THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 50, No. 7, September, 1971
Printed in U.S.A.

TH-3 Microwave Radio System:

Microwave Transmitter and Receiver

By A. HAMORI and R. M. JENSEN

(Manuscript received February 8, 1971)

The features and performance of a 6-GHz transmitter and receiver are described in this paper. The system objectives of 41 dBrnc0 for 4000 miles at 1800-circuit loading derived in the previous paper are applied to the design. With the exception of the 10-watt traveling-wave tube, the equipment is all solid state.

I. INTRODUCTION AND FEATURES

The microwave transmitter and receiver constitute the basic units of a radio system. They provide the gain necessary to compensate for the transmission loss of the station-to-station air path and the selectivity required to keep the radio channels properly separated. Since many of these units may be connected in tandem, each must meet stringent thermal noise, cross-modulation noise, selectivity, and equalization requirements in order to satisfy the overall system objectives.[1]

All the equipment required for transmitting and receiving a frequency-modulated 6-GHz signal is contained in one bay, including the channel separating and combining circuits, as shown in Fig. 1. The radio bays are mounted side-by-side with direct waveguide connections at the top of each bay; the waveguide used throughout is WR-159. With the exception of the traveling-wave tube, all circuits are solid state; only a −24-volt supply is required for primary dc power.

Two types of bays, main station and repeater, are made. The main station bay contains independent transmitter and receiver units. The reason for this is illustrated in Fig. 2. In main station A the transmitter serves the W-E direction while the receiver in the same radio bay serves E-W. An equipment outage or maintenance work on the transmitter requires the use of a protection channel only in the W-E

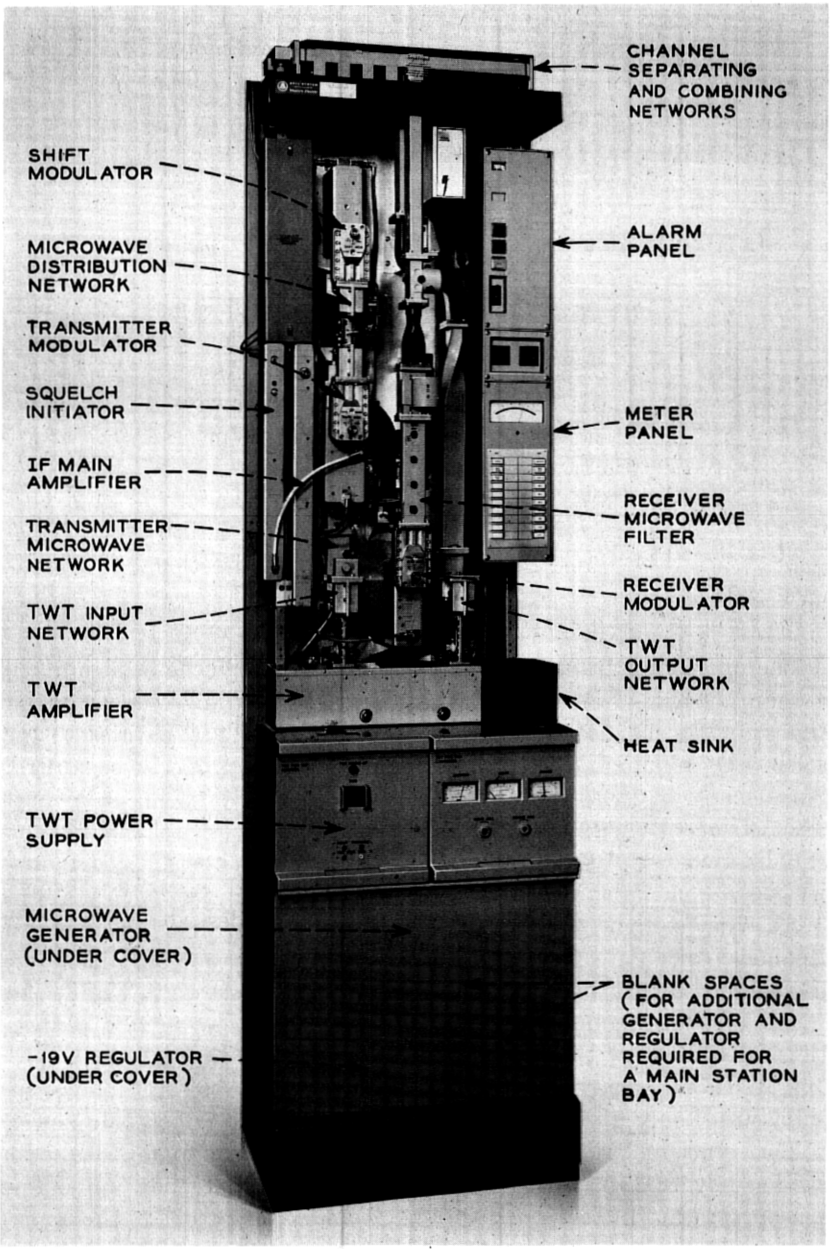

Fig. 1—TH-3 transmitter-receiver bay (repeater bay).

direction without affecting the E-W direction. This improves the overall system reliability and reduces maintenance problems. It also makes receiver- or transmitter-only bays possible. These bays can then be fully equipped at a later time.

In the repeater stations, however, the transmitter and receiver of the same bay serve the same direction of transmission. Since there is no advantage to independence here, some of the circuit functions are combined leading to a simpler radio bay.

A special feature of the bay is the use of directional waveguide filters for channel separation and combination. The use of these filters greatly reduces the number of waveguide components and eliminates the need for hybrids or circulators. Associated with the microwave filtering is another new feature: microwave delay equalization. The equalization of RF filters at RF is more accurate and consistent than the traditional IF equalization.

