SECTION 4

PERFORMANCE STANDARDS

4-1. OBJECTIVE.

The objective in the design of electronic equipment and systems is to meet performance standards specified to obtain the maximum utility and to operate with minimum interference to the performance of other equipment and systems. Standardization to the extent necessary to permit inter-service operation is considered. Technical standards include type of signal in a communication system, bandwidth, signal levels, permissible degradation, radar range and definition, and accuracy of navigational aids. Performance standards have been established for equipment and systems which will assure performance to meet operational requirements and, for communication systems, the military standard, Military Communication System Technical Standards, MIL-STD-188, contains design objectives and standards which are applicable to Navy systems. In order to meet these standards, equipment must be maintained in a high state of operating efficiency. Equipment seldom operates individually; more often several units of equipment are inter-connected to form a system, designed to perform a specific function. The objective of this section of the handbook is to delineate performance standards and factors affecting performance of equipment and systems in which the equipment operates.

4-2. CRITERIA.

Operation of the electronic equipment must be in accordance with terms of international agreement and as prescribed by authority of the Federal Communication Commission and the Department of Defense. Continued vigilance must be exercised to insure efficient and reliable operation in compliance with the prescribed performance standards.

Criteria from "Military Communication System Technical Standards, MIL-STD-188A," are used for specification performance standards and are defined as follows:

System standards are either of the following:

"The minimum required electrical performance characteristics of communication circuits which are based on measured performance of developed circuits under the various operating conditions for which the circuits were designed, or

"The specified characteristics not dictated by electrical performance requirements but necessary in order to permit interoperation. (For example, the values for center frequencies for telegraph channels, test tone, etc.)."

As further qualified, "*design objectives* are electrical performance characteristics for communication circuits which are based on reasonable engineering estimates of the performance required but which have not been confirmed by actual measurement of operating circuits. A design objective is in reality a projected standard to serve until such time as a system standard can be established by actual measurement under operation conditions of the developed circuit."

4-3. TEST EQUIPMENT CALIBRATION.

a. GENERAL.—Without test instruments known to be within their designed accuracy tolerances, there is no way of accurately knowing whether a measured discrepancy is really a change in the equipment of a system, or is caused by inaccurate or improperly calibrated test equipment. To assure the necessary accuracy in repeatability of measurements, the station's test equipment must also be precisely calibrated to the same basic reference standards as the contractors' and installation activities' instruments.

Serious problems have arisen in the field, factory, developmental, evaluation and installation activities because measurements by one activity do not agree with those of another, even though identical items are being measured. In the past this incompatibility has been written off as a variation of the items being measured, whereas in reality much of the variation results from inaccurate and improperly calibrated testing instruments.

Since metrology, the science of measurement, is growing ever more demanding in the manufacture, installation, and maintenance of modern electronics and missile equipment and systems, the technical bureaus of the Navy Department have recognized the need for calibration programs that will insure that test instruments are properly maintained within their designed accuracy tolerances.

b. DEFINITIONS.—The following definitions have been adopted by the Bureau of Ships in collaboration with Naval Air and Ordnance activities in the program for test equipment calibration:

(1) Standards: Basic instruments, embodying

physical quantities, which serve as references against which instruments of lower accuracies are compared in order to verify results obtained with the lower level instruments.

(2) National Primary Standards: Those standards held by the National Bureau of Standards which are the most basic, ultimately referring to prime standards of length and mass, and which serve as the nation's prime source of measurement verification.

(3) Navy Primary Standards: Those standards held by Navy Primary Standards Laboratories which are the ultimate standards within the Navy but are subordinate to the National Primary Standards.

(4) Navy Reference Standards: Those standards held by Navy Reference Laboratories which comprise the second echelon of standards within the Navy.

(5) Navy Local Standards: Those standards held by Navy field activities, tenders, repair ships, inspectors and contractors which are employed in the calibration of test and inspection equipment. These standards are normally the third and final echelon of Navy standards.

(6) Test and Inspection Equipment: All special and general purpose devices utilized as measuring equipment.

c. PROGRAM.—The program to insure the accuracy within design limits of all electronic and electrical testing and measuring systems is implemented by the establishment of calibration facilities aboard tenders, repair ships and at major industrial activities in the Shore Establishment. The program is coordinated by The Bureau of Ships with Naval Air and Ordnance activities to assure compatibility of measurements by using the same calibration procedures and equipments whenever possible, thus assuring the feasibility of inter-bureau cross-servicing.

Technical control and scientific guidance of the coordinated programs are provided by the Metrology Department (formerly Measurements Standards Division), Bureau of Naval Weapons Representative, Pomona, California.

Under this program the Bureau of Ships has established calibration facilities (Reference and Local Standards Laboratories) in the following activities:

(1) Portsmouth Naval Shipyard.
(2) Norfolk Naval Shipyard.
(3) Charleston Naval Shipyard.
(4) Long Beach Naval Shipyard.
(5) San Francisco Naval Shipyard.
(6) Pearl Harbor Naval Shipyard.
(7) Industrial Manager, Ninth Naval District.
(8) Puget Sound Naval Shipyard.
(9) New York Naval Shipyard.
(10) Philadelphia Naval Shipyard.
(11) Mare Island Naval Shipyard.
(12) Naval Repair Facility, San Diego.
(13) Boston Naval Shipyard.

Local Standards facilities are available at all nine Naval and Marine Corps Air Station O and R departments. Primary and Reference Standards are contained within Avionics Standard Laboratories at the Naval Air Stations, Alameda, Norfolk, North Island, and Pensacola.

The test equipment calibration program for ordnance material is organized with Primary Standards Laboratories at the Naval Weapons Plant, Washington, D. C., (eastern) and the Bureau of Weapons Representative at Pomona, California, (western). Secondary Standards Laboratories are located at NAD, Oahu; NTS, Keyport, Washington; NAD, Concord, California; NAND, Seal Beach, California; NAD, Crane, Indiana; NOP, Forest Park, Illinois; CTO, Newport, Rhode Island and NWS, Yorktown, Virginia.

Procedures to be followed in utilizing this program and allowance lists for activities concerned with fulfillment of the program requirements are contained in current Bureau of Ships and other departmental instructions.

4-4. FREQUENCY STABILITY.

In accordance with MIL-STD-188A, the following frequency tolerances are "standard (S)" or "design objectives (D.O.):"

TABLE 4-1, FREQUENCY STABILITY

Frequency Range	Low Performance Equipment (Percent)		High Performance Equipment (Percent)	
VLF	0.1	S	0.001	S
LF	0.02	S	0.001	D.O.
MF	0.01	D.O.	0.005	D.O.
HF	0.01	D.O.	0.003	D.O.
HF (surface to air)			0.003	S
VHF	0.02	S	0.005	D.O.
VHF (surface to air)			0.0025	S
UHF	0.02	S	0.005	S
UHF (surface to air)			0.0025	S

Single sideband equipment in the HF range shall operate with tolerances as follows:

For *low performance* single and multiple channel speech, the frequency stability and accuracy of a transmitter or receiver, with or without automatic frequency control, shall be such that the frequency shall not deviate more than plus or minus 30 cps at any time. The frequency deviation shall not exceed 5 cps in one minute nor 15 cps in one hour.

