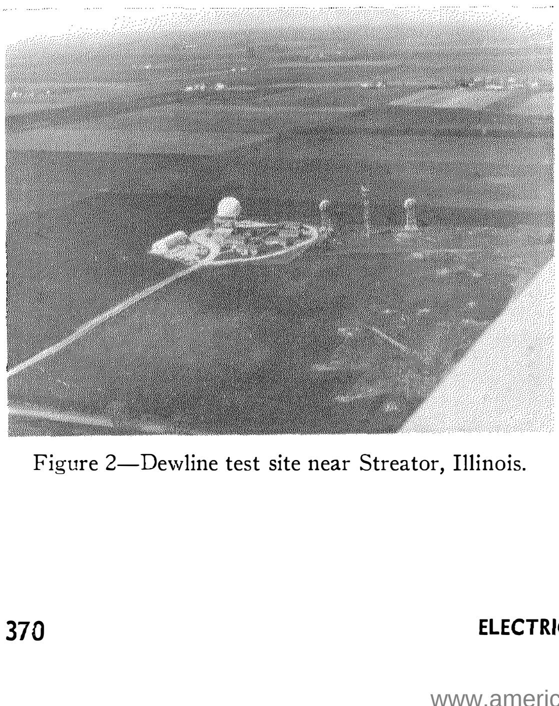

Figure 2—Dewline test site near Streator, Illinois.

While the experimental designs of buildings and electronic systems have not been retained, the trial installation did answer the question of feasibility. It also supplied the necessary experimental background for the ultimate design of all facilities, including plans for manpower, transportation, and supply.

It was known that the designs of detection and radio communication then current were not suitable to Arctic weather and atmospheric phenomena. Likewise, logistics problems assumed greatly added importance and made it mandatory that the Dewline operate with severely reduced manpower compared with military standards.

In December of 1954, the letter contract was released to begin construction of the Dewline, extending from Cape Lisburne, Alaska, above the Arctic Circle, and terminating at Cape Dyer on the east coast of Baffin Island, Canada. Target date for an operational line was the summer of 1957. It was apparent immediately that with but two short summer arctic construction seasons, the permanent quarters (with heat, water, and electricity) had to be ready for the first installation of electronic gear before the end of the second summer in 1956. The saga of how more than 50 isolated and desolate sites were simultaneously constructed within this short period has been fully covered in many publications. From a standing start in December, 1954, to an ultimate peak of 25 000 people, men of countless skills were transported to the arctic wastes, sheltered, fed, and supplied with tools, machines, and materials to build houses, water and oil tanks, towers, roads, airfields, hangers, warehouses, antennas, et cetera. Operations necessarily were telescoped and design and construction of the many facilities proceeded concurrently. There wasn't time for a development period. The electronic equipment and the new buildings and outside plant were constructed directly from breadboards. It was recognized that many design problems would be encountered during operation and maintenance of the systems.

In April of 1956, Federal Electric Corporation was named the prime operation and maintenance contractor of the Dewline. During the following months of May, June, and July, the Dewline training center was started. Many thousands of technical personnel have passed through this training center to help operate and maintain the system. Meanwhile, the construction, design, and installation of equipment were proceeding. Sites were selected, surveyed, and laid out consistent with exacting criteria; this was done mostly while temperatures were registered at the bottom of thermometers and often with snows measuring 10 to 20 feet in depth. There could be no guesswork on the proper siting, as the radar coverage and the new tropospheric-scatter communication system called for exact and critical selection of sites. Military and civilian airlifts and sealifts embracing the volume and sizes of cargo and distances not heretofore dreamed of were devised and carried out in the dead of arctic winter. Every item that man would need to enable him to live and work in the Arctic had to be purchased and transported to barren and almost-inaccessible locations. Then equipment had to be assembled and put into operation under the severest weather conditions. Survey teams traveled more than 1 million miles (1 600 000 kilometers) to select Dewline sites and access routes and obtained more than 80 000 photographs for their part of siting and mapping. Existing maps were not accurate enough for the siting work.

More than 113 400 purchase orders were issued to 4651 companies in the United States and Canada. 459 900 tons (417 million kilograms) of materials and supplies were delivered by aircraft, naval convoy, caterpillar trains, and

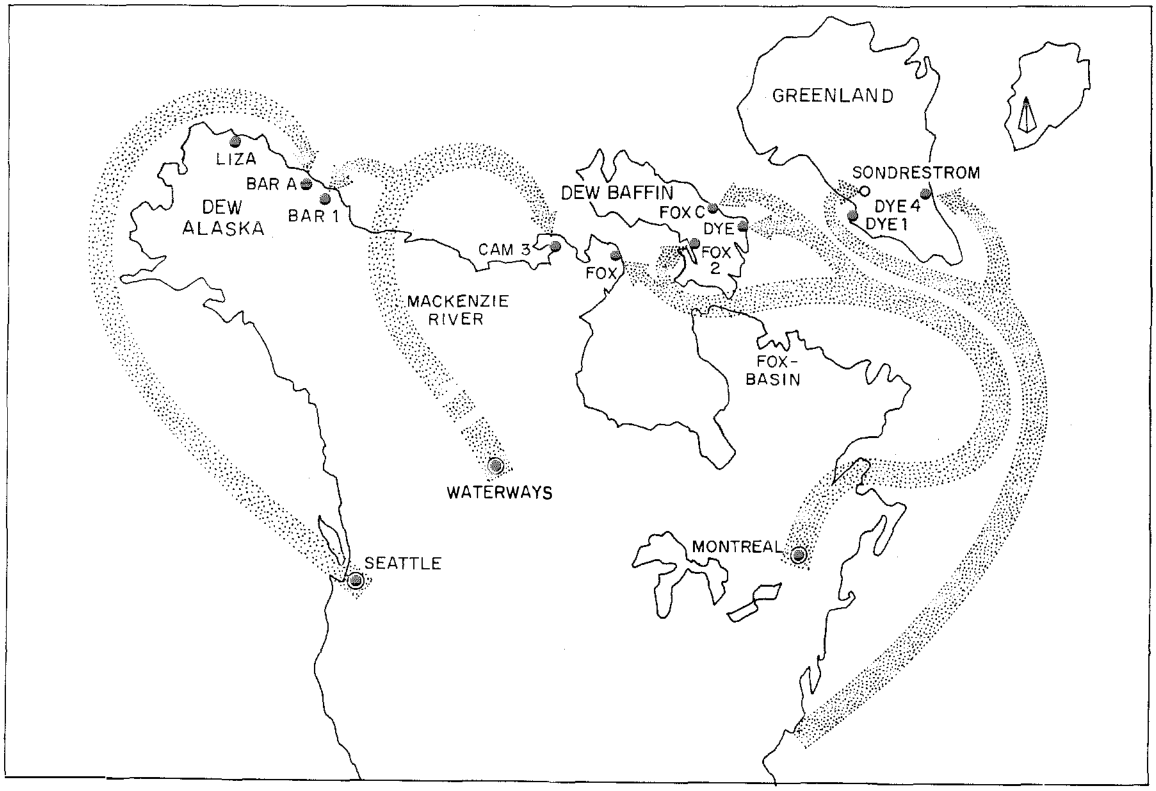

Figure 3—Sealift routes.

barges. 58 000 aircraft flights carried 110 million ton-miles of materials and supplies. During the first two summer seasons, the military sea transport service used hundreds of vessels (Figure 3) to deliver these thousands of tons of cargo to beaches and waters for which there were no navigational charts. As expected, summer seasons were too short to complete all the work. The men dug and hauled gravel, erected steel, and poured concrete in the arctic winter as well as the summer. 75 million gallons (284 000 000 liters) of petroleum, oil, and lubricant were shipped to the Dewline. More than half of this was delivered in approximately 1 million drums and the balance by tankers.

More than 9 600 000 cubic yards (7 300 000 cubic meters) of gravel were used in Dewline construction, enough to build an 18-foot (5.5-meter) road 1 foot (0.3 meter) thick from New York to San Francisco. At many sites no gravel deposit existed and all roads, pads, and airstrips were built of rockcrusher gravel. Stocks of spare parts covering 33 000 separate line items were established at Dewline stations and bases.

The permanent quarters to house the delicate and complicated electronic gear were ready as required. Installation and test were started on the intricate detection and communication system, most of which was newly designed. Over 1 million formal tests were performed, some requiring as much as 7 weeks each.

As can be seen in Figure 1, by far the largest part of the Dewline is on Canadian soil. A construction of this magnitude, with its great masses of personnel and movement of cargo, would have been impossible without the historic cooperation, trust, and understanding of Canadian government agencies and Canadian citizens as well. The fact that this whole cooperative undertaking was completed without a single incident being referred to diplomatic sources in either country stands as a monument to good international relations.

Federal Electric Corporation took over the operation and maintenance of the Dewline in July of 1957, after 15 months of preparation. We were faced with the maintenance and operation of a complex military system with a supply line that extended up to 10 000 miles (16 000

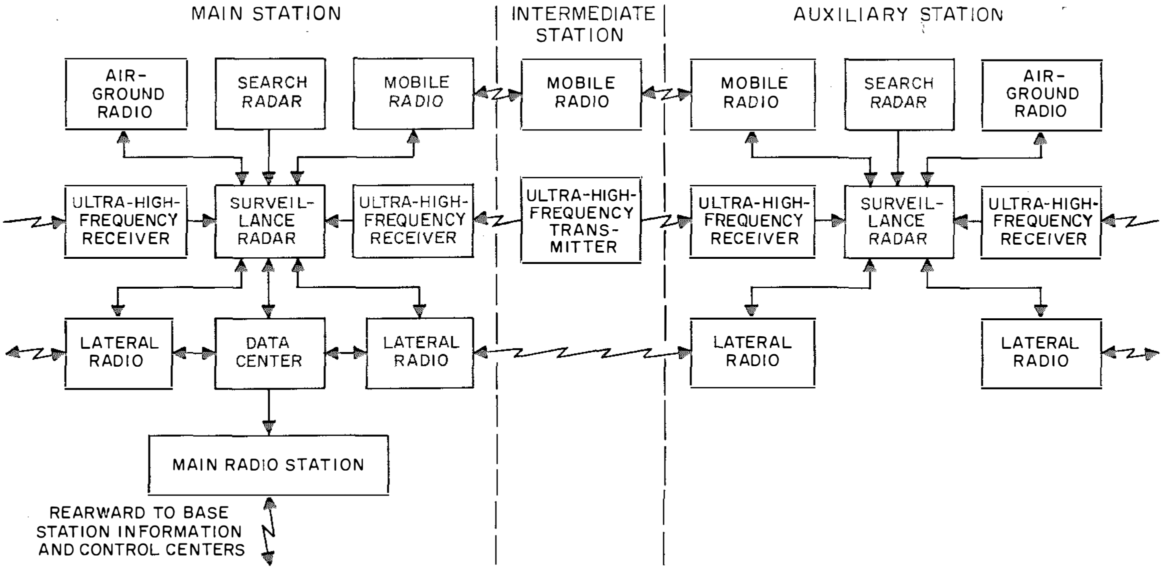

Figure 4—Basic Dewline facilities. The intermediate stations have been deactivated recently because of changes in operational requirements.

kilometers). Ahead were many problems not normally encountered by operation and maintenance personnel. Because of the urgency most of the electronic equipment did not enjoy a normal development period before installation and use. Some of the operation and maintenance problems faced by technicians were the result of design deficiencies. This meant that problems normally encountered and remedied during the development period now had to be solved during the initial period of operation, with no permissible diminution of operational reliability. Many modifications were necessary before the electronic equipment, building, and outside equipment could cope with the still-strange environment.

3. Operation and Maintenance Phase

The original Dewline consisted of three types of stations—main, auxiliary, and intermediate. The main station is the hub of a sector that includes auxiliary and intermediate stations. The only military personnel on the Dewline are at main stations, which are approximately 500 miles apart. These personnel receive the surveillance information, interpret it, and send it rearward to the North American Air Defense Command. Figure 4 shows the layout of electronic equipment for main, auxiliary, and intermediate stations.

At the main stations (Figure 5) are the largest airstrips, the biggest fuel tanks, and the greatest numbers of men. The main station as originally designed has two trains of buildings, each composed of 25 to 30 modules joined together. It has facilities for surveillance detection, lateral communication, and rearward communication.