All modulators are unbalanced (single diode) and with the exception of bias adjustment they contain no tuning adjustments. Two-port access is provided by the use of either a directional filter or a circulator.

Three microwave integrated circuits are used in each radio bay. With the exception of the modulators, TWT, filters, microwave generator, and one isolator, all microwave circuits are contained in these integrated circuits. This contributes greatly to the simplicity of the radio bay.

A new circuit feature called RF squelch is introduced in place of a carrier resupply used in other similar systems. This approach decreases complexity and improves reliability.

The bay can be equipped with some optional components for a frequency-diplexed auxiliary channel which is described in a later paper.

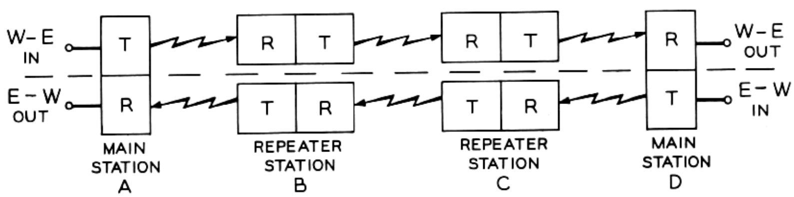

Fig. 2—Simplified radio route.

II. CIRCUIT DESCRIPTION

2.1 *Microwave Transmitter*

The block diagram of the signal portion of the transmitter is shown in Fig. 3. The input is a frequency-modulated 70-MHz signal at −7 dBm, which comes from an FM terminal transmitter or from a preceding radio receiver. This signal is applied to the IF limiter amplifier[2] which removes essentially all amplitude modulation and then drives the transmitter modulator. The limiter amplifier has another output which is used by the squelch initiator unit. The transmitter modulator[2] converts the 70-MHz IF signal into the transmitted microwave signal by modulating the transmitter microwave carrier (TMC)* generated by the microwave generator and associated circuitry as described later. The TMC power applied to the modulator is +18 dBm.

The squelch initiator[2] monitors noise in a narrow slot at 86 MHz. When this noise approaches the noise level corresponding to an open channel (front-end noise amplified by the full gain of the repeater), an offset voltage is applied to the transmitter modulator diode bias. At this new operating point the efficiency of the modulator is decreased so that the transmitter output drops 29 dB, sufficient to prevent adjacent channel interference. The squelch initiator also produces a relay contact closure, delayed by 45 seconds, to indicate the operation of the unit for remote observation. The delay is intended to eliminate any indication which might be associated with normal fading activity, since deep fades are of short duration.[3]

The transmitter modulator output passes through a portion of the microwave distribution network[4] which contains an isolator in the signal path before it connects to the transmitter microwave network. Since the TH-3 microwave carrier is always located 70 MHz below the signal, the circuit function of this network is to pass the upper sideband of the modulator and reflect the lower sideband and all other spurious outputs. This network contains half the total transmitter selectivity. The next active circuit in the signal path is the TWT. Since the TWT can contribute to the repeater distortion by converting amplitude modulation into phase modulation, it is very important to

---

* In this article the traditional "LO", "BO", "Pump", etc., is called the microwave carrier, since the microwave modulating process produces a suppressed carrier single-sideband output signal. This carrier should not be confused with the signal carrier, which is part of the frequency-modulated signal. For simplification and ease of identification, the transmitter and receiver microwave carriers are abbreviated as TMC and RMC, respectively.

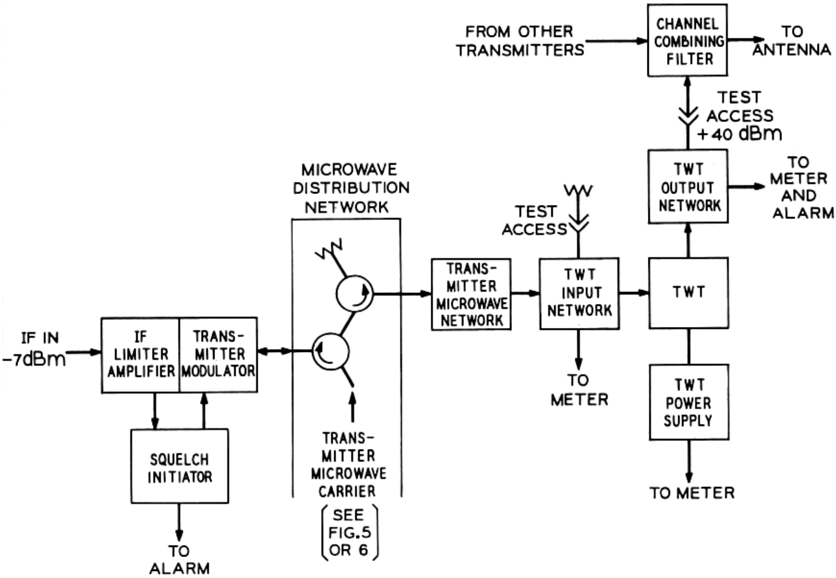

Fig. 3—Microwave transmitter block diagram.

eliminate all sources of AM from the signal.[5] The signal up to this point has negligible AM because of the limiter and the insignificant contribution of the transmitter modulator. The bandpass filter,[6] however, has delay distortion which does introduce AM into the signal. To eliminate this, the delay distortion of the transmitter microwave network is equalized by an RF delay equalizer,[7] which is factory-tuned.