For *multiple channel teletype*, the carrier frequency accuracy of the transmitter shall be better than plus or minus 30 cps. After contact has been established the receiver frequency shall be capable of being adjusted to coincide with the transmitter frequency. The frequency stability shall not be poorer than plus or minus 2.5 cps over a period of at least eight hours.

For *high performance*, single sideband equipment shall have a frequency stability and accuracy at any of the 1-kc points in the HF spectrum such that the carrier or reference frequency can be maintained within plus or minus 3 cps of the assigned frequency at all times, either through the inherent stability and accuracy of the equipment, or by means of a regularly scheduled check against an accurate frequency source.

4-5. HARMONICS AND EXTRANEOUS EMISSIONS.

For transmissions in the VLF, LF, MF, and HF range, the power of any extraneous emissions including harmonics shall be at least 60 db below the power of the fundamental but in no case shall it exceed 200 milliwatts.

In the VHF and UHF range, the average power of any extraneous emissions excluding harmonics shall be at least 80 db below the average power of the fundamental but in no case shall it exceed 5 microwatts; radiation of harmonics of the carrier frequency shall be at least 50 db below the average power of the fundamental.

In the HF range, for frequency, phase, or pulse modulation, the power of any extraneous emissions including harmonics shall be at least 60 db below the power of the fundamental but in no case shall it exceed 200 milliwatts.

In single sideband modulation, the power of any extraneous output including harmonics, but excluding intermodulation distortion products shall be at least 60 db below single sideband reference level. It shall be a design objective to limit the power of extraneous radiation, excluding intermodulation products, to 200 milliwatts. The power of any one of the intermodulation products shall be at least 40 db below single sideband reference level for voice frequency input power to a single sideband transmitter and shall be the power of one of two equal tones which together cause the transmitter to develop its full rated power output.

The current MIL-STD-188 contains specification for measurement of transmitter spurious emissions in the VLF through the HF range and for measurement in the VHF range and above.

4-6. MODULATION.

For maximum efficiency, an amplitude modulated transmission should be modulated 100 percent. Overmodulation produces distortion. A range from 30 to 70 percent modulation for voice-modulated transmissions is practical for normal operation and equipment adjustment should provide for maintenance within this range. Standard practice dictates that a V.U. meter be provided in the operator's position in order that initial adjustment by the operator to obtain optimum modulation values can be effected.

Modulation of any kind to radio frequency transmissions imposes bandwidth requirements, which are delineated in Table 4-2.

Pulse modulation requires rigid standards of operation. Instruction book procedures on equipment such as the UQ microwave link should be meticulously followed.

4-7. BANDWIDTH.

As defined in MIL-STD-188, the normal bandwidth is the maximum band of frequencies, inclusive of guard bands, assigned to a channel. The use of the term, "nominal bandwidth," applies particularly to those circuits operating on frequencies between the lowest and highest audio frequencies needed to provide a required type of service, and the frequency spectrum in the immediate vicinity of the carrier at radio frequencies.

Provision for a "flat" response curve is essential for high-quality performance. For example, the specifications for a channel with a nominal bandwidth of 4 kc are:

"*Amplitude versus frequency distortion.*—The nominal 3 db points for the band shall be at 300 and 3500 cps. For all frequencies between 1000 cps and 325 cps, the attenuations shall be within the limits of minus 1 db and plus 2 db with respect to the attenuation at 1000 cps. For all frequencies between 1000 cps and 3450 cps, the attenuations shall be within the limits of plus and minus 1.5 db with respect to the attenuation at 1000 cps."

At radio frequencies, "the r-f emission bandwidth of a transmitter is the difference between the highest and the lowest emission frequencies, in the region of the carrier or principal carrier frequency, beyond which the amplitude of any frequency resulting from modulation by signal and/or sub-carrier frequencies and their distortion products is less than 5 percent (–26 db) of the rated peak output amplitude of:

"a. The carrier or a single tone sideband, whichever is greater, for single channel emission; or

"b. Any sub-carrier or a single tone sideband thereof, whichever is greater, for multiplex emission."

Bandwidth is generally defined as the included frequency range between the points where the voltage has dropped to 1/2 (–6 db) its peak value in a band pass circuit. The ratio of the bandwidth at –60 db to that at –6 db is called the "Band Pass Ratio" and a measure of selectivity of a circuit.

In order to faithfully reproduce the intelligence, a band pass characteristic must be established which will pass all the essential frequency components of a signal. Telegraph signals require less bandwidth than voice or facsimile but as keying speeds are increased, an increase in bandwidth must be provided.

An optimum bandwidth in reception must be a compromise between allowable distortion and tolerance for noise. The wider the pass band, the greater the fidelity of the signal and minimum distortion will be present; however, the wider the pass band, the greater will be the spectrum noise and possibility of adjacent channel interference. Equipment design makes provision for the establishment of adequate bandwidth; system tests measure such characteristics to assure high performance.

The transmission bandwidths of Table 4-2 are in accordance with the standards of MIL-STD-188A.

TABLE 4-2, BANDWIDTH

	Modulation (See Note 1)			
	AM		FM/PHASE	
Frequency Range	Telegraph	Voice-Fax	Telegraph	Voice-Fax
VLF	500 cps			
LF	4 kc	8 kc	2 kc	8 kc
MF	4 kc	8 kc	2 kc	8 kc
HF	4 kc	8 kc	2 kc	8 kc (Note 2)
VHF (Nom 4 kc)		8 kc		40 kc
VHF (Nom 16 chan)		40 kc		300 kc (200 kc min)
VHF (Nom 48 chan)		136 kc		900 kc (600 kc min)
UHF (Nom 4 kc)		8 kc		40 kc

Aircraft Systems, Amplitude Modulation

HF	8 kc
VHF	12 kc
UHF	12 kc

Note 1: All bandwidths are maximum except where indicated.

Note 2: In the HF range, the design objective for RF bandwidth for multichannel voice operation is 20 kc (maximum). The RF bandwidth for SSB, suppressed carrier modulation shall be a multiple of 4 kc. For a single voice channel, the RF bandwidth shall be 4 kc (maximum).

4-8. KEYING SPEEDS.

Performance standards of equipment and systems based on keying speed capability (telegraph WPM) are determined by the inherent characteristics of individual equipments and interconnecting components of the systems. Telegraph intelligence, manual or machine, on-off keying or FSK, consists of the generation and propagation of a series of "square" pulses of electrical energy. The duration and spacing of these pulses determine "words per minute." The preservation of the square characteristic and precise duration of the individual pulses, is the ultimate factor which determines keying speed capability.

In transmitters, mechanical keying relays impose a limitation on WPM. Design of such relays is such that a keying speed of 60 WPM, single channel typewriter, is seldom exceeded. Electronic keyers permit much higher keying speeds and are most frequently used. Where high power in the VLF range is concerned, the generation of square pulses of extremely short duration in order to reach high keying speed is a difficult engineering problem due to high power and high Q radio frequency circuits involved. At the higher frequencies, this is a lesser problem and higher keying speeds are effectively transmitted.