The auxiliary stations (Figure 6), of which there are 27 approximately 100 miles apart on Dewmain and Deweast, are similar to the main

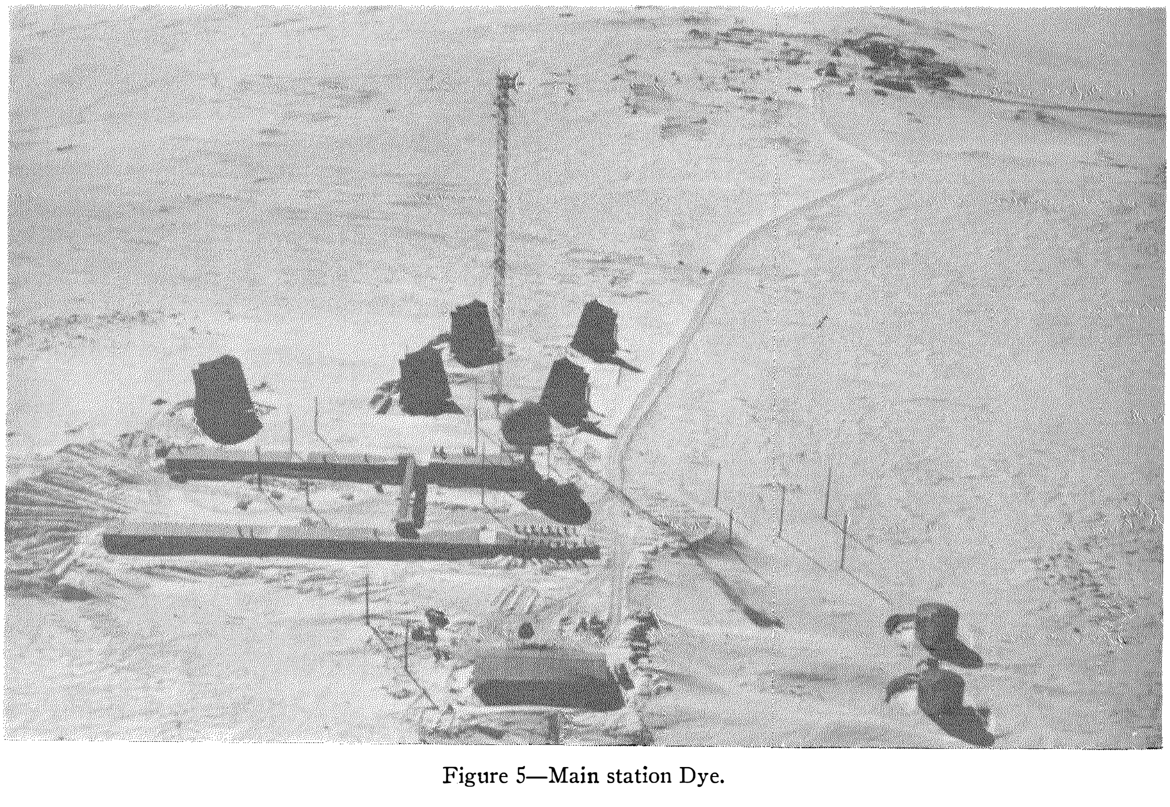

Figure 5—Main station Dye.

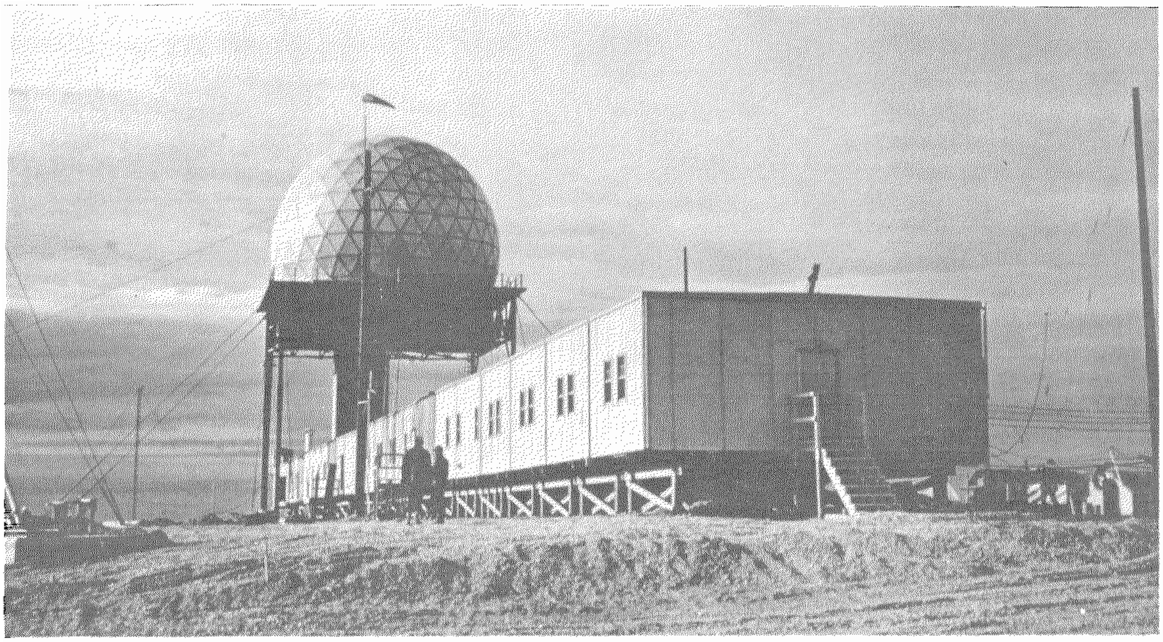

Figure 6—Typical auxiliary station.

stations except that auxiliary sites do not have the rearward reporting facility.

The intermediate stations (Figure 7) lay halfway or approximately 50 miles between auxiliary stations and consisted of only a doppler radar transmitter and a very-high-frequency communication facility. The intermediate stations were maintained by a crew of 3 to 5 including Eskimos. These stations have recently been deactivated because of changes in operational requirements.

As the first year of operation and maintenance of the Dewline began in the summer of 1957, several major problem areas immediately arose.

(A) Much of the initial equipment failed to meet test specifications, and some 60 unsatisfactory reports were submitted on the various units. The installation contractor stayed on to help modify the equipment to correct deficiencies, and also to technically re-evaluate the Dewline. This imposed a very-heavy workload on station personnel to support the installation contractor and made it difficult to conduct normal operations while modifications to the equipment were being made.

(B) When the Dewline became operational, few of the required technical orders and technical manuals were available. The illustrated parts breakdowns were particularly deficient. Thus it was practically impossible for technicians to identify and order required parts by proper designations. The full complement of manuals were not received for approximately 1 year; these did not include the installer's modifications and contained numerous errors. This problem was solved by issuing temporary "pink sheets" until the normal Air Force procedures could effect changes to the manuals.

(C) The logistic support of the Dewline was originally planned to be done by the United States Air Force depot at Ladd Air Force Base in Fairbanks, Alaska. This arrangement produced a severe bottleneck in technical supplies so that by May of 1958, 36 equipment outages were reported daily because personnel were awaiting parts. At this point the Air Force

Figure 7—Typical intermediate station.

authorized us to introduce our central-control-point concept. This called for removal of a major part of the workload of logistics support from Air Force depots by researching and machine-processing requisitions at our project headquarters in Paramus, New Jersey. Under this concept the situation changed from the point where Wright Air Force Base had received approximately 20 000 requisitions and had serviced 33 percent to where in early 1960 there were only 5 or 6 equipment outages per day reported.

(D) To complicate the logistics support, part-failure rates on numerous components exceeded by many times the failure rates that had been programed for. Many of the failures were due to design faults that would normally have been solved during a development period. An extensive and exhaustive engineering effort was made to review the failure rates and determine the proper corrections. An average of 60 modifications per equipment type were necessary to bring the failure rates within a reasonable and manageable range.

Figure 8 shows the reduction of equipment outages with time. The sharp reduction from the fourth quarter of 1957 to the second quarter of 1958 was due to the installation of modifications, the receipt of adequate instruction manuals, the improvement of performance of parts as a result of modifications, and the formulation of adequate preventive-maintenance schedules.

Further improvement from the fourth quarter of 1958 to the second quarter of 1959 was due mostly to the improvement resulting from the central-control-point concept. Of all the outages indicated, the *FPS-23* and the *FRC-45* equipments usually were responsible for between 60 and 80 percent. This seems to have been caused by inadequate depot stockage and the inclusion in these equipments of unique components that were hard to procure.

Fortunately the equipment outages did not affect the operation of the Dewline as a system, because of 100-percent redundancy. The ability to transfer immediately to spare equipment assured a fairly high operational status in the early days. Figure 9 clearly shows the high degree of equipment availability. This situation has since been improved by publishing maintenance handbooks that are accurate condensations of the more-massive technical orders.

TABLE 1

Analysis of Part Replacements by Part Type Group on AN/FPS-23, AN/FPS-19, AN/FRC-45V, AN/FRC-39A(V), and IS-101 Equipments Over 6-Month Period

Part Type Group	Total Replacements						Percent of Total Replacements by Equipment					
	FPS-23	FPS-19	FRC-45V	IS-101	FRC-39A(V)	Combined	FPS-23	FPS-19	FRC-45V	IS-101	FRC-39A(V)	Combined
Tubes	973	3042	2172	1351	682	8220	77.0	87.4	83.9	82.1	58.9	81.0
Resistors	38	93	144	36	49	360	3.0	2.7	5.6	2.2	4.2	3.6
Capacitors	26	38	25	41	10	140	2.1	1.1	1.0	2.5	0.9	1.4
Relays	19	75	9	4	11	118	1.5	2.2	0.3	0.2	0.9	1.2
Coils	2	5	1	13	6	27	0.2	0.1	0.0	0.8	0.5	0.3
Transformers	19	17	3	18	6	63	1.5	0.5	0.1	1.1	0.5	0.6
Motors	41	12	2	1	8	64	3.3	0.3	0.1	0.1	0.7	0.6
Switches	2	8	4	1	8	23	0.2	0.2	0.1	0.1	0.7	0.2
Crystals	31	103	23	62	74	293	2.4	3.0	0.9	3.7	6.4	2.9
Lamps	36	54	133	57	11	291	2.8	1.5	5.1	3.5	0.9	2.9
Transistors	—	—	—	—	11	11	—	—	—	—	0.9	0.2
Miscellaneous	76	34	74	62	283	529	6.0	1.0	2.9	3.7	24.5	5.1
Parts Totals	1263	3481	2590	1646	1159	10 139	100.0	100.0	100.0	100.0	100.0	100.0

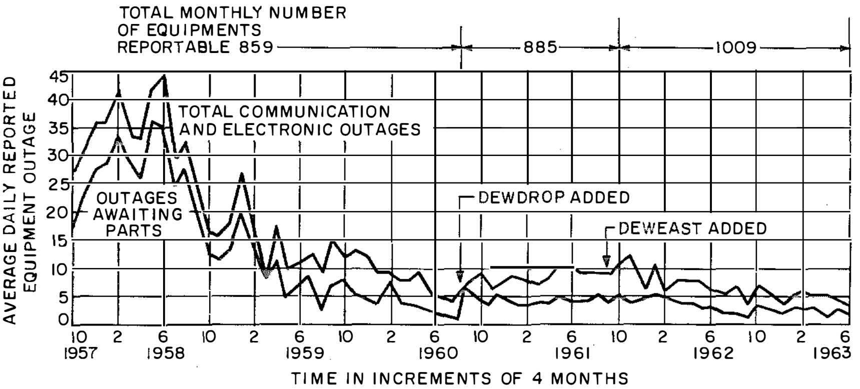

Figure 8—Equipment outages.

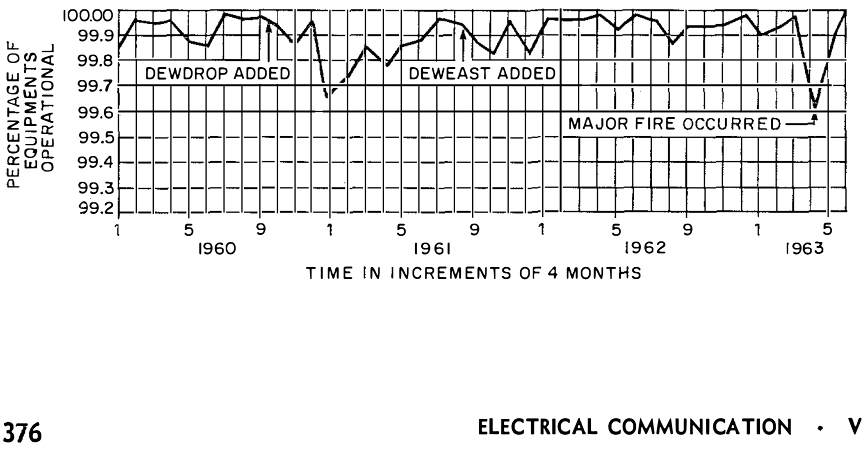

Figure 9—Mission-equipment availability.

In the fall of 1960, Project Dewdrop was added to the Dewline. Project Dewdrop is a 1-hop broad-band tropospheric-scatter system stretching 691 miles from Thule Air Force Base to the Dewline at Cape Dyer (Figure 10). Because of the new *FRC-47* equipment we again suffered initial equipment and parts problems.

