Mr A L Sommerville

ELECTRICAL COMMUNICATION

Technical Journal of the
International Telephone and Telegraph Corporation
and Associate Companies

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MICROWAVE RELAY SYSTEM BETWEEN SAINT JOHN AND HALIFAX

RADIO LINK BETWEEN PUERTO RICO AND THE VIRGIN ISLANDS

MICROWAVE TELEVISION RADIO RELAY SYSTEM

BIHELICAL TRAVELING-WAVE TUBE WITH 50-DECIBEL GAIN

SAMPLING PROCEDURES ON FINISHED CHASSIS AND EQUIPMENTS

UNITED STATES PATENTS ISSUED TO THE INTERNATIONAL SYSTEM

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ELECTRICAL COMMUNICATION

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Repeater building and self-supporting tower at Otter Lake. The transmission lines are mounted on the safety hoops around the ladder. The screens above the paraboloids are for protection from falling ice.

Microwave Relay System Between Saint John and Halifax*

By H. C. SHEFFIELD

Standard Telephones & Cables Manufacturing Company (Canada) Limited; Montreal, Canada

A MICROWAVE relay system employing time-division multiplex has been constructed to provide toll telephone circuits for the New Brunswick Telephone Company and the Maritime Telegraph and Telephone Company. This system links Saint John in New Brunswick and Halifax in Nova Scotia via five intermediate unattended repeaters and yields 46 four-wire circuits of toll quality that provide out-of-province connections to Montreal, Toronto, Boston, and New York. This system has been in partial use since December 1952, and the complete system has been in continuous service since December 1954. A description of the radio relay link is given primarily from the system-planning aspects. Performance figures are outlined.

1. *Preliminary Planning*

In 1948, the Maritime Telegraph and Telephone Company, which provides the bulk of the long-distance and local circuits in the province of Nova Scotia, was faced with the problem of providing a considerable increase in out-of-province telephone circuits. These circuits would form part of the trans-Canada telephone system, which is operated by the Trans-Canada Telephone Association comprised of seven major Canadian telephone companies (the Maritime and New Brunswick companies are two of these) to provide coast-to-coast telephone service in Canada.

The New Brunswick Telephone Company was planning in conjunction with other telephone companies the installation of two *J*-type carrier systems from Saint John to Montreal and another from Saint John to Bangor, Maine. Many of these circuits were to be extended to Halifax to provide much-needed direct circuits between Halifax and Montreal, Toronto, Boston, and New York. These requirements, coupled with a large increase in traffic between Halifax and Saint John, made imperative the provision of additional circuits between those two cities. Since Halifax had been established as the toll switching centre for Nova Scotia in the national toll-dialing scheme, all long-distance circuits are routed through this point.

The existing circuits were provided by *C*-type carriers operating on open wire pole lines. The pole line followed roughly the path through Moncton and Truro indicated on the map of Figure 1. It is necessarily long to circumvent the Bay of Fundy and was subject to severe icing conditions in winter particularly where it crossed the Isthmus of Chignecto. Severe damage had been experienced several times.

Consideration was therefore given to a microwave relay system running from Halifax across the Annapolis valley and then spanning the Bay of Fundy to Saint John. Such a system would be much shorter than the route around the bay thus allowing a decrease in toll fares. In addition, all maintenance would be confined to a few repeater points and the entire system would be essentially invulnerable to weather conditions. Preliminary investigations indicated that the cost of a microwave system should be appreciably less than that of rebuilding and transposing the pole-line leads to allow the operation of 12-channel carrier systems. Accordingly, engineers of the Maritime Telegraph and Telephone Company, Federal Telecommunication Laboratories, and Federal Electric Manufacturing Company, Limited (now Standard Telephones and Cables Manufacturing Company (Canada) Limited) conducted field surveys of possible repeater points in Nova Scotia in the autumn of 1948.

2. *Propagation Surveys*

Since accurate contour maps of this area were available and weather conditions were generally such as to encourage stable propagation, propagation surveys were considered necessary only over the Bay of Fundy.

This particular 50-mile (80-kilometre) path is nearly all over water. The Bay of Fundy is famous for its prodigious tides, which are as high

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* Preprinted from *Transactions of the IRE Professional Group on Communications Systems.*

as 40 feet (12.2 metres). This constant churning action brings the cold water to the surface, frequently causing dense fogs extending several hundred feet above the water. Without doubt, severe temperature inversions also occur. Fortunately, elevations of about 800 feet (245 metres) are available on each side of the bay so that the use of vertical space diversity is practicable. Furthermore, the minimum clearance for these elevations is slightly more than two Fresnel zones, thus allowing considerable abnormal refraction before the path becomes non-optical.

A propagation survey was made in 1950. Previous experience had shown that the most-abnormal propagation could be expected in the spring, and therefore the tests were conducted during April, May, and June. Bloomsbury Mountain in New Brunswick was chosen as the

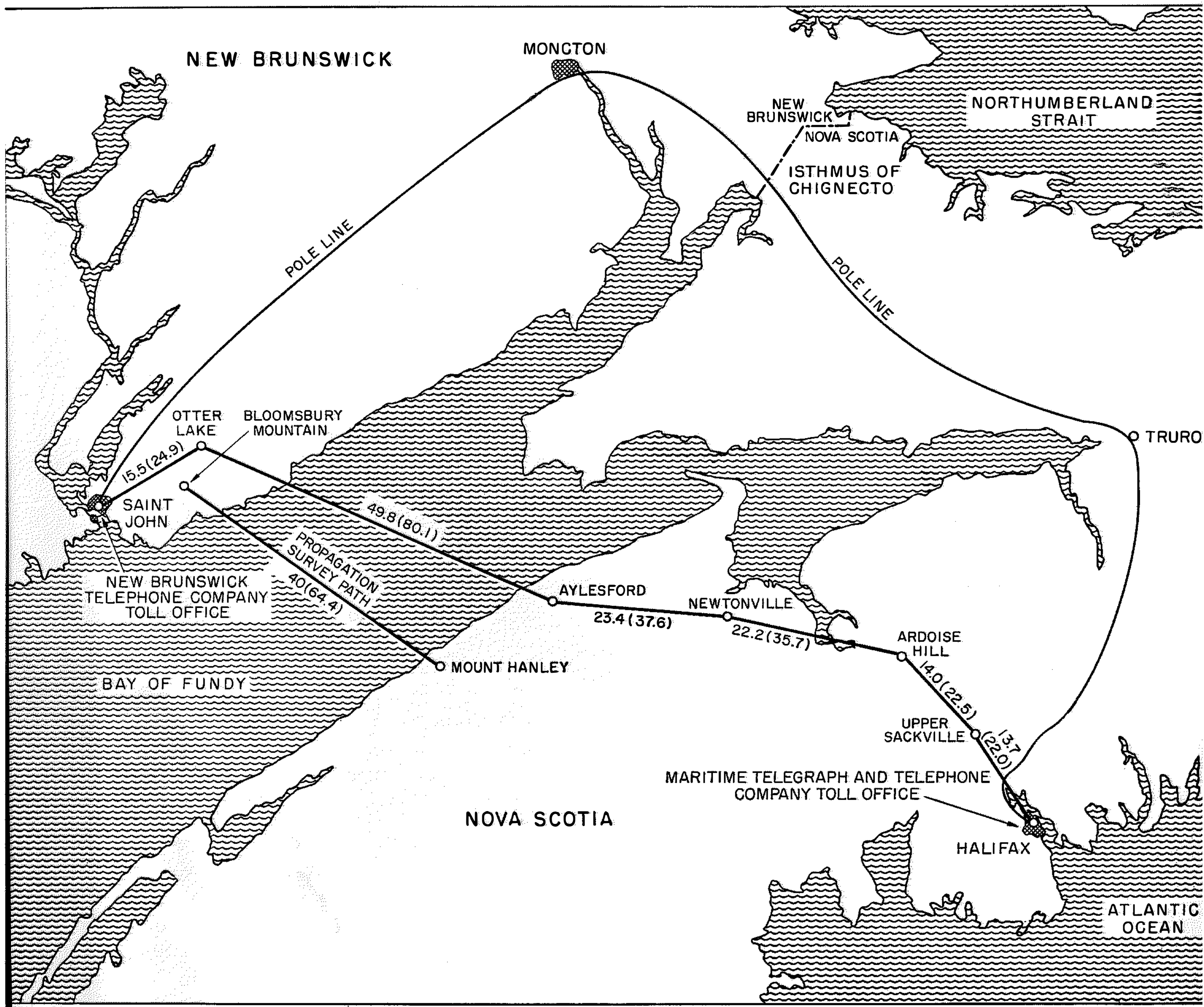

Figure 1—Map showing original pole-line path and radio relay system between Saint John and Halifax. Distances are in miles (kilometres).

likely site for the proposed repeater on the north coast of the Bay of Fundy and was used as the transmitting location. A 6-foot (1.83-metre) paraboloidal antenna, later replaced by a 10-foot (3.1-metre) unit, was installed on a 35-foot (10.7-metre) pole.

In Nova Scotia, the receivers were installed on Mount Hanley. Although it was realized that this would not be the repeater site in the permanent microwave system, it was selected mainly for convenience since it was the terminal of an existing very-high-frequency link. A special 90-foot (27.5-metre) guyed tower was constructed using spliced poles arranged in the form of an A. One receiving dish was located at the top of this and a second one 52 feet (15.9 metres) lower. The signal strengths received by each receiver were continuously recorded as well as their sum. The frequency of the signal was 2000 megacycles per second.

The lower antenna was moved up and down and it was found that the optimum diversity spacing under normal propagation conditions was 52 feet (15.9 metres) as calculated.

The results of the survey indicated that diversity reception was perfectly practicable over this path. Although the fades on individual receivers were frequent, rapid, and very deep (at least 40 decibels), the best signal did not fall more than 10 decibels below the mean for 95 percent of the time. For the remaining 5 percent of the time, fades as deep as 25 decibels were experienced. Based on these results and the use of a microwave time-division system, it was predicted that the signal-to-noise ratio would not be worse than 46 decibels (a considered outage value) for 0.02 per cent of the time, nor worse than 58 decibels for more than 0.2 per cent of the time. All these ratios are based on the measurement of noise in a derived audio channel using an *F1A*-line-weighting curve.

It was observed that the deeper fades occurred on days when poor propagation might be expected, and it was logical to assume that they were caused by abnormal refraction that could upset the diversity spacing. This assumption was further borne out by the fact that the fog layer, which sometimes was prevalent over the Bay of Fundy, was not sufficiently high to intercept the direct ray. Under these conditions, the reflected ray conceivably could suffer severe refraction, while the direct ray suffered only normal refraction. To alleviate this condition, a third antenna could be placed at a distance of one-half the normal diversity spacing below the lower antenna. This would guard against an increase or decrease in the correct diversity spacing for complementary operation.

A propagation survey was also conducted for two days between Bloomsbury Mountain and the roof of the telephone building in Saint John, the proposed terminal site. This path was grazing but could not be improved since the additional height that would be required in Saint John could not be provided by a tower that could be erected on the telephone building. Although it was decided to utilize this grazing path, it was later found necessary for other reasons to move the Bloomsbury Mountain repeater to Otter Lake, thus obtaining a path with full Fresnel-zone clearance.

3. Repeater Site and Path Planning

It was decided in February 1951 to proceed with the installation of a microwave relay system from Halifax to Saint John. This system was to employ time-division multiplexing in the 1700–1990-megacycle-per-second band. Two completely separate radio-frequency equipments were to be supplied as well as two separate multiplex equipments each capable of providing 23 voice channels. Only one multiplex equipment was to be provided with channel units. Subsequently, the second multiplex equipment was provided with channel units bringing the total circuit capacity to 46. In December 1954, a third radio-frequency equipment was added as a standby.

The final repeater sites were chosen from maps and ground surveys as shown in Figure 1. In choosing these sites, specific attention was paid to accessibility since this can be a problem in winter. Typical winter road conditions are shown in Figure 2. With the exception of Upper Sackville, it was possible to locate all Nova Scotia sites near an established roadway from which snow is regularly removed. Upper Sackville is on a maintained bush road half a mile (0.8 kilometre) from a highway. All Nova Scotia repeater points are within 5 miles (8 kilometres) of a major highway. In New Brunswick, a half-mile access road up Bloomsbury Mountain had to be constructed. All sites were within easy reach of existing power lines.

Figure 2—Typical conditions on a secondary road in Nova Scotia during winter.

Subsequent to the establishment of the Bloomsbury Mountain repeater, a new airport was constructed nearby, and the antenna tower was ruled an air navigational hazard. Consequently, a new location at Otter Lake was chosen, which although more remote actually provided a better path into Saint John. An access road approximately a mile long had to be constructed. The equipment was moved to this new site in the autumn of 1954, coincident with the installation of the third radio-frequency unit.

The tower heights were computed to yield at least 70 per cent of the first-Fresnel-zone clearance, using the true radius of the earth. This criterion is quite conservative and in keeping with the reliability required for toll telephone circuits. The resulting profiles are shown in Figure 3. Since the system has been in service, failures or noisy conditions due to propagation have been negligible.

The transmission lines and antenna gains were chosen so that the net attenuation of any given path would not exceed 75 decibels. This would provide a fading margin of 27 decibels on any one path at one time for a resultant (*F1A*-weighted) overall signal-to-noise ratio of 48 decibels. At this ratio, toll circuits must be removed from service. Alternatively, combined fades could occur on more than one path in such a manner that the overall ratio dropped by 19 decibels.

In planning antenna gains for the third radio-frequency equipment, it was decided to use only 10-foot. (3.1-metre) paraboloids. Experience with the first two systems indicated that the increased signal strengths would allow the use of vacuum tubes with lower transconductances in the receiver intermediate-frequency amplifiers. This can result in a considerable saving in vacuum-tube replacements that will eventually offset the additional cost of the larger antennas.

Automatic transfer was not provided for the radio systems. Instead, all connections between the multiplex (pulse modulator and demodulator) and radio equipments at terminals are through coaxial patch cords. The spare radio system is put in service simply by changing the patch cords at each terminal. Parallel jacks are provided so that this can be done with no interruption to service. The unused radio system is normally bridged across an operative system through a special video amplifier to ensure that it will be continuously available for service.

Patch cords and jacks are provided at repeaters also. This allows service-channel equipment to be inserted in any radio system and also

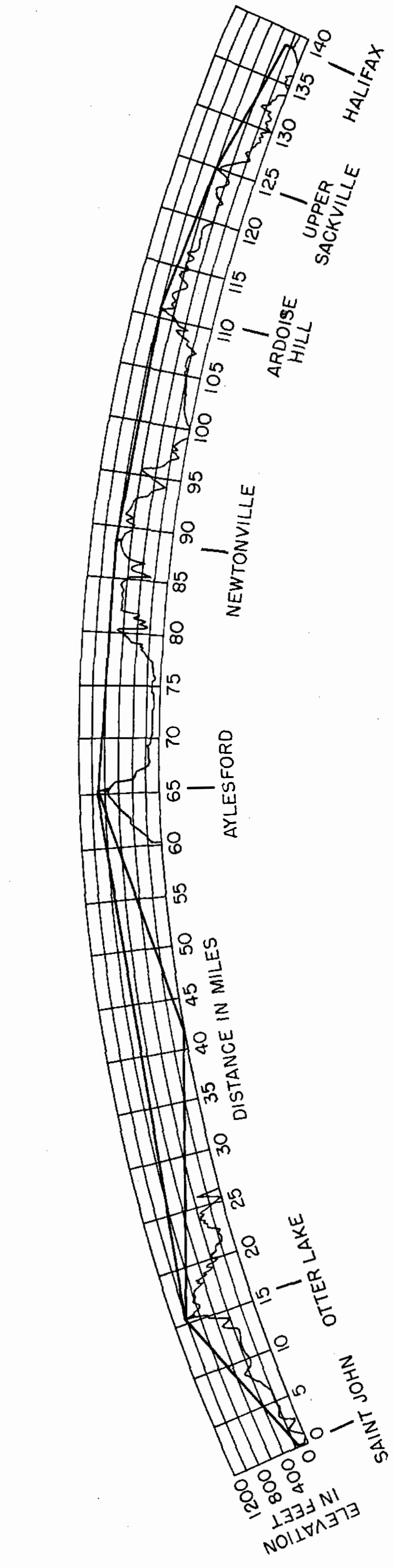

Figure 3—Profile of terrain along the route between Saint John and Halifax taken by the microwave relay system. The curvature of the earth is plotted to 4/3 actual radius.

provides means for changing radio systems at any repeater.

4. Basic Equipment

The type-*10B* pulse-time-modulated system of Federal Telecommunication Laboratories shown in Figure 4 was installed. The basic design of this equipment has been described elsewhere[1–3] and will be treated only briefly herein.

The channelling equipment provides multiplexing by time division. A train consisting of 23 channel pulses and one synchronizing pulse is developed. Each channel pulse is of 0.35-microsecond duration at the half-amplitude points and has a rise time of 0.15 microsecond. The synchronizing pulse actually is two such pulses spaced 1.3 microseconds from leading edge to leading edge. The spacing between pulses is 5.2 microseconds; so the length of one frame is 125 microseconds, and the frame-repetition rate is 8000 per second. Each voice circuit of the 23 that the equipment accommodates is assigned to one of the channel pulses and samples it once each 125 microseconds. The information is imposed on the pulse by moving it back and forth in time relative to the synchronizing pulse. This commonly corresponds to a deviation of ±1 microsecond. Therefore, the noise improvement is equal to the ratio of the pulse-deviation time to the pulse-rise time, or 16 decibels.

Separation of channels is accomplished at the receiving end by comparing the average position of each pulse with respect to the synchronizing pulse. Demodulation results from an exact comparison of each pulse position in a channel series with that of the synchronizing pulse.

Each of the 23 voice channels has a bandwidth of 200 to 3400 cycles per second and the total harmonic and spurious distortions do not exceed 5 per cent at 100-per-cent modulation. The bandwidth required to transmit the composite pulse

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[1] D. D. Grieg and A. M. Levine, "Pulse-Time-Modulated Multiplex Radio Relay System—Terminal Equipment," *Electrical Communication*, volume 23, pages 159–178; June, 1946.

[2] D. D. Grieg and H. Gallay, "Pulse-Time-Modulated Multiplex Radio Relay System—Radio-Frequency Equipment," *Electrical Communication*, volume 24, pages 141–158; June, 1947.

[3] S. Metzger, N. H. Gottfried, and R. W. Hughes, "Microwave Radio Links of Bonneville Power Administration," *Electrical Communication*, volume 29, pages 87–92; June, 1952.

train without pulse deterioration and consequent interchannel crosstalk is 2.8 megacycles per second.

The radio-frequency transmitter is a simple pulsed oscillator operating into a high-Q cavity with a frequency stability after warm-up of ±0.05 per cent. The oscillator operates in the frequency range from 1700 to 2100 megacycles per second. The composite pulse train from the multiplex modulator equipment is amplified and pulses the oscillator directly. A low-power continuous-wave oscillator, operating at the carrier frequency, is used as a "catalyzer" to stabilize the point on the leading edge of the modulating pulse at which the transmitter oscillates. This substantially reduces the random modulation that would be added by the transmitter. The transmitter delivers a peak power of 40 watts.

The radio-frequency receiver employs a continuous-wave local oscillator operating into a high-Q cavity, a crystal mixer, and an intermediate-frequency amplifier with a centre frequency of 30 megacycles per second. The total receiver gain, including video gain, is 85 decibels. An improved receiver, incorporating an untuned microstrip mixer crystal holder and an additional 15 decibels of intermediate-frequency gain, was supplied as part of the third radio-frequency equipment. This receiver exhibited a noise figure of 12 decibels compared to a noise figure of 14 to 16 decibels for the older receiver. A repeater installation is shown in Figure 5.

One innovation incorporated in this system was the demodulation of the information from the trailing edge of the pulse rather than the leading edge. This was required by the type of transmitter used. At a repeater, the transmitters operating in opposite directions are assigned the same carrier frequency, as is common practice in such systems. It was found that one transmitter tended to catalyze the other, increasing the random modulation noise on the leading edges of the

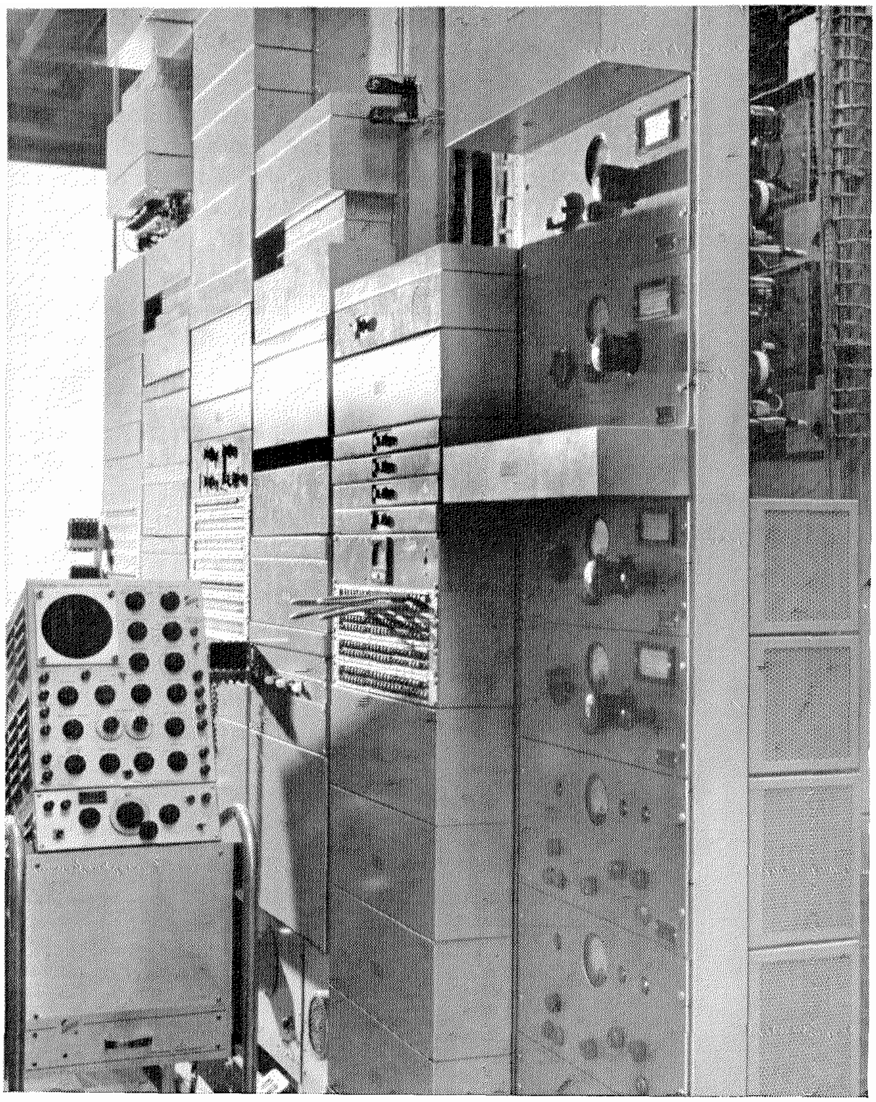

Figure 4—Terminal installation at Halifax. The radio-frequency equipment is in the foreground. Next is an alarm bay, beyond which are 4 bays incorporating 2 sets of multiplex modulator and demodulator apparatus. A test oscilloscope is on its trolley.

pulses. This was eliminated by suppressing the leading edges and detecting the trailing edges. An additional advantage of trailing-edge detection is that the transmitter catalyzers become relatively insensitive. If the isolation between leading and trailing edges of the pulses were better, or if a 4-decibel degradation in signal-to-noise ratio could be tolerated, the catalyzer could be dispensed with completely.

5. Antenna Systems and Transmission Lines

With a pulsed-oscillator type of transmitter that is subject to frequency pulling, it is not practicable to multiplex transmitters on one antenna. It is possible however to duplex a transmitter and receiver on one antenna using a filter of the non-band-pass type. This system was therefore adopted and only one antenna is required for each radio-frequency system for each direction of transmission. For the 3 parallel systems, this requires 3 antennas at terminals and 6 at repeaters not employing diversity reception.

As previously mentioned, the antennas for the first two radio-frequency systems were designed to yield net path attenuations of about 70 to 75 decibels. This called for 6-foot-diameter (1.83-metre) paraboloidal antennas on all hops except the Bay of Fundy path, which required 10-foot (3.1-metre) paraboloids. Both sizes of antennas are energized by dipole–reflector assemblies and exhibit gains of 29 and 34 decibels respectively above an isotropic radiator.

For the third radio-frequency system, all paraboloids were 10 feet (3.1 metres) in diameter. These were of expanded steel mesh. A coaxial-to-waveguide transformation and a horn were used to illuminate the paraboloids. This method produces a low standing-wave ratio over a band from 1700 to 2400 megacycles per second. Future expansion may be accommodated therefore by multiplexing additional transmitters and receivers onto these antennas provided master-oscillator–modulated-amplifier transmitters are

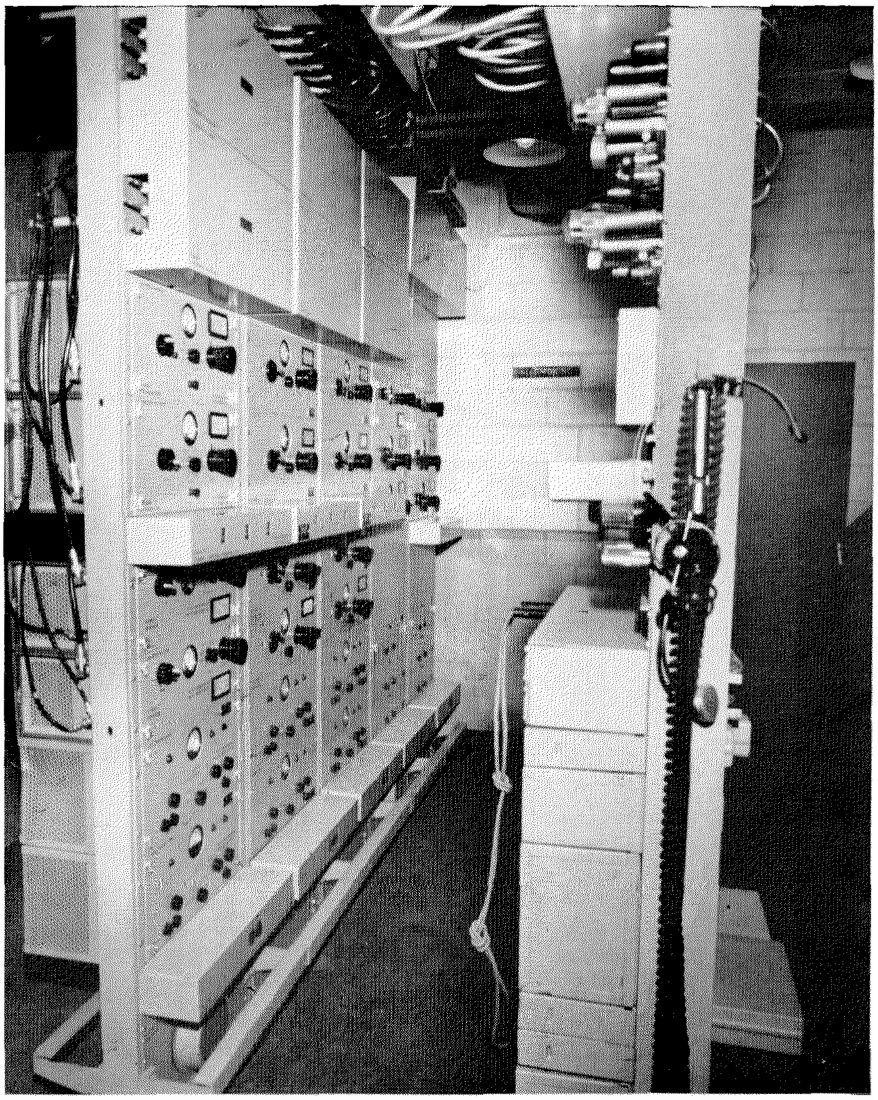

Figure 5—Repeater installation at Otter Lake. At the right are the alarm and the drop-and-insert equipment. The first 3 bays at the left are the radio transmitting apparatus and the other 2 bays are the diversity receivers.