In the reception of telegraph signals, the band pass of the receiver is a determining factor in WPM capability. The higher the speed, the greater must be the pass band.

In telegraph carrier terminal equipment, the lower audio frequency channels are reserved for single channel teletypewriter or for manual keying. The wide band channels occupy the higher audio frequency channels and are used for high speed keying such as four channel MUX.

System test procedures involving circuits for high speed keying should be based on tests made at normal working speed.

4-9. AUDIO LINE TRANSMISSION LEVELS.

a. SPECIFICATIONS.—In accordance with MIL-STD-188.

(1) The total output power of a telegraph transmitting group which is normally applied to a line shall be zero dbm and have a minimum adjustable range of from minus 10 to plus 5 dbm.

(2) The sensitivity of the receiving equipment shall be such as to provide satisfactory operation when the power per telegraph channel received from the line is between minus 40 dbm and plus 6 dbm.

(3) Channel output power shall have a minimum adjustable range of from minus 24 to plus 5 dbm.

b. CIRCUIT CONTROL.—The design and engineering of shore communication stations will provide facilities for compliance with the foregoing specifications pertaining to multitone channels and which also apply to audio line levels. Optimum performance of equipment requires accurate maintenance of such audio levels and is accomplished through exercise of "Circuit Control."

Although "Circuit Control" is generally considered to be an operational function, equipment layout and facilities must be such as to provide assurance that each channel or circuit is operated properly and within tolerances. Signal levels on all lines and at all points on the circuit must be *established* and *meticulously* maintained. Measuring, monitoring, and distortion-checking procedures on all signal lines must be scrupulously followed. Some channels, such as multitone teletype, SSB, etc., will require continuous measuring and/or monitoring to assure reliable and accurate operation. Circuit control must be exercised with a thorough knowledge and intelligent application of all available measuring techniques.

c. MEASUREMENT.—To make intelligent measurement of signal level power values, the control circuit operator or technician should have a knowledge of the nature of the signal undergoing measurement. A power level or VU type db meter behaves differently in the presence of voice (telephone) signals as compared to a multitone audio signal containing multiple tones of equal amplitude.

The standard VU meter is designed with damping which will tend to average out the signal peaks and will provide a reading which approaches an average power value. The signal peaks, however, are important and cannot be neglected because peaks in excess may cause crosstalk, or over-modulate link channels in a microwave circuit. As an example, in a circuit for which zero dbm has been specified as the maximum steady-signal operating level, a signal adjustment of −5 dbm on telephone (voice) signals is standard practice.

Audio transmission line level measurements and other communication applications employ values expressed in dbm (db referred to one milliwatt). Table 4-3 relates approximate values of dbm to power and voltage measurements for various load values. Unless a more precise figure is needed, in-between values can usually be approximated close enough for practical work.

EXAMPLES:

(1) If a 10μ V signal into a 75 ohm receiver input produces a +10 dbm signal into a 600-ohm load, the gain of the receiver is approximately 100 db.

(2) Meter is calibrated for dbm across 600-ohm load, and reading across 600 ohms is +36 dbm.

$$P \text{ (6 db above 30 dbm)} = 4 \times 1\text{w} = 4 \text{ watts}$$

$$E = 2 \times 24.5 \text{ volts}$$

$$= 49 \text{ volts}$$

Multichannel operation imposes a certain limitation on permissible signal attenuation. The nomograph Figure 4-1 provides a means of determining total power of a number of equal tones. Where 12 channels are used, such as for FCC-3 operation, in order that total input to the line does not exceed zero dbm, individual channel levels should be set about minus 11 dbm. A further look at the nomograph will indicate that if maximum attenuation is permitted (24 db), the power level of individual tones will approach specification limits for individual channel receiving equipment.

Initial system design and routine maintenance should assure operation well within the above tolerances. System test procedures should measure and record performance so that early degradation can be detected and remedial action taken.

d. AUTOMATIC SIGNAL LEVEL CONTROL.—The signal power input to a line is specified at zero dbm so that crosstalk levels into other lines do not exceed a certain maximum. For this purpose, and for signal application to microwave link channels, the Bureau of Ships has provided passive limiters and limiting amplifiers which, by means of a "compression control," will permit line operation within specification limits. The following discussion of the AM-413 and AM-413-A amplifiers will provide criteria for such operation.

The 413 has a fixed compression circuit which provides constant level output for signal inputs of −30 dbm and greater. The 413A has a variable compression circuit which will provide a "threshold of com-