The TWT input network is a microwave integrated circuit[4] which performs a series of functions. First, it provides a good match for the transmitter microwave network by the use of an isolator. It also contains an attenuator for setting the input power of the TWT to +7 dBm. This attenuator consists of a circulator which has one port terminated in an adjustable mismatch and an external waveguide termination. The insertion loss of the attenuator is the return loss of the adjustable mismatch. When the external termination is removed and the mismatch eliminated, the transmitter modulator output is available at that port for testing. Finally, the signal leaves the network through a reduced-height waveguide port which mates with a similar input port of the TWT. A built-in detector serves as a monitor for the transmitter modulator output and is connected to the bay metering panel.

The traveling wave tube is a periodically-focused packaged tube.[8] The tube output is a nominal +40.5 dBm with a minimum gain of 33.5 dB. The tube is used at constant gain by adjusting the helix voltage above the synchronous voltage. This operating point provides lower thermal noise and less AM-to-PM conversion than if the tube were operated at maximum gain, at synchronous voltage. The transmission shape, however, is not flat. The linear slope component is typically −0.01 dB/MHz. This is tolerable since linear slope does not contribute to cross-modulation distortion.[5] The parabolic and cubic components are so slight that the loss that would be involved in flattening the transmission shape would increase the thermal noise more than it would improve the cross modulation. Consequently, the output impedance of the tube is matched by a tuner in the TWT output network to provide maximum output power. This also ensures maximum efficiency.

The TWT power supply[9] is a dc-to-dc converter operating from the −24-volt supply. It generates all the voltages required by the tube. The tube collector current is monitored externally on the bay metering panel.

The TWT output network[4] is a microwave integrated circuit similar to the TWT input network; it performs the same functions with the exception of providing attenuation and test access. A waffle-iron low-pass filter in the network is used to suppress harmonics of the output by at least 30 dB. (The input network also contains this low-pass filter because it is part of the die-cast housing but it serves no function there.) The output power monitor is connected to both the meter and alarm panels for alignment and alarm purposes.

The test access port is a waveguide joint where a precision high-power attenuator can be attached for test purposes. This is the point where the output power is 10 watts (+40 dBm). The signal then enters the channel combining filter.[6] This is a directional filter[10] consisting of a complementary bandpass and bandstop filter. The output signal passes through the bandpass section thus encountering the final selectivity required in the transmitter. The other radio channel signals pass through the bandstop section with a typical loss of 0.1 dB and combine with the bay output at the common output port. The common output port presents a good match at the channel frequencies across the whole radio band and can be connected in tandem with other similar filters tuned to other radio channels or connected to the antenna system. The delay distortion of these filters is equalized in the succeeding receivers.

2.2 *Microwave Receiver*

Figure 4 shows the block diagram of the receiver. The signal enters the receiver from the antenna waveguide or from the preceding bay through the channel separating network.[6] This network consists of a directional filter, similar to the channel combining filter, and a waveguide delay equalizer. This filter has more selectivity than the one in the transmitter to protect the receiver from interference caused by other channels. The delay equalizer equalizes the delay shape of both the channel separating filter and the preceding transmitter channel combining filter. The equalizer is associated with the channel separating filter because this filter has about twice as much delay shape as the channel combining filter. The test access port (a removable waveguide twist) is the reference point where the received signal power on a nominal length path is −23 dBm.

The receiver modulator[2] receives the input signal through an isolator and another directional filter.[6] The purpose of this filter is to combine the received signal and the receiver microwave carrier. The very narrow bandpass filter is tuned to the RMC, thus suppressing the noise sidebands and other spurious signals. The complementary band-reject filter in the signal path attenuates the RMC but does not interfere with the received signal. The receiver modulator converts

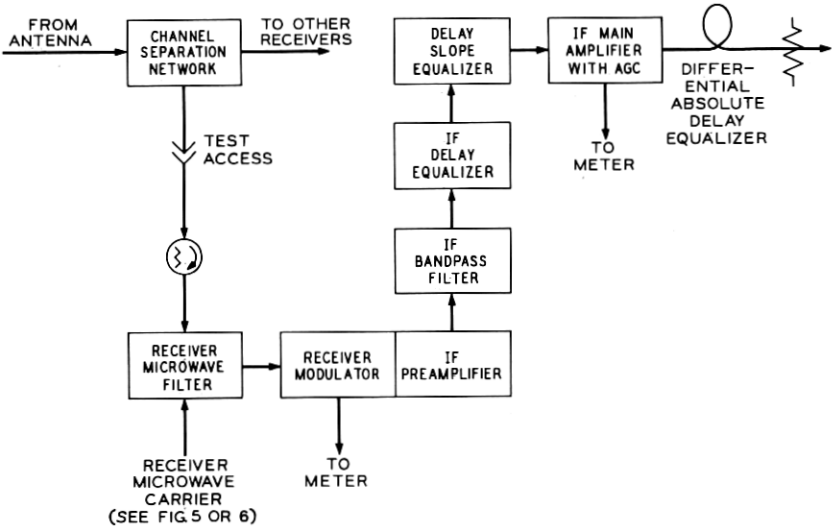

Fig. 4—Microwave receiver block diagram.

the microwave signal into a 70-MHz IF signal. The microwave image signal (2 × 70 MHz below the input signal) generated in the modulator is absorbed by the isolator ahead of the filter. To achieve a low noise figure, the modulator uses a GaAs Schottky barrier diode. The 70-MHz output of the low-noise preamplifier is −1.5 dBm with the nominal RF input and varies with the received signal power. The IF bandpass filter[6] that follows the preamplifier provides additional selectivity at the adjacent channel frequencies and at the IF harmonics. Two filter designs are available for this purpose, the 1044A filter for regular use and the 1009A filter which has greater selectivity at the adjacent channels. This latter filter contributes more to intermodulation noise and is used only when the signal-to-adjacent-channel-signal ratio is less than 22 dB at the bay input. This may occur when both channels are on the same polarization or on converging routes.