Figure 11 shows the apparent impact of the *FRC-47* (Dewdrop) equipment when it was included in our reporting system in December 1960. In the initial operating quarter, 700 hours of circuit outage were suffered by this system. Problem areas connected with Dewdrop have largely been solved. Also indicated are the effects of adding Deweast in the fall of 1961 and of an unusually severe ice storm during the winter of 1962.

As the years of Dewline operation progressed, new concepts in operation and maintenance of complex systems were evolved. The following represent some of the highlights of the decade of operation.

(A) Tables 1 and 2 indicate the maintenance required on the Dewline. Table 1 shows typical parts consumption during preventive and corrective maintenance on prime mission equipment of a typical 6-month period. As might be expected, tubes account for the great majority

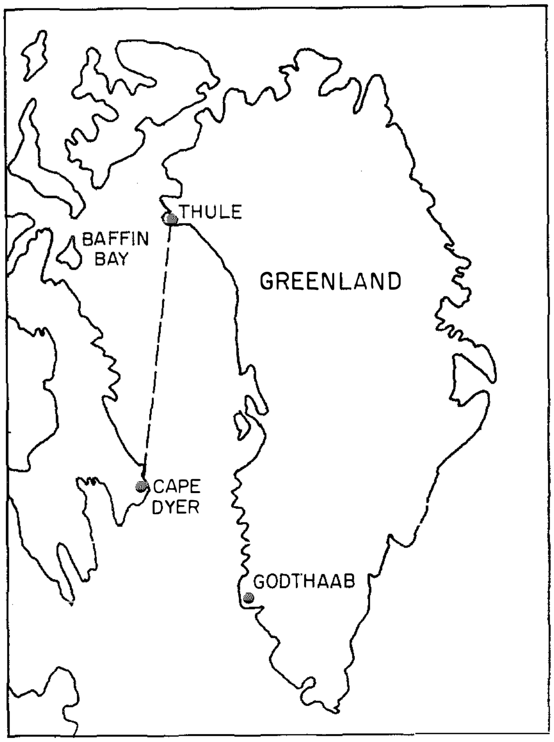

Figure 10—Dewdrop link from Thule Air Force Base to the Dewline at Cape Dyer.

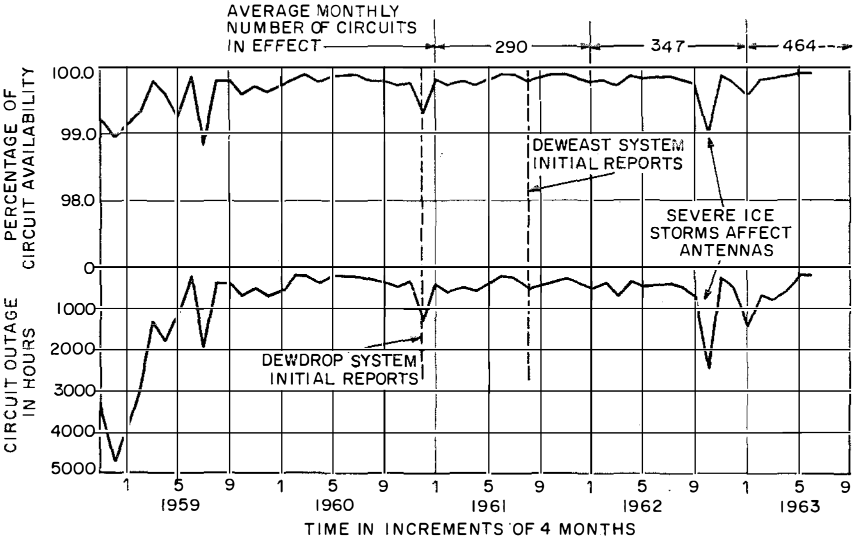

Figure 11—Summary of Dewline communications reliability.

of replacements. Table 2 indicates the average hours spent on the Dewline for preventive and corrective maintenance repairs. It can be seen from these tables which equipments require the most attention. From tables such as these and from other studies, we learn where to apply the most engineering effort to improve maintainability and reliability.

TABLE 2
ANALYSIS OF CORRECTIVE AND PREVENTIVE MAINTENANCE

Equipment	Average Monthly Corrective Maintenance In Hours	Average Monthly Preventive Maintenance In Hours	Total
AN/FPS-19	112.1	142.2	254.3
AN/FPS-23 FPR-2	20.4	121.5	141.9
FPT-4	49.8	42.8	92.6
AN/FRC-45V	77.4	335.4	412.8
IS-101	86.5	41.5	128.0
AN/GPX-26	14.8	25.7	40.5
AN/FSA-14	24.9	10.4	35.3
AN/FRC-39A(V)	272.8	145.7	418.5
Total	658.7	865.2	1523.9

(B) In 1958, during the peak of the sun-spot cycle, our ionospheric-scatter system (*IS-101*) was subject to many back-scatter multipath propagation problems. These affected our time-division-multiplex equipment to the extent that we had to devise a frequency-stepping anti-multipath modification. This proved to be a highly satisfactory solution.

(C) A fair amount of anomalous refractive-index gradients have been observed in the Arctic. These atmospheric phenomena, which are not observed as frequently in the more-temperate regions, have caused both enhancement and degradation of the performance of the communication and radar equipment. The operators have learned to adjust and operate through these phenomena. Particularly problems were experienced with our *FPS-23* doppler radar system.

(D) Our experience in the general field of operation and maintenance in the remote Arctic regions indicates that system engineering should call for highly conservative designs of antennas and outside plant equipment. One of the largest antennas on the Dewline is the *IS-101* corner reflector, which consists of many towers with a wire configuration. There have been cases of a complete reflector assembly collapsing from the weight of ice. It also has been our experience that electronic equipment not subject to outside environmental conditions has been greatly overdesigned for safety, and that much economy can be realized by reducing these safety factors.

We have covered in these short paragraphs approximately 10 years of operation and maintenance of a very-complex system. There have been many papers and reports on individual systems in the Dewline complex. This paper summarizes many additional papers on this subject and on other activities of the Dewline. A list of references is attached for the convenience of the reader who desires more-detailed and more-specific information.

4. Future Potential of the Dewline

Figure 12 reflects the addition of the Deweast extension from Cape Dyer to Iceland in October 1961 and shows the vast potential of the Dewline for present and future aerospace activities. Some of the possible future uses of the Dewline for aerospace activities follow.

(A) In its present configuration the Dewline can be used as a vital east-west communication network for exchanging data with polar-orbit satellites and for intertheater applications.

(B) Because of its location in the Arctic where there is relative freedom from atmospheric and man-made noises, many of the Dewline sites are ideally situated for experimental programs in aerospace communication and telemetry. Although the Dewline was designed primarily for air-breathing vehicles, it can be readily adapted to support the various aerospace sciences and offers a vast network of operational systems and facilities for future use.

5. Summary

As mentioned previously, there was no development period of consequence for the electronic equipments used on the Dewline. The equipments were constructed directly from breadboards. As was expected, many design problems were encountered during the initial operation and maintenance period.

Our operational and maintenance problems would have been significantly fewer if greater reliability and more maintainability design features had been built into the equipment. During the early years of our operation and maintenance responsibility, however, many recommendations affecting reliability and maintainability were made through effective use of failure reports and analyses, and these eventually resulted in equipment design modifications. Modifications have ranged from the introduction of rugged tubes to completely new circuit designs.

Because of these and other modifications, engineers had to monitor the effect of the modifications long after the system-engineering phase of the program was over. Although this procedure was costly and created an extremely heavy workload, it resulted in the Dewline's high level of performance. We have come to appreciate, during the initial operation and maintenance period of the weapons system, the importance of effective installation-engineering and implementation procedures. The importance is most-vividly borne out by the fact that during the preoperational phase of the Dewline, over 1 million formal tests were required to prove out the system, and almost 400 technicians per year had to be trained to operate and

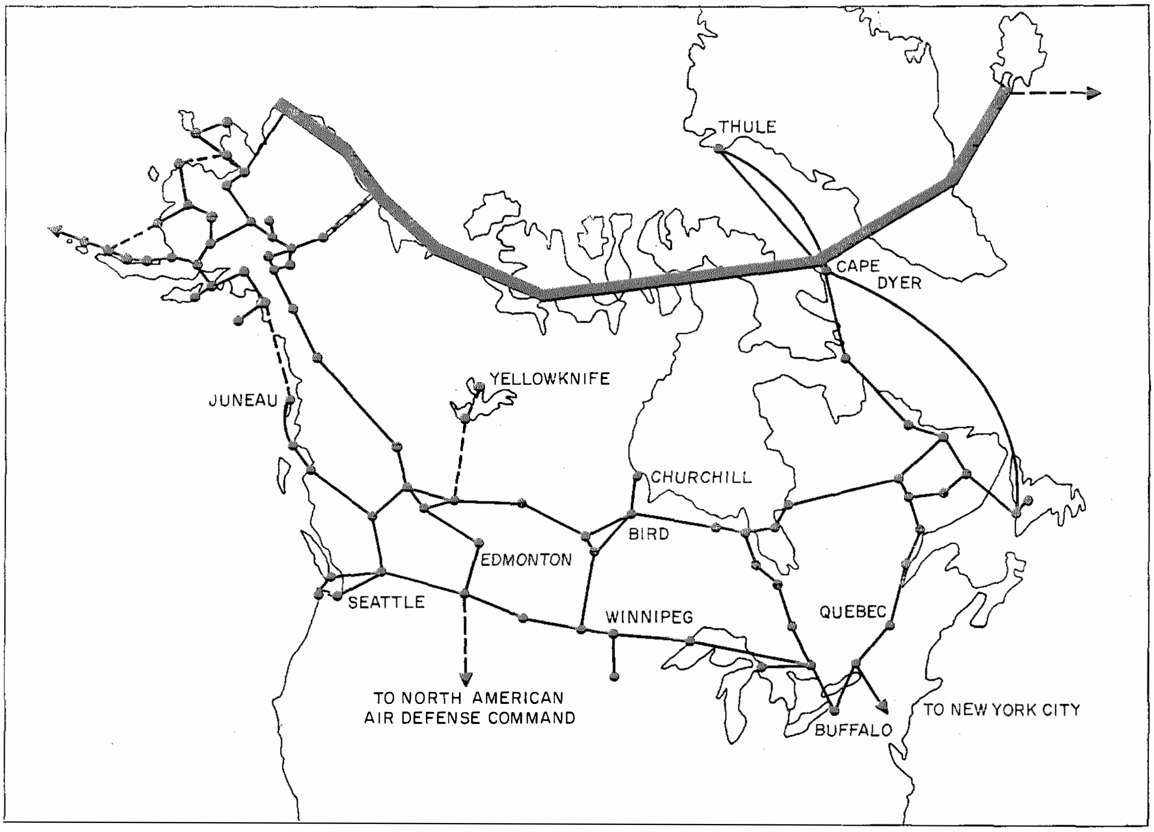

Figure 12—Principal existing broad-band communication systems in northern North America.

maintain the vast array of communication and detection equipment. We have since used this experience in the implementation of many communication systems, both in the United States and abroad.

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William G. Donaldson was born in Dubois, Pennsylvania, on 10 December 1921. He received a BS degree in 1945 from the United States Coast Guard Academy in New London, Connecticut. He took graduate courses at the University of Connecticut and at New York University.

While on active duty during the Korean conflict, he designed the Coast Guard port security communication systems for New York and Philadelphia. In 1955, he joined Western Electric Company and as a transmission engineering section chief was responsible for design and development phases of the Dewline communication and detection systems. He joined Federal Electric Corporation in 1957 and is now the technical director. He is presently concerned with upgrading the Dewline system and several other major overseas system-implementation programs.

Mr. Donaldson is a Senior Member of the Institute of Electrical and Electronics Engineers, and holds memberships in the Armed Forces Communications and Electronics Association, the American Management Association, the American Institute of Aeronautics and Astronautics, the National Society of Professional Engineers, and the Maintenance Advisory Committee of the National Security Industrial Association. He is a registered professional engineer in New York, New Jersey, Connecticut, Kentucky, and Missouri.

Estimating Voltage Surges on Buried Coaxial Cables Struck by Lightning

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1. Introduction

Special devices are usually provided in the repeaters of transistor coaxial systems to protect against lightning surges propagated along the cable. However effective these devices may be in protecting the repeaters and ancillary equipments, they afford no protection to the cable. To reduce the risk of arcs caused by surges in the cable that could burn the insulation or fuse conductors, additional protective measures are needed in the construction of the cable itself. The smaller the cable, the greater is this need. This study gives special attention to cables containing only a few, say 4, 6, or 8 coaxial pairs of 1·2/4·4 millimetres (0·047/0·174 inch) and associated service pairs.