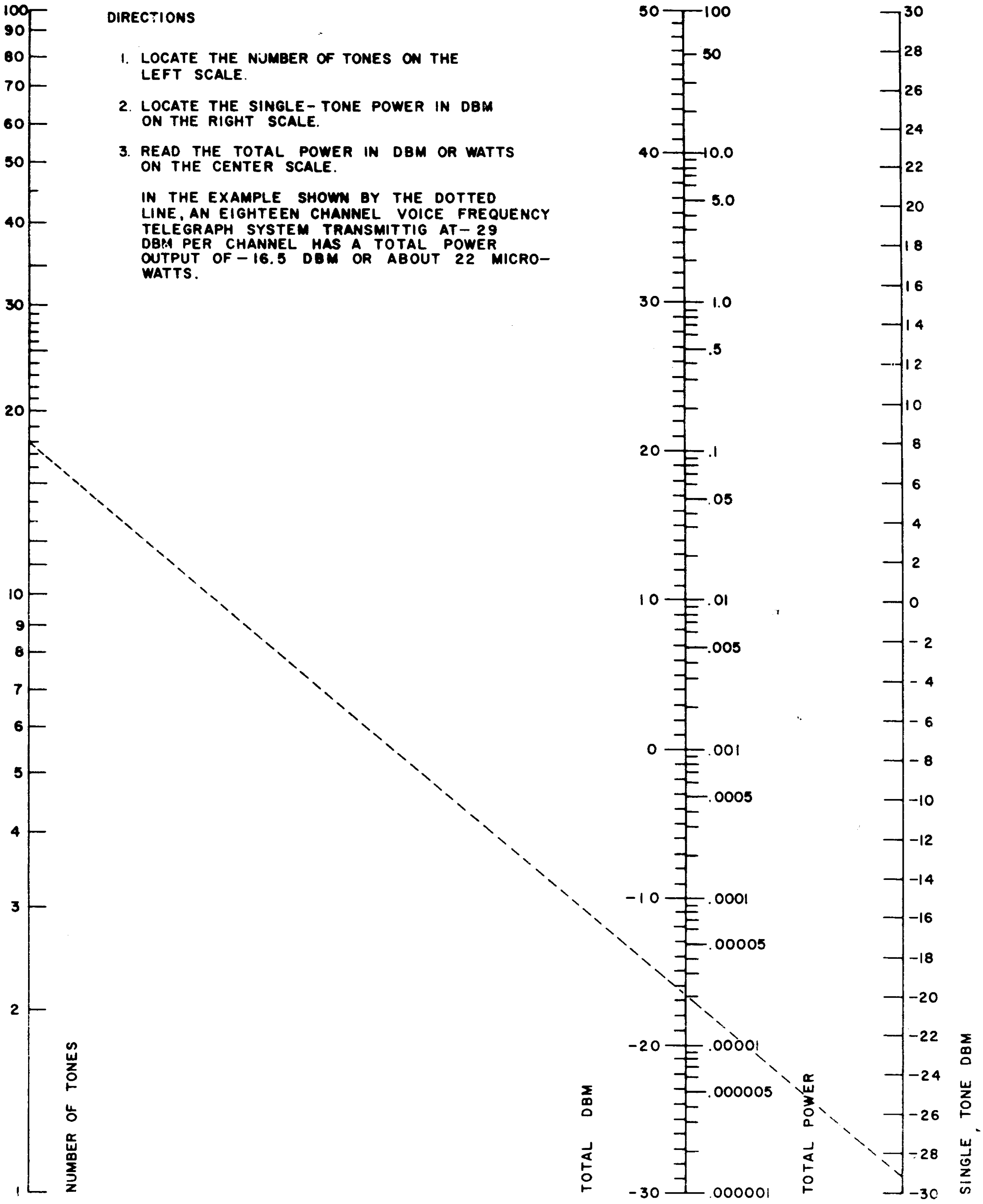
DBM	POWER	VOLTS ACROSS							
		600 Ω	200 Ω	135 Ω	75 Ω	50 Ω	16 Ω	8 Ω	4 Ω
+60	1KW	775V	447V	367V	274V	223V	126V	89.5V	63.2V
+50	100W	245V	141V	116V	86.5V	70.7V	40V	28.3V	20V
+40	10W	77.5V	44.7V	36.7V	27.4V	22.3V	12.6V	8.95V	6.32V
+30	1W	24.5V	14.1V	11.6V	8.65V	7.07V	4.0V	2.83V	2.0V
+20	100MW	7.75V	4.47V	3.67V	2.74V	2.23V	1.26V	895MV	632MV
+10	10MW	2.45V	1.41V	1.16V	865MV	707MV	400MV	283MV	200MV
0	1MW	775MV	447MV	367MV	274MV	223MV	126MV	89.5MV	63.2MV
−10	100μW	245MV	141MV	116MV	86.5MV	70.7MV	40MV	28.3MV	20MV
−20	10μW	77.5MV	44.7MV	36.7MV	27.4MV	22.3MV	12.6MV	8.95MV	6.32MV
−30	1μW	24.5MV	14.1MV	11.6MV	8.65MV	7.07MV	4MV	2.83MV	2.0MV
−40	.1μW	7.75MV	4.47MV	3.67MV	2.74MV	2.23MV	1.26MV	895μV	632μV
−50	.01μW	2.45MV	1.41MV	1.16MV	865μV	707μV	400μV	283μV	200μV
−60	10^3μμW	775μV	447μV	367μV	274μV	223μV	126μV	89.5μV	63.2μV
−70	10^2μμW	245μV	141μV	116μV	86.5μV	70.7μV	40μV	28.3μV	20μV
−80	10μμW	77.5μV	44.7μV	36.7μV	27.4μV	22.3μV	12.6μV	8.95μV	6.32μV
−90	1μμW	24.5μV	14.4μV	11.6μV	8.65μV	7.07μV	4.0μV	2.83μV	2.0μV
−100	.1μμW	7.75μV	4.47μV	3.67μV	2.74μV	2.23μV	1.26μV	.895μV	.632μV

LEGEND:

KW	Kilowatt	V	Volt
MW	Milliwatt	MV	Millivolt
μW	Microwatt	μV	Microvolt
μμW	Micromicrowatt	Ω	Ohms

POWER	SAME OR EQUAL R_L
3 DB = 2 P1/P2	6 DB = 2 E1/E2
6 DB = 4 P1/P2	12 DB = 4 E1/E2
9 DB = 8 P1/P2	18 DB = 8 E1/E2
10 DB = 10 P1/P2	20 DB = 10 E1/E2
20 DB = 100 P1/P2	40 DB = 100 E1/E2

TABLE 4-3 DBM–POWER–VOLTAGE



DIRECTIONS

1. LOCATE THE NUMBER OF TONES ON THE LEFT SCALE.
2. LOCATE THE SINGLE-TONE POWER IN DBM ON THE RIGHT SCALE.
3. READ THE TOTAL POWER IN DBM OR WATTS ON THE CENTER SCALE.

IN THE EXAMPLE SHOWN BY THE DOTTED LINE, AN EIGHTEEN CHANNEL VOICE FREQUENCY TELEGRAPH SYSTEM TRANSMITTIG AT -29 DBM PER CHANNEL HAS A TOTAL POWER OUTPUT OF -16.5 DBM OR ABOUT 22 MICROWATTS.

FIG. 4-1 DETERMINING TOTAL POWER OF A NUMBER OF EQUAL TONES

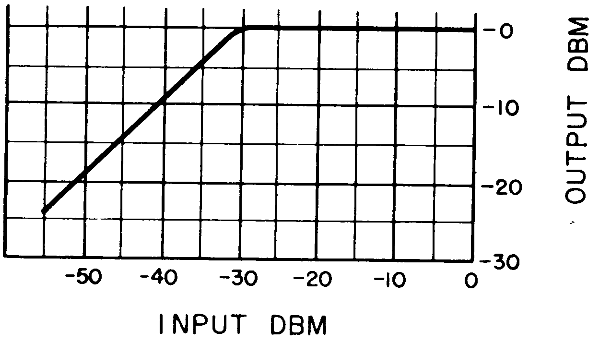


FIG. 4-2 AMPLIFICATION CURVE WITH COMPRESSION

pression" which may be varied from −30 dbm to around −8 dbm of signal input. In either amplifier, when the compression circuit is in use, the "level" control knob setting determines the maximum output, and after once being set for the desired maximum output level (usually 0 dbm), this knob should not be touched while the amplifier is being used on an active circuit. See Figure 4-2.

The amplifier will provide best quality output (least distortion) for input signals applied which are in the range of −30 dbm to around −60 dbm. For optimum performance, the compression control of the 413A should be set for a threshold of about −30 dbm. This setting for the 413A and the fixed compression of the 413 at −30 dbm provides an amplification characteristic for both amplifiers as shown in the accompanying sketch. The level control has been set for a 0 dbm maximum output.

Operation of the amplifier for optimum performance should be such as to provide an input signal that is as high as possible on the sloping portion of the curve (just under the −30 dbm threshold of compression). Where control of the input signal is available, such as at the output of a receiver, satisfactory operation with a fixed 30 db attenuation pad between receiver output and amplifier input will provide optimum amplifier output (input to a line). An occasional signal in excess of 0 dbm from the receiver will be compressed so as not to exceed specification limits for line operation.

Where more precise signal control is required, a variable pad should be provided, which will permit adjustment of the input signal level to the amplifier. This will permit operation of the amplifier for greatest linearity without degradation of signal-to-noise ratio.

