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RADIO ENGINEERING
MICROWAVE RADIO
FM TERMINALS
GENERAL

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1. INTRODUCTION

A. Function of FM Terminals

1.01 An FM terminal transmitter is modulated by multiplex message or other broadband baseband signal to produce an FM signal at an intermediate frequency for application to a heterodyne-type microwave radio system. An FM terminal receiver, located at the far end or at an intermediate drop point of the microwave system, recovers the original baseband signal.

1.02 Modulated signals on microwave radio systems are bands of frequencies alternately located at baseband, at IF, or at RF. Figure 1 shows the translation stages involved in placing a baseband signal on a microwave radio channel, and the reverse process of recovering the baseband signal after it has traveled over a radio route. This illustration depicts the translations made in a TD-2 or TD-3 radio system when 1200 telephone message circuits (two mastergroups) or one television signal are placed on or removed from the lowest frequency radio channel in the 4-GHz common carrier band (channel 7A).

1.03 For long-haul radio relay facilities, the message load may consist of from 600 message circuits in older TD-2 systems to a maximum of 1860 message circuits in TH-1 and TH-3 systems. FM terminals are not required at repeater stations nor at main stations that only provide IF protection switching, since the message load is not reduced to baseband at these stations. However, FM terminals may be temporarily employed at switching main stations to perform equalization measurements and adjustments.

1.04 Typical locations of FM terminals are shown in Fig. 2. This is a rudimentary presentation since wire line entrance links (WLEL), FM terminals, and radio transmitters and receivers are usually interconnected through automatic protection switching equipment, patch bays, and other auxiliary equipment. Only a very limited portion of a radio system and one direction of transmission is shown in Fig. 2. For system design purposes, it is usually assumed that as many as 16 pairs of FM terminals may be connected in tandem in a 4000 mile transcontinental system.

1.05 The FMT at the transmitting end and the FMR at the receiving end of an MUR constitute an FM ***terminal pair.*** Measurement of