Figure 6—Repeater building and antenna arrangement at Upper Sackville.

used to permit multiplexing by means of simple band-pass filters.

At all repeaters except the two employing diversity reception, antenna elevations of 70 feet or less were required. It was possible therefore to use just two guyed poles with horizontal stringers between them to support the antennas. The four 6-foot (1.83-metre) antennas for the first and second radio systems at a repeater were supported between two poles. For the 10-foot (3.1-metre) antennas of the third system, another pole was added. The antenna arrangement at a typical repeater can be seen in Figure 6. This structure has been found very economical and possesses more than the required rigidity. It can be constructed entirely by a telephone or power company with a consequent saving in cost. The centre pole was equipped with a ladder and safety hoops for climbing. These hoops, which can be seen in Figure 6, have already prevented at least one serious injury.

At the repeaters at each end of the Bay of Fundy hop, a 127-foot (38.7-metre) tower was required for the diversity arrangement. A self-supporting steel tower was chosen to ensure the required rigidity. A view of the tower at Otter Lake is shown in the frontispiece; the one at Aylesford is essentially identical.

At each terminal, a steel billboard type of structure was erected on the roof of the telephone building. A problem arose at Halifax, where the 3-storey telephone building was designed so that a fourth storey could be added. To avoid interfering with such an addition, the steel framework of the building stair well was extended an additional storey and the billboard was mounted on top of this structure. This can be seen in Figure 7.

When the original radio systems were installed, ⅞-inch (22-millimetre) air-dielectric rigid transmission lines were used. By the time the third system was installed, semi-flexible line employing a helical insulator to support the centre conductor had become available and ⅞-inch (22-millimetre) cable of this type was used. At the same time, the complicated sections of rigid line employing three elbows to provide a flexible entry to each antenna of the first and second paths, were replaced with short lengths of the new cable. This improved the voltage standing-wave ratios considerably, reducing them to less than 1.5 to 1 throughout the band from 1700 to 2100 megacycles per second. This figure is more than adequate to prevent frequency pulling of the transmitter, which is the chief criterion in this type of system. For the same reasons, the entire runs at Saint John, which were particularly tortuous, were replaced with the semi-flexible cable. The continuously supported semi-flexible line has been found to be cheaper in initial cost, much easier to install, and requires essentially no maintenance.

Automatic pressurizing equipment was installed at all stations. Since the antennas are pressure-tight right up to the radiating element, the complete transmission-line system is protected from moisture. All transmission lines terminate on the top of the first radio-frequency bay and by means of coaxial patch cords any radio equipment can be connected to any antenna.

Semi-circular hoops were lagged to the antenna poles at the repeaters, and the transmission lines were mounted on the outside circumference of these. Since the hoops could hinge at the pole, expansion and contraction of the transmission lines were accommodated. At the two repeaters where steel towers were provided and at the terminals, the lines were fastened to the ladder safety hoops, which functioned in the same manner.

6. Bay of Fundy Diversity Arrangement

Based on the results of the propagation survey conducted over the Bay of Fundy, it was decided to use a three-receiver diversity system. Accordingly, at the Aylesford and Otter Lake repeaters, the following antenna arrangement was adopted. The antennas for the transmitters and main receivers of the three radio systems were located at the top of the 127-foot (38.7-metre) tower at an average height above ground of 120 feet (36.6 metres). The first diversity antenna was located at 60 feet (18.3 metres) above ground and a second diversity antenna 30 feet (9.1 metres) lower. Diversity receivers for each path were associated with each of these antennas. Multiplexing of the three receivers to each antenna was accomplished by band-pass filters.

A special diversity switching equipment was developed to select the receiver possessing the

Figure 7—Halifax terminal showing how the steel structure of the stair well was extended to support the antennas and still permit another storey to be added to the building later.

highest signal. This unit monitors the automatic-gain-control voltages of the three receivers and biases off the video-frequency stages of the two receivers producing the weaker signals. This device operates on a differential of 0.3 volt, which corresponds to a signal-level difference of less than 2 decibels. To prevent the introduction of noise into the system by the switching process, the receiver being enabled is unbiased one second before the receiver being disabled is biased off.

While no specific data are presently available to establish the value of a three-antenna system over a two-antenna system, on several occasions when personnel happened to be at Aylesford or Otter Lake, it was observed that the main and normal diversity receivers were completely faded and the system was carried only on the remaining diversity antenna. It is true that compensation for changes in diversity spacing due to anomalous propagation can be obtained by choosing an antenna spacing less than the theoretical optimum. However, it is considered that in this case, in view of the reliability and overall signal-to-noise ratio required and obtained, the additional expense of a three-antenna system has been justified.

7. *Alarm System*

In a system intended to provide extremely reliable operation, it is important that all abnormal conditions throughout the link be automatically reported to control points. Means for doing this on radio relay systems for telephone companies may be simplified where local telephone lines interconnect the repeaters and terminals. In this system, it was possible to extend all alarms via wire lines to the terminals. The alarms are therefore transmitted regardless of whether the microwave link is operative or not. Continuity of operation of the alarm system is further ensured by using storage-battery power supplies. The alarms from the four Nova Scotia repeaters, Upper Sackville, Ardoise Hill, Newtonville, and Aylesford, are extended to Halifax. The alarms from Otter Lake are extended to Saint John. In addition, the primary alarms that indicate the status of the radio equipments at Otter Lake and at Saint John are extended via an existing land-line telegraph circuit to Halifax. The Halifax terminal, which acts as control for fault clearance, is thus cognizant of the operation of the radio equipment at all stations.

After considering the particular requirements of the alarm system for this link, it was felt that no suitable one existed, and therefore a new equipment was developed. An alarm coder at each repeater point is capable of sending a slow-speed pulse train that consists of a 1.5-second-long synchronizing pulse followed by 18 pulses occurring normally at a 4-pulse-per-second rate. Each of these pulses corresponds to a condition to be monitored. Should a particular monitored condition show a fault, the corresponding pulse is increased to 0.5 second from its normal 0.125-second duration. The message is therefore indicated by pulse width. On occurrence or clearance of any fault, the equipment sends one complete pulse train.

At each control point (Halifax and Saint John) one decoding equipment is supplied for each associated coding equipment. The decoder is prepared for operation and all alarms are cleared by the synchronizing pulses. The following alarm-condition pulses are then demodulated and those that are wide, corresponding to a fault, cause the appropriate alarm circuits to be energized. The alarms are actually displayed by means of switchboard lamps mounted in a standard jack field. The display board and decoding equipment at Halifax can be seen in Figure 4.

The capacity of this system can be increased in blocks of 18 alarm conditions by the addition of slave units to each coder and decoder. In addition to the alarm display, any alarm lights the aisle pilot and sounds the office audible alarm. A novel circuit is used to permit manual cut off of the audible alarm without preventing it from operating again if an additional fault is registered. Both remote and local alarms are tied into this system.

The alarms are transmitted from the repeaters to the terminals by means of frequency-modulated voice-frequency telegraph equipment. The highest-frequency channels are used in a speech-plus-duplex arrangement. In this way, the same line provides an order-wire channel.

The following alarms are transmitted from each repeater.

A. System *1*, west-to-east failure

B. System *1*, east-to-west failure

C. System *2*, west-to-east failure

D. System *2*, east-to-west failure

E. System *3*, west-to-east failure

F. System *3*, east-to-west failure

G. Commercial power failure

H. Diesel failure to start

I. Low voltage of 130- or 24-volt batteries

J. Low transmission-line pressure

K. Illegal building entry.

Four alarms are reserved for two future radio systems leaving three alarms for miscellaneous uses.

8. Service Channels

Three service channels are provided. One utilizes the alarm-system land line and is intended for use during emergencies, such as complete failure of the radio system. The other two are provided individually by the two multiplex systems. A drop-and-insert equipment is supplied at each repeater to provide access to either of these service channels. A drop-and-insert equipment removes the service-channel pulse from the pulse train and demodulates it. A new pulse, which may be modulated from a local telephone, is formed and is inserted in the pulse train in place of the removed one. The local telephone set and voice inputs and outputs of the two drop-and-insert equipments for the two directions of transmission are interconnected by a 12-wire hybrid as shown in Figure 8. This hybrid circuit isolates the two directions of transmission yet provides a 4-wire party-line connection for a local telephone. Amplifiers in the telephone send-and-receive leads serve to improve the matching and provide the required gain. By this arrangement, the service channel may be used as a party-line connection to all stations and provides at each point a circuit with a 6-decibel net loss to any other point. At any repeater, information is passed straight through the drop-and-insert and 12-wire hybrid without any net attenuation.

Alternatively, by manipulating two keys the service channel can be broken between any two repeaters. Independent conversations can then proceed on either side of the break. These same keys allow the drop-and-insert equipment to be switched to monitoring only, in which case the pulse trains are allowed to pass through unaltered although the service channel is demodulated on a bridging basis. When the drop-and-insert equipment is in circuit, its output is continuously monitored, and it will be automatically by-passed should it fail. This prevents the loss of the traffic circuits due to drop-and-insert-equipment faults. Outbound signaling to the repeaters is accomplished on the drop-and-insert equipment as well as on the Nova Scotia land-line wire by means of an amplifier speaker. It is believed that this system is the simplest and most reliable form of selective signaling. Signaling from repeaters to terminals may be accomplished in the same way. As an added means, a ringer receiver responding to 20 pulses per second of 1000-cycle-per-second tone is equipped at each terminal and a suitable signaling whistle is supplied at each repeater. Signaling on the New Brunswick land-line order wire is by means of magneto telephones.

9. Standby Power Equipment

Since the system carries important toll circuits, some of which are arranged for operator toll dialing, it is essential that no interruptions occur due to commercial power failure. All repeaters therefore are equipped with a no-break standby power system. The terminals were already equipped with non-automatic standby power facilities and these were deemed satisfactory.

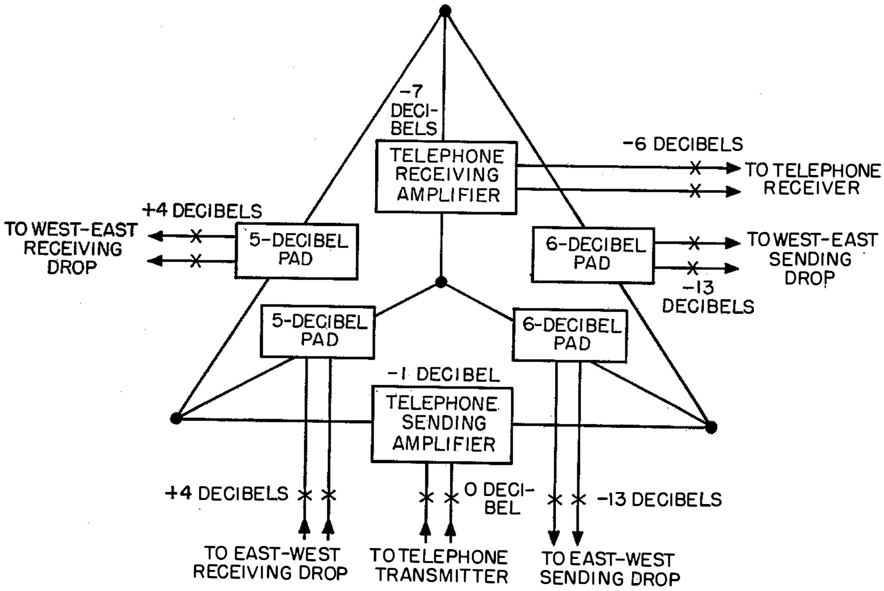

Figure 8—Block diagram of the 12-wire junction hybrid for a party-line service channel. The hybrid loss is 6 decibels. The levels indicated are in decibels related to 1 milliwatt.

In considering alternative designs for this system, it was decided that storage batteries offered the most reliable standby source. While they do require some service, telephone companies are very familiar with them and thus skilled in their maintenance. A well-maintained storage-battery plant can be depended on to supply power for a known period of time under practically any circumstance. Therefore a system employing a primary standby source derived from battery power was chosen. A secondary standby source was provided by a diesel-driven alternator. A diesel was chosen in preference to a gasoline engine due to its reliability and its relative ease of starting after lengthy idle periods.

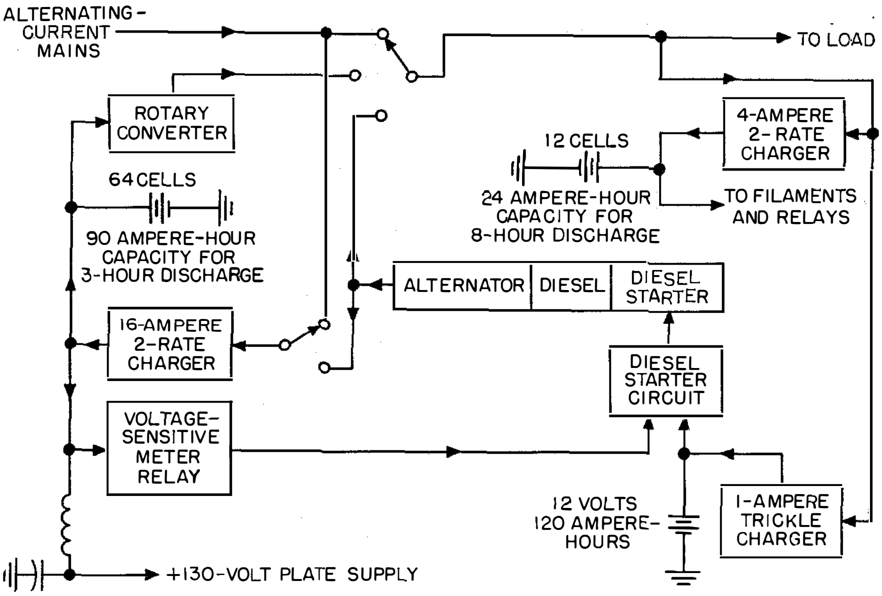

Figure 9—Power supply system with standby facilities for both short- and long-time mains power outages.

The system is shown in block-diagram form in Figure 9, and the various components can be seen in Figures 10 and 11. Power is normally supplied to the load directly from the alternating-current mains. The rotary converter runs idle and is driven from the direct-current side by the 130-volt battery. The running current for the converter is actually supplied by the 130-volt battery charger. This charger is a voltage-controlled two-rate type and maintains the battery in a fully charged condition.

If the mains supply fails completely or if the voltage drops below 95 volts, the load is automatically transferred to the alternating-current output of the rotary converter, which has been running at full speed and can deliver full power instantaneously. The rotary converter is governor regulated to maintain a constant output frequency of 60 cycles per second.

If the line power returns within a period of about 30 minutes, it automatically reassumes the load following a 5-minute wait. This period is introduced to prevent the line taking over on momentary returns, which often occur following a power failure. The 130-volt battery has a capacity of 90 ampere–hours for a 3-hour discharge rate and can carry the load for that period. When the terminal voltage of the battery drops to a predetermined value (normally corresponding to a 15-ampere–hour discharge or 30 minutes of operation), a contact-making voltmeter initiates the diesel starter circuit. This circuit is the three-strikes-and-out type; that is, three cranking cycles with a rest period after each one are provided. If after the three attempts the diesel has not started, the circuit is de-energized and an alarm initiated. To date, no cases of the diesel failing to start have been observed.

After a 1-minute diesel warm-up period, the normal load and the 130-volt battery charger are transferred to the alternator. The rotary converter is stopped to minimize battery drain. The alternator, in addition to supplying the load, charges the 130-volt battery at a 10-ampere rate. The alternator remains on load until the line power returns and until the battery plant is recharged to approximately 90 per cent of full capacity. In any case, the 5-minute delay previously described is introduced between the time when the line power returns and when the load is transferred to the line. After transfer, the diesel is stopped and the rotary converter is restarted.

A low-voltage relay initiates an alarm when the battery terminal voltage has dropped to 1.8 volts per cell. Another low-voltage relay operates at 1.7 volts per cell. This condition could occur only if the diesel had failed to start and the rotary converter was obliged to carry the load for 3 hours. In this case, the 1.7-volt-per-cell relay makes a final attempt to start the diesel and, if this fails, shuts down the entire plant to guard against battery damage.

A safety feature is provided that causes the diesel to start and run idle in preparation for receiving a load should the rotary converter fail. Alternatively this feature can be bypassed so that the diesel will not run continuously but will function on a regular standby basis. This type of operation would be used if extensive maintenance work were being done on the battery or rotary converter.

A further advantage of the 130-volt battery is its value as a plate supply for critical equipment such as the alarm system. A 24-volt battery was also included to act as a filament and relay supply for these critical equipments, to provide talking battery, and to energize the control relays of the standby power system. It has a 24-ampere–hour capacity for an 8-hour discharge rate. A 4-ampere two-rate battery charger is supplied to maintain the battery in a charged condition. This charger receives its power from the load circuit and is thus energized under all normal and standby conditions. A 1.8-volt-per-cell relay monitors the condition of the 24-volt plant in the same fashion as for the 130-volt plant.

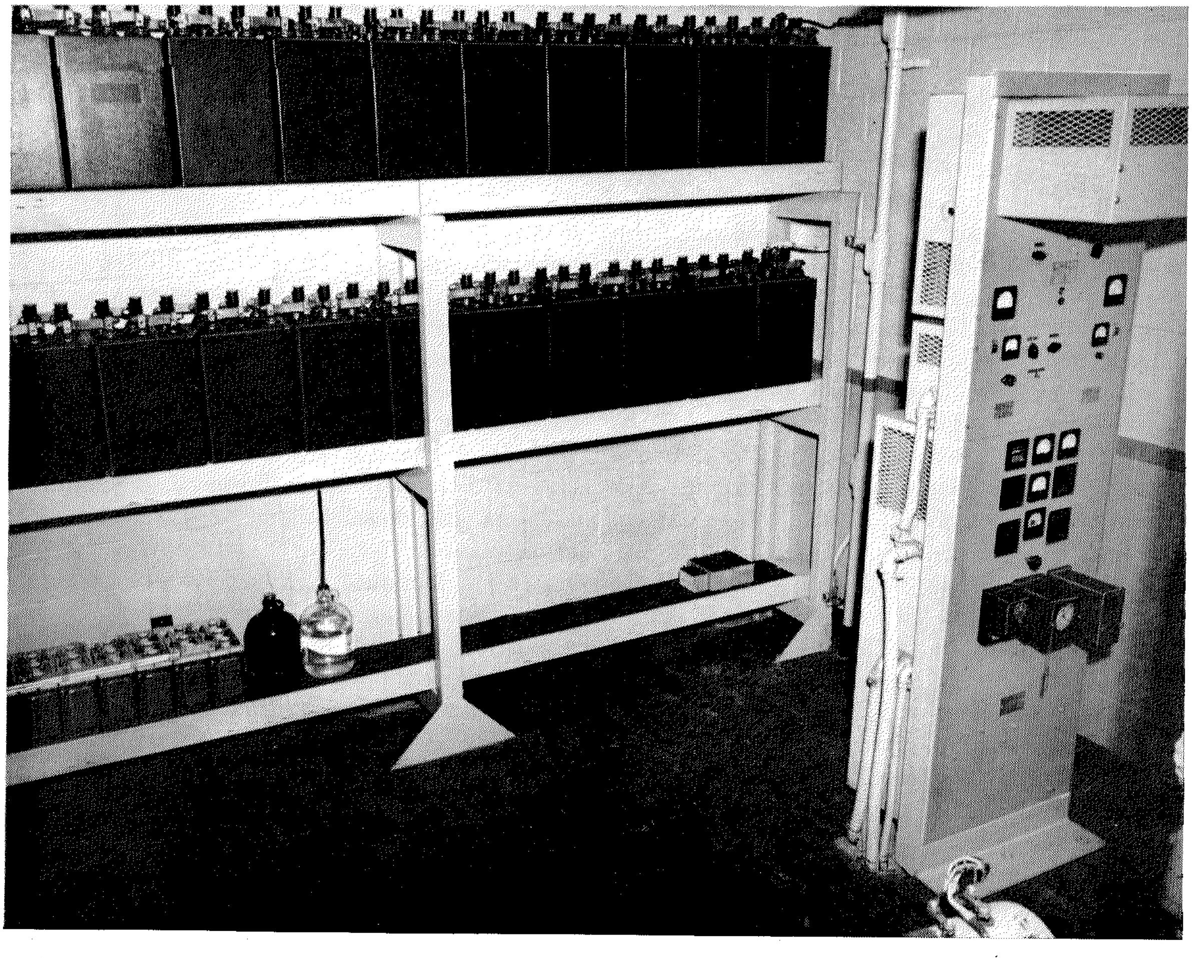

Figure 10—Power room at Otter Lake showing the 130- and 24-volt batteries, control panel, and battery chargers.

10. Test Equipment and Maintenance

In a pulse system, the principal test instrument is an oscilloscope. It permits the maintenance man to "see" the results of his work. A test oscilloscope having a special synchronizing attachment to allow any channel pulse to be selected and viewed was provided at each terminal. Another was supplied to the Otter Lake repeater primarily because of the difficulty of getting test equipment to that site during winter. A fourth oscilloscope was provided for use at the four Nova Scotia repeaters.

In addition to oscilloscopes, a microwave signal generator was supplied to each telephone company and a vacuum-tube voltmeter at each station. The telephone companies each had available a vacuum-tube checker and a noise-measuring set. A portable trailing-edge detector was supplied to the Maritime Telegraph and Telephone Company to allow accurate noise measurements to be made at repeaters. Lengths

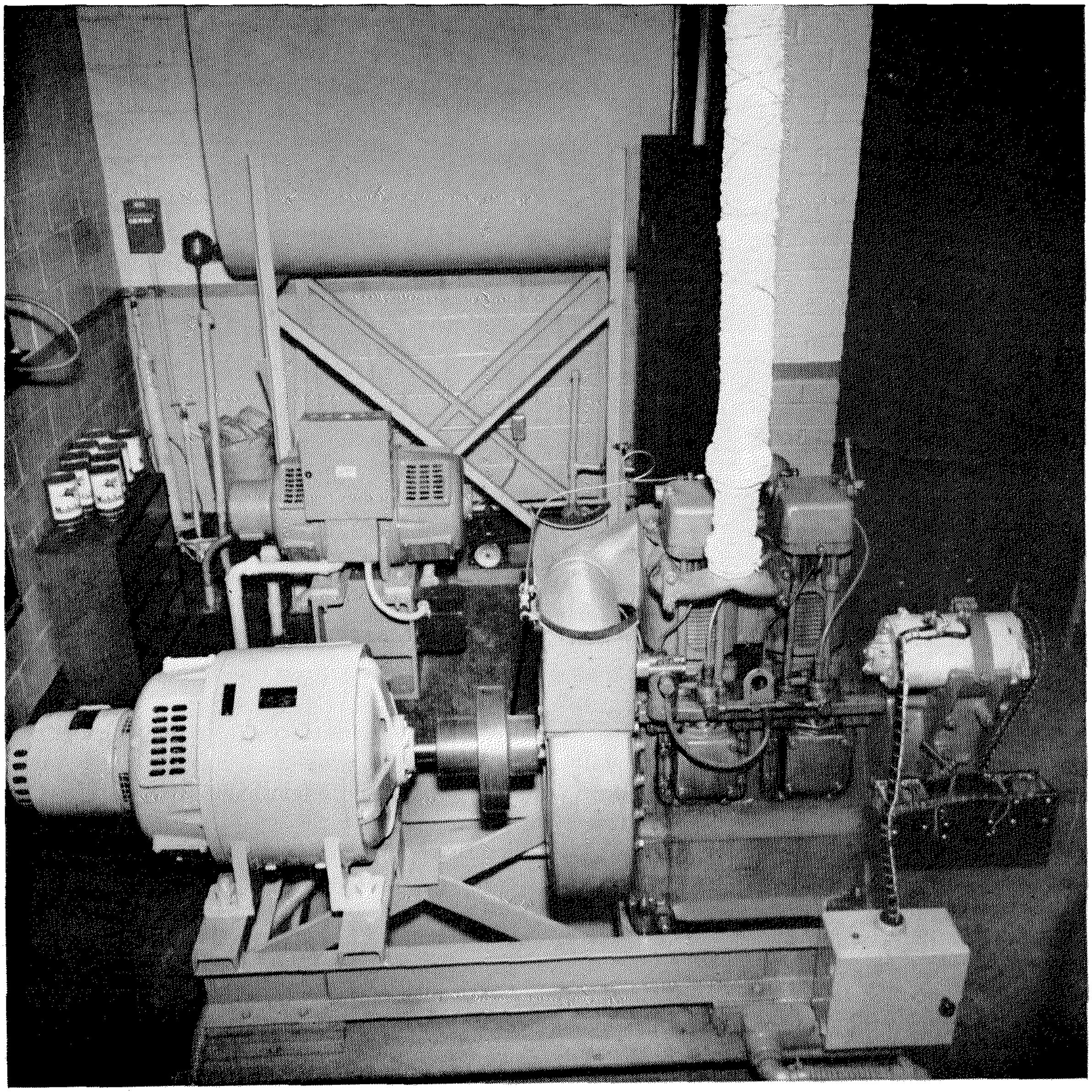

Figure 11—Diesel–alternator, rotary converter, and tank for diesel fuel at Otter Lake repeater station.

of lossy line producing 10, 20, and 30 decibels of attenuation were provided by the telephone companies to act as radio-frequency loads and to simulate fades. This equipment comprises the total test facilities.

Maintenance routines were based on the manufacturers technical knowledge of the equipment and the telephone companies general knowledge of toll maintenance. The experience gained during the initial stages of operation was of course taken into careful consideration. The routines thus developed have proved to be satisfactory. It is probable that further experience will alter the routines, most likely in the direction of reduced testing as a result of increasing skill of the service forces. The routines that were adopted can best be considered in two parts, multiplex-equipment maintenance and radio-equipment maintenance.