4-10. CROSSTALK.

Crosstalk is the phenomena in which a signal transmitted in one circuit or channel of a transmission system is detectable in another circuit or channel. Crosstalk coupling between a disturbing and disturbed circuit is the ratio of the power in the disturbing circuit to the induced power in the disturbed circuit observed at definite points of the circuit under specified terminal conditions. It shall be expressed in db.

Under the design objective of MIL-STD-188, the crosstalk coupling between channels on a single link shall be numerically greater than 50 db when referred to equal level points.

The effects of crosstalk in a circuit, which is one of the cumulative "noise" factors in circuit operation, is discussed further under "NOISE."

4-11. NOISE.

a. DEFINITIONS.

NOISE.—Noise is the summation of the unwanted or disturbing power introduced into a system. It includes power generated by sources which produce atmospheric disturbances, cosmic radiations, power line noises, crosstalk, ignition noises, thermal voltages, electron tube and transistor noises. Included are harmonics and spurious emissions and spurious signals generated within the receiving system.

ATMOSPHERIC NOISE.—This radio noise is produced mostly by lightning discharges in thunderstorms and is thus dependent of frequency, time of day, weather, season of the year, and geographical location. It consists in general of short pulses, with random recurrence-superimposed upon a background of random noise. The received noise level varies with frequency because the noise radiated by the thunderstorm and its efficiency of propagation are functions of frequency. Other atmospheric noises are: rain static, snow static, and dust static; all irregular in character and occurrence.

MAN-MADE NOISE.—This includes interference produced by sources such as power lines, industrial machinery, ignition systems, certain telegraph and facsimile equipments, and other sources as outlined in Paragraph 2-15*e*.

COSMIC NOISE.—This noise originates outside the earth and may become the limiting factor in reception between 10 and 300 megacycles. It consists of galactic radiations, thermal noise from celestial bodies, and anomalous solar radiations dependent on sunspot cycle.

THERMAL NOISE.—This disturbance consists of noise voltages generated in a circuit or circuit component due to minute currents caused by thermal motions of the conduction electrons. The thermal noise power available from the passive resistance of a circuit is expressed as:

$$P = Ktb$$

Where: K = Boltzmann's constant, 1.38×10^{-23} watts/degree Kelvin/cps.
t = reference room temperature in degrees Kelvin at which noise figure measurements are to be made.
b = effective noise bandwidth in cycles per second.

NOISE FIGURE.–Used to express the noise quality of a network, receiver or amplifier in terms relating to the average available noise power, P_r, which results exclusively from sources other than thermal, and the thermal noise present in the network. Defined as:

$$f = \frac{P_r}{Ktb}$$

NOISE GRADE.–A number which defines the relative noise at a location with respect to other geographical positions throughout the world. It may be arbitrarily expressed numerically from 1 to 5, with noisiest localities having a noise grade of 5. A later method of expression is shown in Figures 4-3 and 4-4, where the noise grades are evaluated in terms of a median noise figure, Fam, of a short vertical antenna at 1 mc, expressed in db above Ktb.

b. DISCUSSION.–By definition, noise is unwanted signal energy that interferes with the normal functioning of electronic devices. It is present in all circuits and at all frequencies, audio and radio, and the amount of noise power under consideration must take into account the noise bandwidth of the measuring device as well as the noise bandwidth of the circuit undergoing measurement. Noise reaches the ear in a telephone receiver in the form of babble, crosstalk, etc., and interferes with telephone conversation. It obscures the signal in manual communications. It appears as "grass" on the radar screen. In all cases noise determines the weakest signal that can be used for communications. The most minute signal can be amplified to almost any level in a receiver and associated amplifiers. However, unless the desired signal has a certain minimum amplitude in relation to the accompanying noise, no amount of amplification will render the signal intelligible. The ultimate design objective, where the transmission of intelligence is involved, is to transmit the intelligence without impairment of its quality, maintaining the signal-to-noise ratio as high as possible.

Measurements and discussion concerning noise always center around a quantity "Ktb," which is the thermal noise power that is always present in any network and is the irreducible minimum noise power in watts present in a circuit. The factor, "K" = 1.38×10^{-23} watts per degree Kelvin per cps. The factor "t" is the reference room temperature in degrees Kelvin, and for practical calculations can be assumed to be 290 degrees K, or about 63 degrees F. This provides a workable figure upon which rough calculations can be made. The most significant factor in determining the amount of thermal noise power available then is "b", which is the effective noise bandwidth in cycles per second and will be determined by the transmission characteristic of the circuit undergoing consideration.

Other noise power sources contribute to the total noise power available. These noise power sources may be of atmospheric, galactic, or man-made origin and will also include noises generated within a receiver or amplifier by vacuum tubes and other circuit components which are, in themselves, noise generators.

As defined previously, the relationship that exists between thermal noise and the noise present in a network due to other sources is a measure of circuit merit, described as its "noise figure." It is expressed as the ratio of total noise power available from sources other than thermal, to that of thermal origin within the network, and for most efficient operation should be as low as possible. As it is a power ratio, it is usually expressed in decibels. Circuit design and choice of environment are factors which contribute toward keeping the noise figure small and thus permit the transmission of lower values of signal energy and still maintain a workable signal-to-noise ratio.

Circuit design includes a selection of resistors, tubes, and other circuit components which are as noise-free in operation as possible. Shielding, bonding, transposition of telephone wires and cables, and the use of balanced circuits, are also elements of circuit design which materially reduce the introduction of noise from external sources.

Choice of environment includes the location of receiving facilities geographically in low noise grade areas. Isolation from industrial areas and housing and the rigorous, continuing pursuit and elimination of man-made noise sources are essential factors in keeping the noise figure of a system as low as possible.

NBS Circular 557, "Worldwide Radio Noise Levels Expected in the Frequency Band 10 KC to 100 MC," contains a discussion of radio noise. The discussion relates noise to the quantity Ktb for various circuit components and provides charts of worldwide noise grades for various seasons. Median values of radio noise expected for a short vertical antenna are charted.