The IF delay equalizer equalizes the delay shape of channel separating and combining networks of other channels located between this radio bay and the antenna.[1] The delay slope equalizer is field selected after overall system measurements have been performed. This equalizer is available with five different slopes ranging from −0.5 to +0.5 ns/MHz.

The IF main amplifier[11] operates at a nominal 9-dB gain with a +1.0-dBm output. The built-in AGC circuit varies the gain to follow 40-dB fades or 10-dB upfades without output power variation. The differential absolute delay between the radio channels on the same route can be equalized by the use of appropriate lengths of IF cable at the output of the IF main amplifier. A pad builds out the cable loss to obtain −7-dBm IF output.

2.3 *Microwave Carrier Distribution*

Both the microwave receiver and transmitter modulators require a locally-generated microwave carrier. The TH-3 frequency plan places the receiver and transmitter frequencies 252.04 MHz apart and, by choice,[1] the carrier is always 70 MHz below the signal. As explained earlier in conjunction with Fig. 2, the main station transmitters and receivers operate independently and therefore require independent microwave carrier generators. In the repeaters, however, a single microwave generator is shared between the transmitter and receiver of the same bay. Because of these differences the two types of bays are discussed separately.

2.3.1 *Repeater Bay*

The repeater bay microwave distribution circuit is shown in Fig. 5. The microwave generator[12] is crystal-controlled at about 125 MHz and produces a nominal 1-GHz output at +29 dBm. This output is multiplied by the 6-GHz varactor multiplier[12] to obtain the desired transmitter microwave carrier frequency. The microwave carrier filter attached to the output of the multiplier is required for removing unwanted 500- and 1000-MHz sidebands around the TMC which are generated as harmonics of the lower frequency portions of the multiplier chain.

The output of the microwave carrier filter may pass through the auxiliary channel modulator which phase-modulates the TMC as described in a following paper.[13]

The receiver microwave carrier must be obtained from the TMC since there is only one microwave generator in a repeater bay. The frequency difference between the TMC and RMC is 252.04 MHz (the difference between the transmitter and receiver signals). Whether the TMC or the RMC is higher depends on the bay being a low-high or high-low repeater. This frequency shift is accomplished by a shift modulator.[2]

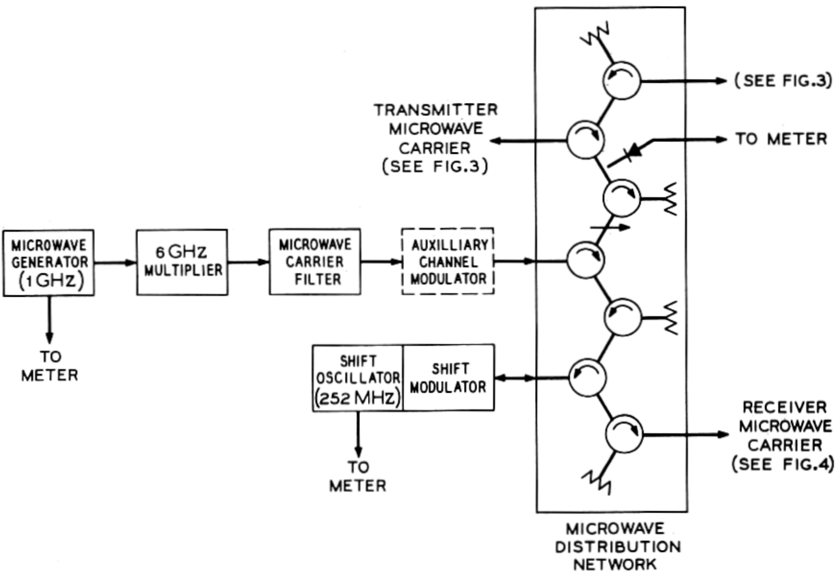

Fig. 5—Microwave carrier distribution (repeater bay).

The distribution of the TMC is performed by the microwave distribution network.[4] The TMC for the transmitter modulator is adjusted for +18 dBm, and the remaining carrier power is applied to the shift modulator. Both the transmitter and shift modulator are single-diode modulators which require a circulator to separate the microwave input and output signals. In addition, other circulators are used as isolators to provide isolation between the transmitter and shift modulator and to terminate the unwanted sidebands of both modulators reflected from their bandpass filters. At the transmitter modulator this filter is the transmitter microwave network, and at the shift modulator the selectivity is provided by the bandpass section of the receiver microwave filter.

Detectors are provided in both the microwave generator and in the microwave distribution network for power monitoring.

2.3.2 *Main Station Bay*

As stated above, the TMC and RMC for the main station transmitter and receiver are generated independently. Each source consists of a 1-GHz generator and a 6-GHz multiplier with the associated microwave carrier filter, as shown in Fig. 6.