2. Analytical Approach

By reason of symmetry, the coaxial pairs in such cables are all equally subjected to the effect of lightning that strikes the cable. In consequence, we may confine ourselves to a single coaxial pair. On this basis, equations have been derived using the same method that E. D. Sunde has used for calculating lightning surges along cables with uniformly distributed parameters [1]. In coaxial cable systems the uniformity of the cable circuits is disturbed by the presence of repeaters. Thus the capacitances existing between repeaters and their housings, augmented in some cases by other capacitances, are introduced into the circuit formed by the sheath and the coaxial outer conductor. Likewise, power-separating filters and power equipments are introduced into the low-frequency circuit formed by the outer and inner conductors of a coaxial pair. The capacitance of a repeater to its housing and the surge impedance of the power equipment are generally so small that they have no significant effect on the circuit parameters. On the other hand, it may be necessary to allow for the effects of power-separating filters and any other components that are added in particular repeater designs.

There appear to be three ways to take account of these additional elements: (A) to treat them as irregularities in otherwise uniform transmission lines, (B) to regard them as uniformly distributed over the repeater sections, and (C) to ignore them altogether, at least if they are relatively small.

Investigation of the first of these alternatives has led to great analytical complications that make it doubtful whether any practical use could be made of an exact solution, even if it could be stated explicitly. Moreover, since only an estimate of the order of magnitude of these surges is required, the study of this alternative has not been pursued further. There remain the second and third approaches, to each of which the equations appropriate to uniform transmission lines are applicable. In calculating the parameters of the equivalent uniform transmission lines, no account has been taken of inductance. Consequently, voltage surges inside the coaxial pairs are underestimated. However, this error is not considered to be significant.

There are three types of surge that are of interest. A surge of the first type appears between the metallic cable sheath and a coaxial outer conductor, or between the cable sheath and an interstice conductor. A surge of the second type appears between the coaxial inner and outer conductors, so long as the dielectric between sheath and outer conductor remains intact at the point of entry. If this dielectric breaks down, then a surge of the third type appears between the coaxial inner and outer conductors. The three types are hereafter referred to as V, $\bar{V}$, and $\bar{V}_1$, respectively. The object of the study is to express these surges in terms of the characteristics of the cable system, the soil resistivity, and the characteristics of the lightning current. The results are recorded in the Appendix.

3. Discussion of Results

The general equations (1), (2), and (3) express the values of the respective surges at any point along the cable and at any moment of time. It can be shown that in all three cases the surges are highest at the point of entry and, for the present purpose, attention may be confined to the surges as they appear at this point. As shown by (1A), (2A), and (3A), the forms of the equations now admit of considerable simplification, each being expressible as a product of three functions. The first of these functions depends only on the parameters of the cable and is thus a constant for any given cable. The second function depends only on the soil resistivity, and the third depends only on the time and the characteristics of the lightning stroke considered. Moreover, this third function is the same for all three types of surge.

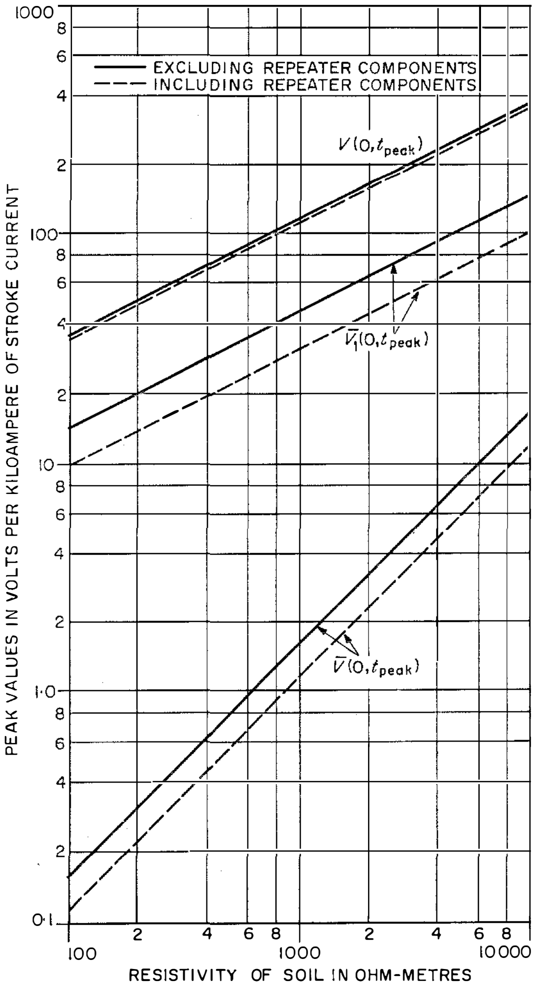

Figure 1—Peaks of surges at point of entry. The resistance of the cable sheath = 1 ohm per kilometre, the peak of lightning current = 1 kiloampere, and the rise and decay times of the lightning current = 7·5 and 65 microseconds respectively.

V (0, t_{peak}) occurs between sheath and coaxial outer conductor; $\bar{V}$ (0, t_{peak}) occurs between coaxial inner and outer conductors (the insulation between outer conductor and sheath remaining intact); and $\bar{V}_1$ (0, t_{peak}) occurs between coaxial inner and outer conductors (the insulation between outer conductor and sheath having broken down).

It follows that all surges have the same shape and that their peaks occur at the same moment of time. The time of special interest is that associated with their peaks. Confining attention to this moment, it is seen that the lightning function is also reduced to a constant; hence the peaks of all three surges vary only with the resistivity. This dependence is illustrated for a typical case in Figure 1. The solid lines refer to the peaks calculated without regard to the components at repeater points; the dashed lines refer to peaks calculated on the assumption that these components are uniformly distributed over the cable section. It is seen that, by either method, the results are of the same order of magnitude. In the case of surges between sheath and outer conductor, the solid and dashed lines practically coincide.

The cable constants used in Figure 1 were taken from measurements made on a cable containing four small-diameter coaxial pairs and on repeaters designed for a 300-channel coaxial system conforming to recommendations of the Comité Consultatif International Télégraphique et Téléphonique. Equations (1A), (2A), and (3A) contain the sheath resistance R_s as a common factor. It is convenient, therefore, to normalize this resistance in Figure 1 to 1 ohm per kilometre, which is a value within the range realized in practice. The resistance of the sheath thus affords a means of controlling, at least in some measure, the peaks of all three surges.

The third function in (1A), (2A), and (3A) implies a lightning current of any given peak value and any given rise and decay times. A peak value of 1 kiloampere and rise and decay times of 7·5 and 65 microseconds have been assumed for Figure 1. Rise and decay times of this order are generally regarded as representative of the average form of stroke.

Using the above-mentioned values, the third function has a maximum value of about 6 at the point of entry. For other current peaks the values given by the curves must be adjusted proportionally. For instance, for a stroke of 100 kiloamperes in a region of soil resistivity of 3000 ohm-metres, the full lines would give V as 20 000 volts, $\bar{V}$ as 480 volts, and $\bar{V}_1$ as 8000 volts. These figures are rough estimates of the peaks that may be expected if the sheath resistance is 1 ohm per kilometre. They are directly proportional to the sheath resistance. The peak values of 480 and 8000 volts that appear inside the coaxial pair, with and without adequate insulation between the cable core and sheath, emphasize the considerable importance of the role played by the dielectric strength of this insulation.

4. Reference

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5. Appendix

5.1 Equations of Voltage Surges

5.1.1 *Symbols*

x = distance along cable from point of entry of stroke current in metres

t, τ = time in seconds

ρ = resistivity of earth in ohm-metres

μ = permeability of earth in henries per metre

R_s = resistance of cable sheath in ohms per metre

R, C = resistance in ohms per metre and capacitance in farads per metre of the transmission line or equivalent uniform transmission line formed by the sheath and the coaxial outer conductor

$\bar{R}, \bar{C}$ = resistance in ohms per metre and capacitance in farads per metre of the transmission line or equivalent uniform transmission line formed by the coaxial outer and inner conductors

$J(t)$ = stroke current in amperes in lightning channel at the point of entry.

$$\alpha = \frac{\mu}{2\rho} = \frac{4\pi 10^{-7}}{2\rho}\,; \quad \beta = RC; \quad \bar{\beta} = \bar{R}\bar{C}$$

$$g(\sigma, t) = \int_0^t J(t-\tau)\,\frac{e^{-\sigma^2/4\tau}}{(\pi\tau)^{1/2}}\,d\tau$$

σ = variable of position denoting $\alpha^{1/2}x$, $\beta^{1/2}x$, or $\bar{\beta}^{1/2}x$ as required

$V(x, t)$ = voltage surge along circuit formed by the sheath and the coaxial outer conductor in volts

$\bar{V}(x, t)$ = voltage surge along circuit formed by the coaxial inner and outer conductors, inner and outer conductors being insulated from the sheath, in volts

$\bar{V}_1(x, t)$ = voltage surge along circuit formed by the coaxial inner and outer conductors, the coaxial outer conductor being in contact with the sheath at the point of entry and the inner conductor being insulated from the outer conductor and sheath, in volts

5.1.2 *General Equations Applicable at any Position*

$$V(x,t)=\frac{R_s}{2(\alpha-\beta)}\times\{\beta^{1/2}g(\beta^{1/2}x,t)-\alpha^{1/2}g(\alpha^{1/2}x,t)\} \qquad (1)$$

$$\bar{V}(x,t)=\frac{R_s(R-R_s)C}{2(\alpha-\beta)}\left\{\frac{\bar{\beta}^{1/2}}{\bar{\beta}-\alpha}g(\bar{\beta}^{1/2}x,t)-\frac{\alpha^{1/2}}{\bar{\beta}-\alpha}g(\alpha^{1/2}x,t)-\frac{\beta^{1/2}}{\bar{\beta}-\beta}g(\bar{\beta}^{1/2}x,t)+\frac{\beta^{1/2}}{\bar{\beta}-\beta}g(\beta^{1/2}x,t)\right\} \qquad (2)$$

$$\bar{V}_1(x,t)=\frac{R_s(R-R_s)C}{2(\alpha-\beta)}\left\{\frac{\bar{\beta}^{1/2}}{\bar{\beta}-\alpha}g(\bar{\beta}^{1/2}x,t)-\frac{\alpha^{1/2}}{\bar{\beta}-\alpha}g(\alpha^{1/2}x,t)-\frac{(\alpha\bar{\beta})^{1/2}}{\beta^{1/2}(\bar{\beta}-\beta)}g(\bar{\beta}^{1/2}x,t)+\frac{(\alpha\beta)^{1/2}}{\beta^{1/2}(\bar{\beta}-\beta)}g(\beta^{1/2}x,t).\right\} \qquad (3)$$

5.1.3 *Equations Applicable at Point of Entry*

If in the above equations x is made equal to zero, if the terms that are insignificant under the conditions that occur in practice are dropped, and if α, β, and $\bar{\beta}$ are replaced by the quantities they represent, the following forms are obtained.

$$V(0,t)=\frac{R_s}{(8\pi 10^{-7})^{1/2}}\times\rho^{1/2}\times g(0,t) \qquad (1A)$$

$$\bar{V}(0,t)=\frac{R_s(R-R_s)C}{4\pi 10^{-7}\{(RC)^{1/2}+(\bar{R}\bar{C})^{1/2}\}}\times\rho\times g(0,t) \qquad (2A)$$

$$\bar{V}_1(0,t)=\frac{R_s(R-R_s)C^{1/2}}{(8\pi 10^{-7})^{1/2}R^{1/2}\{(RC)^{1/2}+(\bar{R}\bar{C})^{1/2}\}}\times\rho^{1/2}\times g(0,t). \qquad (3A)$$

Although these equations are approximations they differ from the exact equations (1), (2), and (3) only by amounts that are insignificant. They are therefore convenient working equations.

John Kemp received a diploma in electrical engineering in 1921 from the Imperial College of Science and Technology in London. He then joined the International Western Electric Company and, after training in the United States in the Bell System cable factories and laboratories, he assisted in introducing into Europe the loaded long-distance telephone cable developed in the United States.

Since 1946 Mr. Kemp has been a member of the senior technical staff of Standard Telecommunication Laboratories, engaged chiefly with inductive coordination of communication and power lines and with the protection of communication cables against lightning.

Since 1935 he is a Member of the Institution of Electrical Engineers. He has published several papers on waveguides. He has served for many years on several study groups of the Comité Consultatif International Télégraphique et Téléphonique.

Characteristics and Applications of Reed Contacts

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1. Description

The reed contact is an electromagnetic component [1] primarily used in relays and switches. With conventional relay types, the electromagnetic circuit actuates mechanical parts that in turn operate the contacts of the circuit to be controlled. Hence, the life of such components depends not only on the wear of contacts, which is a function of current to be interrupted and type of load, but also on the wear of the associated mechanical parts. Furthermore, the masses of the mechanical parts may also importantly determine the shortest possible switching times.

Figure 1 shows the reed contact that is the basic element of an electromagnetic relay. The contact comprises two magnetic tongues hermetically sealed in a glass tube filled with protective gases. In a magnetic field, the tongues attract each other and make contact. Thus they combine both magnetic and electric functions. No other moving mechanical parts are used. In addition, hermetic sealing of the contacts offers substantial advantages over the nonprotected contacts of conventional relays. For instance, reliable contact operation is assured even after long idle periods and for small loads such as in transistor circuits. Moreover, manufacture of reed contacts can be largely automated to achieve utmost reliability and low cost. The switching times of the reed contact are extremely short as only very-small masses are moved for short distances. Also, no maintenance is required.