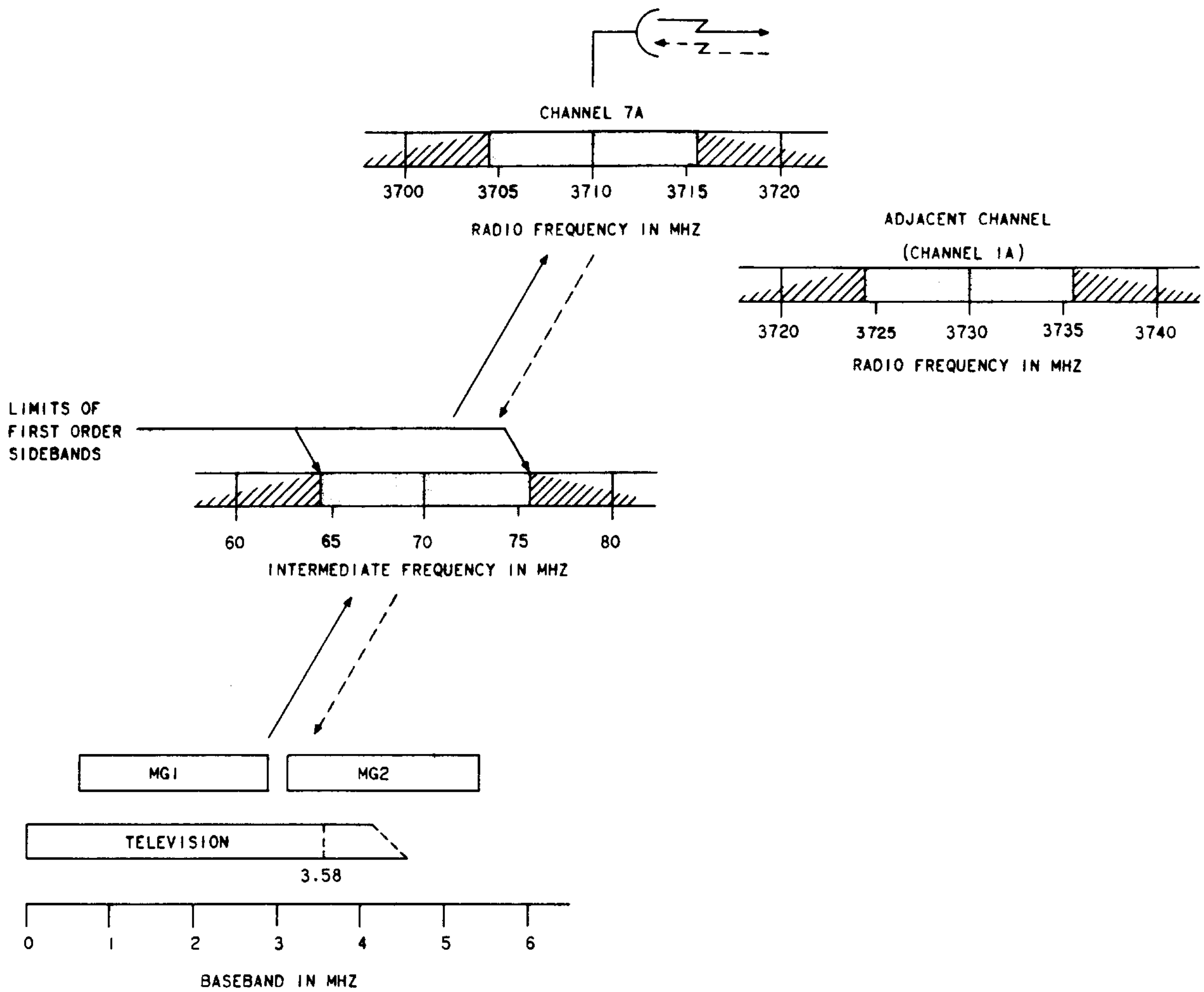

Fig. 1—Frequency Translation Stages

a terminal pair is useful in determining the noise contribution of FM terminals of a radio route, differential gain and phase characteristics, channel net gain from FMT input to FMR output in an MUR, and expected baseband signal degradation considered separately from degradation imposed by the radio equipment. Such baseband measurements cannot be made conveniently on the actual terminal pair used on an MUR since they may be several hundred miles apart. A spare terminal is substituted for the one at the distant end of the MUR in order to perform the tests. Associated multiplex and WLEL noise contributions to the total noise of an MUR are separate factors in noise calculations.

B. Methods of Modulation

1.06 A number of methods exist for converting baseband signals into FM signals. Two methods, beat-oscillator heterodyne modulation and push-pull heterodyne modulation are briefly described here.

Beat-Oscillator Heterodyne Modulation

1.07 TD-2 and TH-1 FM terminals both use the beat-oscillator heterodyne modulation principle. The basic arrangement is shown in Fig. 3, with frequency values given for a TD-2 FMT. Center frequencies for the deviation and beat oscillators of a TH-1 FMT are in the 6-GHz band and the IF output is centered at 74.13 MHz rather than the 70-MHz frequency shown for the TD-2 FMT.

1.08 Both oscillators of the FMT use reflex klystron tubes. Any change of applied repeller voltage causes the frequency of a reflex klystron oscillator to change. Therefore, a baseband