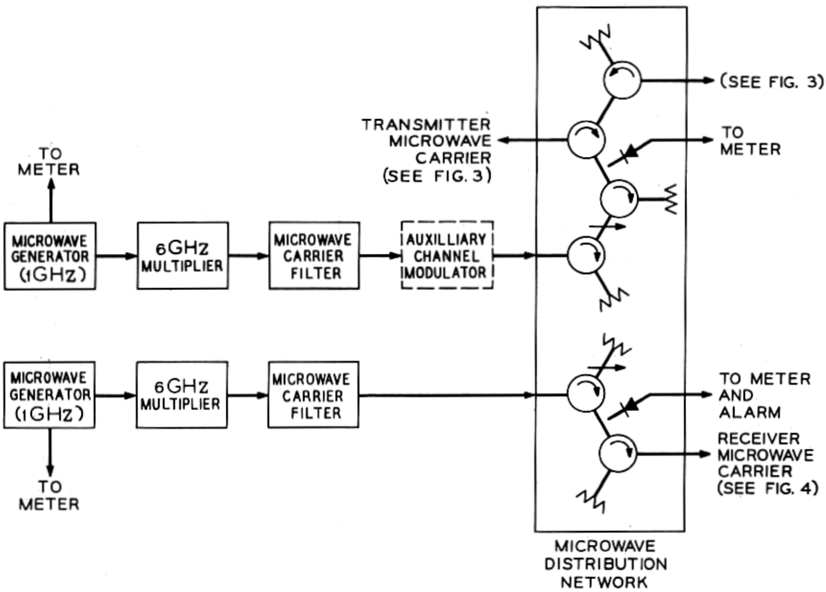

Fig. 6—Microwave carrier distribution (main station bay).

A microwave distribution network accepts the two microwave carriers. The transmitter portion performs as in the repeater bay. On the receiver side a coaxial input is provided in place of the shift modulator port and the circulator at this port is used as an attenuator. This network also contains an additional monitor to meter and alarm the RMC power.

2.4 *Power, Metering, and Alarms*

The radio bay is powered from −24-volt office battery. A −19-volt regulator[14] provides a stable voltage for the solid state circuits in the bay. This choice of voltage provides regulated output even with an emergency battery voltage low limit of −21 volts. The traveling-wave tube has its own power supply, a dc-to-dc converter.

Maintenance is simplified by the use of monitors provided at all significant points in the bay. The centrally located meter panel provides in-service access to these points to allow minor adjustments.

The alarm panel converts certain monitor outputs to alarm and status indications. These may also be used for remote surveillance.

III. PERFORMANCE

3.1 *Thermal Noise*

The thermal noise allocation for the radio line is 36.9 dBrnc0.[1] This noise is contributed by 100 repeaters and 50 main station bays in a typical 4000-mile system. There are two groups of thermal noise sources: the noise figure of the circuits in the transmission path and the carrier-to-noise ratio of the microwave carriers.[12] The typical noise figure and gain of the major blocks of a repeater are shown in Fig. 7.

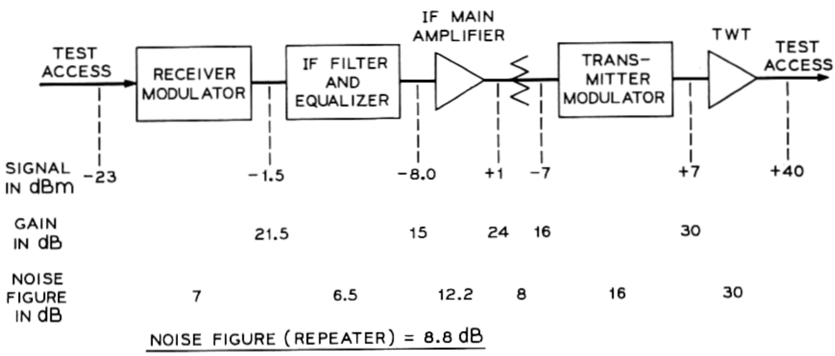

Fig. 7—Repeater noise figure.

The overall repeater noise figure is typically 8.8 dB. Based on the system parameters of Ref. 1, the noise contribution of the transmission circuits can be calculated and it is shown for 150 transmitters and receivers on Fig. 8, Curve A. At the top message circuit this is 36.6 dBrnc0.

The second significant noise contributor is the microwave carrier. FM noise on the carrier is transferred onto the signal in both the receiver and transmitter modulators. In the transmitter modulator this occurs across the full baseband. In the receiver modulator, however, the RMC is filtered by the narrow-band receiver microwave filter. The result is that the scalloping due to the introduction of the same noise at two places in the repeater[15] is noticeably only below 4 MHz, as shown on Fig. 8, Curve B.

The first null occurs at around 3.3 MHz corresponding to a typical value of 300 nanoseconds absolute delay in the receiver.

The total thermal noise (Curve C on Fig. 8) is 36.7 dBrnc0 at 8.524 MHz, which is slightly below the objective.

3.2 *Selectivity*

It was discussed in Ref. 1 that all selectivity is controlled by passive RF or IF networks. In the microwave receiver this is accomplished by the channel separating network and the IF bandpass filter.

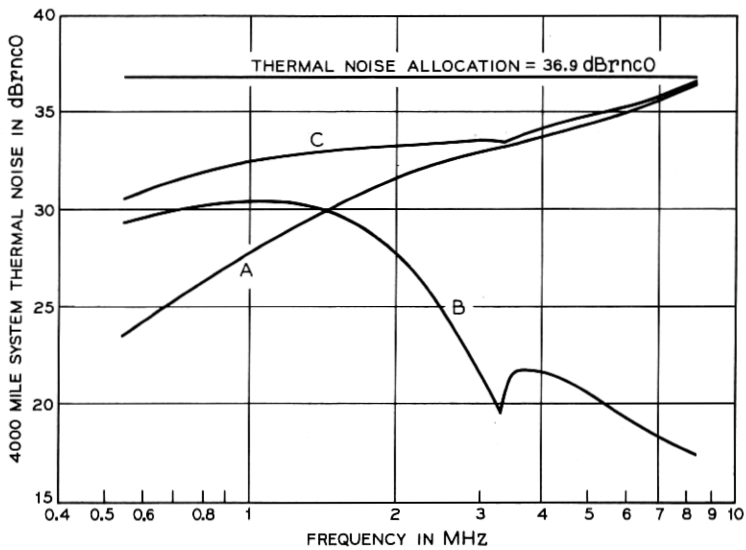

Fig. 8—Radio line thermal noise. Curve A is noise figure, curve B is microwave carrier noise, and curve C is total thermal noise.