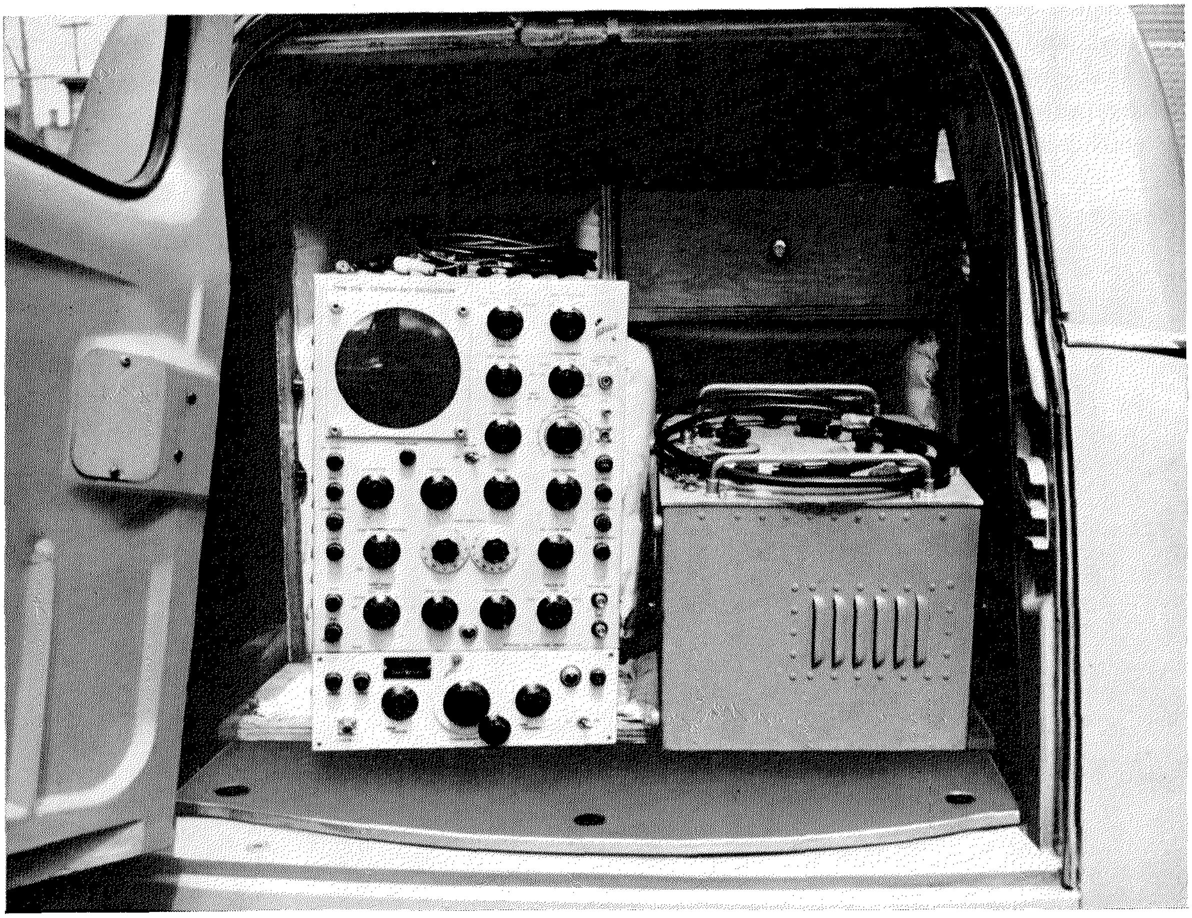

Figure 12—Rear view of maintenance truck displaying some of the test gear normally carried.

The Maritime Telegraph and Telephone Company acquired a panel truck for servicing the four Nova Scotia repeaters. This vehicle was fitted with padded compartments to accommodate the necessary test gear as shown in Figure 12. A microwave signal generator, vacuum-tube checker, oscilloscope, and portable trailing-edge detectors are normally carried in the maintenance vehicle.

Following the installation, a one-week instruction course was conducted for all personnel who would be associated with the system maintenance. This included both basic theory of the equipment and maintenance procedures.

The terminal multiplex equipment is serviced completely by means of the test oscilloscope. The few key wave shapes in the common equipment are checked daily and the intermediate ones on a monthly routine. Vacuum-tube replacement is effected on the basis of these tests. In an amplitude-limited pulse system, a vacuum tube will operate beyond end-of-life transconductance values without appreciable change in output wave shape. At some point, deviation in output will then begin to occur quite rapidly. The waveform test routine described takes advantage of this characteristic to obtain maximum usage of the vacuum tubes without endangering equipment performance or reliability. The condition of the vacuum tubes in the electronically regulated plate supplies are checked by noting the range over which regulation is maintained.

The loss of a single channel is not considered serious, and therefore the vacuum tubes in channel units are run to destruction or until the channel circuit requirements cannot be met. The channel net loss is adjusted on a regular basis and daily operational checks carried out on each channel in exactly the same manner as for any toll circuit.

The radio-frequency equipment at terminals is checked once a week. The same schedule applies at repeaters if the roads permit access. Complete metering of the transmitter is provided including power output at normal and reduced filament voltage. The condition of the vacuum tubes can readily be ascertained from these readings and replacement made as required. The local-oscillator stage of the receiver is completely metered and these readings indicate the requirement for replacement of this vacuum tube. The receiver intermediate-frequency amplifier cannot be checked in this fashion. Therefore the receiver overall gain is checked once a month using a microwave signal generator. When the gain is reduced by a certain amount, any faulty intermediate-frequency-amplifier vacuum tubes are replaced using either a trial substitution method or the vacuum-tube checker as a criterion.

During the weekly visit to repeaters, the alarm system and the standby power system are given an operative check. The vacuum tubes (which are all 10 000-hour type) used in the alarm system are checked once each three months on the vacuum-tube checker. The service-channel equipment, including the drop-and-insert apparatus, is routine checked as required except that a preventative maintenance check is made once each 6 months. Antennas, antenna structures, transmission lines, and pressurizing equipment are carefully checked before and after each winter season.

11. Interference

In a microwave radio relay system, the signal-to-noise ratio is a function of the total noise power introduced into the system from four sources.

A. Multiplex noise; with this equipment this noise is comparatively small.

B. Transmitter noise; this is small if the transmitter is properly catalyzed.

C. Receiver noise; the effect of this is controlled by the receiver noise figure and the magnitude of the incident signal. As previously mentioned, the net path attenuations have been kept conservative, thus insuring that a large signal is applied to each receiver.

D. Stray sources.

In any radio relay system, noise power is always introduced into the system by stray paths. In this system, four separate stray sources introduced noise that far overshadowed the first three conventional noises discussed above. These stray sources were as follows.

A. Stray catalyzation of transmitters. As mentioned in section 4, it was found that transmitters physically adjacent and operating on the same frequency or adjacent frequencies catalyzed one another. Although the cause could be eliminated by using more frequencies or elaborate electrical screening, it was possible to eliminate the effect before demodulation by discarding the pulse leading edges and using only the relatively noise-free trailing edges. This incidentally places a lower limit on the pulse widths of the system because the pulse must have some flat top or the noisy leading edge will modulate the quiet trailing edge. The upper limit of pulse width is fixed by the duty-cycle capabilities of the system. To facilitate pulse-width maintenance, delay-line devices were installed ahead of the transmitters at the terminals and at the midpoint repeater in Newtonville. These automatically correct the pulse width to the optimum value.

B. Interference from transmitter to receiver at video frequency. This was caused by the high-level modulator pulse interfering with the second detector of an adjacent receiver. It was eliminated by simple shielding of the receiver.

C. Direct radiation from one antenna to another. This occurred where the antenna dipoles lay in parallel planes, that is, where horizontal polarization was in use and the antennas were mounted one above the other, or where vertical polarization was used and the antennas were mounted side by side. This effect was eliminated by inserting between the antennas suitable electric shields made of bonded-brass-wire cloth.

D. Signals arriving through the effective back-to-front ratio of an antenna. This subject has been studied thoroughly by others.[4] The theoretical back-to-front ratio of an antenna assumes it to be located in true free space. The practical or effective back-to-front ratio differs from the theoretical in that the antenna receives random signals reflected from surrounding terrain. Some of the possible cross-talk paths in a typical system are illustrated in Figure 13. The true front-to-back ratio of the antennas are of the order of 60 to 65 decibels. The unwanted signal will be at about the same level as the receiver noise and therefore its effect is not too serious. However, the actual interfering signals received on the third radio system, due to foreground scattering, were as high as 15 decibels above the noise and averaged about 10 decibels above the noise. With the receiver noise that exists and assuming a path attenuation of 70 decibels (a fair figure for the third radio system with 10-foot (3.1-metre) paraboloids), the interfering signals are about 53 decibels below the desired signal. This corresponds fairly well with results obtained on other systems. Unfortunately, it is impossible to eliminate this interference unless four frequencies are used for each radio system. This is impracticable as sufficient frequency assignments are not available. With a ratio of 53 decibels between the carrier and interfering signals and making allowance for the modulation improvement, weighting improvement, and cumulative effect of 6 tandem hops, an overall channel signal-to-noise ratio of 64 decibels (*F1A* weighted) would be expected. This corresponds exactly to the figure obtained.

This interference explains why the signal-to-noise ratio provided by the third radio system, which has 6 decibels more antenna gain per hop and a receiver noise figure better by 4 decibels than those of the first two systems, exceeds that of the first two systems by only 2 decibels and not 10 decibels. If this interference were eliminated by the use of four frequencies per hop, the radio signal-to-noise ratio would increase to 74 decibels, which combined with the multiplex noise would result in an overall channel signal-to-noise ratio of approximately 70 decibels.

There are two other types of interference worthy of mention. The first is overreach and the second is direct radiation from transmitter to receiver due to their proximity in frequency.

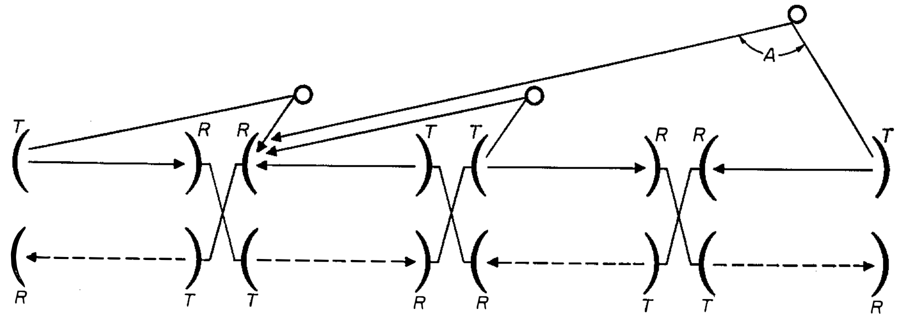

Figure 13—Some possible paths for cross-talk among the several radio links. Two radio frequencies are used, one being indicated by solid arrows and the other by broken-line arrows. *T* and *R* indicate the transmitting and receiving paraboloids. The terminal and repeater equipments are omitted. Reflecting regions are indicated by small circles. Path *A* is not necessarily a reflecting region: transmission can occur in this particular path through the normal methods of propagation (usually beyond the horizon).

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[4] H. W. Evans, "Cross-talk in Radio Systems Caused by Foreground Reflections," *Convention Record of the IRE 1953 National Convention*, Part 2, Antennas and Propagation, pp. 59–63.

Both of these were accounted for in the basic system engineering and did not occur. Overreach is radiation from one station to the third station away and can be effectively prevented by the geographical layout of stations. Direct radiation is dependent on the frequency assignments. In this system, the transmission frequencies of the parallel radio links are separated by 40 megacycles per second. The transmitter and receiver at any station are separated by 120 or 180 megacycles per second. This wide spacing is required since the transmitter and receiver are connected to a single antenna through duplexing filters. The closest spacing between a transmitter and a receiver of any system is 40 megacycles per second and the closest spacing between a receiver local oscillator and the carrier frequency of any other receiver is 10 megacycles per second.

TABLE 1

SIGNAL-TO-CROSS-TALK RATIOS IN DECIBELS ON SYSTEM *1* AT HALIFAX

	Listening Channel																						
Modulated Channel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1		74	72	70	62	73	74	77	69	72	68	74	67	75	75	72	71	79	66	74	70	74	69
2	80		79	80	74	80	80	74	80	80	76	80	80	75	80	80	75	80	80	76	80	77	78
3	78	78		74	74	72	80	80	72	80	80	72	80	80	71	80	80	72	80	80	69	80	80
4	74	80	80		78	80	73	80	80	75	80	80	72	80	80	74	80	80	74	80	80	69	80
5	80	80	80	80		80	80	75	80	80	80	80	80	80	80	80	80	80	80	76	80	80	80
6	78	76	76	78	76		75	74	70	80	80	80	76	80	80	80	79	80	80	80	76	80	80
7	80	75	75	73	75	75		76	73	72	80	80	80	80	80	80	79	80	76	80	76	64	79
8	80	79	78	74	76	76	76		78	75	80	80	76	76	80	80	80	80	80	75	80	77	76
9	80	80	74	80	80	71	80	80		75	80	80	80	80	75	80	80	79	80	80	75	80	80
10	80	80	80	80	80	80	74	80	74		80	72	74	80	80	80	80	80	80	80	80	66	80
11	80	80	74	74	78	73	75	75	73	77		66	74	76	80	80	80	78	79	80	76	78	80
12	80	80	80	80	80	75	80	80	77	80	80		73	78	72	80	80	76	80	80	80	80	80
13	79	80	80	75	80	80	75	80	80	79	80	80		75	73	71	80	80	80	80	80	67	80
14	80	70	80	80	70	80	80	70	80	80	70	80	80		70	80	68	80	80	80	80	75	74
15	80	80	75	80	80	71	80	80	73	80	80	75	79	80		80	80	70	80	80	75	75	80
16	80	80	78	80	80	80	80	76	74	80	78	78	75	77	71		75	72	69	80	80	75	76
17	77	77	78	80	76	78	80	80	74	80	80	78	74	77	75	75		80	73	80	74	75	75
18	80	80	79	80	80	80	80	80	76	78	78	80	75	75	75	75	74		69	76	68	78	80
19	80	80	80	80	80	80	80	80	80	80	80	80	75	79	80	78	77	78		78	79	65	79
20	80	80	80	80	80	80	80	80	80	80	80	80	77	78	80	78	78	73	78		80	71	79
21	80	80	80	80	80	80	80	80	80	80	80	80	79	80	75	80	78	79	73	76		69	75
22	80	80	80	80	80	80	80	80	80	80	75	75	80	80	77	75	77	80	80	80	80		73
23	76	68	79	78	76	78	80	95	75	75	73	73	73	72	75	75	80	80	80	70	73	75	

12. Performance

There are three basic parameters in a time-division multiplex radio relay system that indicate the overall performance. These are the channel signal-to-noise ratio, the channel signal-to-cross-talk ratio, and the reliability. These three factors are functions of both equipment and system design. Other factors, such as channel frequency response and distortion, are solely dependent on equipment design. In installations employing wide-band pulse-position modulation, cross-talk is only slightly influenced by system design.

Table 1 shows typical interchannel cross-talk ratios. These figures were actually taken at Halifax with the modulator and demodulator equipments of one system patched back to back.

This method of checking multiplex cross-talk is preferred to operation over the radio path because cross-talk can be more easily distinguished from multiplex noise, which is lower than the radio system noise. In the table, the figure of 80 decibels represents the limit of the measuring equipment and actual ratios were often better.

TABLE 2

Signal-to-Noise and Signal-to-Cross-Talk Ratios in Decibels on Second Multiplex System Over the Third Radio Path from Saint John to Halifax

		Listening Channel																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
S/N*		64	65	63	64	63	63	64	63	65	63	63	64	61	63	62	63	63	64	64	66	64	63	64
Modulated Channel	1		69	67	68	69	67	68	70	71	65	69	66	63	65	70	65	69	70	70	73	70	69	68
	2	68		61																				
	3		71		64																			
	4			69		69																		
	5				68		65																	
	6					69		64																
	7						69		69															
	8							70		71														
	9								69		67													
	10									71		67												
	11										69		68											
	12											69		65										
	13												68		65									
	14													67		68								
	15														67		65							
	16															67		69						
	17																68		68					
	18																	69		68				
	19																		69		70			
	20																			70		64		
	21																				70		67	
	22																					72		66
	23	61	70	65	64	67	65	66	67	69	65	65	66	69	65	66	67	65	66	66	68	64	65	

* Signal-to-noise ratio in decibels for *F1A* weighting.

Experience has shown that the inclusion of the radio path changes only the cross-talk from a channel to the immediately following channel (in time) and from the channels adjacent to the synchronizing pulse (channels 1 and 23) to all other channels. Table 2 shows these figures for the second multiplex system over the third radio path in the Saint John-to-Halifax direction. The channel signal-to-noise ratios are also shown. The noise in the first and second radio system is about 2 decibels higher. The minimum signal-to-noise ratio specified was 55 decibels for 99 per cent of the time. Thus safety margins of 5 decibels for the first and second systems and 7 decibels for the third system exist. With this margin, no difficulty has been experienced since the initial shakedown in maintaining the required signal-to-noise ratios.

The Maritime Telegraph and Telephone Company has kept a careful log of system outages. Tables 3, 4, and 5 summarize outage figures for 1953 through the first 5 months of 1955. In 1953, the first year of operation, total outage was 0.62 per cent or 0.09 per cent per station. In 1954, these figures were 0.69 and 0.097. It would be expected that outages would have decreased in 1954, which was the second year of operation, as a result of the clearance of initial troubles and the increased skill of the maintenance staff. In 1954 however, 35 circuits were in use, 23 on multiplex *1* and 12 on multiplex *2*. Since the third radio equipment had not been installed, there was no standby and any failure resulted in the loss of at least 12 circuits. These circuits were also lost while radio maintenance was in process. The advantage of the standby radio system can be clearly seen in the report for 1955, which shows a total outage figure of only 0.094 per cent or 0.014 per cent per station. It will be noted that in 1955 the fraction of the per-cent outage due to testing activities dropped to 5.42 per cent while the outages due to vacuum-tube failure rose to 64.41 per cent of the total. The balance among the various causes of outages during 1955 is considered as it should be. It will be noted that propagation outage in 1953 was 0.21 per cent of the total; in 1954, none; and in

TABLE 3

Monthly Summary of Outages in 1953

Based on 24-Hour-per-Day Operation and Both Scheduled and Non-Scheduled Outages

Month	Number of Circuit Troubles*	Circuit Hours in Trouble†	Per Cent Time in Trouble	Trouble Classification in Per Cent of Total Outage Time						
				Propagation	Power Mains	Tubes	Radio Equipment	Associated Equipment	Testing	Other
January	187	135.73	1.22	2.20	57.58	32.70	—	1.45	6.07	—
February	151	30.81	0.38	—	41.90	28.43	—	1.33	29.15	—
March	63	144.91	1.36	1.20	—	11.99	16.84	15.94	54.03	—
April	241	197.64	1.83	—	—	5.96	—	14.37	79.67	—
May	160	58.29	0.50	—	18.44	11.53	—	46.54	23.49	—
June	79	53.76	0.44	—	1.49	1.49	—	0.78	96.25	—
July	188	81.57	0.49	—	15.83	20.35	—	8.90	54.92	—
August	68	15.40	0.09	—	—	—	—	16.00	84.00	—
September	191	53.80	0.33	—	12.58	65.54	—	8.05	13.83	—
October	112	74.38	0.45	—	10.06	20.70	2.92	15.27	51.05	—
November	27	31.32	0.20	—	—	83.81	3.18	1.40	11.61	—
December	6	17.34	0.11	—	—	18.34	—	—	81.66	—
Total	1,473	894.95	7.40	3.40	155.88	300.84	22.94	130.03	585.73	—
Average	122.75	74.58	0.62	0.28	13.09	25.07	1.91	10.84	48.81	—

* Number of circuit troubles equals the number of troubles times the number of circuits affected.

† Circuit hours in trouble equals the outage time in hours times the number of circuits affected.

TABLE 4

Monthly Summary of Outages in 1954

Based on 24-Hour-per-Day Operation and Both Scheduled and Non-Scheduled Outages

Month	Number of Circuit Troubles	Circuit Hours in Trouble	Per Cent Time in Trouble	Trouble Classification in Per Cent of Total Outage Time						
				Propagation	Power Mains	Tubes	Radio Equipment	Associated Equipment	Testing	Other
January	149	351.05	1.79	—	0.57	3.17	0.38	25.10	68.37	2.41
February	187	169.53	1.09	—	1.63	21.30	—	61.15	15.92	—
March	174	58.68	0.34	—	—	1.55	1.96	72.12	24.37	—
April	2	1.93	0.01	—	—	—	—	88.08	11.92	—
May	92	7.50	0.05	—	—	39.87	—	—	55.60	4.53
June	154	11.88	0.07	—	—	51.90	—	5.50	18.50	24.00
July	132	40.32	0.19	—	3.50	62.40	—	21.80	12.30	—
August	272	398.24	1.78	—	16.90	6.50	26.50	0.40	47.60	2.10
September	423	167.63	0.78	—	8.27	5.88	3.23	13.18	66.67	2.77
October	171	150.63	0.67	—	—	33.76	—	3.68	61.01	1.55
November	567	260.87	1.07	—	7.74	41.80	1.74	20.40	19.10	9.22
December	312	113.38	0.42	—	—	1.27	—	18.15	75.46	5.12
Total	2,635	1,731.64	8.26	—	38.61	269.40	33.81	329.56	476.82	51.70
Average	219.58	144.30	0.69	—	3.22	22.45	2.82	27.46	39.75	4.31

1955, 2.48 per cent of the total. These figures, expressed as percentages of the total operating time, are only 0.0012, none, and 0.0023 per cent, respectively.

The allowable-outage figures specified were 1 per cent of the total (assuming 100-per-cent radio standby) of which 0.5 per cent could be due to propagation and 0.5 per cent to equipment failure. It can be seen that from the beginning the system has operated substantially within the overall limit, and after completion at the close of 1954 has been operating very well within the limit for equipment failures. Propagation outages have of course been negligible.

One point worthy of comment is storm performance. Since the system has been in operation, several severe storms involving snow, ice, and wind have been successfully weathered. For instance, when hurricane Edna swept Nova Scotia in 1954, causing extensive damage, all toll circuits out of Nova Scotia except those provided by the radio relay system were out of service. Although all Nova Scotia stations were operating throughout the storm on standby power, this system performed without break except for a very short period while the Halifax office was being transferred to standby power. Thus one of the main goals in choosing a radio relay system, that is, invulnerability to storms, has been attained.

13. Summary and Conclusion

The Saint John-to-Halifax radio relay system utilizes two 23-channel time-division-multiplex equipments and three microwave pulse-amplitude-modulated radio-frequency systems to provide 46 toll-quality voice circuits between Saint John in New Brunswick and Halifax in Nova Scotia via 5 repeaters. These circuits form an important part of the trans-Canada telephone toll network. This system has been in successful operation for two and one half years. As a result of this experience, the following conclusions may safely be drawn.

A. Time-division multiplex equipment of this type (broad-band pulse-position modulation) is appliciable to medium-density medium-haul requirements for toll-quality circuits.

B. Parallel systems may be employed to yield multiples of the basic group of 23 circuits.

C. When proper care is taken in system design, signal-to-noise ratios can be obtained that have sufficient margin above the requirements for toll circuits as not to cause trouble.

D. If path calculations and engineering are done on a conservative basis, outages due to propagation fading in the 2000-megacycle-per-second region can be practically eliminated.

E. The equipment can be maintained by telephone toll maintenance personnel so that outages due to equipment failure are reduced to a small figure (less than 0.05 per cent per station). This assumes that a standby radio system and a standby power source are provided.

TABLE 5

MONTHLY SUMMARY OF OUTAGES FOR JANUARY–MAY 1955

Based on 24-Hour-per-Day Operation and Both Scheduled and Non-Scheduled Outages

Month	Number of Circuit Troubles	Circuit Hours in Trouble	Per Cent Time in Trouble	Trouble Classification in Per Cent of Total Outage Time						
				Propagation	Power Mains	Tubes	Radio Equipment	Associated Equipment	Testing	Other
January	198	25.30	0.08	—	—	91.31	—	—	—	8.69
February	280	38.50	0.12	—	1.76	22.10	58.02	7.18	—	9.94
March	270	27.63	0.09	12.40	2.30	76.80	2.30	—	3.90	2.30
April	82	2.64	0.01	—	—	61.50	15.30	—	23.20	—
May	352	55.00	0.17	—	4.78	69.32	1.59	9.96	—	14.35
Total	1,182	149.07	0.47	12.40	9.84	321.03	77.21	17.14	27.10	35.28
Average	236.4	29.81	0.094	2.48	1.97	64.20	15.44	3.43	5.42	7.06

F. A 50-mile (80-kilometre) overwater path at 2000 megacycles per second is practical if a space-diversity arrangement is used. If the path is no worse than grazing under the poorest conditions of abnormal refraction, outages due to propagation fading will be small. Some improvement is apparently obtained through the use of 3 receiving antennas properly located, but the exact degree of improvement to be expected is not known.

This system has confirmed other known advantages of microwave radio relay systems. Some of these are: invulnerability to storms, low initial cost, concentration of maintenance at a few points, and shorter possible routes. Because of the ability of a microwave system to span the Bay of Fundy, the toll-circuit distance from Halifax to Saint John was greatly reduced. This resulted in better toll service at substantially reduced rates.

14. Acknowledgments

The author acknowledges with gratitude the efforts of the staff of Standard Telephones & Cables Manufacturing Company (Canada), Federal Telecommunication Laboratories, Federal Telephone and Radio Company, and Federal Electric Corporation, who assisted in the planning and installation of this system, and most especially acknowledges indebtedness to Federal Telecommunication Laboratories for its technical assistance and to the members of the engineering and toll test departments of the Maritime Telegraph and Telephone Company and the New Brunswich Telephone Company for their valuable technical advice, aid, and cooperation throughout the installation period. Without the combined efforts of all these groups, this system could not have reached so successful a conclusion.

Recent Telecommunication Development

"Transistors and Other Crystal Valves"

Mr. T. R. Scott, director of research of Standard Telecommunication Laboratories, is the author of a recently published book on "Transistors and Other Crystal Valves" issued by Macdonald and Evans, 8 John Street, Bedford Row, London WC1, England. The book is intended for engineers who may be required to make use of these devices. It is divided into 10 chapters, 2 appendixes, a bibliography of 277 items, a short list of abbreviations, and an index.

The book is $5\frac{1}{2}$ by $8\frac{3}{4}$ inches (14 by 22 centimeters) and is bound in hard covers. It contains 236 pages of text, 17 pages of bibliography, 1 page of abbreviations, 4 pages of index, and 16 pages of preliminary material. Its price is 45 shillings. Copies may be obtained in the United States from Essential Books, Incorporated, 114 Fifth Avenue, New York, New York, at $7.20 each, postpaid.

Very-High-Frequency Radio Link Between Puerto Rico and the Virgin Islands*

By ROGER McSWEENY

American Cable and Radio Corporation; New York, New York

PUERTO RICO, together with Cuba, Hispaniola, and Jamaica, comprise the Greater Antilles or West Indies; Puerto Rico being the most easterly of the group. About 50 to 75 statute miles (80 to 120 kilometers) farther east of Puerto Rico are the Virgin Islands, which are at the end of an extensive chain of islands called the Lesser Antilles. This paper is concerned with Puerto Rico and with Saint Thomas and Saint Croix, two of the Virgin Islands, which are about 18 degrees north of the equator, 1000 miles (1600 kilometers) east of Miami, Florida, and 1600 miles (2600 kilometers) southeast of New York City. The Virgin Islands are closely associated through both travel and trade with Puerto Rico and, consequently, require intercommunication with it and through it to the American mainland. Puerto Rico is a commonwealth associated with the United States of America while Saint Thomas and Saint Croix are territories of the United States.

Prior to installation of the very-high-frequency links to be described in this paper, telecommunication facilities available for public use were limited to submarine telegraph cables and to high-frequency radiotelephone and radiotelegraph circuits. The latter were not very satisfactory because of unstable sky-wave transmission over distances of about 75 miles and the high levels of noise and interference on amplitude-modulated frequencies between 4 and 7 megacycles per second.

The new facilities operated by the Radio Corporation of Porto Rico and All America Cables and Radio are based on a 150-megacycle frequency-modulated system that provides several telephone channels that connect with the public telephone systems of the islands. In addition, telegraph printer channels are provided to cable offices for general public use and other printer channels are leased to airlines and shipping companies. The telephone services are extended to the mainland through high-frequency radio circuits from Puerto Rico to the United States. Telegraph services are extended to the mainland through the cable or radio facilities of All America Cables and Radio.