Figure 4-3 is a typical chart taken from CCIR (International Radio Consultive Committee) predictions and shows noise grade contours for the months

Crichlow: Noise Investigation at VLF by NBS

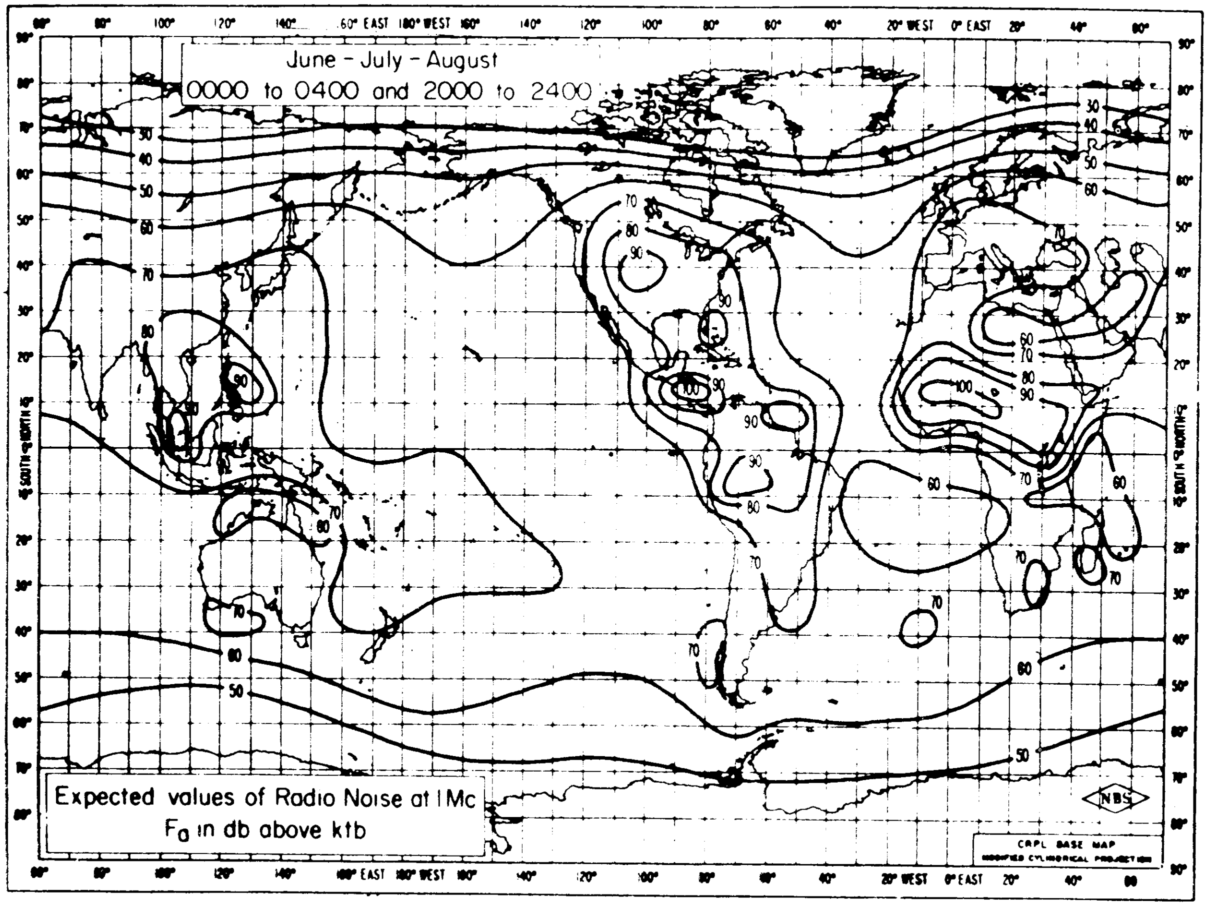


FIG. 4-3 TYPICAL WORLD DISTRIBUTION OF NOISE GRADES

of June, July, and August and for night-time hours, local time. This chart illustrates the geographic distribution of noise, and as the storms progress from the northern hemisphere to the southern hemisphere with seasons, the noise level as received at any particular location will, therefore, show a systematic variation. Similar charts have been prepared which show the systematic variation of the noise contours with time of day, and twenty such charts cover both the diurnal and seasonal variations.

Figure 4-4 is taken from CCIR predictions and illustrates the systematic variation of noise level with frequency. Having determined a noise grade at a particular location from a chart similar to Figure 4-3, it is then possible, by use of these curves, to determine the expected noise level at any other frequency. This particular graph is for night-time propagation conditions, and a similar set of curves is available to show the frequency variation during daytime propagation conditions.

In the figure, Fam is defined as the median noise figure of a short vertical antenna expressed in db above Ktb. The median value is obtained by observations on a time basis in which the noise figure will exceed this value 50% of the time.

As shown by Figure 4-4, of all noise sources at the lower communication frequencies, atmospheric noise is the largest contributing factor in determining receiver performance. Around 30 mc, galactic disturbances predominate, falling off above 100 mc.

c. MEASUREMENTS.—The measurement of noise energy can be roughly classified in two categories, (1) measurements involving radio frequency interference, and (2) measurements of noise in the audio spectrum which affect telephone and associated apparatus.

At radio frequencies, noise is propagated in the same manner as other radio frequency energy. The