In the transmitter there are two RF filters, the transmitter microwave network before the TWT and the channel combining filter at the bay output. It is desirable to have minimum delay distortion, therefore minimum selectivity ahead of the traveling-wave tube due to its AM-to-PM conversion properties. A minimum of 16 dB is required, however, at 40 MHz above the center of the channel to eliminate the interference of the second harmonic of the IF during swept measurements. This and the overall requirement led to splitting the selectivity evenly between the two filters in the transmitter.

The controlling selectivity requirements as explained in Ref. 1 and above are shown in Table I. Typical RF characteristics are shown on Fig. 9. Only one of the transmitter filters is shown on the figure; therefore the full transmitter characteristic is twice the curve shown. The IF characteristics are shown on Fig. 10. Two filters are shown, the 1044A and the optional 1009A. As described earlier, the 1044A filter is normally used.

The IF filters and the transmitter microwave network are delay-equalized units. The channel separating network is over-equalized to compensate for the delay distortion of the previous transmitter channel combining filter.

3.3 *Tone Performance*

There are interferences which do not enter through the antenna, therefore can not be controlled by the selectivity. These interferences are interbay and intrabay leakages, and microwave carrier generator and dc-to-dc converter harmonics.

The most serious interbay interferences can occur from transmitters to receivers. Special care was taken to reduce these leakages: eight screws are used at all waveguide flanges instead of quick-clamps; all

Table I—Selectivity Requirements Relative to Channel Center Frequency in dB

Freq (MHz)	Chan Sep Net	IF BPF	Trmtr Mwv Net	Chan Comb Flt
±29.7	9	25		
+40.0			16	
±59.3	47			
±70.0			46.5	46.5
−74.1	45			
−133.4	97			

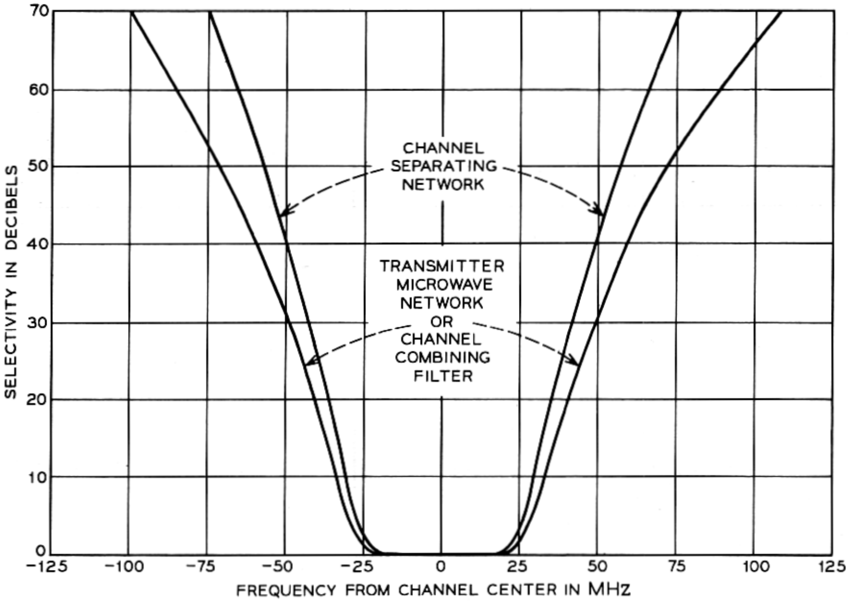

Fig. 9—RF selectivity.

joints are well-machined surfaces or sheet metal covers which seat on gaskets.

Intrabay interference is controlled mainly by the microwave distribution network in the repeater bay which connects the transmitter and receiver together. To avoid interference from the transmitter modulator to the shift modulator, at least 60 dB of isolation is provided, and in the opposite direction more than 68 dB.

A very critical source of potential interference is the dc-to-dc converter used for powering the TWT. This converter operates with a 24-kHz square wave and therefore is very rich in harmonics. If these tones find their way onto the TWT electrodes, they modulate the signal. Special shielded filtering is provided at the interface between the tube and the power supply, and the input leads connecting to the common −24V feeder is also well filtered.

The microwave carrier generator consists of multipliers; therefore it has unwanted harmonics on its output. Due to the last doubler and the sextupler, the output contains tones at approximately ±500 and ±1000 MHz relative to the TMC which could seriously interfere with the signal. For example, a tone occurs at 502 MHz above the TMC