Using these reed contacts, a variety of relays can be designed [2]. Figure 2 shows relays for printed-circuit boards and for mounting strips. If only a few relays are connected to electronic components, they may be fitted on printed-circuit boards using the flow-soldering technique suitable for the other components. However, if relays are the predominant components or if large relay groups can be formed without difficulty, mounting strips are preferred [3, 4]. As shown in Figure 2, the relay coils are fitted into simple *U*-shaped mounting strips that also form part of the magnetic circuit.

Figure 3 shows two specially designed relays. The upper relay is for a very-low operate power. The contact tongues are coupled as closely as possible to the iron circuit.

Figure 3*B* shows a relay with a permanent magnet that holds the contacts closed when no current is flowing in the coil. If the coil is energized, however, the contact breaks. This is a normally closed or break-contact relay. This type of relay is manufactured with one or two sets of contacts, the operating characteristics of which would still be within reasonable tolerances. Also, contact sets with or without a magnet in the same coil form are available. However, close operating tolerances may

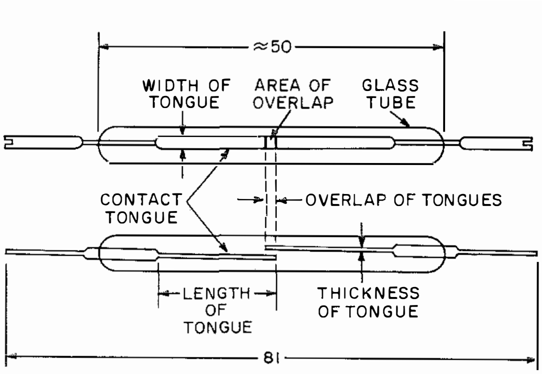


Figure 1—Herkon contact. Dimensions are given in millimeters.

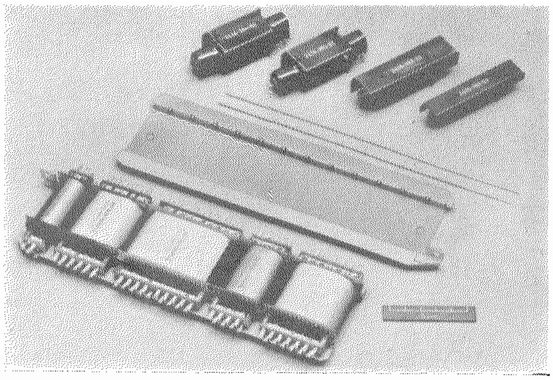


Figure 2—Relays for printed-circuit boards are at the top and for mounting strips at the bottom.

present difficulties, the solution to which may partly require closer mechanical tolerances of the contacts. If the permanent magnet is adjusted so that it cannot close the contact by itself but can hold an already closed contact in the make condition, a pulse-operated latching relay is obtained. In this case also, careful studies of tolerances are mandatory.

2. Reliability

Before discussing the reliability of reed contacts, some clear definitions are required. The end of life of a contact may result from a variety of changes in properties, depending on the type of circuit in which the component is used.

(A) Contact sticks or welds.

(B) Contact resistance increases.

(C) Release excitation changes beyond a given value.

(D) Operate energization changes beyond a given value.

While **(A)** represents an unquestionable failure, the influence of effects **(B)**, **(C)**, and **(D)** obviously depends on the types of circuit used. By including adequate safety margins for the energize and hold currents as well as adequate circuit resistance, a failure in operation can be avoided. The following discussion will be limited to sticking and welding caused by contact erosion.

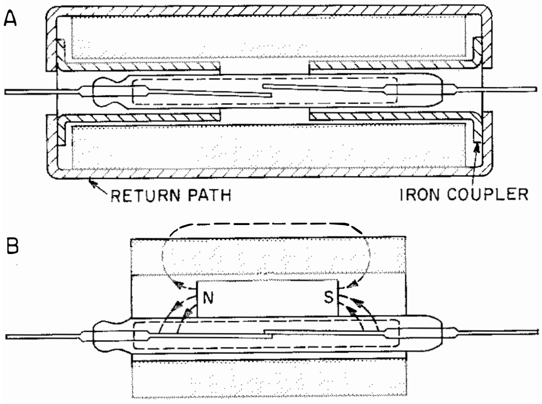


Figure 3—Herkon relays. *A* is the sensitive type, while *B* is the break-contact type.

Component reliability is usually expressed as the number of failures per component-hour. For example, a rate of 10^{-7} failure per component-hour means that in an equipment containing 10^{4} components of the type concerned, a failure of the equipment must be expected every 10^{3} hours. However, if 10^{6} such components were contained in the equipment, a failure would have to be expected every 10 hours, beginning from the moment the equipment is put in operation.

A corresponding failure rate for contacts as a function of the number of contact operations should be defined. Such a definition would show in principle that failures can happen at any early time if enough components are involved. Does this view meet the practical conditions?

The use of a constant failure rate is justified only if, beginning from the moment the equipment is put in operation, various disturbing influences are exerted at random. The effects of these influences, however, must not depend on time. Basically, influences of wear cannot therefore be considered to be the cause of failures defined by the failure rate, because wear of components begins with a normally constant effect right after the equipment has been put in operation. However, as the components have been designed for a specified life, wear is unable to cause the end of life immediately at the beginning of the life tests if the contacts have been properly checked during manufacture.

Processes such as corrosion and the absorption of humidity that lead to breakdowns basically have no constant wearing influence on the life of components to justify a constant failure rate [5]. Also, if these processes continue at a uniform speed (corrosion of metal at coil taps or at capacitor foils, ingress of humidity through very-small leaks), they will not be effective in causing failures until a certain zero time elapses after the start of the test, during which time they cause practically no failures [6].

The length of such a zero time, however, depends on the design of the components, the ability to test their critical properties, and the conscientiousness of the manufacturer. Such a time without failures can be assumed for reed contacts if manufacture and testing are under adequate control. In this respect, significant variations may be found among reed contacts of various manufacturers. Even if an accelerated life test reveals no differences between the reed contacts of two manufacturers, the test result may be quite different after several years of storage; contacts showing small leaks may then have different properties as a result of the ingress of oxygen. The customer therefore finds it very hard to get a clear picture of the behavior of a reed contact unless he is given further reliable data on long-time storage of contacts, plus information on the number of contact operations to be expected at a definite load. Since a large number of contacts must be tested to obtain clear information, and as this information certainly must be backed by continual supervision of contacts already operating in the field, all the data given in this paper are necessarily limited to contacts of type *H 80* manufactured by Standard Elektrik Lorenz. In this designation, the number indicates the approximate overall length in millimeters of the contact unit.

To reduce the time and cost of testing, the failurefree period was determined in only one experiment, which lasted for several years. More than 1500 contacts were tested continuously at 25 operations per second with an inductive load on direct current of 30 milliamperes and 60 volts. Every contact was supervised during each operation to detect whether it had released within 5 milliseconds after interruption of the coil current. If the result was negative, this was taken as the end of contact life. Figure 4 represents on a Gaussian scale the total percent of contact failures as a function of the number of operations shown on a logarithmic scale. Within the range of wear, it is obvious that the results of the life test correspond extremely well with the Gaussian distribution above about 6 × 10^6 operations. For a confidence level of 90 percent, the departure at the lower end of the curve is well within the rules of statistics. Below about 6 × 10^6 operations, practically no failures are expected.

Figure 4 confirms by test the existence of the failurefree period. For this test, samples were also selected from the time manufacture of contacts was started a few years ago, although the production process had not then been optimized. A curve for contacts manufactured today would, of course, give more-favorable results. Figure 4 shows that for the specified load it would be useless to define a failure rate if fewer than about 6 × 10^6 operations are involved, since practically no failures occur in this area. For, say, 10^{-10} failure per contact operation, this would result in a contact failure every 10^5 operations for a system equipped with 10^5 contacts. This is impossible, however, according to Figure 4. Hence, the only correct method of

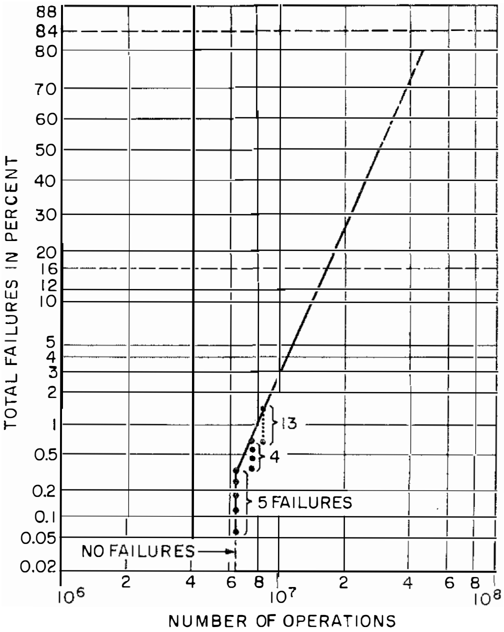


Figure 4—Total failures in percent among 1500 *H 80* contacts as a function of the number of contact operations. The load on each contact, without spark quench, was a flat relay of 1000 ohms (14 000 turns) requiring 30 milliamperes at 60 volts.

predetermining the contact behavior in a certain circuit is to use a failure curve according to Figure 4. Using this curve, applicable of course only for a specified load, the risk the user takes under the statements of warranty is clearly defined. Thus, knowing the number of equipments, the number of contacts contained in each equipment, the costs, and the maintenance that can be provided, designs can be made for different numbers of operations without contact failures. As can be derived from the above, the lowest possible risk exists for the user if the contact load is chosen so that the number of operations to be warranted is still within the failurefree period. This number of contact operations without any failures increases as the load is reduced. With a sufficiently small load, no upper limit of failurefree operations appears to exist, as recent investigations have shown. Needless to say, the so-called failurefree area represents in general only a zone of considerably fewer failures since, for example, mechanical damage during or after assembly will no doubt result in failures or disturbances that cannot be represented in the Gaussian distribution or in other predictions.

Long-term reliability of *H 80* Herkon relays has also been proved by experience. Since 1959, more than 10^5 contacts have been used by the German Post Office in toll dialing systems (translators) and have proved to be extremely reliable in operation. In addition, several hundreds of thousands of contacts have been operating since July 1963 in the quasi-electronic experimental exchange *HE 60* in Stuttgart with the same high reliability, and for telemetering data transmission a large number of contacts have been in operation for years carrying out 30 to 150 million operations annually.

3. General Properties

It is, of course, impossible to work out such detailed statistics as represented in Figure 4 for every case of possible application. As a consequence, engineers usually depend on interpolations and extrapolations of values obtained from tests using smaller test lots under different loads.

In the following paragraphs, more life test data on *H 80* contacts with gold diffused contact area are discussed.

There is a variety of general characteristics in which contacts produced under various conditions may differ substantially.

As mentioned earlier, Herkon contacts can be used for switching very-low voltages and currents without difficulty even after long idle periods. This was demonstrated in a test with 100 contacts, the contact resistance being tested with an electromotive force of only 500 microvolts and a direct current of 1 milliampere immediately after the first operation was made following an idle period of one year. Even after this period, the resistance of all 100 contacts was still below 40 milliohms.

Another test with 10 contacts stored at 150 degrees Celsius for more than two years without operation likewise revealed no noticeable changes of contact resistance. During this laboratory test, one solder lug of each contact was loaded with a 100-gram weight applied in the vertical direction to the plane of the contact tongue to find whether a flow of glass would cause changes of magnetic data. The result showed that all changes were below 3 percent. Within the admissible operating temperatures it can be taken for granted that, for instance, permanent forces of such size caused by wiring will have no effect on the relay data.

Due to the diffusion technique employed, reed contacts that have been closed for a while may not release (cold diffusion). To test for this fault, groups of 20 permanently closed contacts carried currents of 1 ampere, 100 milliamperes, and 20 milliamperes during a 6-month period, while another 700 contacts were stored in closed condition for several months with no load applied. It was found that no contact had suffered changes in its magnetic characteristics even for the first contact release after storage.

TABLE 1

INSULATION RESISTANCE IN MEGOHMS AS A FUNCTION OF RELATIVE HUMIDITY AND TEMPERATURE

Temperature in Degrees Celsius	Relative Humidity in Percent				
	30	50	70	80	90
25	$>3 \times 10^5$	$>5 \times 10^4$	2×10^3	4×10^2	2×10^2
40	$>3 \times 10^5$	$>10^4$	10^3	1.5×10^2	10^2

In addition, the dangers of corrosion were studied. Tests performed with 20 contacts revealed that corrosion does not jeopardize the contact seals. Contacts were exposed for 18 months to a program of 8 hours at 40 degrees Celsius and 100 percent relative air humidity dewed, followed by 16 hours at 20 degrees Celsius and 60 to 70 percent relative air humidity according to German Industrial Standard *DIN-50017*. No changes of contact resistance were found. The solder lugs were completely rusted through, but operational reliability was fully maintained.