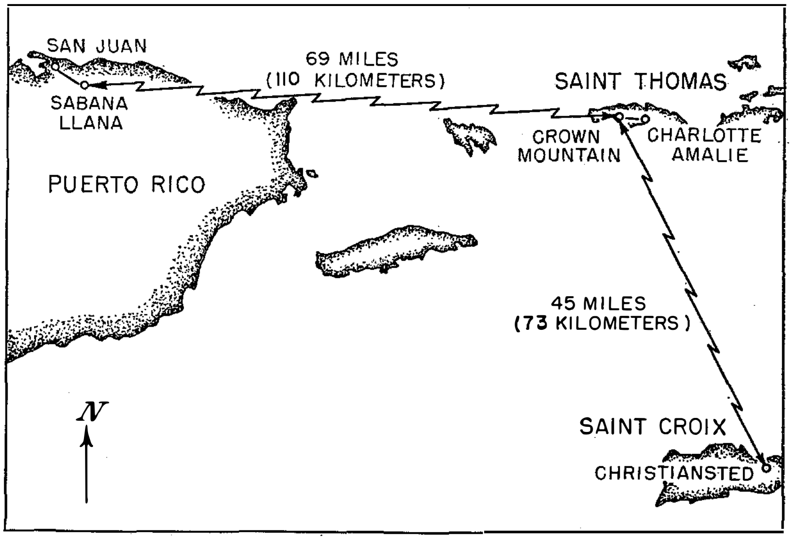

Figure 1—Map of radio system.

1. General Description

Figure 1 is a map of the system. There are two very-high-frequency radio links involved, one of 69 miles (111 kilometers) from Sabana Llana, Puerto Rico, to Crown Mountain on Saint Thomas and one of 45 miles (73 kilometers) from Crown Mountain to Christiansted on Saint Croix. At the Puerto Rican end, the Sabana Llana radio station is connected through 10 miles (16 kilometers) of cable to the telephone exchange and telegraph office in the city of San

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* Reprinted from *Communication and Electronics,* volume 74, pages 781–785; January, 1956. The illustrations are not identical with those in the original publication.

Juan. Both radio equipment and carrier apparatus for deriving the individual telephone channels are located at Sabana Llana.

On Saint Thomas, the Crown Mountain radio station is connected through 4 miles (6.4 kilometers) of cable to the town of Charlotte Amalie, where carrier equipment, telephone exchange, and telegraph terminals are located. On Saint Croix, the radio and terminating equipment are both at the telephone office in the town of Christiansted.

Voice and carrier provide 4 telephone channels on the radio link from Sabana Llana to Crown Mountain and this may be increased to 5 channels if required. Of the present 4 channels, the first is transferred at Crown Mountain to the Christiansted link to provide a direct telephone circuit between Saint Croix and San Juan. The second is connected at Sabana Llana to other radio equipment to provide a direct telephone circuit between Charlotte Amalie and New York. The third is for telephony between Charlotte Amalie and San Juan, and the fourth is subdivided by voice-frequency carrier equipment into 4 telegraph printer channels. This circuit may be increased to 9 printer channels, if needed.

Voice and carrier provide 3 telephone channels on the radio link from Crown Mountain to Christiansted and this may be increased to 4 channels, if required. Of the present 3 channels, the first is transferred at Crown Mountain to San Juan; the second provides a telephone circuit between Charlotte Amalie and Christiansted, and the third now carries a telegraph printer channel. This may be increased to 4 printer channels, if needed.

TABLE 1

RADIO FREQUENCIES

Frequency in Megacycles	From	To
158.01	Sabana Llana	Crown Mountain
152.75	Crown Mountain	Sabana Llana
152.57	Crown Mountain	Christiansted
157.83	Christiansted	Crown Mountain

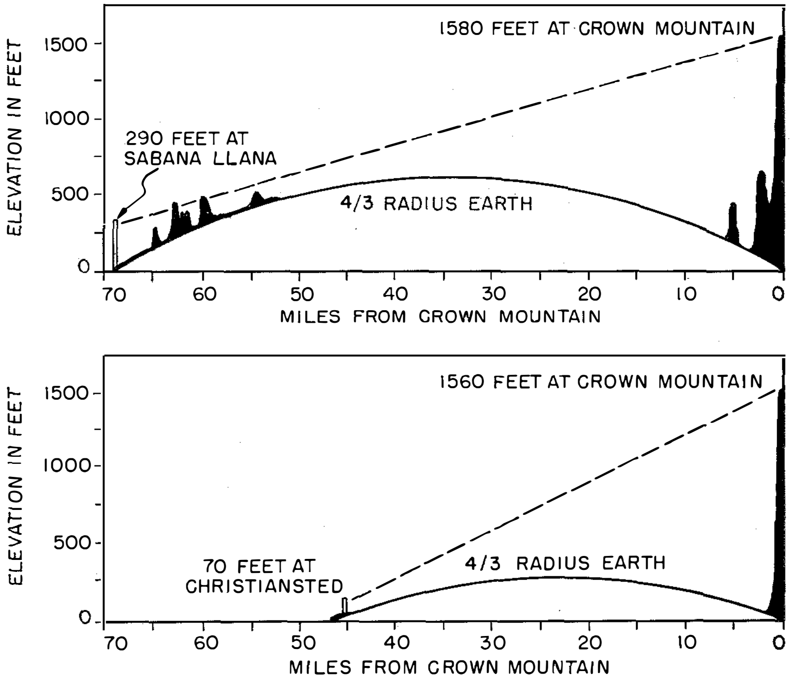

Figure 2—Profiles of radio paths.

The system may be expanded in the future to connect two other Virgin Islands, Saint John and Tortola, to Saint Thomas through the Crown Mountain radio station.

2. *Frequencies and Sites*

The radio frequencies employed are listed in Table 1. While lower frequencies in the very-high-frequency band probably would produce better results over these paths, the frequencies used are the lowest for which licenses could be obtained.

Prior to selecting the station site on Saint Thomas, a small transmitter was set up at Sabana Llana and operated for six weeks on 158.01 megacycles with a corner-reflector antenna mounted 260 feet (80 meters) above ground. Received field strength was observed at 19 places on Saint Thomas and continuous recordings for one week each were made at 6 locations. These tests indicated that a substantially stronger and steadier signal could be obtained at the top of Crown Mountain than elsewhere on the island.

As a result of this rather remote station location, the cost of radio equipment at Crown Mountain was only a fraction of the cost of necessary auxiliary facilities such as improvements to roadway, construction of power and telephone lines, building, et cetera.

3. *Radio Paths*

Figure 2 shows profiles of the two radio-frequency paths. The elevations shown are the heights of the antennas above mean sea level. Antenna elevation of 1580 feet (480 meters) at Crown Mountain is largely responsible for the satisfactory performance of the system. From this elevation, the 45-mile (73-kilometer) path to Christiansted is above the geometric horizon and presents little difficulty although a first Fresnel-zone clearance is not obtained. The 69-mile (111-kilometer) path to Sabana Llana falls below the "smooth-earth geometric horizon" but is above the "effective radio horizon" based on a $\frac{4}{3}$-radius earth. Tests indicated that the maximum practical height of the antenna (290 feet (99 meters) above sea level) using an existing tower at Sabana Llana produced signals that were 3 and 10 decibels better, respectively, than for heights of 120 and 70 feet (36 and 21 meters) at the same location. The maximum height does not clear the tops of two hills that project into the path as may be seen in Figure 2.

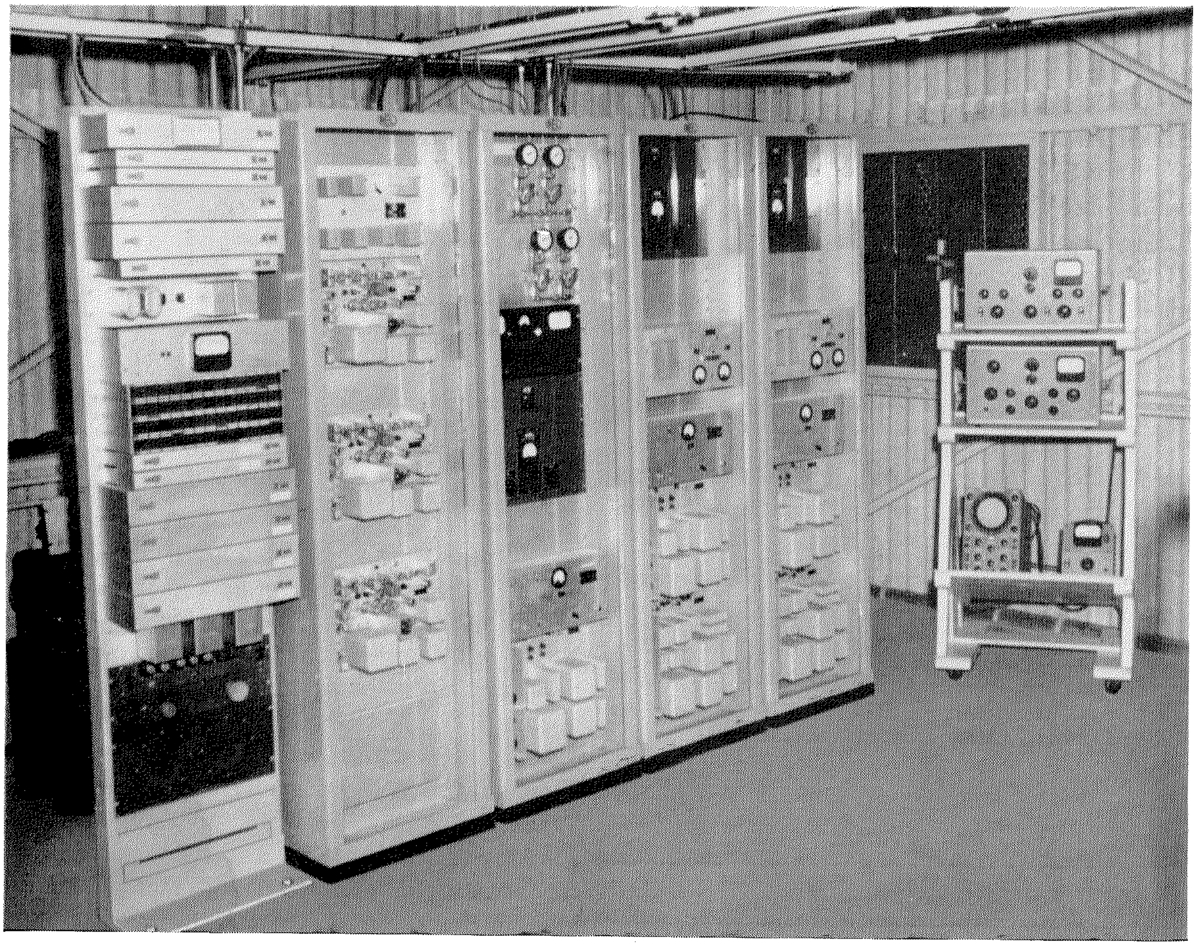

Figure 3—Installation at Crown Mountain. The left-hand bay is for line-terminating apparatus, the next rack holds three receivers, the center bay has coaxial-line pressure gages and valves and frequency monitors, while the remaining two bays are of transmitting equipment. Testing apparatus is in the small frame at the extreme right.

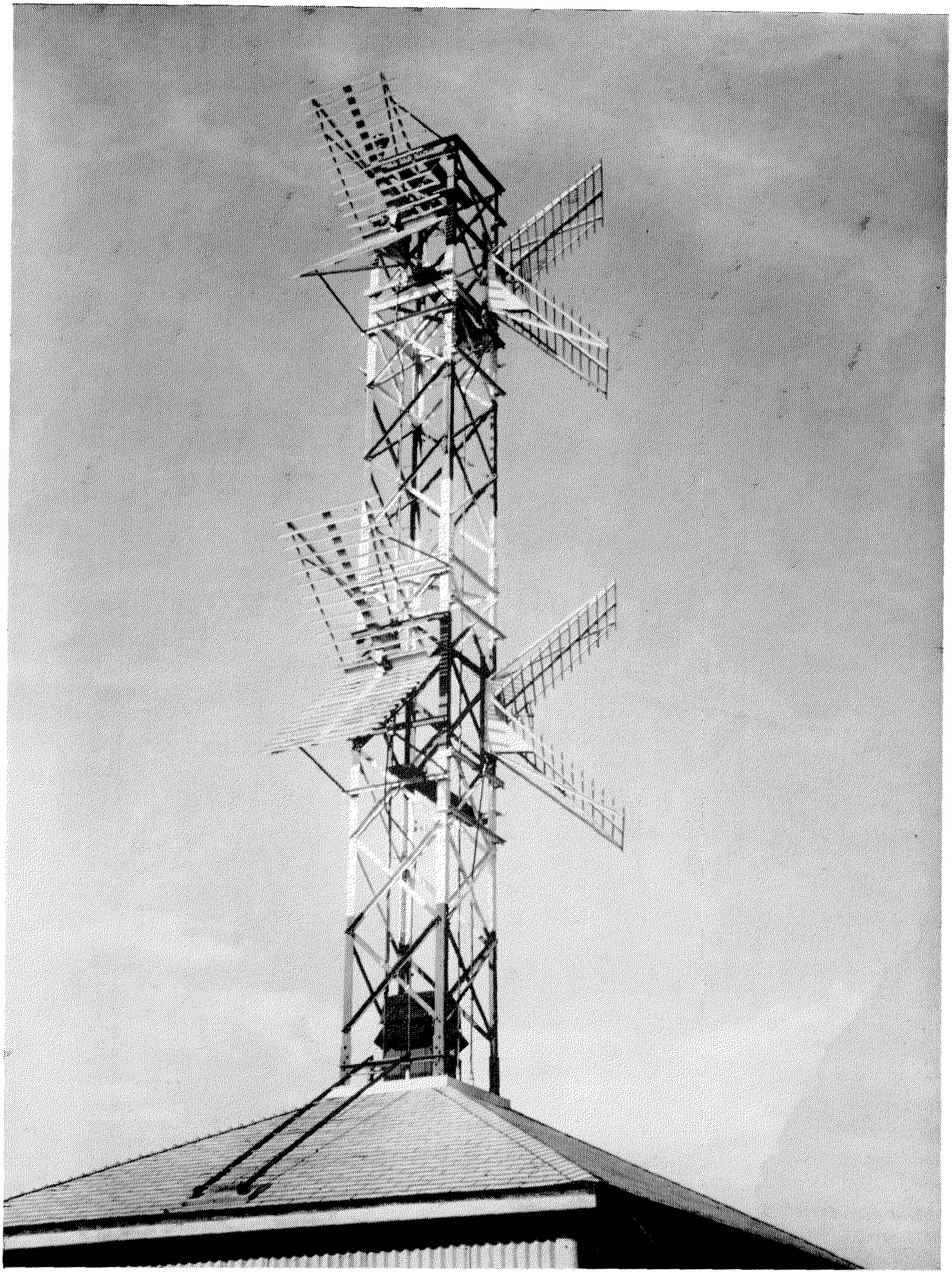

Figure 4—Original installation of 4 antennas at Crown Mountain.

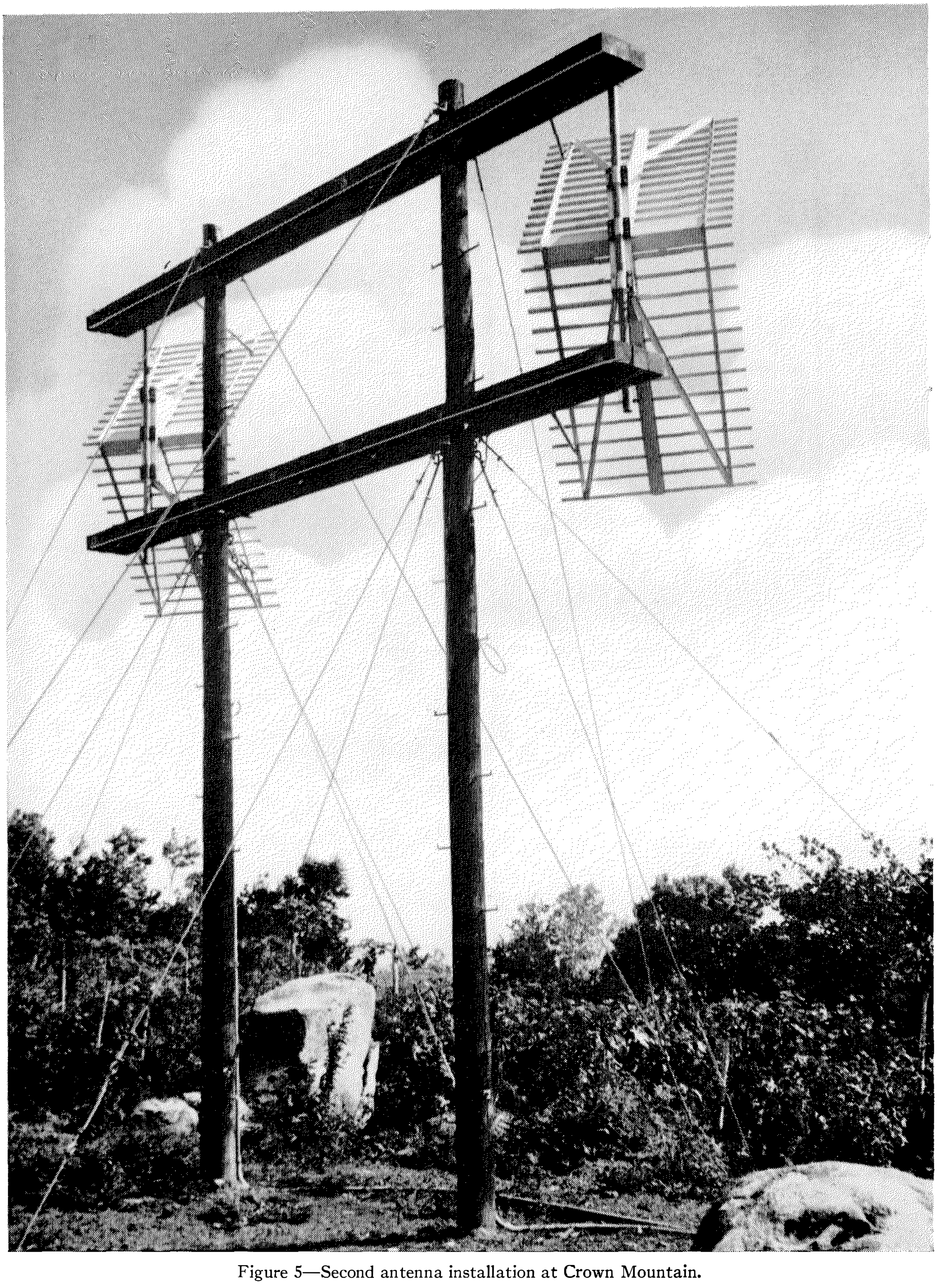

Figure 5—Second antenna installation at Crown Mountain.

Measured space losses (excluding estimated antenna gains and line losses) on the paths from Crown Mountain to Christiansted and Sabana Llana are opproximately 110 and 120 decibels, respectively. Calculated free-space losses for the same distances between isotropic antennas are 113 and 117 decibels. The low loss on the Christiansted path appears to indicate that signals reflected from the surface of the sea between the islands arrive approximately in phase with the directly propagated signals.

Usually there is little fading on either link, but slow fluctuations in field intensity of the order of 3 decibels occur continuously. In the first 18 months of commercial operation that started in August 1953, several periods lasting from 5 to 15 minutes have been observed during which field intensity dropped to approximately 15 decibels less than normal in both directions on the Sabana Llana–Crown Mountain link. Commercial operation continued without interruption during these periods. No correlation of the abnormally low fields with weather or time of day was observed.

4. Transmitters and Receivers

The frequency-modulated transmitters employed on the Christiansted–Crown Mountain link have a power output of 25 watts. Similar transmitters followed by power amplifiers of 100 watts output are employed on the Crown Mountain–Sabana Llana link. Peak deviation is limited by regulations of the Federal Communications Commission to ±15 kilocycles for this band. Limiting amplifiers are installed ahead of the transmitters to prevent excessive deviation due to unusual line levels. An outstanding feature of the transmitters is their low level of distortion.

Figure 3 shows typical transmitting and receiving equipment. The center cabinet contains air-pressure indicators for coaxial lines, a frequency and shift monitor, a limiting line amplifier, and a transmitter with power supply. The two cabinets at the right end each contain a limiting line amplifier, a transmitter with power supply, and a power amplifier with power supply.

The receivers are crystal-controlled double-conversion superheterodynes with automatic volume control, 2-stage limiting, and discriminator.

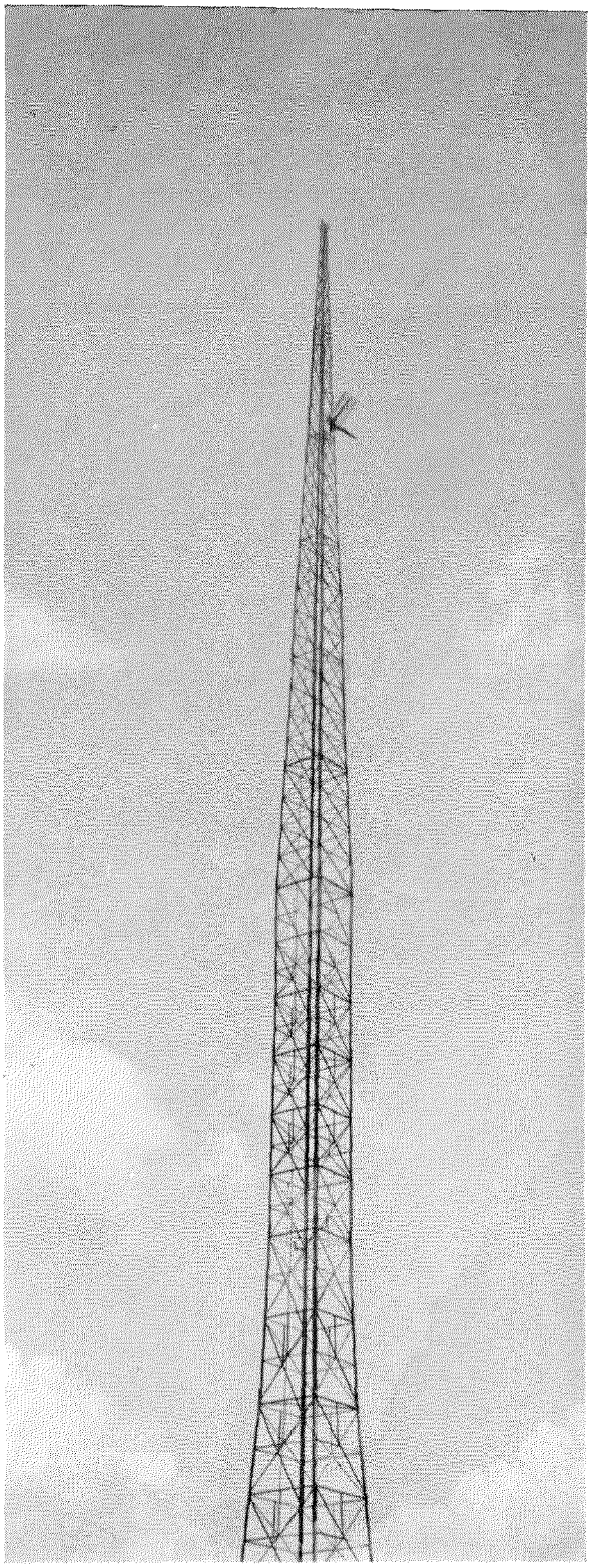

Figure 6—Antennas and portion of supporting tower at Sabana Llana.

The frequency-modulation improvement threshold is 1 microvolt and the noise figure is 7 decibels. The signal normally present at the receiver input terminals is approximately 500 microvolts on the Sabana Llana–Crown Mountain link and approximately 1000 microvolts on the Crown Mountain–Christiansted link.

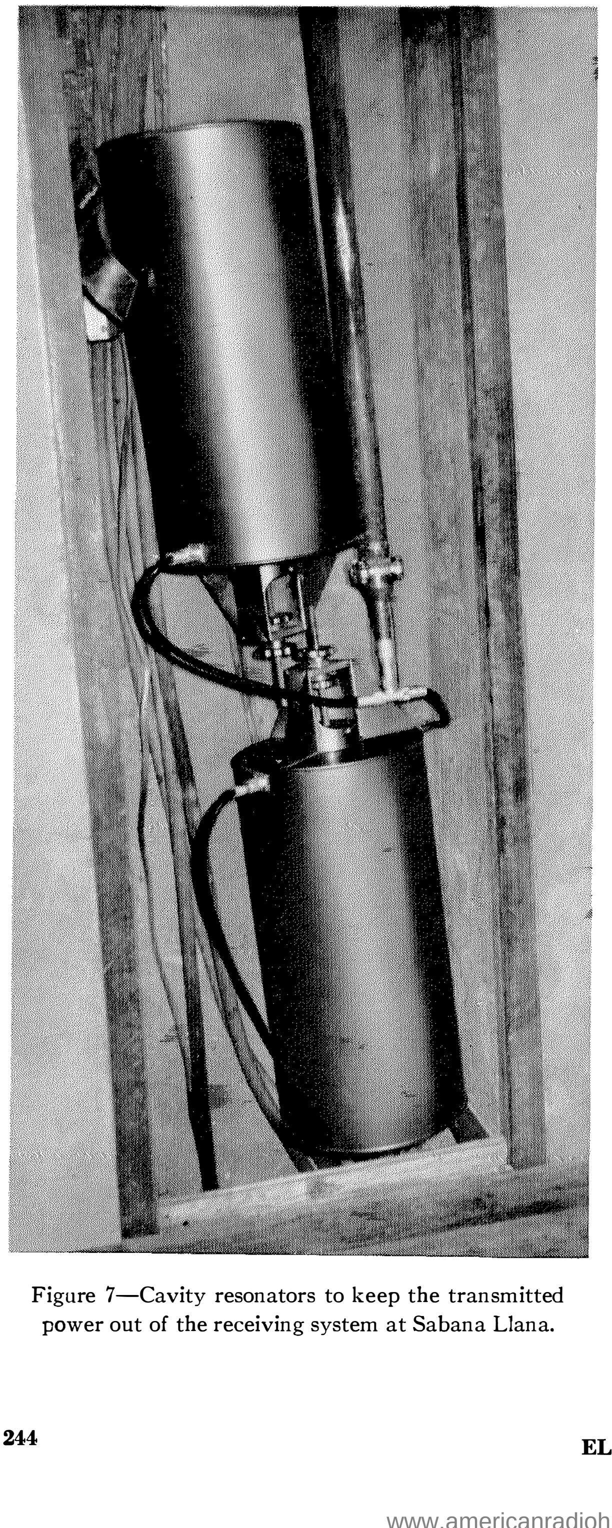

Figure 7—Cavity resonators to keep the transmitted power out of the receiving system at Sabana Llana.

The rack at the left of Figure 3 contains apparatus associated with the cable lines such as repeating coils, volume indictor, filters and jacks. The cabinet to its right contains a remote-control relay panel and three receivers.