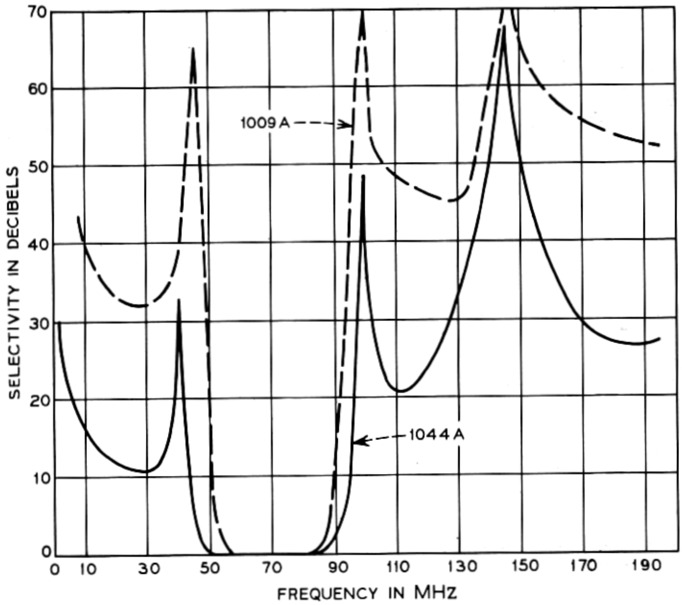

Fig. 10—IF selectivity.

for channel 16T which is shifted 252 MHz by the shift modulator to produce a 2-MHz tone in the RMC of channel 26T. In the transmitter modulator, unwanted TMC tones mix with harmonics of the 70-MHz IF to produce tones in the transmitter output signal. Taking the baseband tone requirements, multiple exposure factors, and conversion losses into account, the requirements shown in Fig. 11 were derived for these tones.

3.4 *Baseband Amplitude Response*

The baseband amplitude response of a radio repeater is shown on Fig. 12. The characteristic is smooth and consistent. The rolloff at 8.524 MHz is about 0.06 dB, at 10 MHz about 0.08 dB, and at 12 MHz about 0.12 dB.

3.5 *Environmental Effects*

The TH-3 transmitter-receiver bay was designed to operate at 75 ±20°F ambient temperature for long-haul 4000-mile systems. Outside these limits the frequency stability and the output power may be

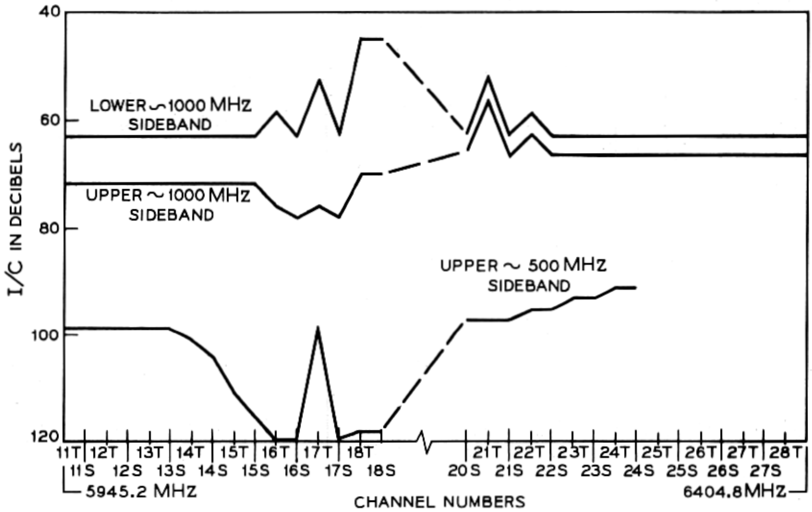

Fig. 11—TMC tone requirements.

affected but the changes are very minor up to the 40 to 120°F limits which are specified for medium haul, up to 1000-mile applications.[16]

One reason for this stability is that the waveguide filters are kept internally at less than 10-percent humidity. This is accomplished by tapping dry air from the station supply feeding the antenna system. The dry air enters the bays through the antenna (indoor) waveguide and leaks through all waveguide components at a slow (one cubic foot per hour) rate.

IV. EQUIPMENT DESCRIPTION

The components of the microwave receiver and transmitter are mounted on a 7-foot or 9-foot, 19-inch unequal flange, duct-type bay framework which is 22½ inches wide and 15½ inches deep. Figure 1 shows the components assembled on a 7-foot bay framework. When a 9-foot framework is used, the components are mounted in the lower 7 feet of the framework and are arranged in the same format used for the 7-foot bay. This leaves the upper 2 feet of the framework open. In general, 7-foot bays will be used in shelters or other low-ceiling buildings[17] whereas 9-foot bays will be used in central offices or other high-ceiling buildings.

All components are accessible and removable from the front of the bay. The bays can, therefore, be mounted back-to-back or against a

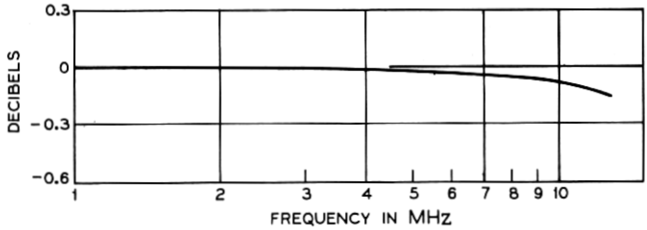

Fig. 12—Baseband amplitude response.

wall. Only one transmitter and one receiver are mounted on a bay framework. This alleviates tight packaging of waveguide components which minimizes use of waveguide spacers and bends, eases assembly during manufacture, eases maintenance by making the test ports more accessible, and minimizes system noise by keeping the waveguide connections between the channel networks as short as possible. Making the test ports more accessible eliminates the need for quick-clamps in that the waveguide screws are easy to remove and reinsert.

Many of the components of the bay are fabricated as die castings. For example, all modulators and the frame for their associated IF circuits, and the microwave integrated circuits, are die castings. This results in manufactured product that is economical and physically and electrically uniform.

Referring to Fig. 1, the −19-volt regulators and microwave generators are mounted in the lower portion of the bay. They are designed as plug-in units for easy removal and are protected by a front cover with quick-release fasteners.