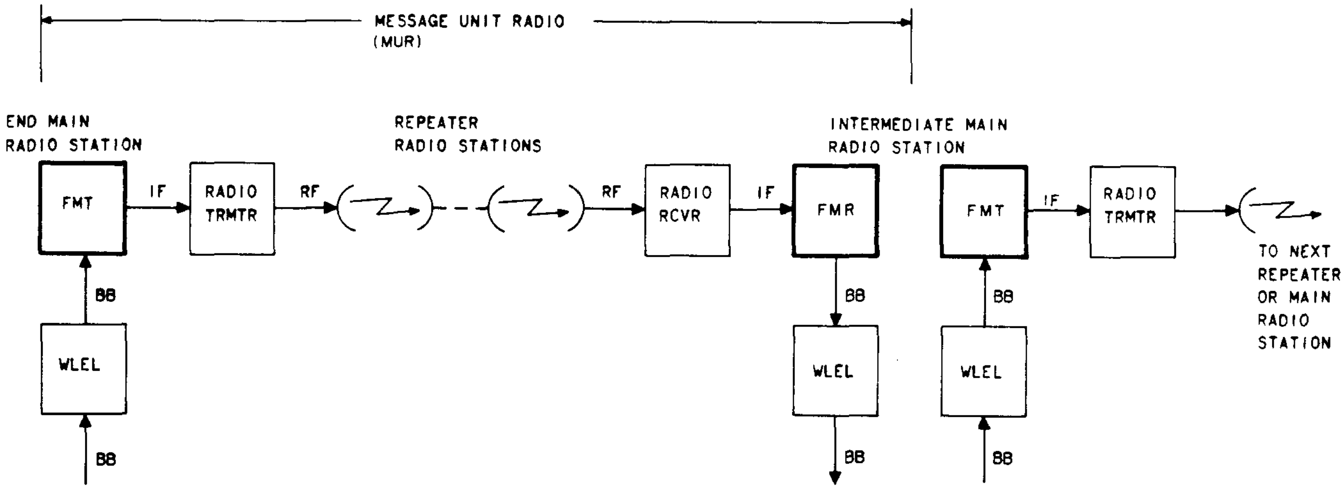

Fig. 2—Typical Locations of FM Terminals For Message Service

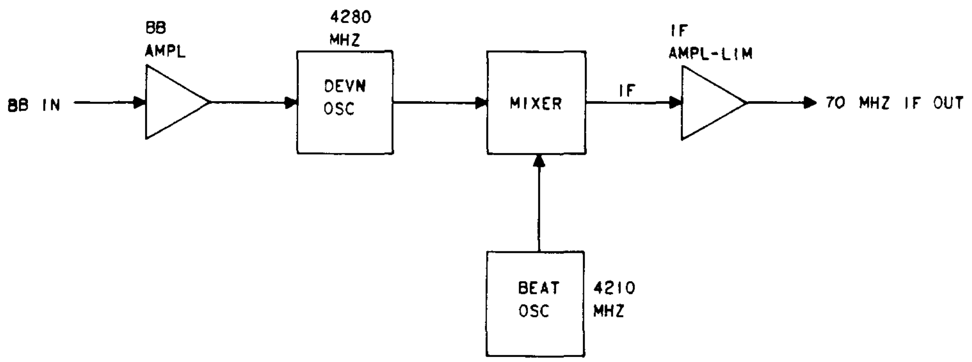

Fig. 3—Beat-Oscillator Heterodyne Modulation

signal is applied through the baseband amplifier to the deviation oscillator repeller. The resultant output of the deviation oscillator is an FM signal centered at 4280 MHz. This signal is mixed with the output of the beat oscillator which operates at 4210 MHz or 70 MHz below the center frequency of the deviation oscillator. The mixer output is a 70-MHz FM signal which is separated from other mixer modulation products, limited, and amplified in the IF amplifier-limiter before application to the radio transmitter.

Push-Pull Heterodyne Modulation

1.09 Two deviation oscillators, using junction varactor diodes in the tuned circuits and driven in antiphase by a baseband amplifier, are used in the push-pull heterodyne modulation system. Since varactor diodes are voltage controlled capacitors, the frequency of the deviation oscillators is varied by the modulating baseband signal. Frequencies shown in Fig. 4 are for the 3A FMT which is used with TD-2, TD-3, and TH-3 radio transmitters. A similar FMT, called the 3B FMT, has slightly different deviation oscillator frequencies and produces a 74.13-MHz IF output for use on TH-1 radio systems.