The transmitter and receiver together are capable of a system response–frequency characteristic that is flat to within 1 decibel from 200 cycles to 20 kilocycles with less than 1 percent of amplitude distortion and a 50-decibel signal-to-noise ratio per 3-kilocycle channel. Intermodulation between two test tones is 50 decibels down. This performance is considerably better than that of frequency-modulated radio equipment commonly used for mobile services or for single-channel telephone service. The higher standards are necessary to prevent crosstalk on multichannel links.

Spare radio equipment is provided at each location but no provision is made for automatic switchover in event of failure. The Crown Mountain station is the only unattended location, and for this point a monitoring receiver is provided at the office in Charlotte Amalie which is 4 miles away, with relays for switching transmitters and receivers through the interconnecting cable.

Alternating current supplied by local public utilities is used at all locations, but voltage regulators and gasoline-engine-driven emergency generators with automatic starting and transfer facilities are provided.

5. *Antennas*

Horizontally polarized corner-reflector-type antennas are used. They have a gain of 8 decibels over a half-wave dipole. With the exception of those at Sabana Llana, all antennas are connected to the equipment through $\frac{7}{8}$-inch-(2.2-centimeter-) diameter air-spaced copper-tube coaxial lines, which are filled with dry air at low pressure. Antennas for diversity reception have not been provided because there appears to be no need for them.

Figure 4 is a view of two transmitting and two receiving antennas, mounted on a tower above the station building at Crown Mountain. After this photograph was taken, two of the antennas were moved from the tower to poles about 60 feet (18 meters) away in order to reduce coupling between the Christiansted and Sabana Llana

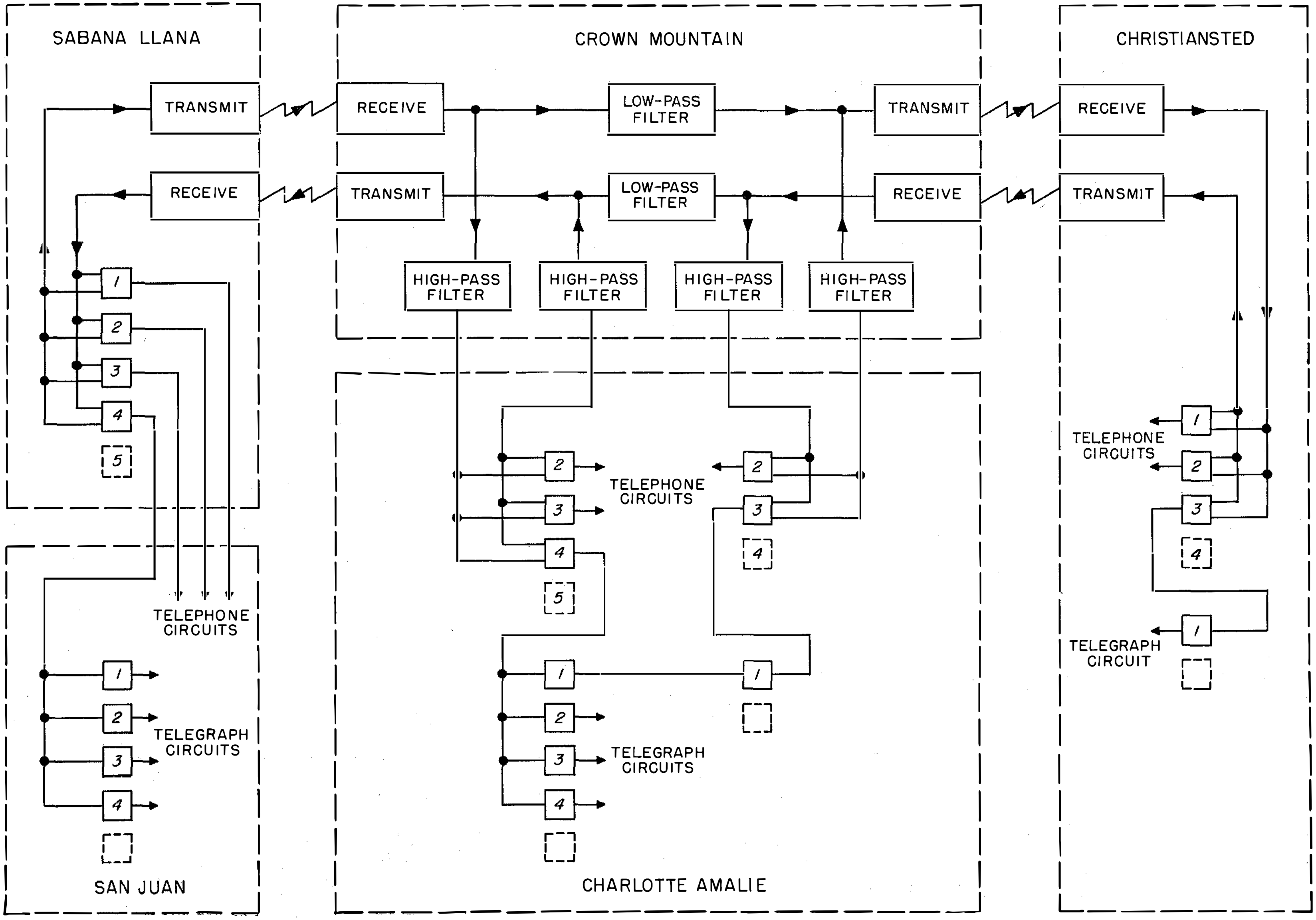

Figure 8—Block diagram of carrier system.

links at Crown Mountain. They may be seen in Figure 5.

Figure 6 shows the single combined transmitting and receiving antenna on a 300-foot (90-meter) tower at Sabana Llana. Since this antenna is 800 feet (240 meters) from the equipment, $1\frac{3}{8}$-inch- (3.5-centimeter-) diameter coaxial line is employed to hold transmission-line losses to 1.6 decibels. At the station end of the line, cavity resonators shown in Figure 7 are used to keep the transmitter radio-frequency energy out of the receiver.

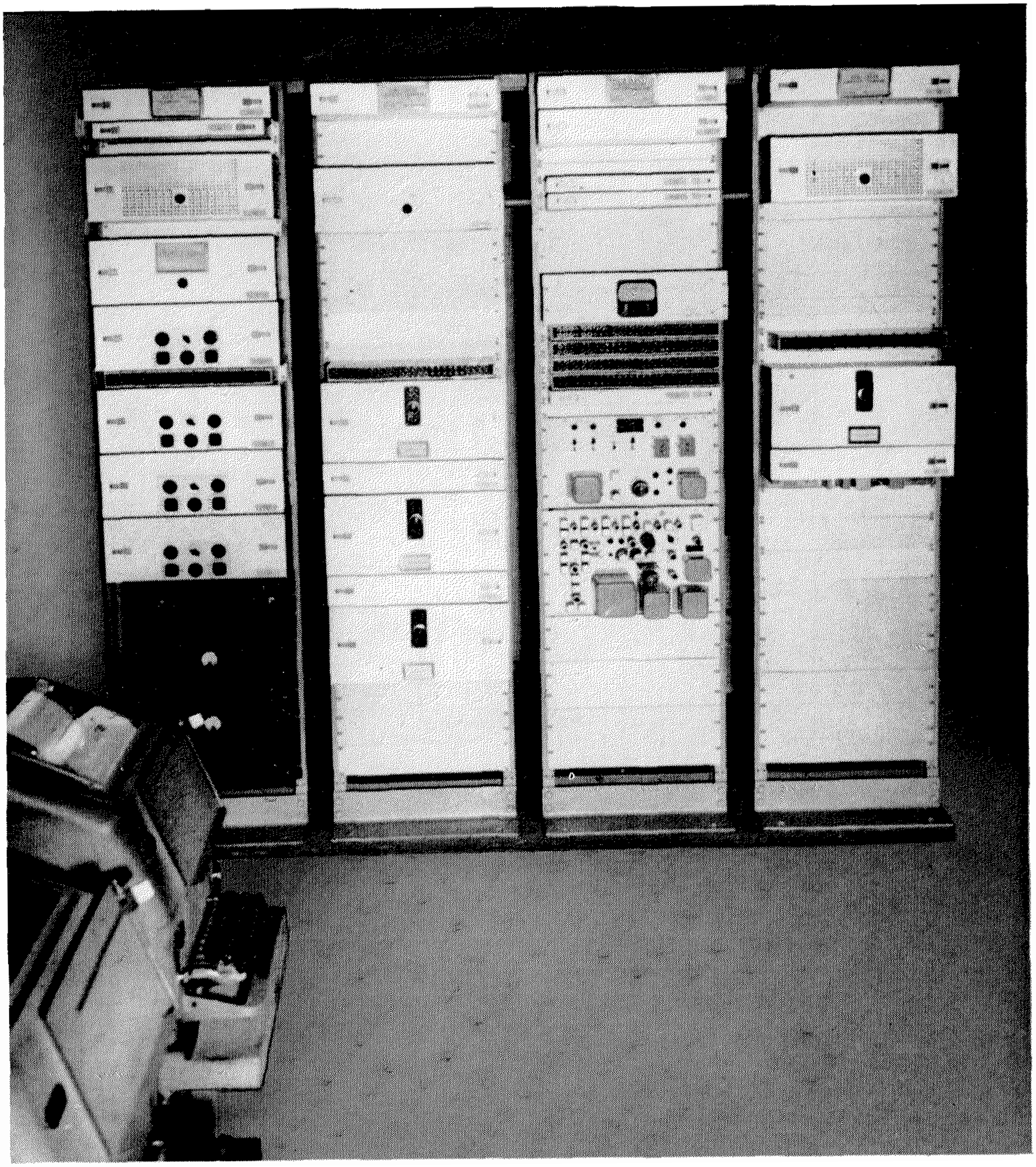

Figure 9—Telegraph carrier equipment at Charlotte Amalie.

At Christiansted, the two antennas are mounted on a 100-foot (30-meter) tower behind the telephone building in the center of the town, where they are exposed to occasional strong ignition radiation from old automobiles on adjacent streets. Interference from this source is generally maintained at 30 decibels or better below speech level by the fairly strong frequency-modulated received signal strength and by the horizontally polarized antennas.

The stations are in the area where hurricanes originate. The self-supporting towers are designed to withstand safely wind velocities of 120 miles (190 kilometers) per hour and they are much heavier than towers commonly used for similar service in the United States. The Crown Mountain tower, which is in the most exposed location, has been strongly guyed in addition.

6. *Carrier Equipment*

Figure 8 is a block schematic of the system. Channel 1 is on voice frequencies while channels 2, 3, and 4 use low-frequency carriers that are of the same frequency in both directions of transmission. Standard telephone-type single-sideband carrier-suppressed equipment is used.

Channel 1 is transferred at Crown Mountain from one link to the other by means of low- and high-pass filters as indicated in Figure 8 to provide the direct circuit between Saint Croix and Puerto Rico.

Hybrid coils are provided where the 4-wire radio circuits and 2-wire telephone exchanges are interconnected. Two-frequency (1000 cycles interrupted 20 times per second) ringers are provided for signaling between telephone operators.

Standard telegraph carrier techniques are used to subdivide one telephone channel into printer channels. Frequency-shift keying is employed and a channel spacing of 120 cycles is used. Figure 9 is a view of the telegraph carrier equipment at Charlotte Amalie.

7. *Operating Results*

Over-all unweighted signal-to-noise ratio at the telephone switchboards, which includes noise contributions from lines, carrier equipment, radio apparatus, and crosstalk is about 35 decibels.

During the initial 18 months of operation, service has been available 99 percent of the time between San Juan and Charlotte Amalie, and 97 percent of the time between San Juan and Christiansted. The latter service involves two very-high-frequency links in series.

Principal causes of lost time have been defective vacuum tubes, open fuses due to power surges, faults in land lines, power failures, and noise due to inadequate bonding on antennas and towers.

The corrective measures already taken have improves these initially unsatisfactory conditions and a concurrent reduction in lost time has resulted.

8. *Acknowledgment*

The successful operation of the system has been due to the work of my associates, K. M. Barbier at Saint Thomas and P. A. Girard and J. Castanera in Puerto Rico.

Microwave Television Radio Relay System*

By O. H. APPELT, KARL CHRIST, AND KURT SCHMID

C. Lorenz, A. G.; Pforzheim, Germany

MICROWAVE relay stations are used to link the television broadcasting transmitters in Köln, Frankfurt, and Neustadt. The main principles that governed the design of these relay equipments are summarized and brief outlines are given of the electrical and mechanical features and of the measurement techniques.

1. *Design Fundamentals*

1.1 TRANSMISSION FREQUENCIES

Transmission frequencies, bandwidth, and interchannel spacing were determined in cooperation with the German Post Administration and with the firms manufacturing the equipment. It was decided that the transmission frequencies be in the 1700- to 2300-megacycle-per-second band, which is in accordance with the frequency allocations of the Atlantic City international radio conference.

It appeared necessary to have a bandwidth of 30 megacycles for each channel and allow 60 megacycles for interchannel spacing. This permitted 10 channels or 5 channel pairs to be accommodated in the band. The reasons for the selection of these data have been stated elsewhere[1,2] and will be touched only briefly here.

The basic frequency range was selected primarily with regard to available microwave tubes such as the *2C39*.

The choice of channel width was influenced strongly by the video band being from zero to 6 megacycles and by the use of wideband frequency modulation to obtain the required signal-to-noise ratio for the transmission of sound signals.

For transmission in only one direction, two radio-frequency channels are required to permit the transmitted and received frequencies of a relay station to be offset from each other and thus avoid feedback. If several propagation paths run parallel or cross each other, additional channels are required. Small interchannel spacing enables many channels to be accommodated in a given band.

In multichannel systems, mutual interference may result from a radiating oscillator and insufficient image-frequency suppression in a receiver. Such interference can be eliminated by arranging the oscillator frequency so that the image band falls between the radio-frequency channels. This requirement determines that the minimum spacing of channels be twice the channel width if the oscillator frequency is at one edge of a channel. For this case, the interchannel spacing would be 60 megacycles.

The lowest possible intermediate frequency (5 × 15 = 75 megacycles) was chosen, with consideration for the availability of wideband amplifier tubes. The oscillator frequency for a radio-frequency channel then falls at the far edge of the adjacent channel. In relay stations, there was still the danger of interferences from the transmitter oscillator frequency being radiated into the receiver channel. This danger has been completely removed by an appropriate frequency distribution[3] of the oscillators.

For two channels, the oscillator frequency for the higher-frequency channel is placed 75 megacycles above the channel edge while the oscillator frequency for the lower-frequency channel is placed 75 megacycles below the channel edge. Thus the set-off frequency or the spacing between the two oscillator frequencies is equal to the sum of twice the intermediate frequency and the interchannel spacing (210 megacycles).

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*Originally published under the title of "Die Dezimeterwellen-Richtfunkgeräte der Fernsehübertragungsstrecke Köln-Frankfurt-Neustadt" in *Fernmeldtechnische Zeitschrift,* volume 6, pages 406–410; August, 1953: and *SEG-Nachrichten,* volume 1, number 4, pages 18–22; 1953.

[1] E. Dietrich, K. O. Schmidt, and E. Weingartner, "Neue Fernseh-Rechtfunkverbindungen der Deutschen Bundespost," *Fernmeldtechnische Zeitschrift,* volume 6, pages 220–233; May, 1953.

[2] H. Behling, G. Brühl, and E. Willwacher, "Die Dezimeter—Richtfunkanlage Freda I," *Telefunken-Zeitung,* volume 26, number 98, page 4; 1953.

[3] German Patent 862 320.

1.3 Signal-to-Noise Ratio

The signal-to-noise ratio required[1,4] for the video signal after transmission through 20 relay links was 35 decibels between peak values or 40 decibels between effective values. Taking into consideration the well-known relations among signal-to-noise ratio, transmitter power, receiver sensitivity, antenna gain, attenuation per radio section, and number of relay stations, the following values were laid down as a basis for the design: transmitter power of 5 watts, receiver noise figure of 25 (14 decibels), frequency swing of 12 megacycles peak-to-peak modulation, frequency band of 6 megacycles, and antenna gain of 33 decibels.

1.4 Other Requirements

Other requirements dealt with transmission distortion. They have been described at length elsewhere.[4] The linearity of the characteristics of modulators, demodulators, and video amplifiers should be such that deviations in transconductance do not exceed 10 percent of the mean value over the video range.

Variations of the group-delay time, which distort transients from black to white, should not exceed 0.1 microsecond after transmission through 20 radio link sections. These delay distortions are usually generated in the intermediate- and radio-frequency elements and also in the antenna leads if there are reflections at the antenna and equipment couplings. In these equipments, variations of group delay time in the intermediate- and radio-frequency sections were kept below 0.005 microsecond and the reflection factor at the antenna input terminals was maintained below 2.5 percent.

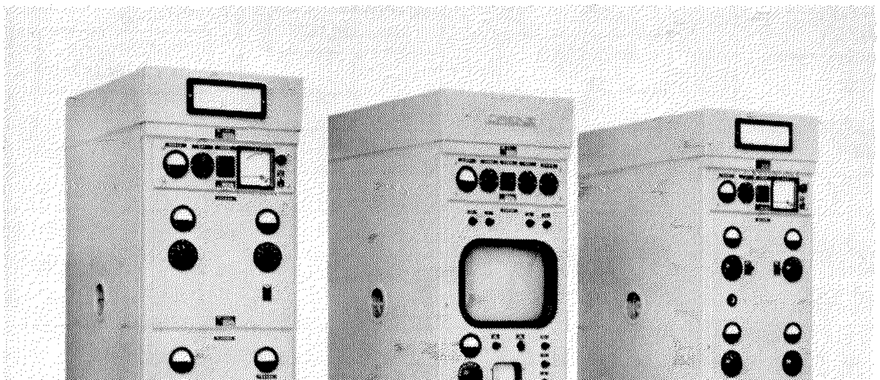

Figure 1—These 3 racks contain the equipment for a terminal station.

2. *Mechanical and Electrical Arrangement*

2.1 Mechanical

Figure 1 shows the terminal-station apparatus mounted in 3 racks. The top panels of the racks contain switchboards with instruments indicating levels and voltages. The antenna switch is mounted under the top cover of the receiver rack. It is remotely controlled and is used

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[4] E. Dietrich, "Fernsehübertragungsstrecke auf Dezimeterwellen zwischen Hamburg–Hanover–Köln–Frankfurt M." and F. Kirschstein, "Die Übertragungseigenschaften der deutschen Fernsehleitungen," *VDE-Fachberichte*, volume 17, pages 1–12, number V; 1953.

to reverse the direction of transmission, which direction is indicated by a lamp signal. The pedestals of the three racks house the blowers.

The rack to the right houses the ultra-high-frequency transmitter, the intermediate-frequency power amplifiers, and the necessary power supplies. The left-hand rack holds in its upper part the ultra-high-frequency receiver, beneath which are its intermediate-frequency amplifier, video amplifier, and two power supplies. The center rack accommodates the picture and intermediate-frequency monitor unit together with the modulator and the power supplies.

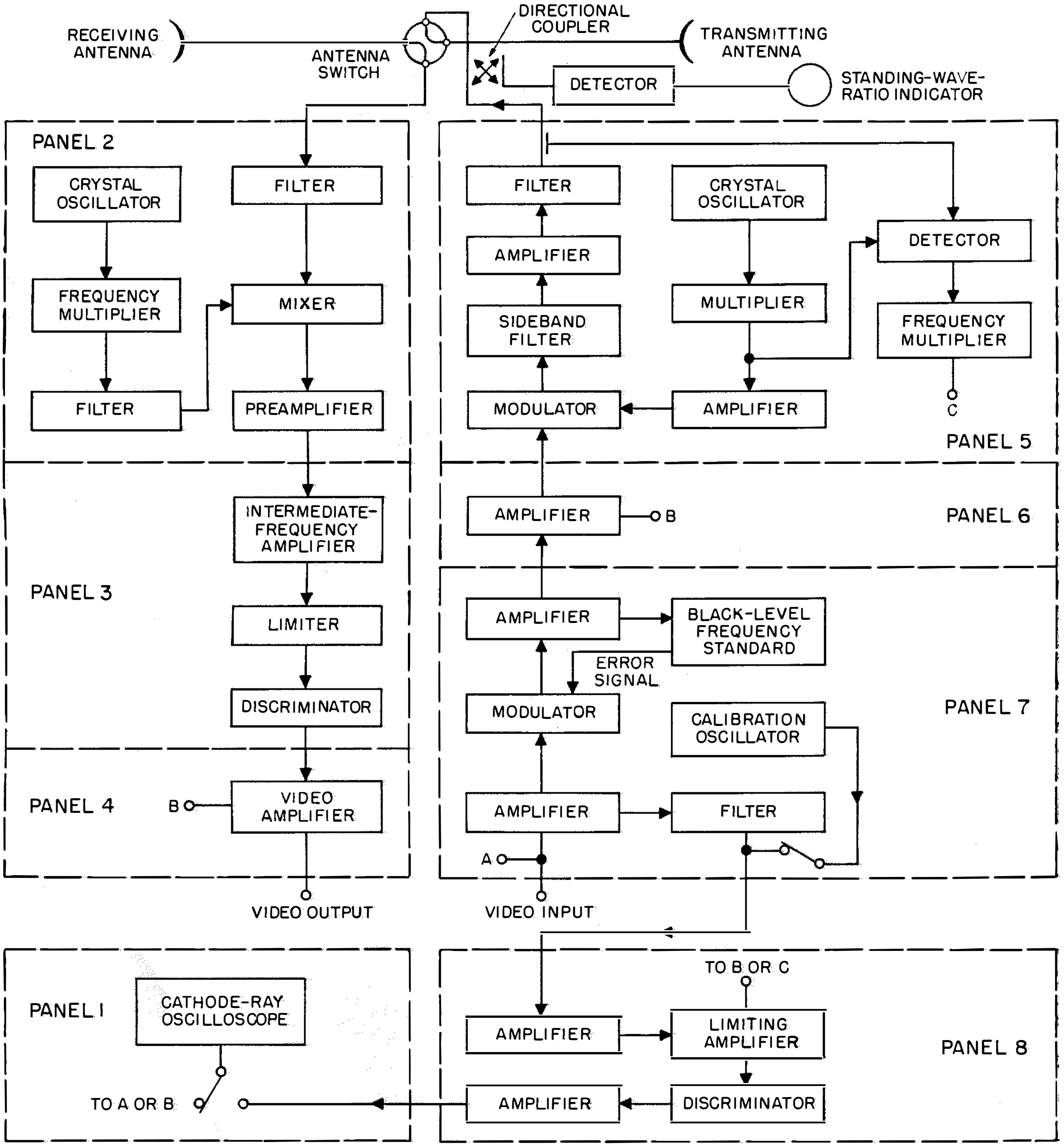

Figure 2—Block diagram of terminal transmitter and receiver.

The relay stations differ from this arrangement only in that they do not have the modulator and its power supply.

The sides of the racks are covered by demountable panels. The individual constructional elements are assembled on a vertical mounting plate that is perpendicular to the front side of the rack. Once the demountable side covers are removed, all parts and the tubes are easily accessible.

2.2 ELECTRICAL

2.2.1 Terminal Station

Figure 2 shows a block diagram of a terminal. In this diagram, the basic elements of the receiver are in vertical alignment in panels 2, 3, and 4 with auxiliary equipment to the left. Similarly, the transmitter elements are aligned vertically in panels 5, 6, and 7, with auxiliary apparatus to the right. This diagram also shows how the various stages are assembled in the individual panels.

The vertical-blanking synchronizing pulse (1.5 volts peak to peak across 75 ohms) is applied to the transmitter through the video-input jack in panel 7. After video-frequency amplification, this signal goes to a modulator that produces an intermediate frequency of 75 ± 6 megacycles. The frequency of 72.36 megacycles corresponds to the black amplitude level. It is compared with a black-level quartz-crystal-generated frequency. In case of a frequency deviation, an error voltage is generated to control the fine tuning of the modulator and bring about a suitable correction.

The modulator panel also includes a calibration oscillator adjustable from 68 to 83 megacycles for alignment of circuits. The synchronizing level is at 69 megacycles, white peaks are at 81 megacycles, and the black level at 72.36 megacycles as mentioned before.

The intermediate-frequency signal obtained from the modulator is amplified in the power amplifier (panel 6) from 0.5 volt to 20 volts and is applied to the modulator of the ultra-high-frequency transmitter (panel 5). There, it is mixed with a quartz-controlled frequency and the desired sideband is filtered out. That sideband is applied to the antenna through an amplifier, an ultra-high-frequency filter, and the antenna switch. The antenna lead is coupled to a measuring instrument for transmission level and a directional coupler to permit the standing-wave ratio to be checked for matching impedances to the antenna. The radiated signal is monitored by a picture monitor.

The received signal passes through the antenna switch and an ultra-high-frequency input filter to the mixer. The oscillator frequency is again generated by a quartz crystal followed by several multiplier stages. The resulting intermediate-frequency signal passes through a low-noise cascade-type preamplifier to the main intermediate-frequency amplifier (panel 3). This amplifier has an automatic gain control that compensates for signal variations as large as 40 decibels. After passing through a limiting stage, the video signal is obtained from the discriminator. This is applied to the video amplifier (panel 4) where it is again amplified, the black-level is adjusted if necessary, and the signal goes to the video output terminals.

The operation of the equipment can be checked by an intermediate-frequency monitor receiver on panel 8 in conjunction with the cathode-ray oscilloscope of panel 1. The former converts the frequency-modulated intermediate-frequency signal into an amplitude-modulated video signal, and the latter shows the television picture on a cathode-ray-tube screen. Below this tube is a switch connecting the cathode-ray tube to a waveform monitor for checking the video level by line and frame sweep frequencies.

2.2.2 Relay Station

A relay station does not differ greatly from a terminal station except for the omission of panel 7 containing the video-to-intermediate-frequency modulator and an arrangement whereby the receiver oscillator frequency is obtained from the transmitter oscillator frequency by a shift of 210 megacycles. The intermediate frequency signal is taken from the intermediate-frequency amplifier and applied to the power amplifier.