The TWT power supply is mounted above the generators. It consists of two plug-in units arranged such that the left unit must be removed before the right unit can be removed. Removal of the left unit deenergizes the high-voltage right unit making it safe for personnel. The voltages are applied to the TWT amplifier by two cables that pass thru an opening in the top of the power supply framework and connect to two receptacles on the tube.

The TWT amplifier is mounted above the power supply with its receptacles facing the opening in the power supply framework. This arrangement completely encloses the power cable for greatest personnel safety. A test load can be connected to the power supply in place of the amplifier to determine if the amplifier or power supply is faulty in case of a transmitter output failure. To achieve long life for the TWT, the collector electrode is equipped with a finned heat sink cooled by natural convection.

The upper part of the bay supports the modulators, IF circuits, integrated circuits, waveguide networks/filters, miscellaneous waveguide components, and the meter and alarm panels. All waveguide components are mounted by special brackets to minimize physical distortion which degrades the electrical performance. In particular, the channel networks are mounted on a rugged casting which when bolted to the castings of adjacent bays aligns adjacent network ports to within a small fraction of an inch and permits them to be connected by short sections of flexible waveguide with minimum stress.

The meter, alarm, and circuit breaker units are mounted in a single box located at the right side of the bay. The meter unit provides means for monitoring the performance of various circuits in the bay. The alarm unit translates transmitter and receiver alarms into closed relay contacts for operation of external audible and visible alarms. It also has an alarm cutoff key for disabling the external audible alarm and a reset switch for resetting the receiver and transmitter meter relays.

V. SUMMARY

A microwave transmitter-receiver has been developed for providing a high-performance, high-capacity radio facility operating in the 5925 to 6425 MHz common carrier band. Its 10-MHz baseband will carry 1800 frequency division multiplexed voice circuits, one wideband TV channel, or equivalent service.

Its unique features, namely the use of directional waveguide filters for channel separation and combination, microwave delay equalization, microwave integrated circuits, RF squelch, and unbalanced (single-diode) modulators, make it a simple, easily maintained, economical system. The choice of 70-MHz IF and the use of many components common to the TD-3 system make it attractive for sharing routes and facilities with the already existing extensive 4-GHz Bell System network.

VI. ACKNOWLEDGMENTS

The development of the transmitter-receiver bay was the result of the work of a team of individuals. Some of them appear as authors of other papers in this issue while others are acknowledged in those papers. Specifically, the authors wish to acknowledge the physical design effort of T. J. Kelly.

REFERENCES

1. Jansen, R. M., and Prime, R. C., "TH-3 Microwave Radio System: System Considerations," B.S.T.J., this issue, pp. 2085–2116.
2. Giust, O., "TH-3 Microwave Radio System: Modulators," B.S.T.J., this issue, pp. 2155–2173.
3. Vigants, A., "The Number of Fades and Their Durations on Microwave Line-of-Sight Links With and Without Space Diversity," IEEE Int. Conf. Commun., June 9–11, 1969.
4. Dietrich, N. R., "TH-3 Microwave Radio System: Microwave Integrated Circuits," B.S.T.J., this issue, pp. 2175–2194.
5. Cross, T. G., "Intermodulation Noise in FM Systems Due to Transmission Deviations and AM/PM Conversion," B.S.T.J., *45,* No. 10 (December 1966), pp. 1749–1773.
6. Drazy, E. J., Sheehey, R. E., and Wang, H. C., "TH-3 Microwave Radio System: Networks," B.S.T.J., this issue, pp. 2137–2153.
7. Abele, T. A., and Wang, H. C., "An Adjustable Narrow-Band Microwave Delay Equalizer," IEEE Trans. Microwave Theory and Techniques, *MTT-15,* No. 10 (October 1967), pp. 566–574.
8. Bradford, C. E., and Waldron, C. J., "TH-3 Microwave Radio System: The Traveling-Wave Tube Amplifier," B.S.T.J., this issue, pp. 2223–2234.
9. Balicki, J. F., Chun, P. S., and Salvo, F. J., "TH-3 Microwave Radio System: Power System," B.S.T.J., this issue, pp. 2235–2248.
10. Abele, T. A., "A High-Quality Waveguide Directional Filter," B.S.T.J., *46,* No. 1 (January 1967), pp. 81–104.
11. Fenderson, G. L., "TH-3 Microwave Radio System: The IF Main Amplifier," B.S.T.J., this issue, pp. 2195–2204.
12. Bedell, H. R., Judkins, R. W., and Lahlum, R. L., "TH-3 Microwave Radio System: Microwave Generator," B.S.T.J., this issue, pp. 2205–2221.
13. Knapp, J. W., and Seastrand, K. L., "TH-3 Medium-Haul Application: Frequency-Diplexed Auxiliary Channel," B.S.T.J., this issue, pp. 2287–2313.
14. Jewett, W. E., and Mottel, S., "TD-3 Power System," B.S.T.J., *47,* No. 7 (September 1968), pp. 1498–1502.
15. Jensen, R. M., Rowe, R. E., and Sherman, R. E., "TD-3 Microwave Transmitter and Receiver," B.S.T.J., *47,* No. 7 (September 1968), p. 1202.
16. Seastrand, K. L., and Williams, D. S., "TH-3 Medium-Haul Application: System Considerations," B.S.T.J., this issue, pp. 2271–2285.
17. Swift, R. A., and Word, J. A., "TH-3 Medium-Haul Application: Equipment and Building Considerations," B.S.T.J., this issue, pp. 2345–2353.