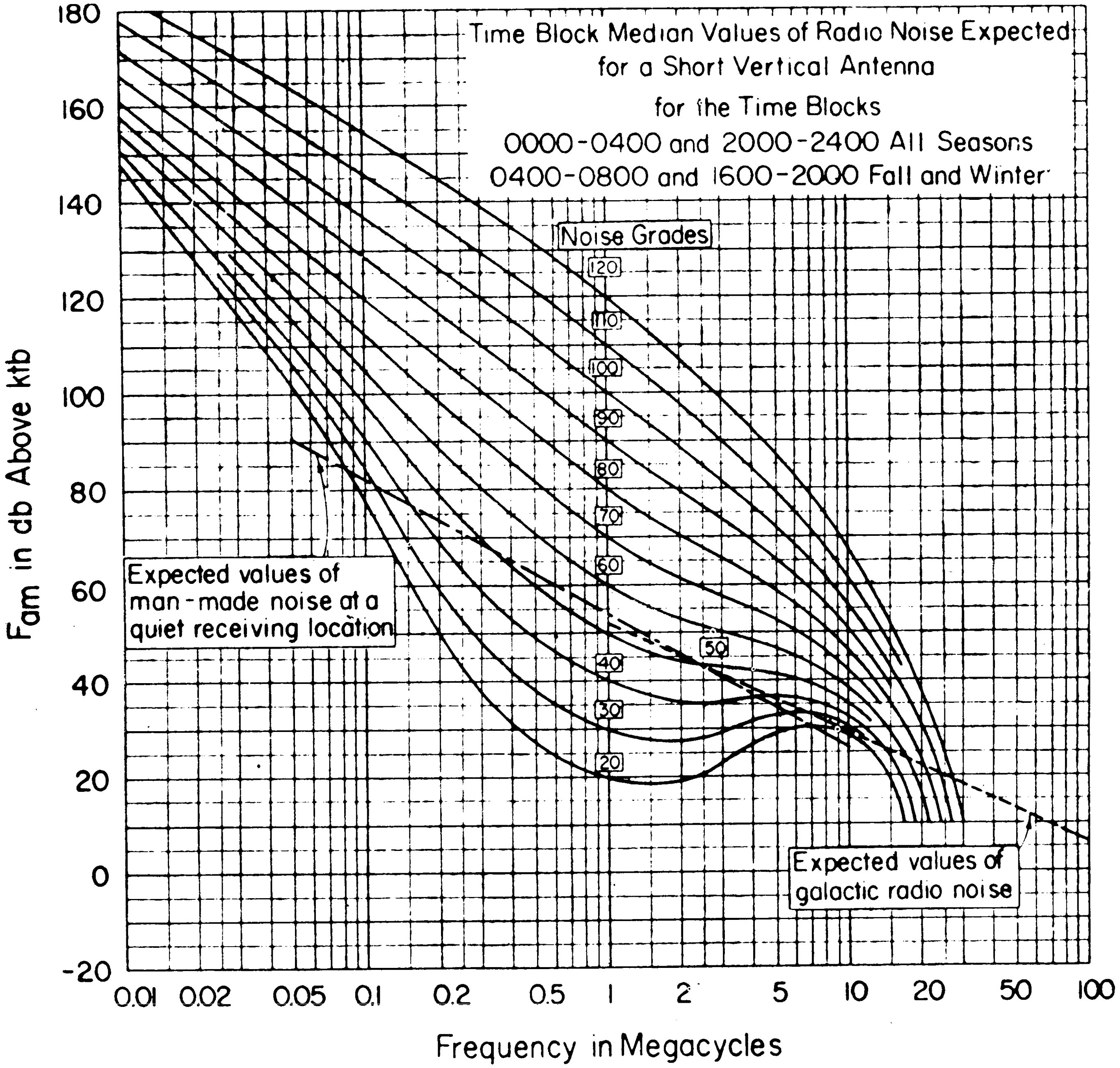
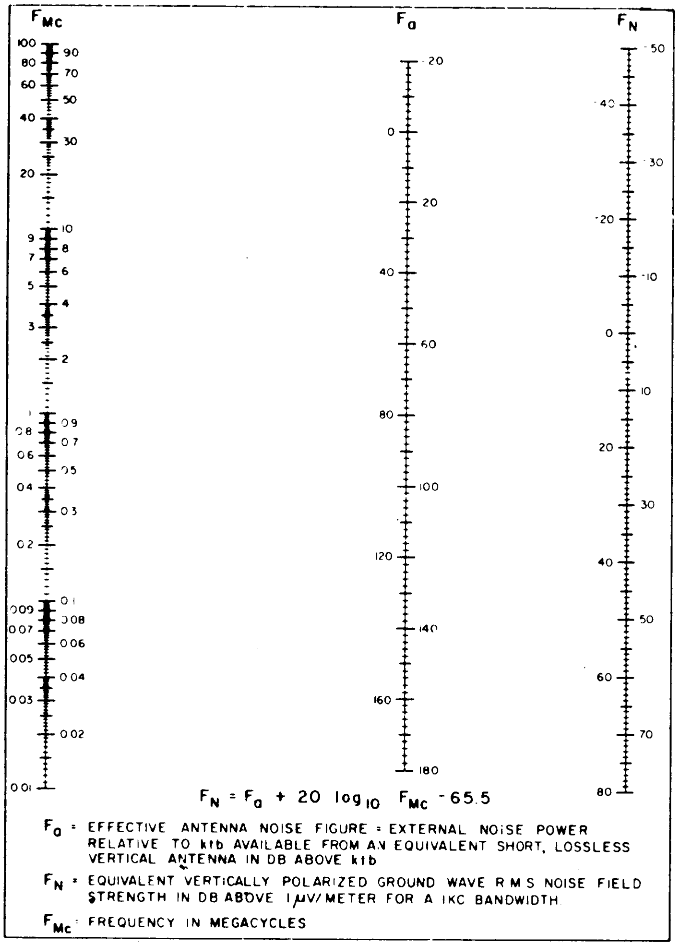


FIG. 4-4 VARIATION OF NOISE LEVEL WITH FREQUENCY



$F_N = F_a + 20 \log_{10} F_{MC} - 65.5$

F_a = EFFECTIVE ANTENNA NOISE FIGURE = EXTERNAL NOISE POWER RELATIVE TO ktb AVAILABLE FROM AN EQUIVALENT SHORT, LOSSLESS VERTICAL ANTENNA IN DB ABOVE ktb

F_N = EQUIVALENT VERTICALLY POLARIZED GROUND WAVE R M S NOISE FIELD STRENGTH IN DB ABOVE 1 μV/METER FOR A 1KC BANDWIDTH

F_{MC} = FREQUENCY IN MEGACYCLES

FIG. 4-5 NOMOGRAM FOR TRANSFORMING EFFECTIVE ANTENNA NOISE FIGURE TO NOISE FIELD STRENGTH AS A FUNCTION OF FREQUENCY

measuring device for this noise energy is a receiver, such as the AN PRM-1A, with an output meter calibrated to measure noise (or signals) in terms of microvolts per meter; and to obtain average, peak, or quasipeak readings of interference. Quasipeak measurements are measurements in which a fraction of the peak of the IF amplifier output voltage is determined, the size of the fraction being directly proportional to the ratio of the discharge time-constant to charge time-constant of the weighted detector circuit. The nature of radio interference is such as to contain peaks which may be much greater than the average or RMS value of a usable communication signal. Because of peak limiting circuits, and tolerance in communication techniques, the quasipeak measure of radio interference may be used for an approximating factor in the determination of a workable signal-to-noise ratio.

Several factors must be considered in connection with noise measurements in order to determine accurately the disturbing effect of noise in a circuit. The first of these factors is the transmission characteristic of the circuit undergoing measurement. Most circuit noise is thermal in origin, or has the characteristics of thermal noise energy; that is, it has fairly uniform distribution on all frequencies within the frequency band under consideration. The transmission characteristic of the circuit undergoing test therefore determines the amount of noise present at its output terminals, permitting the transmission only of those frequency components of noise energy within the 3 db points of its response curve or pass band. Frequency components outside of this transmission characteristic will be attenuated and will therefore have lesser effect on subsequent circuits and their operation, depending on cutoff or the "filter" characteristic of the device.

The second factor to be considered is the transmission characteristic of the circuit or electronic system which is going to be affected by the presence of noise. As an example, all the noise present on a receiving antenna would not seriously affect a receiver's performance, only that noise within the noise pass band of the receiver itself determines the signal-to-noise ratio. Likewise all the noise at the output of a 6-kc line would not affect performance of a device with filtering or line equalization to produce a 4-kc transmission characteristic.

To measure the disturbing effect of noise in audio or video-frequency circuitry, line weighting networks, such as are recommended in maintenance of the UQ microwave relay system, are employed. At radio frequencies, the band pass characteristic of a radio interference meter, such as the AN/PRM-1A must be taken into consideration. In addition, the circuit undergoing measurement must be properly terminated so that its transmission characteristic is not altered by the presence of the noise measuring device.

d. REFERENCE LEVELS.–The reference levels of dbm, dbRN, and dba are defined as follows:

Dbm.–Dbm (db referred to one milliwatt) is employed in communication work as a measure of absolute power values. Zero dbm equals one milliwatt.

Dba.–Db adjusted, abbreviated dba. The reference level is –90 dbm at 1000 cps, and the "adjustment" is dependent on the frequency band characteristic of the measuring device. It is used in connection with measurements employing weighting networks to accurately describe the disturbing effect of the noise measure.

DbRN.–Db above reference noise, abbreviated dbRN, is a unit of measurement of electrical circuit noise in which the noise is referred to a zero reference power of one micro-microwatt at 1000 cps (90 db below 1 milliwatt, or –90 dbm) as measured by Transmission Measuring Set TS-559/FT.