2.3 ANTENNAS

The antennas employ paraboloidal reflectors that are 3 meters (9.8 feet) in diameter. One of these is shown in Figure 3. The matching of the

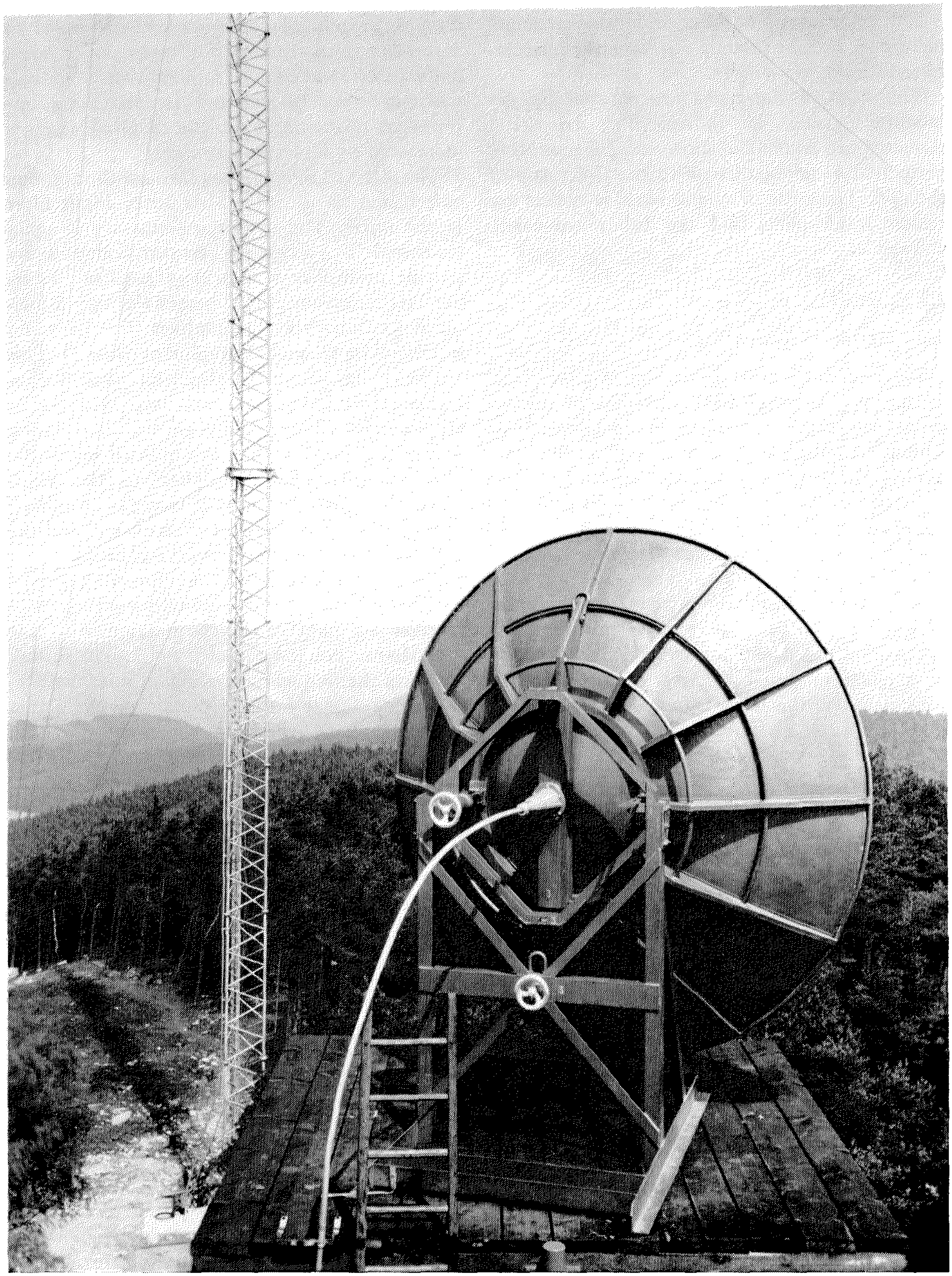

Figure 3—Paraboloidal antennas are used at all of the stations. They are 3 meters (9.8 feet) in diameter.

antenna to the transmission line is better than 0.95. Methods of obtaining this high degree of matching are described later.

3. Measurements

3.1 Receiver Sensitivity

The noise source, which is a gas discharge in a coaxial line, has an internal impedance of 60 ohms and a noise temperature corresponding to $70kT_0$ (k = Boltzmann's constant and T_0 = absolute degrees Kelvin); that is, the noise power appearing across a termination of 60 ohms per cycle bandwidth is 18.4 decibels above $1kT_0$. The noise generator is connected to the receiver input terminals via an attenuator having 1-decibel steps starting with zero. During the sensitivity measurement, the limiter in the main intermediate-frequency amplifier is replaced by an equivalent attenuation resistance.

With the gas in the noise source in an un-ionized state, the internal noise power at the intermediate-frequency output of the receiver is indicated by a rectifier and meter that need not be calibrated. The noise source is then energized, an attenuation of 3 decibels is inserted between the preamplifier and the main intermediate-frequency amplifier, and the ultra-high-frequency attenuation is increased from zero until the initial indication at the output rectifier is again obtained. The receiver noise figure is then 18.4 decibels minus the ultra-high-frequency attenuation. (Example: $18.4 - 5 = 13.4$ decibels, which corresponds to a noise power figure of 22.) Measurements taken on factory-produced equipments showed noise figures from 20 to 27.

3.2 Signal-to-Noise Ratio

A well-known method[5] was used to measure the average noise voltage peaks at the receiver output by means of a broad-band oscilloscope and comparison with a square-wave voltage transmitted over the system.

The square-wave generator supplies a voltage producing the full swing of 12 megacycles peak-to-peak. This voltage is applied to the video input of the terminal-station transmitter through a variable attenuator, which is adjusted so that the noise voltage peaks and square-wave pulses are equal in the receiver output. This gives the peak value of the noise, from which the signal-to-noise ratio can be computed. The signal-to-noise ratio depends substantially on the attenuation over the radio link. The measurements coincide well with computed values for signal-to-noise ratio and for a field attenuation over a radio link section of 15.3 nepers or 133 decibels.

3.3 Distortion Measurement

To obtain an idea on the distortion of a signal after having passed through several relay links, the equipments were tested by circulating pulses. The circulating system includes two open-air links, each of 330 meters (1083 feet), between which the channel is changed in a passive relay station. The arrangement is shown in Figure 4.

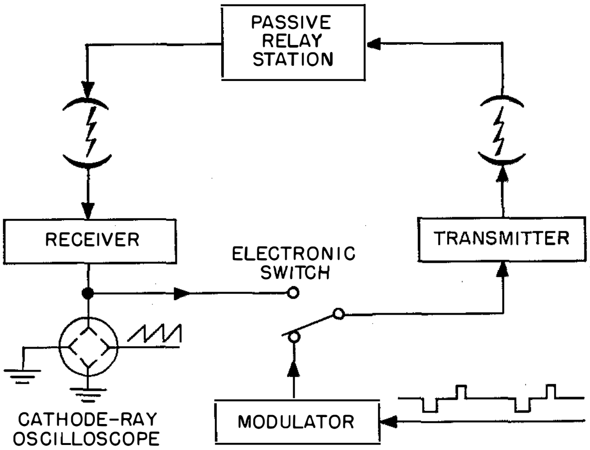

Figure 4—Setup for distortion measurements.

A frame-blanking synchronizing signal is applied to the modulator, which also receives as the contents of a picture a pulse of 1-microsecond duration and a rise time of less than 0.04 microsecond. An electronic two-position switch transfers the pulse to the transmitter intermediate-frequency amplifier and, immediately afterwards, closes the circuit between the intermediate-frequency amplifiers in the transmitter and receiver. The pulse can circulate as many as 20 times during one line sweep.

A gate circuit at the video output of the receiver may be used to inspect the measuring pulse after an adjustable number of circulations.

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[5] C. Cherry, "Pulses and Transients in Communication Circuits," Chapman and Hall, London; 1949.

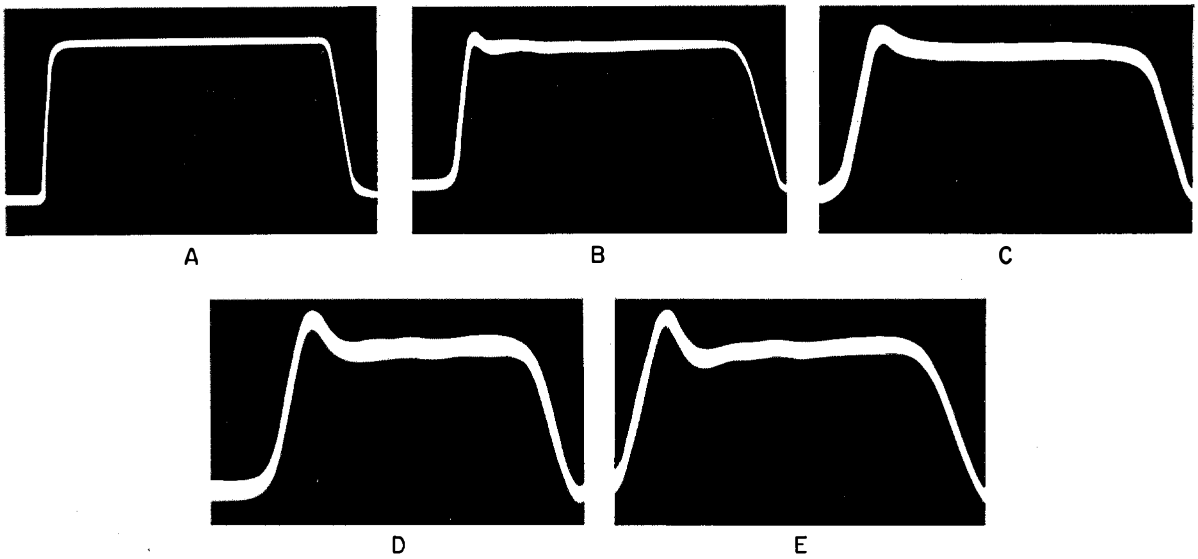

Figure 5—Circulation of square waves through the system of Figure 4. The original 1-microsecond square wave is at *A* and after the specified number of trips around the system at *B* for 1 trip, *C* for 6, *D* for 12, and *E* for 18.

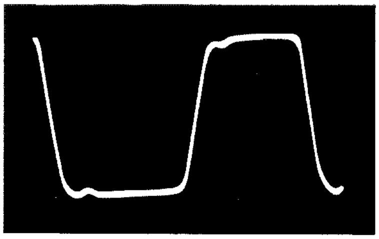

Figure 6—A 500-kilocycle square wave as received at Neustadt from Köln.

Figure 5 shows some examples of such observations: a measuring pulse before being supplied to the circular circuit, and after 1, 6, 12, and 18 runs.[6]

Figure 6 shows as an example of an operational measurement one full square wave at 500 kilocycles transmitted from Köln to Neustadt television station Weinbiet.

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[6] A. C. Beck and D. H. Ring, "Testing Repeaters with Circulated Pulses," *Proceedings of the IRE*, volume 35, pages 1226–1230; November, 1947.

Bihelical Traveling-Wave Tube with 50-Decibel Gain at 4000 Megacycles*

By W. P. G. KLEIN

C. Lorenz, A. G.; Esslingen, Germany

TRAVELING-WAVE tubes are commonly used for transmission in microwave relay installations. The output of the receiver and that of a local oscillator are mixed in a silicon diode to produce the modulated radio-frequency wave that is amplified in the traveling-wave tube for retransmission. The maximum output available from a silicon diode mixer is about 0.5 milliwatt. To produce about 5 watts of power for transmission, some 40 decibels or more of amplification must be obtained at the microwave transmitter frequency, requiring two conventional traveling-wave tubes in cascade. This gain can be obtained with a single tube, which will be described. Substantial savings in space, weight, and power are obtained with an increase in operational reliability for the entire relay system.

1. Requirements

In the 4-gigacycle-per-second† range, the power output required in a relay station is about 5 watts. If the tube is to operate near the saturation range, then the saturation gain of the tube must be at least 40 decibels. For reliability under general operating conditions, a gain of about 50 decibels should be obtained in the linear portion of the modulation range. With this high gain, the selection of the operating voltage is of special importance. Employing a normal oxide-coated cathode, the electron gun will produce a converging electron beam at low cathode loading. Therefore, an electron gun with approximately Brillouin flow was indispensable. The operating voltage was fixed at 1400 volts, permitting a satisfactory compromise between tube length and magnetic field. The magnetic field required for focusing the electron beam is about 550 to 600 gausses and can be produced by a permanent magnet.

The gain is significantly smaller at saturation than for small signals in high-gain tubes if no specific measures are applied to correct for this. To keep this difference within tolerable limits, two helixes were employed that have separate direct-current circuits and are coupled only by the electron beam. This results in a further acceleration of the electron beam by the voltage on the second helix, which is somewhat higher than that on the first helix. The difference between small-signal and saturation gains, which was originally 10 to 12 decibels, was thus reduced by approximately 2 or 3 decibels.

A lossy section is placed in the zone between the two helixes. Since the largest amount of power transfer takes place in a small part of the helix near the output end, the second helix should be as short as possible. On the other hand, the axial length of the lossy section should have a certain minimum for low-reflection wideband matching between it and the helix. The efficiency of the tube should not be unnecessarily reduced by the attenuation of the second or output helix; hence the low-loss section of the output helix should contribute a gain of at least 15 decibels. For these reasons, the localized attenuation occurring in the gap between the two helixes is not inserted in the middle of the total length of the two helixes, but towards the output end. The variation of attenuation along the total length is shown in Figure 1.

It is possible to make the attenuation increase approximately exponentially with various exponents. This is recommended to obtain a very-high additional attenuation from as short an axial extension as possible and with low attenuation in the helix. The rate of increase should be easily reproducible as the wave and the beam still interact in the region of moderate attenuation. The longer input helix is responsible for

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* The contents of this paper were disclosed at a Conference on Electron Tube Research held in Lansing, Michigan, on June 13–15, 1955, under the joint sponsorship of the American Institute of Electrical Engineers and the Institute of Radio Engineers.

† Giga ≡ kilomega = 10^9.

most of the amplification, while the low-loss output helix operates as a final power stage with moderate gain but good efficiency.

The tube elements are assembled in an evacuated envelope of uniform diameter as may be seen in Figure 2. This imparts good structural rigidity to the tube. The inner diameter of the envelope is determined by the diameter of the electron gun including a ferromagnetic shield inside the tube. As an ordinary oxide cathode is used, the electron gun requires more space than would a simple beam system with a dispenser-type cathode. For this reason, the inner diameter of the tube is 18 millimeters (0.71 inch).

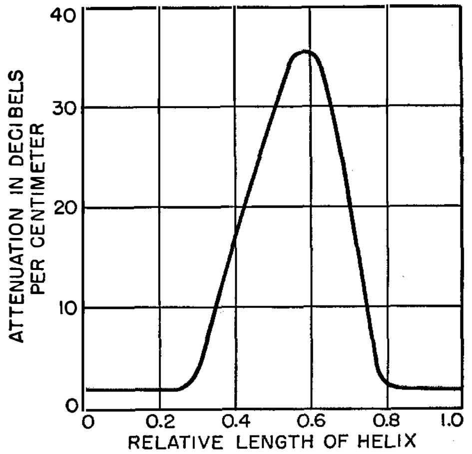

Figure 1—Helix attenuation as a function of relative length. The localized lossy-section attenuation reaches a peak at about 60 percent of the helix structure. The two helixes contribute the horizontal portions of the curve.

Additional precautions must be taken to attenuate fast backward modes but these means must not interfere with the function of the localized attenuation that affects only the fundamental helix wave. A piece of ceramic tubing carries an attenuating layer that has been found experimentally to be of optimum resistivity. The ceramic tubing separates the space between the outer shield and the helix into two heavily attenuated coaxial lines. The diameter of the ceramic tubing is so dimensioned that, for instance, waveguide waves in the space between helix and ceramic tubing do not come into the amplification range of the tube. Due to the high gain at both ends of the localized-attenuation section, the requirements for good

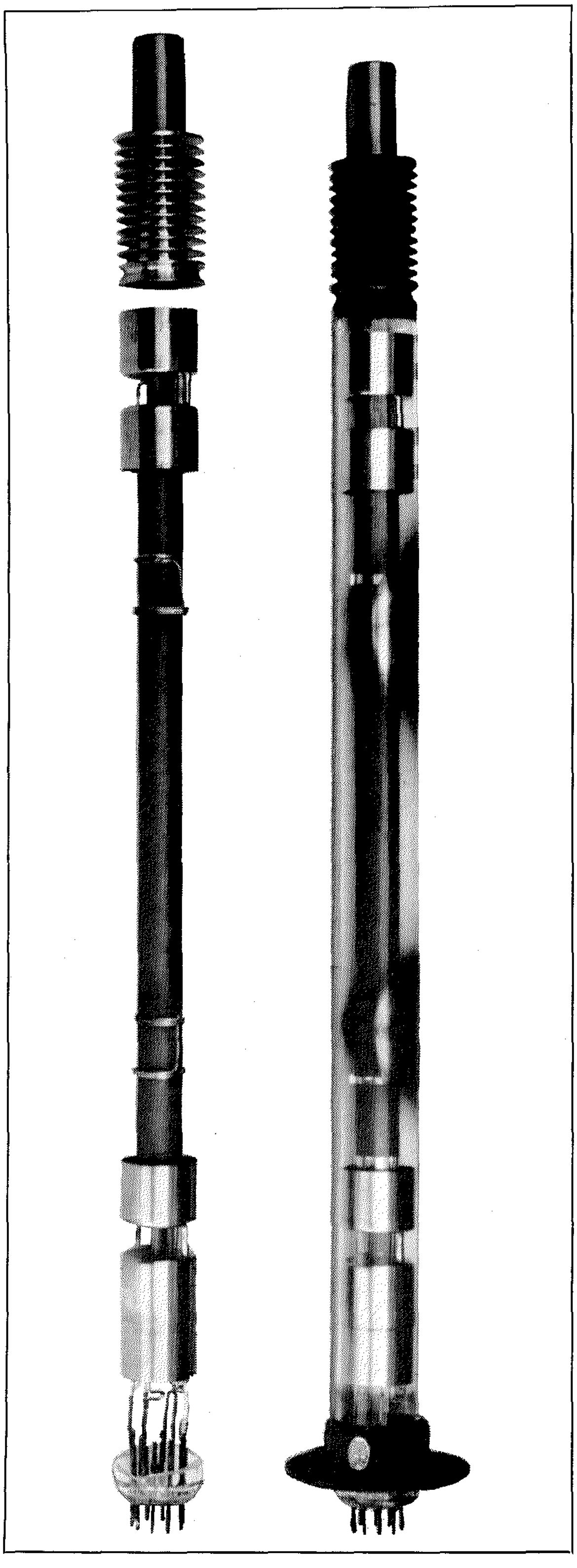

Figure 2—Laboratory sample of *LW53–V* traveling-wave tube. Over-all length is 35 centimeters (13.8 inches).

matching to the helixes are particularly high. This is especially true for the input helix.

To make the input and output impedance independent of variations in the other impedance, the excess of attenuation over gain should not fall below some minimum value, say, 20 decibels, which in this case changes the output impedance by only about 1 percent for full reflection at the input. Therefore, the total reverse attenuation must have a minimum value of 70 decibels. However, the localized attenuation should not require more than a certain portion of the axial length otherwise too large a section of the total helix length of 200 millimeters (7.9 inches) is lost to the process of amplification.

The dimensions of the helix were selected so that the parameter γa for the mean operational frequency is approximately 1.5. Experiments have shown that stability is reduced when a larger γa (for instance, 1.7) was effected by utilization of the same helix diameter and a voltage lower than the rated 1400 volts. With $\gamma a \approx 1.5$, the bandwidth of the tube is about 1 gigacycle between the half-power (3-decibel-down) points of the pass band.

The construction of a localized section of high attenuation and good wideband matching properties without using too much of the axial length of the helix presented a considerable problem. The attenuator is applied to the helix-supporting rods, which are pressed against the helix at several points by elastic clips. The variation of attenuation must be reproducible and capable of being checked by direct-current measurement before assembling the helixes.

The effect of the helix supports on impedance variation should be negligible. Due to the large bandwidth of the tube, an attenuation transition section of about 8 to 10 wavelengths was found experimentally to be desirable although it produces a noticeable difference between small-signal and saturated gain. It is possible to mount two support clips in the region of very high attenuation; the shape of the clips being unimportant. Another pair of support clips—one on the input helix and one on the output helix—are placed in regions of moderate attenuation. Their influence on impedance variations is not so critical in these regions as in regions of low attenuation.

Excepting for a good match to the localized attenuation, the most important requirement is the accuracy of the helix pitch to keep inner reflections to a minimum. In the period of development work, the only helixes available had a noticeable periodic structure. This resulted in heavy inner reflections towards the lower frequencies, that is, below 3.8 gigacycles. The difference in impedance of the tube in the "hot" and "cold" states, that is, with the beam on and off, was large. Only when means were available to reduce the periodic pitch variations of the helix by a special winding technique did this undesirable effect disappear. Also, the electrical stability of the tubes increased. However, even helixes with periodic pitch variations did not show any dips of the gain-versus-frequency curve or appreciable gain variations.

Attention must be paid to the signal-to-noise ratio of a high-gain traveling-wave tube. For a saturation power of 5 watts and a gain of 50 decibels, a noise factor of less than 30 decibels is necessary.

2. Constructional Details and Measurements

Figure 3 shows the small-signal gain and the saturation gain versus frequency; Figure 4

Figure 3—Low-level gain G_0 and saturation gain G_s as a function of frequency (gigacycle = kilomegacycle).

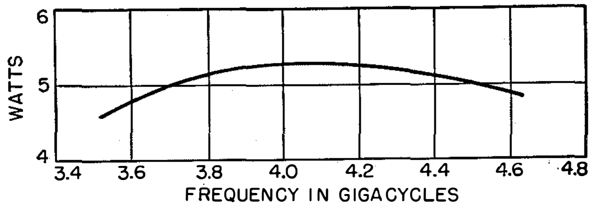

Figure 4—Radio-frequency power output for saturation condition plotted against frequency.

shows the saturation power. The use of an oxide cathode usually requires that the electron gun employ electrostatic focusing. The magnetic focusing of the electron beam within the helix approximates the Brillouin condition.

Measurements revealed that the noise increases with increasing magnetic field in tubes using electron guns having Brillouin flow. The helix current was also higher when the tube was operating near saturation as compared with small-signal performance. If the helix and all other constructional elements of the tube are carefully adjusted, the helix current for negligibly small signals amounts to about 0.3 to 0.6 milliampere for a collector current of 34 milliamperes. At saturation power, however, the helix current rises to about 0.8 to 1.5 milliamperes. The magnetic field required for this current distribution is between 550 and 600 gausses. Figure 5 shows noise and helix current plotted against focusing field strength for two tubes. It will be seen that the noise factor is independent of the focusing field for low values of field. It is only when the field is increased that the noise factor climbs very steeply. The diagram also shows the limits, marked by arrows, of the field strength within which the tube can be operated with maximum output power.

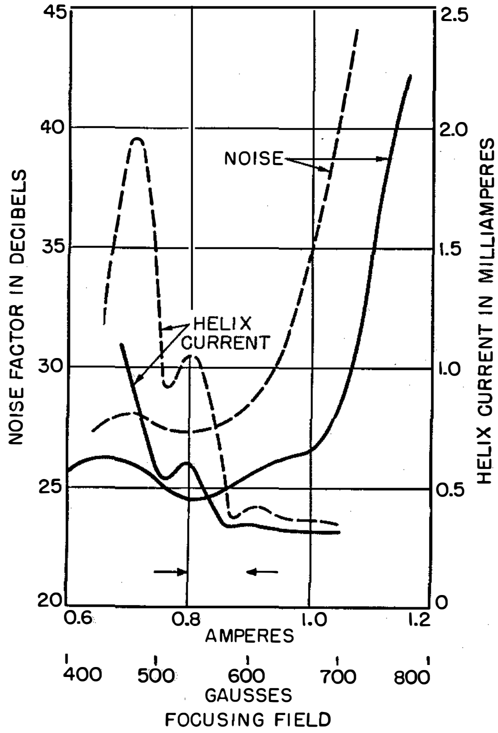

Figure 5—Noise factor and helix current related to focusing field for two tubes, one shown by the solid curves and the other by broken-line curves. The arrows indicate the focusing-field range over which maximum power can be obtained from the tubes.

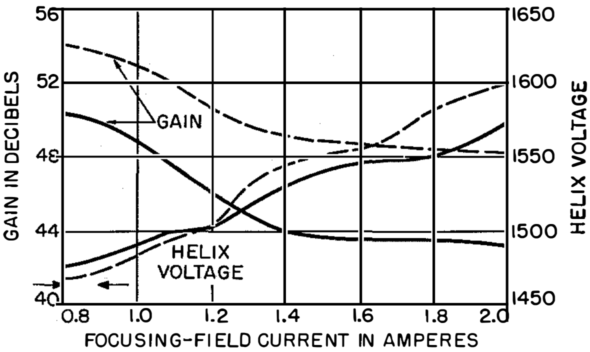

Figure 6—Gain and optimum helix voltage plotted against field current for low-level operation for two tubes. The beam current was 34 milliamperes. The arrows indicate the range of field current over which maximum output may be obtained.

Since the Brillouin condition was necessary for the electron beam, both gain and maximum power output decreased with increasing strength of the focusing field. Figure 6 shows the low-level gain of two experimental tubes versus the magnetic focusing field. The helix voltage was optimized at each measured point and is also shown on the same diagram.

Figure 7 is a plot of the maximum power output of the two experimental tubes against field strength. In the tube corresponding to the broken line, the mounting of the electron gun seems to lack accuracy. This was also indicated in the variation of the helix current with field strength as shown in Figure 5. There are distinct maximum and minimum values of helix current that oscillate about an average value that decreases with increasing magnetic field strength. These peaks are less conspicuous in the curve for the helix current of the other tube. The maximum power output of the first tube plotted against field strength shows the same trend as the helix current, except that a maximum of helix current corresponds to a relative minimum of output power. As to the second tube, increasing field strength results in a steady decrease of the maximum power output.

The effect of the further acceleration of the electron beam by the output helix with its separate direct-current supply can best be observed from the curves of output power plotted against input power of Figure 8. If the direct voltages on both the input and output helixes are adjusted for maximum gain at small signals, curve *A* is obtained. The additional degree of freedom provided by this design permits the output-helix voltage to be adjusted for optimum performance independently of the input helix. The maximum power output for this condition is about 4 watts and the range of modulation is linear up to about 2 watts.

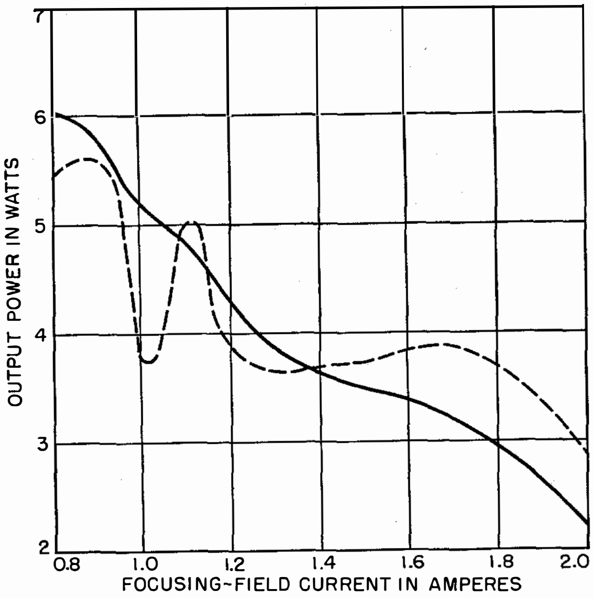

Figure 7—Saturation power output versus focusing field for two tubes.

If both helix voltages are now raised by the same increment to produce maximum power output, curve *B* is obtained. At these higher helix voltages, the gain for small signals is reduced. With increasing input power, the gain of some tubes is also increased and reaches saturation at about 5 to 5.5 watts. If now the voltage of the output helix is raised further above that of the input helix, the maximum power output will be attained and will rise to about 6 or 6.5 watts, as can be seen from curve *C*. In this case, the saturation gain is about 2 decibels higher than for curve *B*. It is seen that curve *C*, after a steady climb, visibly increases its slope, which falls again when the curve reaches the region of saturation. To round off this observation, the gain has also been plotted against power output for these three cases in Figure 9.