Finally, under certain circumstances, some properties can be unfavorable since a Herkon contact, just as any other type of contact, has only a limited field of application. As the contact is fitted with a glass tube, the effect of the relative humidity of the air on insulation must necessarily be considered. Table 1 gives some essential data; the insulation resistance, contrary to the behavior of many other insulating materials, adapts itself within seconds to changing air humidity. It was found that 95 percent of the values were above those given in the table.

Since the influence of temperature is less than the influence of relative humidity, more-favorable insulation values can be obtained by preheating in extremely humid rooms.

When switching very-low currents and voltages, it should be noted that the closing of the contact may produce an alternating voltage of 20 millivolts maximum at about 20 kilohertz, decaying to zero within 1 to 2 milliseconds; this is probably caused by magnetostriction effects.

If the contact itself in closed condition is capable of carrying currents of more than 1 ampere, limits are nevertheless set by the resultant heating within the contact area; with a steady current of 1 ampere, a temperature rise of 15 degrees Celsius (measured at the glass tube) occurs, while a steady current of 5 amperes causes a temperature rise of 80 degrees Celsius.

If the reed contact is to be used for switching high-frequency currents, attention should be given to the skin effect, which may cause a contact resistance of 1 ohm at 1 megahertz. However, frequencies of up to 50 megahertz can be switched and still-higher frequencies can be handled by applying, for instance, a silver coating to the contact tongues.

If inadmissibly high currents are switched, the contacts can stick immediately or after a few operations. Also, short-time current peaks (for example caused by charging and discharging capacitors, or by switching currents for filament lamps) may have this effect. With the *H 80* unit, current peaks of about 3 amperes should not be exceeded during the switching operation. When charging or discharging capacitors (without resistor), the energy switched must not exceed about 10^{-5} joule. The risk to the contacts in capacitor charging and discharging can be considerably reduced by connecting in series a small inductance of between 20 and 200 microhenries, according to the capacitance, or an ohmic resistance if admissible.

Current peaks that make contacts stick may also be caused by wiring. If, for example, a large number of resistors are to be connected over long wires or cables, either star connection as in Figure 5*A* or ring connection as in 5*B* may be used. For the star connection, a switching operation occurs on each wire $l_1, \ldots, l_n$. The initial current depends on the characteristic impedance of each line and on the number of lines. As the impedance of the line system is not matched at the far end, a full reflection is frequently returned to the switching point. At the beginning, the reflection amplitude is independent of the steady-state current, which continues after reflections have died down. In customary wiring, the characteristic impedance is normally between 50 and 100 ohms. For instance, with an impedance $Z = 60$ ohms, a voltage $E = 60$ volts, and 10 elements star connected over lines and cables of sufficient length, an initial peak current of 10 amperes is obtained, which is very likely to cause a welding of contacts. However, if ring-type wiring is used, only a single transmission line contributes to the impedance and greatly reduces the transient. The contact is then not in danger of welding. Finally, it should be noted that with a reed contact having the normal length of 80 millimeters, no interruption due to contact bounce occurs for at least 2 microseconds after the first operation of the contact. Therefore, efforts should be made to ensure that the reflections will have died down within this time. If necessary, the current peaks can be sufficiently flattened by means of a small series inductance.

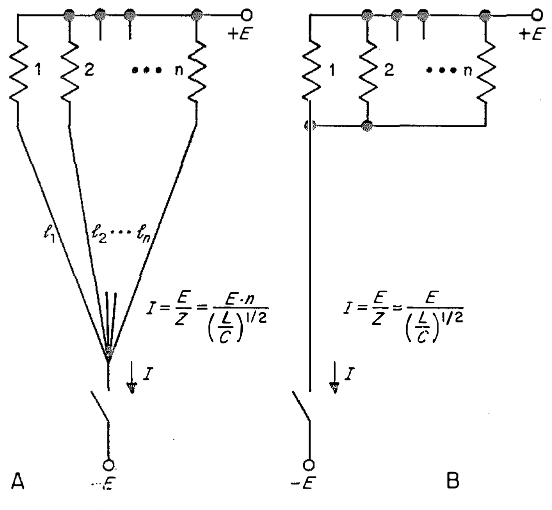


Figure 5—Influence of wiring on initial current. *A* is the star type and *B* the ring type of wiring.

4. Contact Behavior Under Different Loads

Based on a test with 80 contacts that were switched for more than 4×10^9 times without load, it can be considered proved that no mechanical wear occurs, as the operate and release values of the contacts underwent no systematic changes during the test. Variations did not exceed 8 percent.

Figure 6 gives life-test data on 4 groups of *H 80* contacts. The load conditions were as follows.

(A) 60 volts direct current, Herkon relays of different sizes (2 to 11 contacts), no spark quench, magnetic energy from 0.1 to 1 millijoule according to number of contacts, 25 operations per second, 95 contacts.

(B) 60 volts direct current, 100 milliamperes, resistance load, 50 operations per second, 310 contacts.

(C) 60 volts direct current, 300 milliamperes, resistance load, 50 operations per second, 40 contacts.

(D) 60 volts direct current, 30 milliamperes, resistance load, 50 operations per second, 40 contacts.

For a direct current of 1 ampere at 60 volts and a resistance load, failures do not start before about 10^6 operations, while for the same conditions at 24 volts failures occur after about 50×10^6 operations.

Whereas earliest failures for the conditions of Curve *A* of Figure 6, without spark quench, may occur after about 8×10^6 operations, failures among 20 contacts with spark quench (varistor plus capacitor) were not observed until after 195, 213, 391, and 558×10^6 operations. The remainder of the contacts continue to operate satisfactorily and have reached a present high of 750×10^6 operations.

When a flat relay having 1000 ohms, 14 000 turns, was used as load at 60 volts direct current, the first failures, without spark quench, occurred after about 5 × 10^6 operations. With spark quench (resistor plus capacitor) and a test carried out with 10 contacts, failures occurred only after 314 and 680 × 10^6 operations. The remaining contacts continue to operate without disturbance and have now completed 900 × 10^6 operations.

The spark quench should limit the impulse voltage to not more than 200 volts, while the short-circuit current from the spark quench through the closing contacts should not exceed 100 milliamperes if possible.

If operations without current are made (close contact, apply current; switch off current, break contact), many more operations can be performed compared with operations under load. This was verified by a test with 20 contacts at 160 milliamperes. The test was discontinued after more than 600 × 10^6 operations [7]. Another test with 20 contacts at 2 amperes is continuing; 80 × 10^6 operations have been made thus far. In both cases, not a single failure caused by contact welding or sticking has been registered.

When operating contactors it is a favorable factor that during contact bounce (lasting about 500 microseconds) the current is very low because of the long time constant of the load; practically no current flows. After the armature has been attracted, the current decreases, according to the type of magnetic circuit, to a fraction of its maximum value. As a result, *H 80* contacts are capable of reliably operating for about 200 volt-amperes at 220 volts alternating current several million times.

Finally, with currents equal to or greater than 100 milliamperes, the contact resistance normally remains below 500 milliohms. This is adequate for such circuits, which usually are of low resistance.

With lower current—including no-load operation—the resistance can rise to a few tens of ohms, which should be taken into consideration when designing circuits. The number of operations before the resistance rises depends on the type of load; with very-low current and voltage (tested with 10 microamperes and 10 millivolts of direct current), resistance of 1 ohm can be registered after several times 10^7 operations, and values of 10 ohms after several times 10^8 operations.

If reed contacts are operated by movable permanent magnets, or if a long release time is caused by, say, a delay circuit, the contact force may stay below the normal range for a relatively long time. For high load switching capacity, this will considerably reduce the contact life. Hence, in such cases *H 80* contacts must not switch currents larger than about 200 milliamperes.

Unfortunately, the physical and chemical processes in reed contact switching cannot yet be clearly explained to the extent that reliable predictions on contact behavior may be made

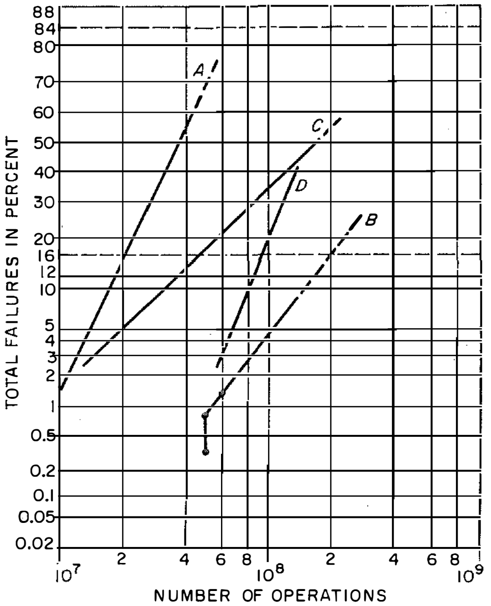


Figure 6—Life tests of 4 groups of *H 80* Herkon contacts, each group being switched under a different load. Curves *A* through *D* correspond to the operating conditions listed in paragraphs **(A)** through **(D)** of Section 4.

TABLE 2

Characteristics of the 4 Types of Relay Compared in Figure 8

Contact	Air Gap in Millimeters	Reset Force in Ponds	Spring Constant in Ponds per Millimeter	Overlap in Millimeters	Wire Diameter in Millimeters
H 80	0.23	23	200	1.2	1.3
H 50	0.18	9.7	107	0.6	0.8
H 40	0.08	2.7	84	0.6	0.55
A	0.15	2.9	38	0.6	0.55

without life tests, although certain pioneer work has been done in this field [8, 9]. From our experience, however, the circuits could in most cases be designed so that a large number of failurefree operations is obtained.

5. Problems of Miniaturization

There is considerable interest in switching very-small loads. If the contact reliability can be made equal to that of normal-size 80-millimeter contacts, a reed contact of smaller size would do this job. However, making reed contacts smaller is unlikely to reduce contact costs. The cost of material is rather low and, moreover, savings in material would be offset by a higher rejection rate. As a consequence, each case should be studied carefully to determine whether the tendency toward miniaturization is indeed technically necessary or just "en vogue."

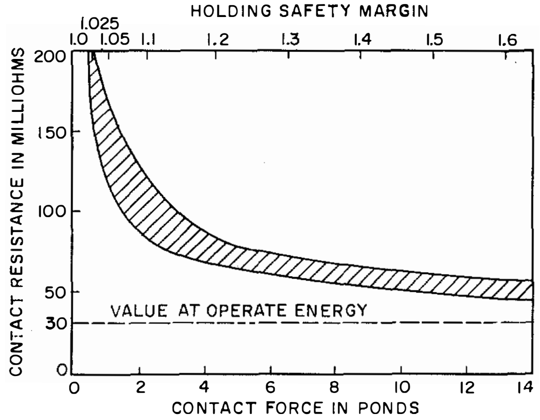


Figure 7—Contact resistance of the *H 80* Herkon relay as a function of contact force and of holding safety margin. The contact surfaces were gold diffused and the contact force at operate energy was 36 ponds.

In the mass production of normal-size reed contacts, the simplest possible form of unit parts is desired with respect to reliability, control of tolerances, and costs. This factor is even-more important for miniature contacts. Therefore, our discussion will be limited to components similar in shape to those in Figure 1 [10].

With the use of smaller contact sizes, lower forces must be expected that may lead to higher contact resistance. Figure 7 shows the contact resistance of a gold-diffused surface as a function of the contact force. With forces below 4 ponds, the resistance increases considerably. This means not only a higher contact resistance but at the same time an increase in sensitivity to vibrations that may modulate the resistance. Such vibrations can be caused by mechanical influences, by current peaks, and by ripples in the coil current, as well as by stray magnetic fields from adjacent components. Contact erosion may cause an increase in the effective air gap and the eroded contact particles may enter the contact gap. Such events tend to increase the contact resistance, so that a minimum contact force of 8 to 10 ponds should by all means be maintained [11]. A comparison of operate energy and reset force for different-size reed contacts is shown in Figure 8 and Table 2. Due to saturation of the cross section of the contact tongues, the contact force approaches a limit as the energization increases.