1.10 The difference between the center or rest frequencies of the deviation oscillators is 70-MHz. With the push-pull arrangement, each oscillator is required to deviate only half the total deviation. Highly linear deviation is obtained and first-order nonlinearities are cancelled by this

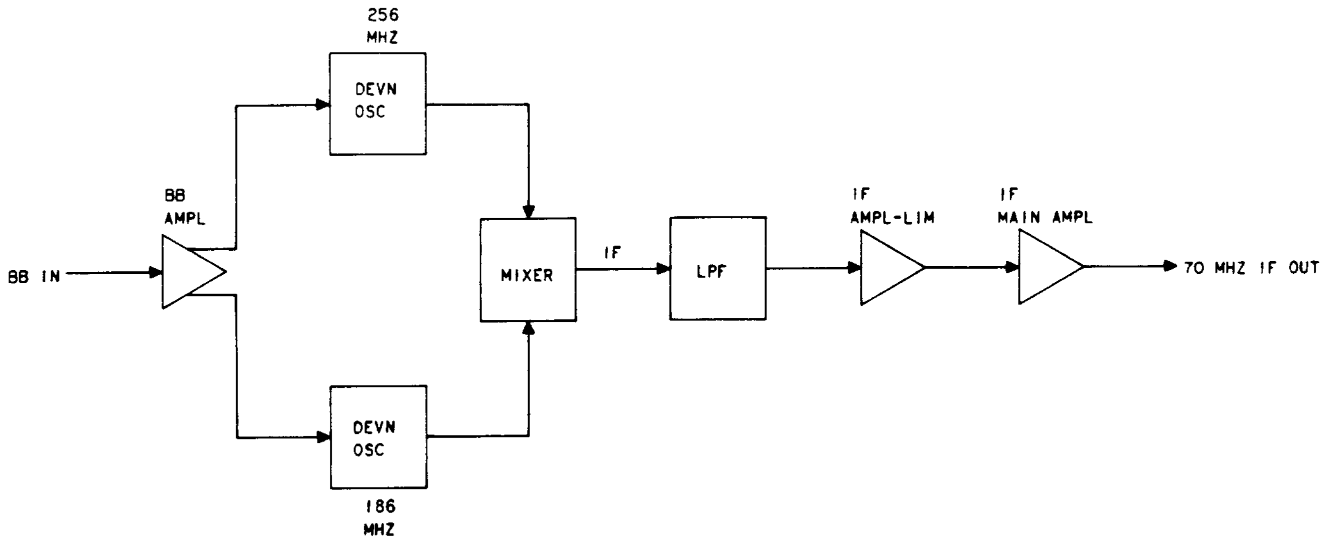

Fig. 4—Push-Pull Heterodyne Modulation

arrangement. The mixer is followed by a low-pass filter which rejects the deviation oscillator frequencies and high-frequency modulation products. The IF amplifier-limiter and IF main amplifier confine the frequency band passed by the FMT and provide AM limiting of the signal and amplification before the IF signal is fed to the radio transmitter.

C. Historical Development

1.11 TD-2 FM terminals (J68336) provided in the first long-haul microwave radio system use electron tubes with attendant relatively high power consumption, heat, noise generation, microphonics and occasional catastrophic failure. The IF is 70 MHz. Up to 600 message circuits or a TV signal can be transmitted over transcontinental routes of 4000 miles using TD-2 FM terminals.

1.12 New FM terminals (J68406) having an IF of 74.13 MHz were developed for 6-GHz TH-1 equipment which was first placed in service in 1960. TH-1 FM terminals can be loaded with 1860 message circuits. In common with TD-2 terminals, TH-1 FM terminals use electron tubes and the beat oscillator heterodyne method of modulation.

1.13 3A FM terminals (J68383) are 70-MHz solid-state terminals developed for use in TD-3 radio systems and handle up to 1200 message circuits. They were designed to be compatible with the older TD-2 electron tube terminals and are also used in modification of TD-2 radio systems to provide 900, 1020, or 1200 message circuit capacity per radio channel. 3B FM terminals, modified versions of 3A terminals with an IF of 74.13 MHz, are replacement units for TH-1 FM terminals and allow up to 1860 message circuits to be placed on existing TH-1 radio systems.

1.14 4A FM terminals (J68418), smaller solid-state units than 3A terminals and capable of carrying up to 1860 message circuits, are part of the new 6-GHz radio system called TH-3. Only the 4A FMR is currently available. Consequently, it is used in conjunction with 3A FMTs. A 4A FMT is under development for use with the 4A receiving terminal.