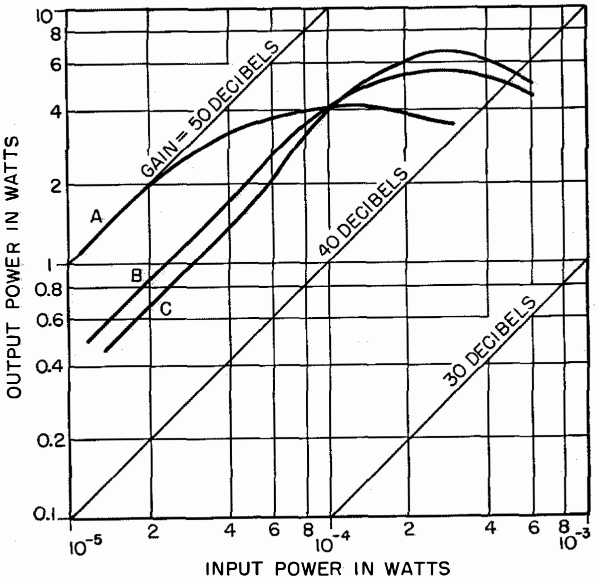

Figure 8—Radio-frequency output power plotted against radio-frequency input power for different values of helix voltages. Curve *A* is for maximum gain under small-signal operation and requires 1470 and 1500 volts on the input and output helixes, respectively. Curve *B* is for maximum power output obtained by simply increasing the helix voltages to 1600 and 1630 volts. By increasing the output-helix voltage to 1670 volts, the further increase in maximum power output shown by curve *C* results. In all cases, the beam current was 34 milliamperes.

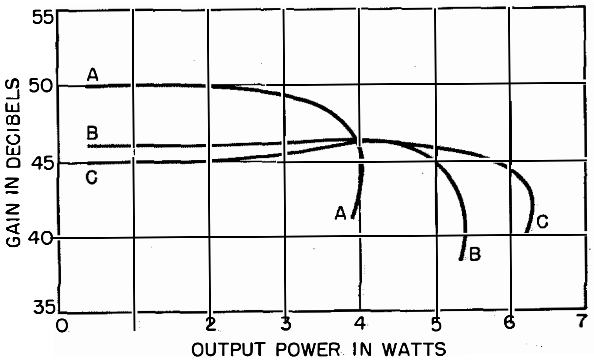

Figure 9—Gain versus output power for the three conditions of helix voltages described in Figure 8.

If an alternating voltage of 50 cycles, for instance, is superimposed on the helix direct voltage, a display may be obtained on a cathode-ray oscilloscope that relates the radio-frequency power output and the direct voltage on the helix. Figure 10 shows such oscillograms; curve *A* is for low-level operation and curve *B* is for saturation operation. These two curves correspond to the conditions outlined for the similarly identified curves of Figure 8. Curves *C* and *D* were obtained when the output-helix voltage was increased further to obtain maximum power output.

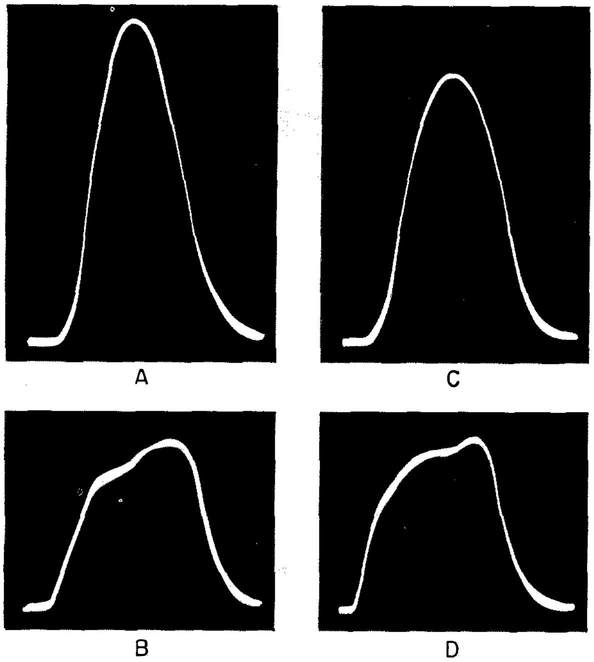

Figure 10—Oscillograms of radio-frequency output power as a function of the helix voltages. An alternating voltage is superimposed on the direct voltage applied to the helixes. *A* and *B* correspond to the conditions for those curves in Figure 8. Curves *C* and *D* were obtained by increasing the output-helix voltage to obtain maximum power output.

In high-gain traveling-wave tubes, it is essential to know about internal reflections in addition to gain, bandwidth, saturation power, noise factor, and stability. There are possibilities for reflections not only at the points of transformation from the helix ends to the waveguides, but also along the helix proper, at the support clips, and at the two transitions to the localized attenuating section. A sensitive method of measuring these reflections is the measuring of the difference in input impedance and output impedance in the "hot" and "cold" states of the tube.

To determine the internal reflections, the waveguide should be sufficiently well matched to the input helix so that there are no reflections at this junction. The impedance can now be observed while the helix voltage is varied. A clear picture of the reflections in the interior of the tube is obtained if a suitable alternating voltage of power frequency is superimposed on the helix direct voltage. An oscilloscope will show a horizontal line if there are no reflections or if the tube is not in operation. The length of this line is proportional to the alternating voltage superimposed on the direct voltage of the helix. If reflections occur at the output end of the helix or elsewhere in the tube, then the horizontal line will be deformed. The ordinate corresponding to each value of the helix voltage will represent a certain degree of reflection.

Two typical examples of such deformations, which can assume sinusoidal shapes, are shown in Figure 11. The amplitude peaks of these oscillations can offer a clue to the magnitude of the internal reflections and the periodicity to the point at which the reflection takes place. Measurements of this type are made at the input and output of the tube and for as many frequencies as possible. At the opposite end of the tube, a waveguide branch can be installed to obtain data on the amount by which the attenuation exceeds the gain.

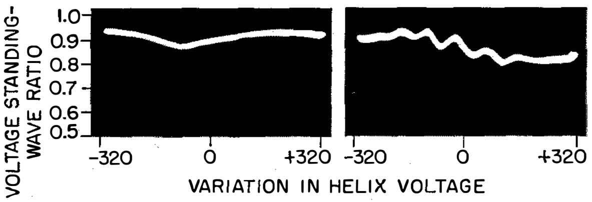

Figure 11—Oscillograms of variations in output impedance caused by internal reflections in two tubes. The abscissa values are for the instantaneous amplitudes of the alternating voltage superimposed on the normal direct voltages on the helixes.

If the maximum impedance deviations caused by reflections in the tube interior are plotted as degrees of matching against frequency, the curves shown in Figure 12 are obtained. These curves are for three different tubes.

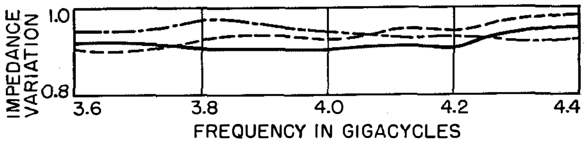

Figure 12—Variation of impedance caused by internal reflections plotted against frequency for three tubes. The impedance variation is the minimum ratio of the impedance with the beam on to the impedance with the beam off.

The input and output impedances of the tube should now deviate from the characteristic impedance of the waveguide coupled to it by only a very small amount throughout a fairly large frequency range. Thus, the tube can be very well matched within a limited frequency range of, say, 30 megacycles to the coupling circuits by means of additional selective tuners. It is well known that this is particularly true for the output impedance. The output impedance of a tube, plotted on a Smith chart, is shown in Figure 13. With the tube switched on and without additional tuning means, the voltage standing-wave ratio is not greater than 1.4 between 3.8 and 4.4 gigacycles.

Due to the large level differences between input and output circuits, the whole amplifier or repeater unit should be carefully shielded to avoid stray couplings that might cause additional undesired impedance variations, and, hence, group-delay time distortions.

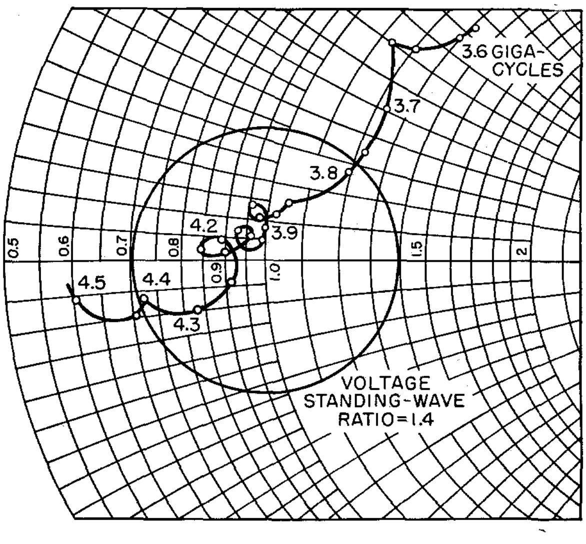

Figure 13—Output impedance as a function of frequency. The frequency values indicated are in gigacycles.

From a recent paper[1], it was learned that the noise behavior of traveling-wave tubes with electron guns producing Brillouin flow in general is not as good as for a tube with a partially shielded gun. Recent measurements show that the noise increases with increasing radio-frequency input power near saturation in tubes with Brillouin flow. Figure 14 shows a plot of the noise figure against radio-frequency input power for three tubes using shielded guns. The noise increases up to some 40 decibels, which is intolerable in the case of a high-gain tube.

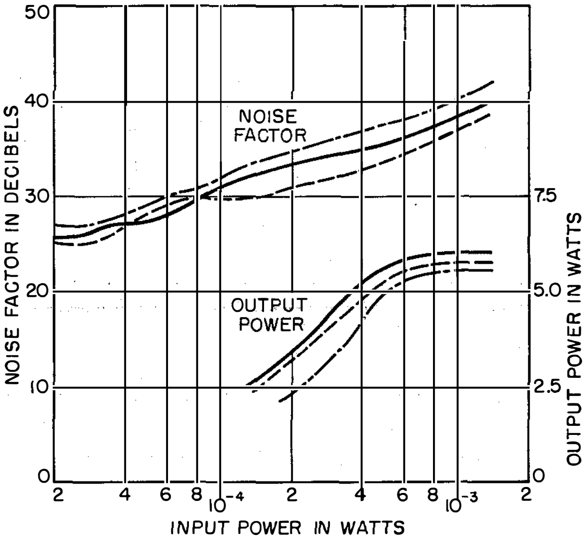

Figure 14—Noise factor versus radio-frequency input for three tubes. The beam currents were 34 milliamperes.

In view of this performance, a modified partially shielded electron gun was developed. The noise factor of three tubes with this gun is plotted against magnetic focusing field strength in Figure 15. It can easily be seen that in this case the noise is almost independent of the field. The measured noise factor plotted against increasing radio-frequency input power is shown in Figure 16. The noise factor of these tubes at low level is approximately 3 to 4 decibels lower

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[1] J. T. Mendel, "Magnetic Focusing of Electron Beams," *Proceedings of the IRE*, volume 43, pages 327–331; March, 1955.

than that of tubes with Brillouin flow. Furthermore the noise factor only increases about 4 to 5 decibels at saturation and its value in general remains below 30 decibels. This occurs if the helix voltage is approximately adjusted for maximum gain for low-level operation.

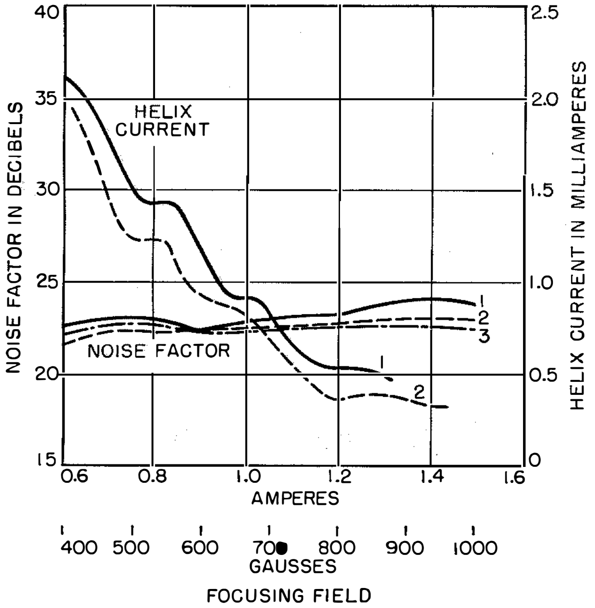

Figure 15—Noise factor and helix current plotted against focusing field for three tubes employing partially shielded electron guns. The beam currents were 34 milliamperes.

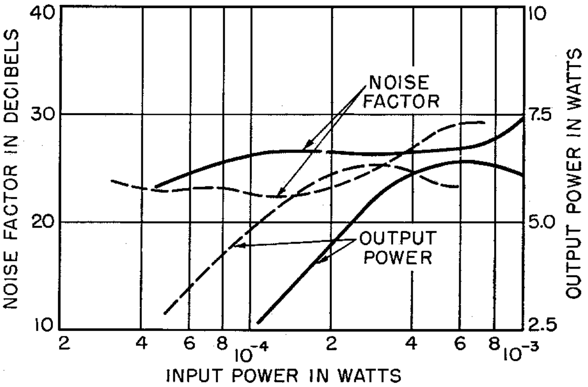

Figure 16—Noise factor and radio-frequency output power plotted against radio-frequency input power for two tubes having partially shielded electron guns. The beam currents were 30 milliamperes.

The tubes with partially shielded electron guns were found to be less critical in operation than tubes with Brillouin flow. Finally, it was observed that the saturation power output of a traveling-wave tube with a partially shielded gun was higher than that of a tube with a Brillouin-type gun with the same electrical data. The average value was 7.5 to 8 watts instead of 6 to 6.5 watts for the tube with Brillouin flow. The gain was also a few decibels higher.

Sampling Procedures on Finished Chassis and Equipment*

By HENRY KNAPP and CHARLES HARTMANN

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UNRESTRAINED demand for high quality and unquestioned reliability is something that everyone in the electronic industry is experiencing today. It cannot be said that these demands are unjust or impossible for all too often the performance of electronic equipment becomes a matter of life and death.

How, then, does a company build equipment possessing these quality characteristics and how do manufacturers assure their customers and themselves that performance of the equipments in the field will be satisfactory before the fact?

Certainly first-rate production techniques and processes must be installed and maintained. But the watchdog of that maintenance is usually inspection of some kind.

The employment of sampling as a technique to replace 100-percent inspection provides additional inspection coverage for the same inspection effort. We accept this as a statement of fact in applying the sampling technique to inspection of completed equipment. Obviously, however, the use of sampling procedures on completed chassis does not in itself warrant blind faith in the product.

The inspection and control of purchased components must be reliable, and statistical-quality-control techniques should be used for incoming inspection to the fullest extent. Additional information beyond that obtained from routine test and inspection pertaining to performance, reliability, and life on critical items is the responsibility of special laboratory groups within the quality-control organization.

The need for good quality control during assembly and soldering cannot be overlooked. Of course, methods and procedures will vary from job to job as well as from company to company, but probably the greatest need in the assembly area is for immediate information about any trouble. It is wise to use wherever possible a system that pin-points the location of the trouble, the type of fault, and the responsible operator or operation. We call it the point-to-point or operator-identification technique. Figure 1 is a point-to-point tally sheet or chart diagram in which each component and soldered joint is identified and listed in sequence. The inspector notes a defect in the proper spot on the tally sheet and

Inspector:
Date:

RT 70 IF CHASSIS POINT-TO-POINT WIRING INSPECTION

	C-156				Ground				0-101												C-157			Ground					Std.-off					TOTALS
	A □	B ⌓	C △	G —	G8	G9	G10	G11	1	2	3	4	5	6	7	8	9	10	11	12	A □	B ⌓	G —	G12	G13	G14 L	G14 C	G15	TP5	TP6	TP7	TP8		
No Solder																																		
Cold, Rosin Solder																																		
Insuf. Excess Solder																																		

Figure 1—Sample section of a wiring-inspection record. Each soldering point is identified on a wiring diagram. The symbols for *C-156* and *C-157* will be recognized as those used for the terminals of electrolytic capacitors. Several of these report sections will be needed for most equipments.

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* Reprinted from *Proceedings National Symposium on Quality Control and Reliability in Electronics*, pages 15–18; 1954. Presented at the Symposium in New York, New York, on November 12, 1954.

the foreman can tell at a glance the source of the trouble and take corrective action.

Such steps as these: incoming inspection control, specialized testing and research-laboratory examinations of purchased components, and pinpointing of area and operator defects on the production line are necessary prerequisites to successful sampling procedures in the inspection of completed chassis.

1. Sampling

Sampling as a technique to replace 100-percent inspection is not a new idea. It has been used in many places and for many different products. In a great many of these instances, the product was fairly simple and inspection error could be kept at a minimum. Sampling of completed chassis and subassemblies has been carried out previously by various government agencies, but in almost all cases this sampling inspection was preceded by a normal 100-percent inspection. The extensive sampling of completed assemblies direct from production is a comparatively new approach especially in complex electronic equipment that by its inherent design and its requirements has a high potential for error.

The chief objective of this sampling procedure being to insure a consistently high quality of manufacture that produces finished equipment of assured reliability, repeated emphasis must be placed on the self-evident observation that *quality must be built into the equipment, it cannot be inspected in.*

An integral part of a production process is the operator on the line. The chief requirement for high-quality work is the desire on the part of the operator to produce that quality. The operator must want to produce good work or no plan ever designed will improve and insure this quality. Together with this desire, the operator must be well trained, must have proper tools and working conditions, and above all must know the difference between good and poor workmanship. Too often, inspection procedures are such that inferior workmanship is never brought to the attention of the operator responsible for it.

An obvious and very effective method of approaching this goal is to return defective work to the operator responsible for it. The faults of a given operator become evident from the defects listed on the inspection tally sheet and from the various repair operations. Moreover, if the defect is a direct result of some previous operation or a component, the operator can inform the foreman immediately and corrective action can be taken. If the operator is working on an incentive plan of the bonus type, the bonus earned will be closely related to the effectiveness of the work done since high-quality work will not be returned for time-consuming repair.

It may be noted that any manufacturing organization is in business for one reason, profit. A high-quality product at high cost will not enable the company to remain in competition very long. Thus the other objective of this sampling procedure is to lower the production cost of the equipment. This objective can be accomplished in part by lowering the amount of scrap and rework and by lowering the over-all inspection cost.

One of the primary considerations in installing a sampling plan is the type of production process to be sampled. One common process to be utilized is the ordinary straight-line procedure where an inspection station is placed at the end of one or more production operations and the inspector is responsible for examining the work from these specific operations. At this point, the responsibility for any defective work must be clearly established or the entire effectiveness of the plan will be lost. It is also possible for the work of each individual operator to pass but for a lot to be rejected because of an accumulation of minor defects. The problem then becomes one of training operators to refine the workmanship techniques.

A second type of process that has proved adaptable for sampling is the batch type. A group of identical chassis are mounted on a multiple-position rotating jig, commonly referred to as a "lazy Susan." A single operator is responsible for performing all of the assembly and soldering operations necessary for completion of each chassis. At the completion of the last operation on the last chassis on the wheel, the entire batch is submitted to the inspector. This type of process has several advantages.

A. All defects can be attributed to a single operator.

B. The lot size is constant and no opportunity for mixing lots is possible.

C. Minimum handling occurs before inspection.

D. The operator can be informed immediately of defects.

A modification of this lazy Susan process is the use of two wheels. In this case, the operator continues production on the second wheel while the work on the first is being inspected. At the completion of the second wheel, the operator makes necessary repairs to the first batch. Until all repairs are reinspected and cleared, no new units may be started on either wheel. This condition reduces the bonus earning time of the operator, who will avoid it.

Difficulties may be encountered in the installation of the sampling procedure, chiefly centered in the attitude of affected personnel. The operator will realize quickly that she no longer has the protection given by 100-percent inspection; she can no longer continue to produce units at the maximum rate with no personal concern over quality. Penalty for careless work given in the form of rework and repair time taken out of production, puts the emphasis for the operator in the place where it hurts, in her pay check. The inspector, on the other hand, may see extensive sampling as a means of greatly reducing inspection personnel by the substitution of "technical services." The production foreman may see in the plan another harebrained idea thought up by the statistical engineer, which will prevent him from meeting his monthly production schedule. Last but not least, the inspection foreman may complain that sampling means a lot more paper work in maintaining effective data and charts and this will overload his already-crowded schedule. To each of these groups must be demonstrated with clarity and emphasis the fact that work originally produced at a high level of quality is the answer to their doubts and fears.

The matter of returning defective work directly to the operator responsible rather than to an especially designated repair operator, as is the custom in many plants, may require some formal negotiation. While some local compromise arrangements may be in order so long as the principle of operator responsibility is not compromised, in the long run successful selling of the idea supplies the solution to all phases of the problem.

Well-planned administration and control of sampling procedures can prevent breakdown of the system because of occasional human weakness. An inefficient inspector can accept a bad lot and claim that defects found in performing subsequent operations were all located in the uninspected portion of the lot. An ill-advised foreman can manage in an extreme case to hold a rejected lot aside and resubmit it at a later date without rework, hoping that selection of different units for a sample will enable the lot to pass. However, controls such as serial numbers on units, the listing of all serial numbers in a given lot on the inspection record, stamping of the items selected for the sample, and signatures on submission tickets can regulate the system successfully.

2. Classification of Defects

The most-important consideration in any sampling is the classification of defects. Unless all inspectors classify each particular type of defect in exactly the same way, no acceptable quality level or process average can be realistic. A classification is the enumeration of possible defects of the unit of product according to their importance. A defect is any deviation from requirements of the specification, drawings, or purchase-order descriptions, and any changes pertaining to any of them made in the contract or order. Defects are customarily classified in the following manner.

2.1 Critical Defects

A critical defect is one that judgment and experience indicates could result in hazardous or unsafe conditions for individuals using or maintaining the product. For major end-item units, a defect that could prevent the performance of the tactical function of the end item is classified as critical.

2.2 Major Defects

A major defect is one, other than critical, that could result in failure or materially reduce the usability of the unit of product for the intended purpose.

2.3 Minor Defects

A minor defect is one that does not materially reduce the usability of the unit of product for its intended purpose, or is a departure from established standards but having no significant bearing on the effective use or operation of the unit.

2.4 Control Defects

A control defect is any departure from good workmanship that will in no way affect the end use of the product.

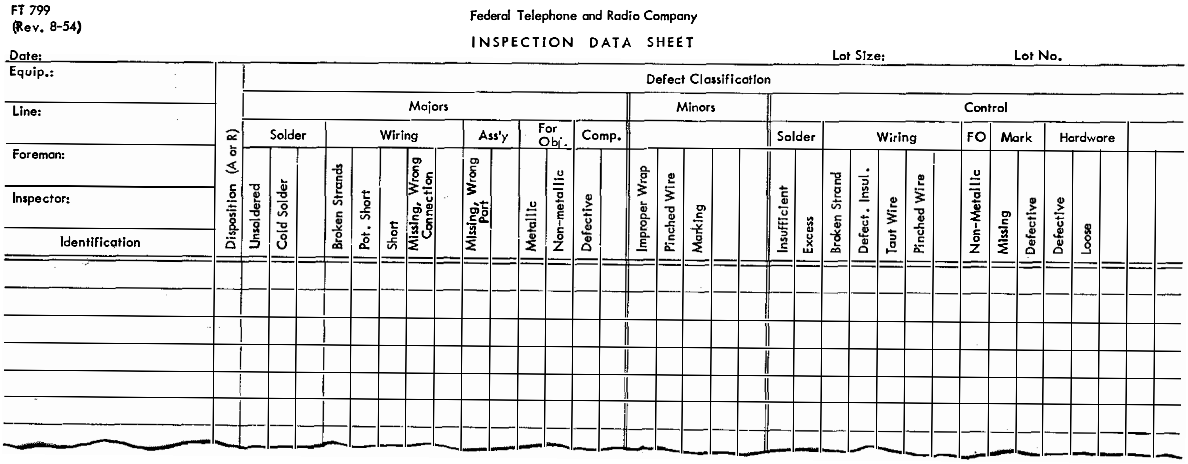
It may be noted from Figure 2 that there is a great similarity between the above classification of defects and that used by various government agencies. Since many of the units produced in our company are sold to the government, it is natural that the defect classification should be in accord, otherwise a lot that was acceptable by the company might be rejected by the government.

The classification will list all categories of defects relevant to the mechanical assembly of the equipments under consideration. Within each category, as many specific defects as possible should be described and classified or weighted in terms of degree of effect on service, maintenance, and performance of the equipment. For example, excess solder on a joint would be named in the category of soldering, and would be defined as a major defect where the amount of solder was sufficient to cause a possible short-circuit. It would be called a minor or control defect, however, when the amount of surplus solder involved only a question of appearance or workmanship standards. The more complete the listing of

TABLE 1

Classification of Defects

Category	Major	Minor	Control
1. Soldering			
1.1 Unsoldered joint	X		
1.2 Insufficient solder	X		X
1.3 Excess solder			X
1.4 Cold solder	X		X
2. Wiring and Cabling			
2.1 Broken strands	X		X
2.2 Poor lead dress	X	X	X
2.3 Defective insulation	X	X	X
2.4 Taut wire	X		X
2.5 Improper wrap	X	X	X
2.6 Improper crimp			X
2.7 Potential short-circuit	X		X
2.8 Short-circuit	X		
2.9 Insulation in solder			X
2.10 Missing or wrong connection	X		
3. Assembly			
3.1 Fastening and hardware	X	X	X
3.2 Improper mechanical operation	X	X	X
3.3 Improper assembly	X	X	X
3.4 Missing, wrong part or component	X	X	X
3.5 Lubrication	X	X	X
3.6 Pinched wire	X	X	X
4. Foreign Objects			
4.1 Metallic	X	X	
4.2 Nonmetallic	X		X
5. Finish			
5.1 Improper finish	X	X	X
5.2 Defective finish	X	X	X
6. Marking and Identification			
6.1 Safety, warning, or operational	X		X
6.2 Identification	X	X	X
7. Components			
7.1 Defective	X		X



FT 799
(Rev. 8-54)

Federal Telephone and Radio Company

INSPECTION DATA SHEET

Date:
Lot Size:
Lot No.
Equip.:
Line:
Foreman:
Inspector:
Identification

Disposition (A or R)

Defect Classification

Majors — Solder: Unsoldered, Cold Solder; Wiring: Broken Strands, Pot. Short, Short, Missing, Wrong Connection; Ass'y: Missing, Wrong Part; For Obj.: Metallic, Non-metallic; Comp.: Defective

Minors: Improper Wrap, Pinched Wire, Marking

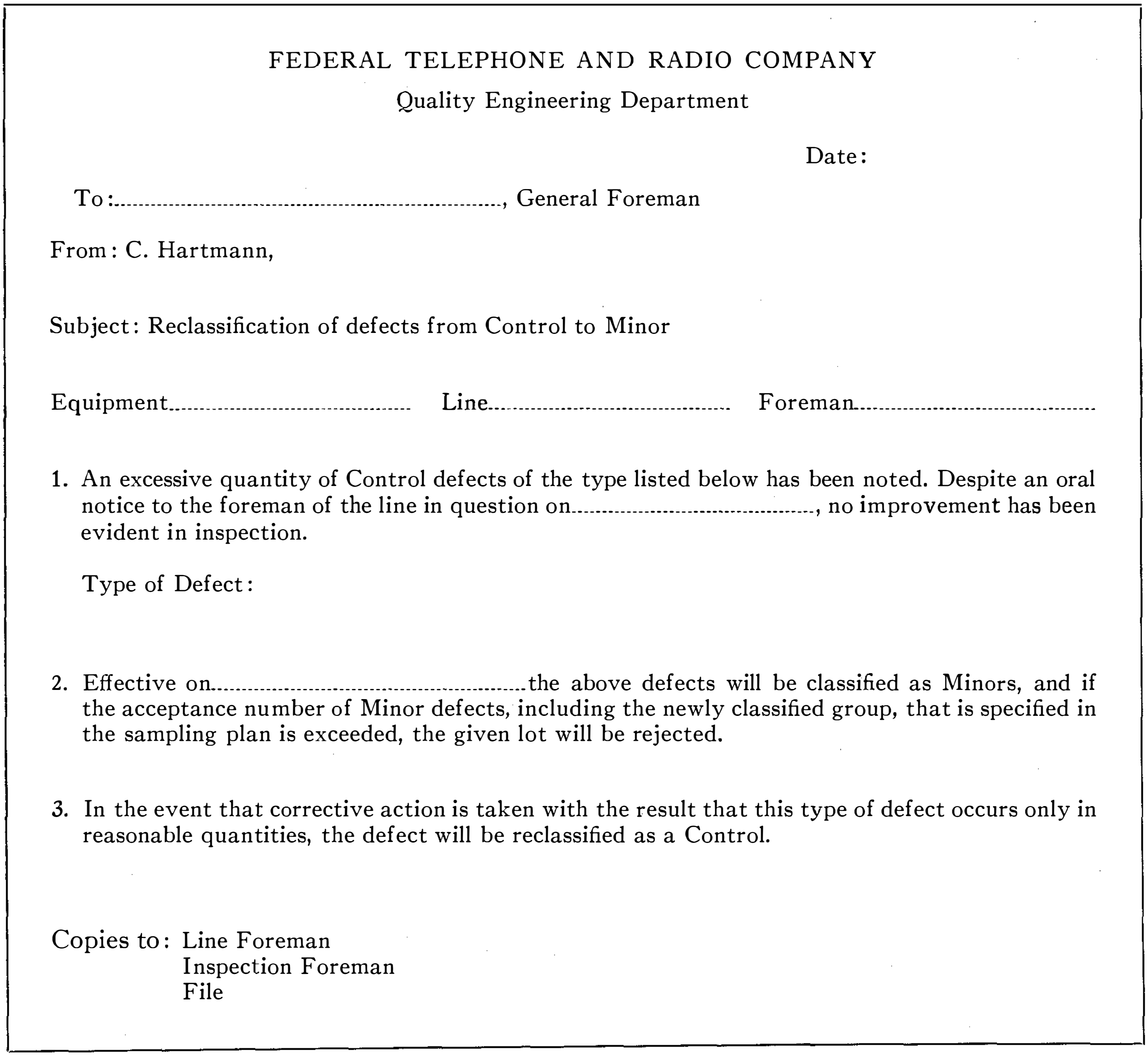
Control — Solder: Insufficient, Excess; Wiring: Broken Strand, Defect. Insul., Taut Wire, Pinched Wire; FO: Non-Metallic; Mark: Missing, Defective; Hardware: Defective, Loose

Figure 2.

defects, the more complete and accurate will be the results of inspection. Table 1 is a classification of defects.