From the width of the air gap, length of the contact tongue, and its mechanical stiffness, the operate value is determined. Figure 8 clearly shows the influence exerted by the cross section of the tongue. The substantial differences between types *H 40* and *A* result just from the stiffness of the tongues and from the air gaps. Mention should be made here that the *H 40* contacts are used mostly in the United States and the *A* contacts in the United Kingdom. The resetting force of the contact tongues, the contact surface, and the air gap considerably influence the switching capacity of the reed contact. Since the Standard Elektrik Lorenz miniaturized Herkon contact is also applied to switching where definite requirements of currents, voltages, and number of operations under load must be met, the need arises for a minimum resetting force of 10 ponds and an air gap of about 0.15 millimeter. Together with these data and the specified material of contact tongues (nickel-iron, with about 53 percent of nickel), the required wire diameters can be calculated for the various contact lengths using the following symbols.

l_o = deflection of one tongue with reed contact closed
E = Young's modulus of the material used
L = length of tongue
h = thickness of tongue
b = width of tongue
P_r = force to produce l_o for a length L (resetting force).

$$l_o = \frac{P_r \times L^3 \times 4}{E \times b \times h^3}. \tag{1}$$

A second equation can be derived from (*A*) the displacement of the contact zone with respect to the center of the glass tube, which is attributable to tolerances in manufacture, and from (*B*) the fact that the tongues must not touch the glass tube when the contacts open.

$$b = 1.7(4 \times l_o + 2h). \tag{2}$$

From (1) and (2) we derive

$$h^4 + 2 \times l_o \times h^3 = \frac{1.18 \times P_r \times L^3}{l_o \times E}. \tag{3}$$

With h derived from the above equation, the required wire diameter can be calculated by (2). Figure 9 shows the result for an air gap of 0.15 millimeter ($l_o = 0.075$ millimeter), with the required wire diameter represented as a function of the length of the moving tongue; this was calculated for different resetting forces. The curves shown still do not include magnetic factors, though. From our experience with mass production of reed contacts, the length of overlap should be at least 0.5 millimeter, and considering the interrelation of forces (Figure 8) it is obvious that a wire diameter of about 0.8 millimeter is required. According to Figure 9, this would call for a length of about 10 millimeters. Unfortunately, the further dimensioning can no longer be accomplished by mere calculation. In particular, the susceptibility of reed contacts to tolerances, which decisively influence the rejection rate, can be determined only by an empirical approach (Figures 10–12). These figures show the operate ampere-turns as a function of the overlap of contact tongues, using air gaps of different widths. With a very-small overlap, the required operate ampere-turns increase as magnetic saturation occurs in the contact area. With a very-large overlap, the operate ampere-turns increase because of the lower magnetic flux density; a greater flux is required for contact operation, thus saturating the cross section of the wire. With

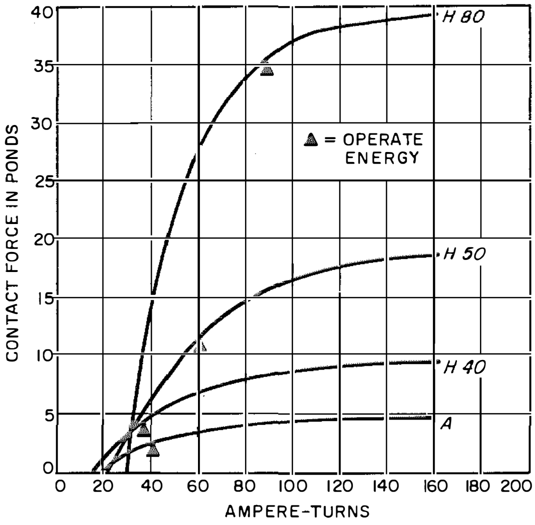


Figure 8—Contact force in ponds of four types of relay as a function of energization. Refer to Table 2.

too wide an air gap, the operate ampere-turns increase as well, because a larger magnetic stray field again leads to saturation in the cross section of the wire and increases the energization required.

When choosing the contact dimensions, manufacture can be simplified by attempting to obtain a "nominal working point" on the curves where the largest possible deviations from nominal can be tolerated, and where the operate ampere-turns will be least affected. Hence, nominal values at the bottoms of the curves should be used. For long life and high breakdown voltage, a wide gap is desirable. However, the curves show that the tolerances of too wide an air gap have a very-great influence on the operate ampere-turns.

The influence of contact length (coupling reluctance) can be derived from a comparison of the curves in Figures 10 and 11. With a shortened contact (Figure 11) the permissible overlap areas are limited earlier compared with the contact dimensions represented in Figure 10, and a displacement of the minimum toward smaller overlap areas (a smaller contact area involves the danger of a shorter contact life) can be noted. Finally, the curves show that a shortening of contacts causes a greater dependence of the operate ampere-turns with respect to the variation of the air gap. This effect of contact shortening can partly be compensated for by slightly reducing the resetting forces. The curves in Figure 12 show that by choosing more-suitable dimensions for the tongue in combination with a slightly wider air gap, which leads to an increase in breakdown voltage, the resetting force was lowered to a tolerable 10 ponds. Thus a considerably lower susceptibility to mechanical tolerances was ob-

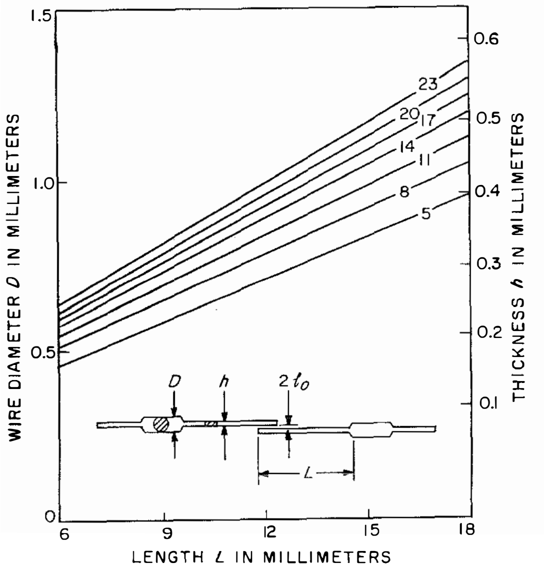


Figure 9—Wire diameter D and thickness h of tongue as functions of the length L of tongue and the resetting force. The numbers on the curves are the resetting forces in ponds. $E = 15 \times 10^6$ ponds per square millimeter, and $l_o = 0.075$ millimeter.

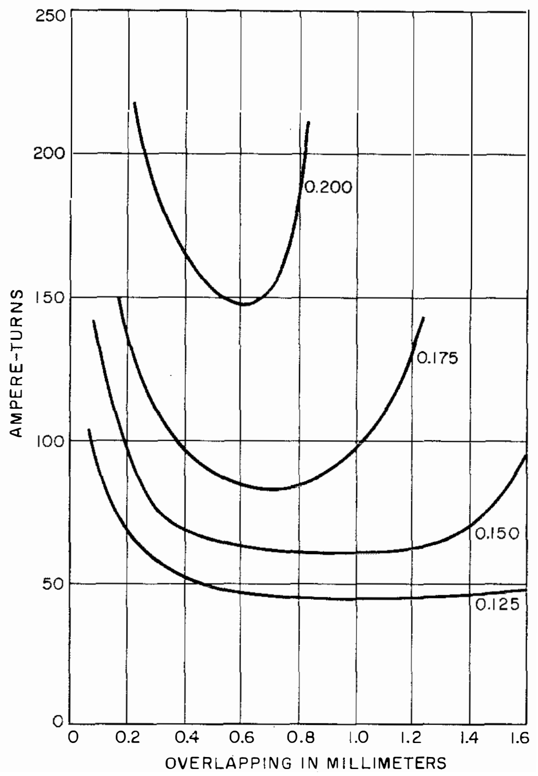


Figure 10—Operate energy as a function of overlap and air gap for the *H 50* contact. Overall length was 55 millimeters, length of measuring coil 25 millimeters, tongue elastic cross section 0.4 × 1.25 millimeters, and length of tongue 12.4 millimeters. The numbers on the curves are the air gaps in millimeters.

tained, which is of great importance for mass production of contacts. As a result, the dimensions shown in Figure 12 with a rated air gap of about 0.17 millimeter were taken as the basic dimensions for the miniature *H 50* Herkon contact.

It goes without saying that smaller reed contacts can also be manufactured (Figure 13). However, the interrelations shown and, as was proved by experiments, the strong dependence of useful life on the switched voltages call for correspondingly larger tolerances of operate and release ampere-turns; they involve the risk of small contact forces and restrict the range of voltages to be switched, unless contact

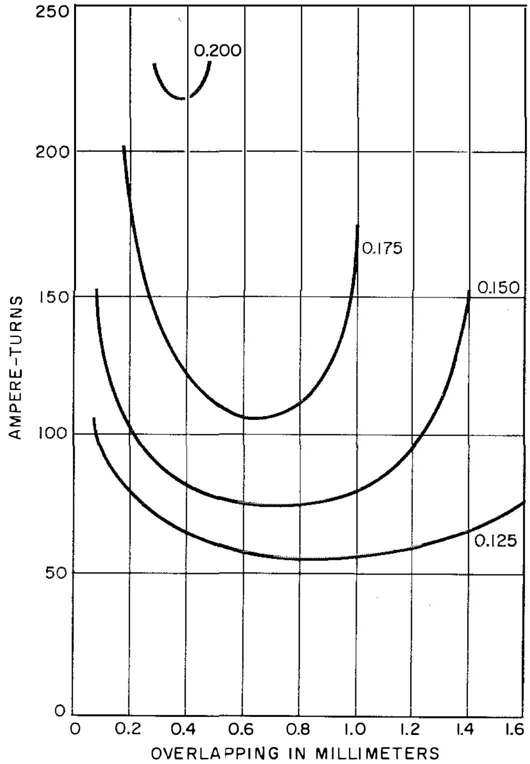


Figure 11—Operate energy as a function of overlap and air gap for the *H 50* contact. Overall length was 49 millimeters and all other parameters were the same as given in Figure 10.

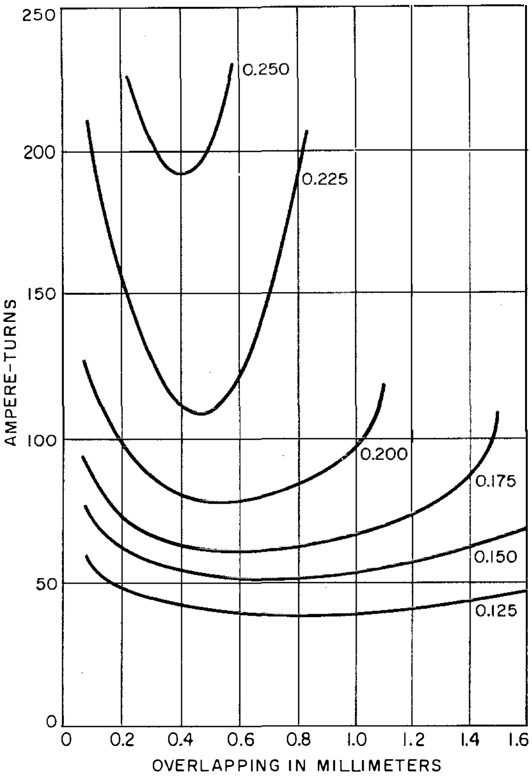
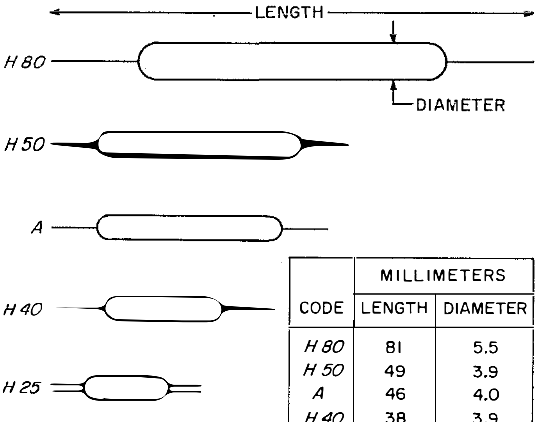


Figure 12—Operate energy as a function of overlap and air gap for the *H 50* contact. The tongue elastic cross section was 0.32 × 1.55 millimeters, the length of tongue 25 millimeters, and all other parameters were the same as given in Figure 11.



	MILLIMETERS	
CODE	LENGTH	DIAMETER
H 80	81	5.5
H 50	49	3.9
A	46	4.0
H 40	38	3.9
H 25	25	4.0

Figure 13—Comparison of sizes of Herkon contacts.

operations without current are required. A considerable number of operations, though, can be obtained when switching voltages of about 24 volts or less at corresponding normal currents. At 60 or more volts, however, considerable restrictions of application must be expected (through use of spark-quench circuits, et cetera).

For the *H 50* contact, the following approximate values have been obtained when tested at 25 operations per second.

(A) 1 ampere, 24 volts direct current, resistance load, first failures after 14×10^6 operations.

(B) 100 milliamperes, 60 volts direct current, resistance load, first failures after 1.2×10^6 operations.

(C) 30 milliamperes, 60 volts direct current, inductance load, without spark quench, (load the same as in Figure 4), first failures after 4.5×10^6 operations.

(D) 60 milliamperes, 60 volts direct current, inductance load, flat relay, 1000 ohms, 14 000 turns, without spark quench, first failures after 1.6×10^6 operations.