2. RELATIONSHIP OF FM TERMINALS TO RADIO SYSTEM PERFORMANCE

A. Channel Net Gain

2.01 Message channels of long-haul radio systems provide a net gain from baseband input to baseband output of the FM terminals (Fig. 5). Channel net gain is essentially determined by the FM terminals and is usually 16 dB overall. An exception to this figure is the 8-dB gain obtained through TH-1 channels when using electron tube terminals. Channel net gain is controlled by terminal pair performance but the modulation index is controlled by the FMT alone. Modulation index must be accurately controlled to ensure proper deviation within the FM portion of an MUR. The modulation index (and consequent peak deviation) of electron tube terminals is set by comparison of the peak frequency deviation of the FMT output produced by a standard drive level signal with the output of an oscillator operating at the required peak deviated frequency. This method is used because of the relative instability of the reflex klystron oscillators used in electron tube terminals. New solid-state FMT oscillators have greater stability. Consequently, a more accurate method, called the Crosby or Bessel null technique, is employed with solid-state terminals to set the modulation index prior to measuring channel net gain.

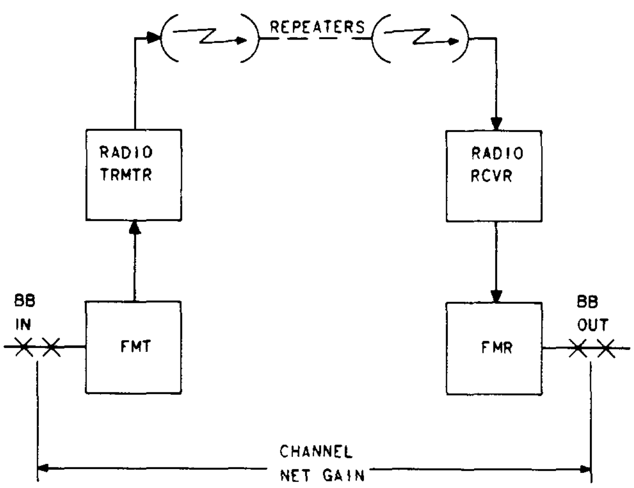

Fig. 5—Channel Net Gain

B. Frequency Stability

2.02 The center frequency stability of an FMT has important bearing on the stability of the RF signal radiated by a radio transmitter. This is illustrated in Fig. 6 were it is seen that an FMT frequency error appears directly as an error in the radiated carrier. Frequency errors in the microwave carrier supply also contribute to transmitted frequency errors. In an overall MUR, however, the FMT frequency error occurs only once; whereas, error contributions from a number of tandem microwave carrier supplies must be taken into account when estimating the total error. To illustrate the relative importance of these error sources, the long-term stability of the 3A FMT is such that it will contribute a maximum of ±100 kHz to the radiated carrier error. On a typical MUR, the corresponding contributions due to microwave carrier supplies will be approximately ±80 kHz.

2.03 The preceding considerations are primarily concerned with long-term frequency variations. Short-term frequency variations are also of interest from a different viewpoint. If the FMT carrier frequency is unsteady, beat notes with interfering tones will also be unsteady and as a result may be more tolerable. This is reflected in less stringent requirements on tones which have this "burbly" character. In general, the older electron tube FMTs have much poorer short-term stability than the newer solid-state counterparts. For this reason, tone interferences that might have been overlooked or were at least tolerable with the older terminals can become more evident and even unacceptable with the more stable solid-state terminals.