One of the most-important phases of the program is the training of inspectors. In our instance, selected quality-control personnel were utilized as instructors. Since most of the inspectors involved were experienced, the training was devoted to an understanding of the function and methods of sampling, the classification of defects, and to the meaning of acceptable quality levels and like terms. One difficulty encountered in the training program was the concept that control defects must be recorded but would not be repaired. The inspectors reasoned that if the defect was not of sufficient importance to need repair, it was not important enough to take time to record. Only when it was emphasized that a record of an increasing trend in control defects pointed to a decreasing quality level and that repair work in a complicated chassis could create new defects like burned or broken wires, did the inspection group accept the validity of the concept.

The recording of large numbers of control defects notifies production personnel that steps must be taken to improve quality. If no improvement is noted, control defects should then be



FEDERAL TELEPHONE AND RADIO COMPANY
Quality Engineering Department

Date:

To:.., General Foreman

From: C. Hartmann,

Subject: Reclassification of defects from Control to Minor

Equipment.. Line.. Foreman..

1. An excessive quantity of Control defects of the type listed below has been noted. Despite an oral notice to the foreman of the line in question on.., no improvement has been evident in inspection.

   Type of Defect:

2. Effective on..the above defects will be classified as Minors, and if the acceptance number of Minor defects, including the newly classified group, that is specified in the sampling plan is exceeded, the given lot will be rejected.

3. In the event that corrective action is taken with the result that this type of defect occurs only in reasonable quantities, the defect will be reclassified as a Control.

Copies to: Line Foreman
Inspection Foreman
File

Figure 3—Form of notification that control items have been reclassified as minor faults until quality improves.

INSPECTION PROCEDURE
FOR
ACCEPTANCE SAMPLING

Equipment.. Effective Date..

Line.. Instruction No...

Inspection Position..

Inspection Foreman..

Sampling Plan

AQL-Major................Defects per hundred units (dphu)

AQL-Minor................Defects per hundred units (dphu)

Lot Size	Sample Size	Acceptance Number			
		Majors		Minors	
		Acc.	Rej.	Acc.	Rej.

Instruction:

1. All lots whose majors and/or minors exceeds the acceptance number will be returned to the Production Department for rework.
2. In event of a concentration of minors in the following catagories, lots will be returned to the Production Department for rework for that catagory even where the lot is acceptable in all other ways.

Catagories: (a) Hardware deficiencies
(b) Identification and/or marking

Prepared by:

Date

....
Quality Engineering

Figure 4.

reclassified temporarily to the category of minors with a resultant effect on the acceptance of a lot. A sample notification form is given in Figure 3.

3. Acceptable Quality Levels

To set a standard of quality, it becomes necessary to take several things into consideration. Such factors as customer requirements, point of inspection (final or in process), and the complexity of the equipment all have a bearing. If the requirements of the customer are strict and the equipment very complex, it becomes exceedingly difficult to design an equitable sampling plan. On the other hand, considering the human factor involved, can we assume that even 100-percent inspection assures equipment of the proper quality? In some cases, it may be desirable to use sampling for purposes of rejection only. When inspection of the sample shows few enough defects to permit acceptance of the lot, then with very complex equipment it may be desirable to modify the plan and do some inspection of the remainder of the lot.

It will be found in general that most equipments lend themselves to some form of sampling procedure. It then becomes necessary to establish the level of acceptable quality (AQL). This level in effect determines the maximum number of major and/or minor defects allowable in the sample while still permitting a given lot to be accepted. Since complexity of the equipment is usually the prime consideration, the following empirical limitations might be used.

$$\text{Major AQL} = 2 \times \text{Soldered Connections}/100,$$

$$\text{Minor AQL} = 10 \times \text{Soldered Connections}/100.$$

An acceptable quality level thus established would be applied to the original line production only. Outgoing quality levels would be considerably tighter.

These limits will be equitable if the majority of operations center around soldering. If a substantial portion of the operations involve mechanical assembly, the percentage of soldering operations can be estimated and the acceptable quality level can be increased in proportion. If soldering constituted half the operation, then the acceptable quality level established by the equation could be doubled. The acceptable quality level represents a target point at which to aim quality standards. If experience and practice proves that the acceptable quality level should be revised upward or downward, such an adjustment should be made.

From previous experience with production processes, it was apparent that installation of regular statistical sampling would result in the rejection of a large percentage of equipment lots. For this reason, it was decided to begin a sampling program using a standard sample of 50 percent of the units of any given lot. This would insure the forward movement of at least some of any production lot. The acceptance numbers were selected from published sampling plans according to the acceptable quality level that had been established in the manner described above. As soon as the process average for any equipment or production line approached closely to the accepted quality level, standard statistical sampling plans were substituted.

After the necessary repair or rework has been carried out on a rejected lot, the lot will be resubmitted to inspection and the plan calls for the selection of another 50-percent sample. In cases where lots are very small, the plan establishes a minimum sample size of 3 or 5 depending on the acceptable quality level. In this second inspection, the plan provides that inspection shall be discontinued as soon as the rejection number of defects in either major or minor classification has been reached, and that the lot be returned for further rework. It should be noted that during the first submission the entire sample must be inspected regardless of the number of defects found.

To administer the sampling plan, information as to the outgoing quality level as shown in Figure 4 is necessary. If work is submitted for government inspection, the inspector or agency involved will have records that indicate that quality level to some extent. Nonetheless, it was found that more-complete data were necessary to make accurate quality decisions. Accordingly, quality-control personnel were again utilized for periodic check inspections. This group would pick at random lots that had been accepted and subject these lots to 100-percent inspection. By noting which units contained defects, it was possible to determine the efficiency of company inspection. Defects found in the portion of the lot that represented the sample meant that a lot that should have been rejected had slipped by. Defects found in an uninspected portion suggested that an adjustment would be necessary in either the acceptable quality limit or the acceptance numbers.

4. Conclusion

When this modified type of end-item sampling has been in operation for a substantial length of time, further reduction in the sample size can be realized. This approach to sampling has been found to be reasonably painless and the opposition from the production people is not strong. For those who have not been able to introduce sampling because of any of the classic reasons, it provides an excellent "foot in the door."

When data and inspection history dictate, the move from modified sampling to the use of published sampling tables can be made with ease and assurance of success.

Recent Telecommunication Development

"Electronique Industrielle"

Professor Georges Goudet, who is relinquishing his duties as director of the superior school of electricity and mechanics at Nancy University to become the Director of Laboratoire Central de Télécommunications on the retirement of the present director, Professor Jean Saphores, has recently published a book on "Electronique Industrielle." The book is divided into 6 sections and 26 chapters.

Section 1—Circuits
- Units
- Lumped-Constant Circuits
- Lumped-Constant Circuit Elements
- Study of Some Lumped-Constant Circuits
- Transmission Lines

Section 2—Electron Tubes
- Solid-State Theory
- Vacuum Electron Tubes
- Gas Tubes
- Power Supply Systems

Section 3—Amplification
- Wide-Band Amplifiers
- Narrow-Band Amplifiers
- Stability of Amplifiers, Noise
- Amplifiers Without Electron Tubes

Section 4—Production and Detection of Electric Signals
- Electric Signal Generators
- Modulation, Frequency Changers
- Detection, Demodulation

Section 5—Electron Optics and Applications
- Laws of Electron Optics
- Cathode-Ray Tubes
- Electron Microscope, Electron Diffractor
- Mass Spectrometer

Section 6—Industrial Applications of Electronics
- Electronic Heating
- Photoelectric Cells and Applications
- Ultrasonics
- General Theory of Servomechanisms
- Components of Servomechanisms
- Examples of Servomechanisms

The book is $6\frac{1}{4}$ by $9\frac{3}{8}$ inches (16 by 24 centimeters) and contains 635 pages including 418 illustrations and 44 tables. It may be obtained for 5500 francs from Eyrolles, 61 Boulevard Saint Germain, Paris 5, France.

United States Patents Issued to International Telephone and Telegraph System May–July, 1955

UNITED STATES patents numbering 27 were issued between May 1, 1955 and July 31, 1955 to companies in the International System. The inventors, titles, and numbers of these patents are given below; summaries of several that may be of more-than-usual interest are included.

P. R. Adams and J. L. Allison, Projection Display Apparatus, 2 714 199.

R. F. Baum, Direction-Finding System, 2 713-164.

R. P. Boyer, Automatic Telephone System and Translator Therefor, 2 710 893.

C. L. Day, Tube Assembly, 2 708 250.

V. J. DeSantis and F. L. Hunter, Method of Forming Protective Coatings for Metallic Surfaces, 2 711 980.

S. H. M. Dodington, Beam Center Finder, 2 709 805.

B. M. Dwork, Microwave Modulator, 2 708 262.

E. Ganitta, Compensation of Direct-Current Bias Magnetization at Repeaters of Reactors, 2 709 721.

W. F. Glover and F. E. Giles, Method of Applying a Protective and Electrically Insulating Covering to Components, 2 713 007.

R. Goerlich, Pneumatic Tube System with Fully Automatic Reload Device, 2 712 910.

L. Goldstein, Electromagnetic Wave Generation, 2 712 069.

D. D. Grieg, H. F. Engleman, and J. A. Kostriza, Supports for Microwave Transmission Lines, 2 710 946.

L. Himmel, Dual-Band Antenna System, 2 710 917.

L. Himmel, Multilobe Omnirange Beacon System, 2 713 163.

J. S. Jammer, Space-Reservation Recording System, 2 710 392.

S. Kaganoff, Jacketing Material for High-Frequency Cables, 2 708 215.

A. Lieb, Voltage-Reference Indicating Valve, 2 712 612.

C. P. Majkrzak and E. R. Jones, Method of Reshaping Tubular Stock, 2 711 055.

A. F. Marlet, Blocking-Layer Rectifier and Housing Therefor, 2 712 620.

K. A. Matthews and R. A. Hyman, Electric Rectifying Devices Employing Semiconductors, 2 713 132.

H. M. Schmidt, Heterodyne Mixer Stage, 2 710 346.

W. Schroder, Carrier-Separating Device, 2 709 555.

I. T. Stonebach, Extrusion Apparatus, 2 708 771.

C. E. Strong, Radio Navigation, 2 709 807.

R. Urtel, Deflection-Coil Arrangement for Cathode-Ray Tubes, 2 713 131.

R. Urtel, Method and Circuit Arrangement for the Selective Cutoff of Vertical Synchronizing Pulses, 2 713 086.

I. Yosano, Antihunt Circuit for Electric-Motor Follow-up System, 2 712 623.

Space Reservation Recording System

J. S. Jammer

2 710 392—June 7, 1955

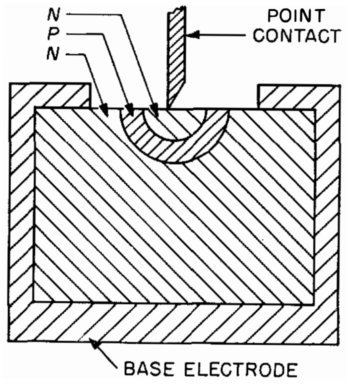
This recording arrangement is used in the space-reservation system known as Intelex in which code designations representing the available space and the reserved space are carried by an extra recorder. In response to signals from any one of several operators, connections can be made to determine from the extra recorder whether requested space is available. The designations on the extra recorder may be changed to be in accordance with new space reservations.

Electric Rectifying Devices Employing Semiconductors

K. A. Matthews and R. A. Hyman

2 713 132—July 12, 1955

Semiconductor rectifiers of germanium or silicon having negative-resistance characteristics at relatively low voltages are particularly useful for trigger circuits. Such properties may be obtained by producing a thin partial layer of different type of conductivity near one surface of a crystal and a central portion on this layer of the same type of conductivity as the main body. An electrode of relatively large area is associated with the main body of the rectifier and a point-contact electrode is associated with the central portion.

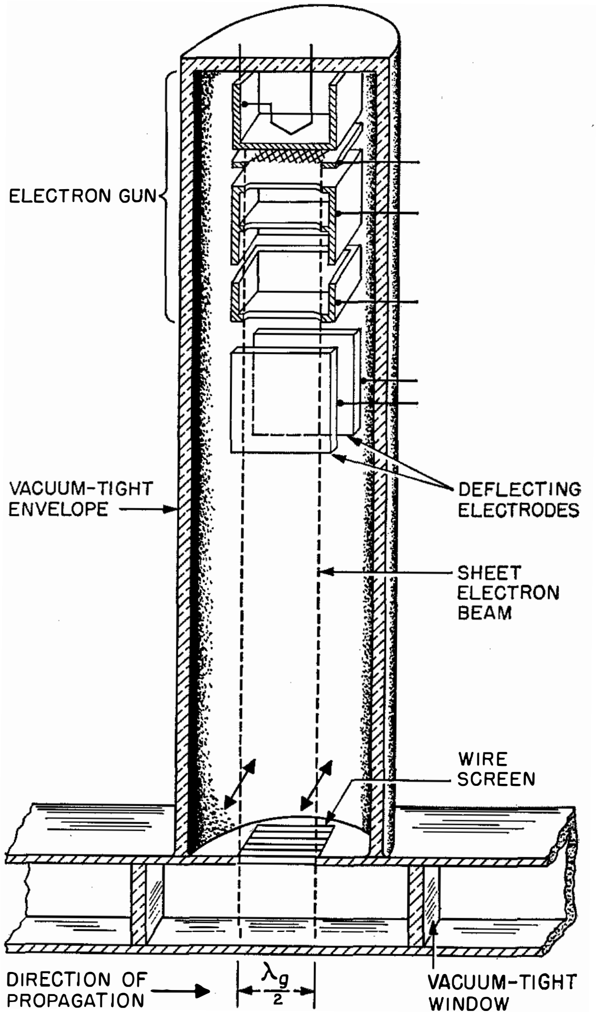


Microwave Modulator

B. M. Dwork

2 708 262—May 10, 1955

This is a method of modulating microwave energy being propagated along a waveguide in which there are vacuum-tight partitions. One wall of the area thus formed is provided with a grid structure communicating with the internal space within an envelope that supports an electron-beam gun. The electron beam is made to have a flat dimension aligned with the length of the waveguide to project through the openings in the grid into the segregated waveguide portion. Deflecting electrodes are provided to shift the position of the beam to different parts of the



segregated portion to control the transmission characteristics of this part in accordance with modulating signals applied to the deflectors.

Selective Control of Vertical-Synchronizing Pulses from the Received Television Synchronizing-Pulse Mixture

R. Urtel

2 713 086—July 12, 1955

A selecting circuit for vertical-synchronizing pulses has been produced to provide more-accurate timing of the vertical sweep than existing arrangements. The normal long synchronizing pulse, which is divided at line frequency, is delayed one-half period of the line frequency and combined with the undelayed pulse to provide a train of pulses at twice the line frequency before integration to select the synchronizing pulse.

Projection Display Apparatus

P. R. Adams and J. L. Allison

2 714 199—July 26, 1955

This adjustable-projector system is used in the Navascreen display. Each of several projectors may be independently controlled in coordinates simulating distance and azimuth. The energy representing these two components is derived from the position of the various craft to be displayed.

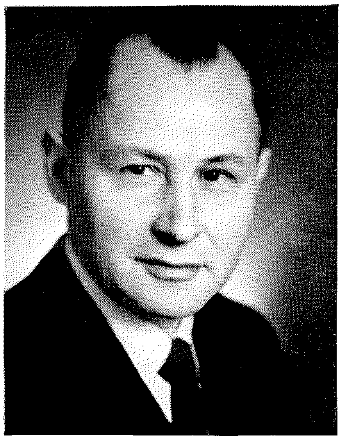
Contributors to This Issue

Otto–Heinrich Appelt

Otto–Heinrich Appelt was born in Reichenberg, Bohemia, on September 11, 1920. He received his early engineering education at the state college and after additional work in Stuttgart received a diploma in telecommunication in 1939.

Mr. Appelt joined C. Lorenz in 1950 and worked on video and pulse-generating equipment for television at Standard Central Laboratories until 1954. He describes some of his work on a television link system in this issue.

In 1954, he emigrated to San Salvador in Central America as a technical advisor to an importing organization in anticipation of the introduction of television in that country.



Karl Christ

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Karl Christ was born on July 30, 1905, in Kallstadt, Germany. He attended as a student and also served as an assistant in the electrophysical laboratory of the Technical College of Munich from which he received a doctorate in 1935.

He then joined the research staff of C. Lorenz. After working in the radar and airborne radio fields, he was appointed head of the laboratory for radio links in 1948. He reports on television links in this issue.

In 1953, Dr. Christ was transferred to Standard Central Laboratories as head of the group on microwave techniques.

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Georges Goudet

Georges Goudet was born in 1912 in Dijon, France. He received several scholarships at the Ecole Normale Supérieure. In 1936, he became an Agrege (fellow) of physical science at the university. After serving as an artillery officer during the war, he completed his work for a doctorate in physics in 1942.

During 1943 and 1944, he worked on microwave tubes at Laboratoire Central de Télécommunications. He then became the head of the ultra-high-frequency laboratory of the French Posts, Telegraphs, and Telephones administration. In 1951, he joined the staff of Nancy University as a professor and director of the special school of electricity and mechanics. He has served as a consultant on semiconductors to Laboratoire Central de Télécommunications and late in 1955 succeeded the retiring Professor Jean Sophores as director of that laboratory.

Dr. Goudet is the author of numerous publications on a variety of subjects, such as: modulation of light, spectrum of selenium in the far-ultraviolet region, ultrasonic propagation in liquids, electron beams, magnetrons, coaxial lines, and microwaves. He collaborated with Louis de Broglie in a book on centimeter-wave elements and with C. A. Meuleau in a forthcoming book on semiconductors. Both co-authors are associated with Laboratoire Central de Télécommunications.

Dr. Goudet is a member of the Société Française de Physique, Société des Radioélectriciens, Société Française des Electriciens, and a Senior Member of the Institute of Radio Engineers.

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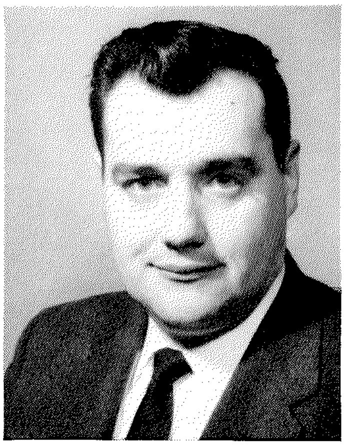
Charles Hartmann attended the Newark College of Engineering, obtain-



Charles Hartmann

ing a B.S. in chemical engineering in 1949 and an M.S. in management engineering in 1953.

During the second world war, Mr. Hartmann served with the United States Marine Corps as an electronics specialist, and in 1951 he was the resident inspector in charge of a plant for the Signal Corps Supply Agency.

In 1952, he joined Industrial Television, Incorporated, as a quality-control engineer. At present, he is superintendent of quality engineering at Federal Telephone and Radio Company. He is a coauthor of a paper on inspection of chassis in this issue.

Mr. Hartmann has taught quality control at Rutgers University.

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W. P. G. Klein

W. P. G. Klein was born in Kattowitz, now Poland, on April 24, 1919. As his studies were interrupted by the war, it was in 1949 that he received an engineering degree from Technische Hochschule Stuttgart. A year later, the doctor of engineering degree was conferred on him.

In 1949, he joined the C. Lorenz organization, being assigned to the Standard Central Laboratories. He is now head of the microwave tube laboratory.

Dr. Klein has worked chiefly on microwave tubes and filters and he describes a traveling-wave tube in this issue.

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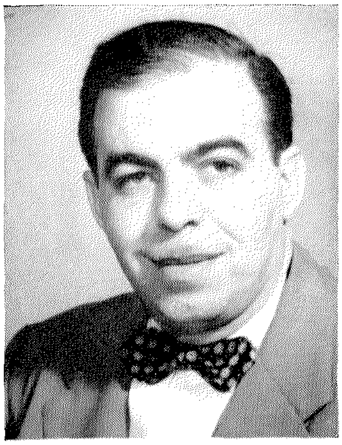
Henry Knapp

Henry Knapp was born in New York City. He attended Rutgers University, where he studied electrical engineering and statistics. He joined International Telephone and Radio Manufacturing Company in 1942.

Mr. Knapp spent two and a half years with the Army Air Force in Europe and as supervisor of Communications at Las Vegas Air Base.

In 1946, he returned to Federal Telephone and Radio Company as an instructor in telephone test and inspection, becoming supervisor in 1947. After four years as supervisor of quality-control engineering, he became superintendent of quality control for quality laboratories, incoming inspection, and fabrication, the position he now holds. He is a coauthor of a paper on inspection of chassis in this issue.

He is a member of the American Society for Quality Control and active with the committee on acceptance procedure of the Radio-Electronics-Television Manufacturers' Association.

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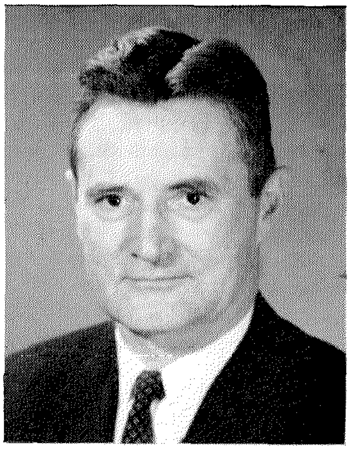
Roger McSweeny

Roger McSweeny was born in New York City on September 14, 1906. He was graduated from Harvard University in 1929 with a degree of B.S. in electrical engineering.

Since 1929, he has been employed by the International Telephone and Telegraph Corporation and various associate companies. His principal work has been on the design and installation of high-frequency point-to-point radiotelephone and radiotelegraph stations in Central and South American and the West Indies. At present he is in charge of radio engineering for South American stations of the American Cable and Radio System. He describes a radio system in the West Indies in this issue.

He is a registered professional engineer in New York State, a Senior Member of the Institute of Radio Engineers, and an Associate Member of the American Institute of Electrical Engineers.

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Kurt Schmid was born on October 10, 1909, in Stuttgart, Germany.

In 1933, he received a diploma in


Kurt Schmid

electrotechnics from the Technical College of Stuttgart.

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INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION

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Divisions of International Telephone and Telegraph Corporation

Capehart-Farnsworth Company; Fort Wayne, Indiana

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Federal Telephone and Radio Company; Clifton, New Jersey

Kellogg Switchboard and Supply Company; Chicago, Illinois

Federal Electric Corporation; Clifton, New Jersey

International Standard Electric Corporation; New York, New York

International Standard Trading Corporation; New York, New York

Kellogg Credit Corporation; Chicago, Illinois

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ARGENTINA — Compañía Standard Electric Argentina, S.A.I.C.; Buenos Aires

BRAZIL — Standard Electrica, S.A.; Rio de Janeiro

CHILE — Compañía Standard Electric, S.A.C.; Santiago

CUBA — International Standard Products Corporation; Havana

MEXICO — Standard Electrica de Mexico, S.A.; Mexico City

PUERTO RICO — Standard Electric Corporation of Puerto Rico; San Juan

Europe

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DENMARK — Standard Electric Aktieselskab; Copenhagen

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Le Matériel Téléphonique; Paris
Les Téléimprimeurs; Paris

GERMANY —

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Divisions
Mix & Genest; Stuttgart
Süddeutsche Apparatefabrik; Nürnberg
C. Lorenz, A.G.; Stuttgart
G. Schaub Apparatebau; Pforzheim

ITALY — Fabbrica Apparecchiature per Comunicazioni Elettriche Standard S.p.A.; Milan

NETHERLANDS — Nederlandsche Standard Electric Maatschappij N.V.; The Hague

NORWAY — Standard Telefon og Kabelfabrik A/S; Oslo

PORTUGAL — Standard Eléctrica, S.A.R.L.; Lisbon

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Standard Eléctrica, S.A.; Madrid

SWEDEN — Aktiebolaget Standard Radiofabrik; Stockholm

SWITZERLAND — Standard Téléphone et Radio S.A.; Zurich

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CHILE — Compañía de Teléfonos de Chile; Santiago

CUBA — Cuban American Telephone and Telegraph Company; Havana

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PUERTO RICO — Porto Rico Telephone Company; San Juan

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UNITED STATES OF AMERICA —

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All America Cables and Radio, Inc.; New York, New York
The Commercial Cable Company; New York, New York
Mackay Radio and Telegraph Company; New York, New York

ARGENTINA —

Compañía Internacional de Radio; Buenos Aires
Sociedad Anónima Radio Argentina; Buenos Aires (*Subsidiary of American Cable & Radio Corporation*)

BOLIVIA — Compañía Internacional de Radio Boliviana; La Paz

BRAZIL — Companhia Radio Internacional do Brasil; Rio de Janeiro

CHILE — Compañía Internacional de Radio, S.A.; Santiago

CUBA — Radio Corporation of Cuba; Havana

PUERTO RICO — Radio Corporation of Porto Rico; San Juan

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