Finally, mention should be made of the *H 25* contact shown in Figure 14. It has an electrically conductive ball of magnetic material that can be moved between two pairs of contact pins, all hermetically sealed in a glass tube. With an overall length of only 25 millimeters, this contact is intended for operation by means of moving magnets and is used mostly where slightly higher contact resistances and longer bounce times are of minor importance. This contact is extremely suitable also for mass production. Keyboards using such contacts, for instance, have the advantage that a suitable arrangement of the ring magnets permits a sequence of contact operations to be programed indefinitely.

However, only few reliable data on the *H 25* contact behavior under different loads are available thus far. Presumably more than 5×10^5 operations at a direct current of 100 milliamperes and 60 volts with a resistance load will be endured safely by this contact type. In other tests under smaller loads, up to 5×10^6 operations have been reached.

Development work on reed contacts described in this paper has demonstrated that not only with electromechanical parts has a reliability been obtained that was considered incredible up to now, but also that a substantial miniaturization of these components has been achieved. Whereas some years ago there was a rather-fanatic trend toward using transistors in relay circuits, the development engineer now faces the problem of determining whether a modern reed component might be more economical and as reliable as circuits with completely electronic components whose dependence on temperature can often be neutralized only by additional components.

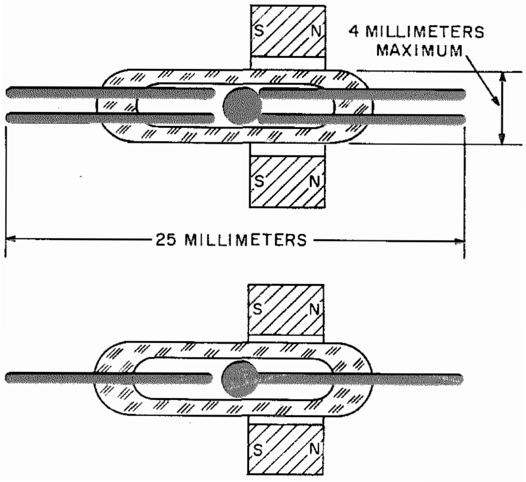


Figure 14—Herkon *H 25* relay with ball contact.

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Heinz Rensch was born in Dresden, Germany. He received a degree in communication engineering from Professor Barkhausen's Institute in 1937. Since that time, he has worked for the International Telephone and Telegraph system uninterruptedly except for the war years.

Mr. Rensch has worked extensively in radio, acoustics, and telephone systems and components.

United States Patents Issued to International Telephone and Telegraph System; February–July 1964

Between 1 February 1964 and 31 July 1964, the United States Patent Office issued 92 patents to the International System. The names of the inventors, company affiliations, subjects, and patent numbers are listed below.

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J. W. Anhalt, ITT Cannon Electric, Quick Detachable Coupling, 3 133 777.

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M. J. Cotterill, International Telephone and Telegraph Corporation, Double Side Band, Suppressed-Carrier, Phase Shift Type Telegraph System, 3 141 066.

J. R. Curran, ITT General Controls, Hydraulic System, 3 131 601.

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P. P. Danesi, Royal Electric, Electrical Terminal Connector, 3 140 909.

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E. P. G. Wright, J. Rice, and D. G. N. Hunter, Standard Telecommunication Laboratories (London), Means for Recording and Modifying Intelligence, 3 130 300.

E. P. G. Wright, D. A. Weir, R. C. P. Hinton, and B. Dzula, Standard Telecommunication Laboratories (London), Buffer System for Transferring Data Between Two Asynchronous Data Stores, 3 130 387.

Crosspoint Network for a Time Division Multiplex Telecommunication System

3 132 210

H. Adelaar

This is a coordinate switching network constructed to produce a shielding effect approaching that of a coaxial line so crosstalk will be minimized on time-division pulse communication links. The active crossing conductors of the network are separated from one another. A shielding conductor insulated from and parallel to each active conductor is positioned between the crossing active conductors.

Quick Detachable Coupling

3 133 777

J. W. Anhalt

This patent discloses a quick detachable coupling having a latching sleeve on the plug or socket of the unit and a latching detent on the other unit to fit into an aperture of the sleeve in coupling position. Hollow tubular conduits fit around the plug and socket assemblies within the sleeve. They do not abut when the parts are coupled. Pressure on the sleeve at the spacing area between the conduits serves to disengage the sleeve and latching detent when detaching the coupling.

Electrical Spring Contact Sockets

3 140 907

G. Davies

A spring contact socket for a printed-circuit board is provided with two spring arms each having two projections extending toward the other arm. The inner projections are larger so that the printed-circuit board will spread the arms to lift the outer projections out of contact with the board surface. A perforation is provided in the supporting base of the printed circuit so that these inner projections may drop into it, permitting the outer projections to make contact with the printed circuit.

Method for the Automatic Recognition of Characters, in Particular Writing Characters (Figures, Letters, and the Like)

3 136 976

W. Dietrich

This character-recognition system causes scanning across the character by a plurality of transducers to produce signals in segmental zones. The outputs of the transducers are coupled on a one-to-one basis to a first set of bistable devices. Bistable devices of a second set are each coupled to a plurality of the transducers. The resultant condition of the two sets of bistable devices after a scan provides an unambiguous indication of the character.

Spraying Equipment

3 130 909

W. L. Sanborn and E. J. Senninger

This patent covers a device of the mobile motor-driven type for spraying fruit trees and other crops. The spray unit contains features that permit efficient operation using spray mixtures that may vary from thin liquids to forms that approach a thick sludge-like slurry. The apparatus may be of relatively small size, but is capable of operating for long periods of time without refilling.

Buffer System for Transferring Data Between Two Asynchronous Data Stores

3 130 387

E. P. G. Wright, D. A. Weir, R. C. P. Hinton, and B. Dzula

This is a data processing system for transferring data between storage units of slightly different rhythms. A buffer store is provided into which data from the slower rhythm storage unit is transferred by means of a synchronized counter. The data stored in the buffer is then transferred to the other storage unit under control of a second synchronized counter.

Method of Producing a Solid Electrolytic Capacitor

3 123 894

J. von Bonin

A method of producing a solid tantalum electrolytic capacitor in which the tantalum body is anodized and coated on the face adjacent to the output lead with insulating material. A semiconductor layer is then formed around the anodized body by immersing the body in a manganese II salt solution, which is reacted with ammonia gas, and the resultant product is then oxidized, the temperature being maintained below the melting point of the insulating material.

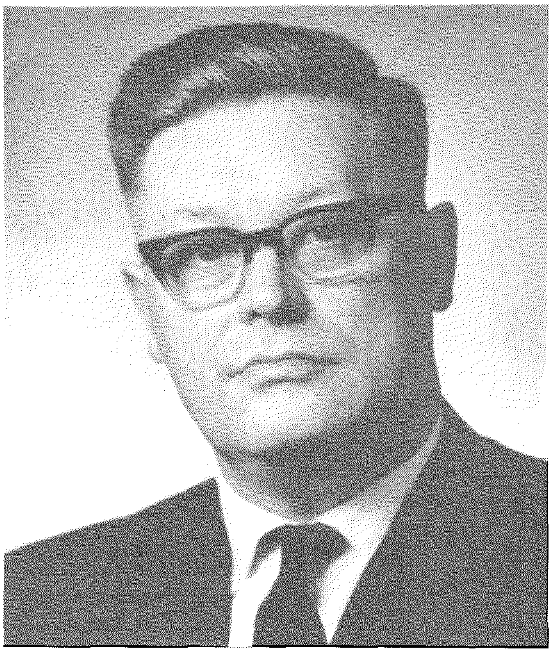
Telephonic Systems

3 121 141

F. P. Gohorel

This patent discloses a telephone switching system having a central exchange and a plurality of distant concentrators. The final selector of each concentrator has a local part including all its elements except talking wires located at the central exchange. The signals identifying a calling line are sent from the concentrators to the central exchange to mark the position of this line on the local part. Signals are then sent from the exchange to the concentrator for setting the part of the final selector located at the concentrator to a position corresponding to the marked position at the exchange.

In Memoriam



GERHARD HAESSLER

Gerhard Haessler was born in Grosschoenau, Germany, on 22 January 1911. He received a Diplom-Ingenieur degree, Summa Cum Laude, from the Technische Hochschule in Dresden. Continuing there he then served as assistant to Professor H. Barkhausen at the Institute for Communication Technology and received a Doktor-Ingenieur degree with honors in 1934.

In 1948, Dr. Haessler joined Mix and Genest and became chief engineer in 1950. Two years later as director of the Central Standard Laboratory he was responsible for coordination of all development work in the German companies of the International Telephone and Telegraph Corporation.

He was appointed technical director of Standard Elektrik and of C. Lorenz and to their boards of management in 1956. When these two companies were combined in 1958 into Standard Elektrik Lorenz, he became director of research and development and a member of its board of management. He became technical director two years later.

In 1962 he was appointed technical director and vice president of ITT Europe assuming responsibility for the coordination of engineering development work of all the European companies of the International Telephone and Telegraph Corporation.

Dr. Haessler died on 4 May 1965 at the age of 54 years after a long illness. His broad knowledge of the expanding fields of telecommunications and electronics was evident from the numerous patents issued to him and from papers of fundamental importance that he wrote.

Principal ITT System Products

Communication 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, radio multiplex...long-distance dialing and signaling equipment...automatic message accounting and ticketing equipment...switchboards: manual (local, toll), dial-assistance...test boards and desk...telephones: desk, wall, pay-station, special-environment, field sets...automatic answering and recording equipment...microwave radio systems: line-of-sight, over-the-horizon ...teleprinters and facsimile equipment... broadcast transmitters: AM, FM, TV...studio equipment...point-to-point radio communication...mobile communication: air, ground, marine, portable...closed-circuit television: industrial, aircraft, nuclear radiation...slow-scan television...intercommunication, paging, and public-address systems...submarine cable systems...coaxial cable systems

Data Handling and Transmission

data storage, transmission, display...data-link systems...railway and power control and signaling systems...information-processing and document-handling systems...analog-digital converters...alarm and signaling systems... telemetering

Navigation and Radar

electronic navigation...radar: ground and airborne...simulators: aircraft, radar...antisubmarine warfare systems...distance-measuring and bearing systems: Tacan, DMET, Vortac, Loran...Instrument Landing Systems (ILS) ...air-traffic-control systems...direction finders: aircraft, marine...altimeters—flight systems

Space Equipment and Systems

simulators: missile...missile fuzing, launching, guidance, tracking, recording, and control systems...missile-range control and instrumentation...electronic countermeasures...power systems: ground-support, aircraft, spacecraft, missile...ground and environmental test equipment...programmers, automatic...infrared detection and guidance equipment...global and space communication, control, and data systems ...system management: worldwide, local... ground transportable satellite tracking stations

Commercial/Industrial Equipment and Systems

inverters: static, high-power...power-supply systems...mail-handling systems...pneumatic tube systems...instruments: test, measuring ...oscilloscopes: large-screen, bar-graph...vibration test equipment...pumps: centrifugal, circulating (for domestic and industrial heating)...industrial heating and cooling equipment...automatic controls, valves, instruments, and accessories...nuclear instrumentation

Components and Materials

power rectifiers: selenium, silicon...transistors...diodes: signal, zener, parametric, tunnel ...semiconductor materials: germanium, silicon, gallium arsenide...picture tubes...tubes: receiving, transmitting, rectifier, thyratron, image, storage, microwave, klystron, magnetron, traveling-wave...capacitors: paper, metalized paper, electrolytic, mica, plastic film, tantalum...ferrites...magnetic cores...relays: telephone, industrial, vacuum...switches: telephone (including crossbar), industrial...magnetic counters...magnetic amplifiers and systems...resistors...varistors, thermistors, Silistor devices...quartz crystals...filters: mechanical, quartz, optical...circuits: printed, thin-film, integrated...hermetic seals...photocells, photomultipliers, infrared detectors... antennas...motors: subfractional, fractional, integral...connectors: standard, miniature, microminiature...speakers and turntables

Cable and Wire Products

multiconductor telephone cable...telephone wire: bridle, distribution, drop...switchboard and terminating cable...telephone cords... submarine cable and repeaters...coaxial cable: air and solid dielectric...waveguides...aircraft cable...power cable...domestic cord sets ...fuses and wiring devices...wire, general-purpose

Consumer Products

television and radio receivers...high-fidelity phonographs and equipment...tape recorders ...microphones and loudspeakers...refrigerators and freezers...air conditioners...hearing aids...home intercommunication equipment... electrical housewares

Optical Character Readers for Automatic Document Handling in Banking Applications
Automatic Postal Check Handling in Germany
Microwave Power Sources Using Solid-State Devices
Aerial Branching System Using Interdigital Filters
Otto Scheller and the Invention and Applications of the Radio-Range Principle
Dewline After a Decade of Field Operation and Maintenance
Estimating Voltage Surges on Buried Coaxial Cables Struck by Lightning
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