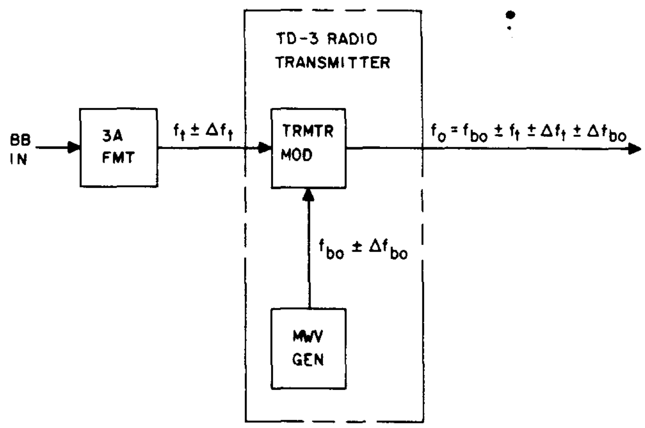

Fig. 6—Frequency Stability Aspect

C. Baseband Response

2.04 Baseband response of an FM terminal pair should be held to approximately ±0.1 dB over the message band of interest. With the exception of TD-2 FM terminals, which are being replaced by 3A and 4A terminals in many installations, the baseband response requirement is achieved by all terminal types. Transmission of television signals further requires relatively flat response down to 60 Hz and below. TD-2 FM transmitters used in video service are modified for improved low-frequency response per SD-59356-01, Issue 8D. Other FM terminals meet this requirement in their original design.

D. Noise Contributions

2.05 Noise allocations of a typical 4000-mile radio system consisting of 16 MURs (a TD-3 system in this example) are shown in Fig. 7. The total noise of 40.6 dBrnc0 is somewhat better than the design objective of 41 dBrnc0 for TD-3. Noise from various sources is accumulated as follows:

32.1 dBrnc0 from multiplex terminals and WLELs

33.0 dBrnc0 from FM terminals

39.0 dBrnc0 from radio line equipment.

2.06 The 33.0 dBrnc0 allocation to FM terminals, when divided by the 16 terminal pairs involved, allows a 21-dBrnc0 contribution per terminal pair (N_{TP} 33 = 10 log 16). Worst-channel noise developed by a newly aligned 3A FM terminal pair is only 18 dBrnc0. This allows a 3-dB maintenance margin per terminal pair which, because of the inherent stability of the solid-state terminals, should seldom be reached or exceeded. The total noise contribution from FM terminals consists of a thermal noise component and an intermodulation component. The thermal noise contribution is in general a design characteristic of the terminals. Typically, terminals using klystrons and other electron tubes are considerably noisier than their solid-state equivalents. Satisfactory control of intermodulation noise depends on the linearity of the modulation and demodulation characteristics of the terminals as well as their delay characteristics. Delay is normally not adjustable whereas the linearity can be optimized on a routine basis.

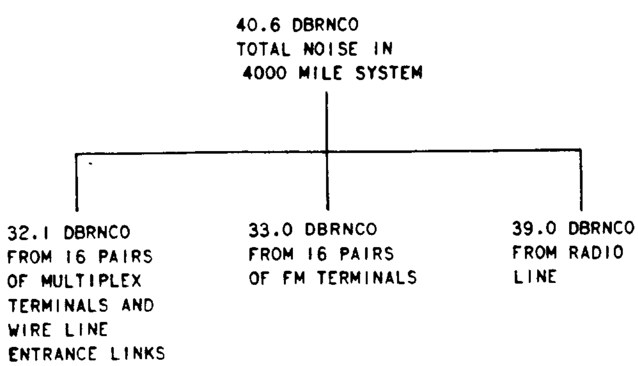

Fig. 7—Intercontinental System Noise Allocations

E. Differential Phase and Gain

2.07 Differential phase and gain through an FM radio system is especially important when the signal is a color television program. Color intelligence is conveyed by phase and amplitude of the 3.58-MHz color subcarrier. It is important that this modulation be transmitted with minimum distortion. The phase of the color subcarrier determines the hue of the picture at any instant and its amplitude determines the saturation of the color.

F. Pre- and De-Emphasis

2.08 Thermal noise is greater in the high-frequency message circuits of a multiplexed baseband signal than in the low-frequency message circuits. A radio system is normally laid out so that the noisiest message circuit just meets an established noise limit. Without baseband shaping, message circuits in the lower part of the baseband would be quieter than really necessary. In the interest of transmission efficiency, it is common practice to gain a signal-to-noise advantage for the higher frequencies at the expense of the lower frequencies of the baseband by emphasizing the high frequencies before transmission. Then, at the far end of the MUR, a de-emphasis network is employed to restore the normal relationship of the signals.

2.09 In the transmission of television signals, pre-emphasis (sometimes called pre-distortion) is used to minimize differential phase and gain of the color subcarrier. Pre-emphasis is not a strict requirement for transmission of monochrome television. However, since a given video channel may carry either color or monochrome signals at any time, the channels are always equipped with a pre-emphasis network.

2.10 The pre-emphasis curve for television transmission provides its greatest attenuation at 1 MHz and below. Luminance information is primarily conveyed by this part of the television signal spectrum and varies at a relatively slow rate. By reducing low-frequency luminance information, and thereby reducing the modulation index at low frequencies, intermodulation between the 3.58-MHz color subcarrier and low-frequency components of the signal is minimized. This, in turn, minimizes differential phase and gain so that color signals may be transmitted with maximum fidelity.

3. COMPARISON OF FM TERMINALS

3.01 Pertinent terminal pair characteristics for FM terminals in wide usage are given in Table A. Characteristics of the 4A FM terminal pair are based on use of a 3A FM transmitter with a 4A FM receiver. This information will be revised, if necessary, when the 4A FM transmitter becomes available.

4. REFERENCES

4.01 The following provide more detailed information on FM terminals and associated equipment.

REFERENCE NO.	TITLE
410-200-101	TD-2 Microwave Radio, FM Terminals, J68336A FM Terminal Transmitter, Description
410-200-102	TD-2 Microwave Radio, FM Terminals, Description, J68336K FM Transmitter
410-220-101	TD-2 Microwave Radio, FM Terminals, J68336G FM Receiver, Description
411-200-100	TD-3 Microwave Radio, FM Terminal, 3A FM Transmitter, Description

TABLE A

TERMINAL PAIR CHARACTERISTICS

CHARACTERISTICS	ELECTRON TUBE TERMINALS		SOLID-STATE TERMINALS•		
	TD-2	TH-1	3A	3B	3A/4A (NOTE 1)
Radio system use	TD-2	TH-1	TD-2, TD-3	TH-1	TH-3
Carrier frequency (MHz)	70	74.13	70	74.13	70
Frequency stability (MHz)	0.8	0.1	0.1	0.1	0.1
Number of message circuits	600	1860	1200	1860	1860
Number of television channels	1	1	1	1	1
Baseband response (0.1 dB)	(Note 2)	60 Hz to 10 MHz	6 Hz to 10 MHz	6 Hz to 10 MHz	6 Hz to 10 MHz
Worst channel noise (dBrnc0)	30	27	18	23	23
Differential gain (dB) (Note 3)	<1	<1.25	<0.05	<0.05	<0.05
Differential phase (degrees) (Note 3)	<3	<0.3	<0.1	<0.1	<0.1
Channel net gain	16	8	16	16	16

Notes:

1. 4A FM receiver operating with 3A FM transmitter.
2. Within −0.6 and +0.1 dB over 600 message-circuit band (0.564 to 3.084 MHz or 0.060 to 2.788 MHz).
3. Measured with pre-emphasis at normal video drive.

REFERENCE NO.	TITLE
411-205-100	TD-3 Microwave Radio, FM Terminal, 3A FM Receiver, Description
412-200-100	TH Microwave Radio, FM Terminal Transmitter and Receiver, Description
412-240-100	TH Microwave Radio, FM Terminals, 3B FM Transmitter, Description
412-245-100	TH Microwave Radio, FM Terminals, 3B FM Receiver, Description
420-215-100	Microwave Radio, FM Terminal, 4A FM Receiver Description
940-390-101	Radio Engineering, Microwave Radio, TD-2 FM Terminals (J68336)
940-390-102	Radio Engineering, Microwave Radio, TH-1 FM Terminals (J68406)
940-390-103	Radio Engineering, Microwave Radio, 3-Type FM Terminals (J68383)
940-390-104	Radio Engineering, Microwave Radio, 4A FM Terminals (J68418)
R.C.A. Review, Vol. 4, No. 4	Crosby, M.G., "A Method of Measuring Frequency Deviation," (April 1940), pp. 473-477