TRANSMISSION CHARACTERISTIC.–A term applied to a network or electronic circuit which describes the manner in which the frequency components of electrical energy are transmitted. Measurements pertaining to the characteristic produce a response curve at audio and video frequencies. The band pass capability at radio frequencies may be termed its "transmission characteristic." See Paragraph 4-4, under BANDWIDTH.

A zero reference level of 1 micro-microwatt (–90 dbm) at 1000 cps (0 dbRN) and a meter calibrated with such a signal can be used to make noise measurements. The noise measured with such a meter would not, however, provide a true picture of the disturbing effect of the noise. For this reason, noise weighting networks are used and the unit of measurement is the dba.

In telephone engineering, the disturbing effect of noise at various frequencies is dependent on the characteristics of the human ear, and upon the frequency response and sensitivity of the standard telephone receiver. For this reason the noise measuring devices such as the TS 559, or Western Electric 2B, used by telephone engineers, employ noise weighting to obtain a noise measurement that is representative of the relative disturbing effect of the noise frequencies in a telephone communication system.

The two types of weighting networks (144 and F1A) used in telephone practice in the United States are based on the relative frequency response of the type-144 and type-F1A telephone handsets. Noise measurements made with the 144 weighting network are expressed in dbRN or dba. Noise measurements made with F1A weighting network are expressed in dba. An expression of noise in dba (db adjusted) is indicative of the disturbing effect independent of the network used.

The use of measurements expressed in dba implies a need for precise knowledge as to the disturbing effect of a noise for a particular application. This requires the employment of weighting networks, calibration for particular use (such as bridging or terminating), and application of a correction factor to provide the "adjusted" readings. Tables and charts for this purpose are supplied with an instrument such as the W.E. 2B measuring set. Unless a more precise figure is required, an "adjusted" noise measurement expressed in dba is obtained by adding 7 db to the dbRN value obtained with available measuring instruments using F1A weighting.

Table 4-4, from the Department of the Army, Technical Manual, indicates the readings of the noise at an input power of 1 milliwatt (0 dbm). The noise meter reading for zero vu speech is also given. The last line shows that average speech may be converted to dba by adding 82. The speech-to-circuit noise ratio in db may, therefore, be computed from known values of speech in vu and noise in dba. For example, if, at some point in a circuit, the speech is –40 vu and the noise is 30 dba, the speech-to-noise ratio is (–40 + 82) –30 = 12 db.

TABLE 4-4, NOISE MEASUREMENTS WITH ADJUSTED READING

Wave Shape of Electrical Source	Noise Meter Reading (dba)
250 cycles – 0 dbm	65

1000 cycles – 0 dbm	85
2000 cycles – 0 dbm	81
3000 cycles – 0 dbm	77
Thermal noise – 0 dbm	82
Speech – zero vu	82 (average)

e. SIGNAL-TO-NOISE RATIOS.—In order to obtain reliable communications over a given transmission path, precise specification and maintenance of a workable signal-to-noise ratio must be established. Naval operations require reliable communications on prime circuits, twenty-four hours a day, every day in the year, and every year in the 11-year sun spot cycle. Circuit and plant engineering, assigned frequencies, antenna design, circuit length and man-made noise must be such that a high order of continuity of communications is obtained in the designated coverage areas. This means that at the time of maximum noise and/or circuit loss the signal-to-noise ratio shall exceed that required for continuity of operation.

The signal arriving at the receiving antenna must be of sufficient magnitude to over-ride the noise (atmospheric, galactic and man-made) which is also arriving at the antenna. If the signal itself is too weak to overcome this noise handicap, nothing can be done to provide communication but to go back to the signal source and increase the signal energy, or shift to another frequency with increased propagation capability. Considering only the noise arriving at the antenna by way of electro-magnetic propagation, only man-made noise can be reduced or avoided. This noise includes radiations from diathermy apparatus, fluorescent lighting, ignition noises and such, which can be eliminated or rendered ineffective by suppression or filtering processes at the source. Interference by other transmissions can be minimized by proper frequency selection and cooperation between communication systems regarding frequency stability, harmonic generation and spurious emissions. Directive antennas help to maintain a higher signal-to-noise ratio because focusing the antenna in the direction of the signal source attenuates noise arriving from other directions. Receiver design with proper selectivity and with noise limiting features will aid in maintaining an adequate signal-to-noise ratio. When the foregoing factors have been given proper consideration with regard to the establishment and maintenance of a workable signal-to-noise ratio, it is essential that further degradation be prohibited or minimized. The noise figure of the receiver system must be maintained as low as possible. Much can be done in this direction by proper installation practices, including grounding techniques which tend to prevent such degradation of the signal-to-noise ratio in the presence of local noise energy sources.

Table 4-5 lists what are described to be the minimum operating signal-to-noise ratios for various classes of commercial service in tele-communications. The table is reproduced as being representative only, and the specified values are not to be considered "design or operating standards" without qualification.

TABLE 4-5. SIGNAL-TO-NOISE RATIO

Type of Radio Service	Approximate Minimum S/N (Decibels)
1. Double-sideband radiotelephone (3-kilocycle bandwidth)	15
2. Single-sideband radiotelephony (3-kilocycle bandwidth)	9
3. Broadcasting (5-kilocycle bandwidth)	26
4. Manual Morse radiotelegraphy (for average operators)	0
5. Frequency-shift radiotelegraphy (60-word teleprinter speed)	6
6. Single-sideband four-tone radiotelegraphy, two tones marking and two tones spacing, 60-word speed	6
7. Single-sideband two-tone radiotelegraphy, one tone marking and one tone spacing, 60-word speed	8
8. Radio facsimile with 8-decibel contrast ratio using double-sideband amplitude modulation	18
9. Radio facsimile with 8-decibel contrast ratio using carrier-shift	12

Note 1: The signal-to-noise ratios given are those required for reliable commercial operation, assuming the limiting factor is only noise.

Note 2: Noise includes all extraneous interference due to atmospheric static, man-made static, or interfering signals from other stations.

Note 3: Professional operators engaged in handling telegraph or telephone traffic often are able to copy faithfully when S/N is 10 to 15 db below the values stated for 1, 2, and 4. The others, with the exception of 3, are intrinsically machine methods.

Note 4: Consult documents of the International Radio Consulting Committee (CCIR) for standards under study on this subject.

From: Radio Antenna Engineering
by E. A. LaPort

McGraw-Hill Book Co., Inc.
1952

f. OPERATIONAL STANDARDS.–The following are from MIL-STD-188:

4-KC Channel

Noise on Trunks.–The noise measured at the receiving end, when converted to the zero db relative transmission level point on 4-kc trunk circuits, shall not exceed 31 dbRN (db above Reference Noise) as measured with a transmission Measuring Set TS-559/FT or equal, using F1A line weighting (Note: This is equivalent to 38 dba).

Radio Circuits

VLF Range.–Carrier Noise Level – Hum, ripple, or other extraneous noise on the carrier shall be at least 40 db below the CW or unmodulated carrier level.

LF Range.–Carrier Noise Level – Hum, ripple, or other extraneous noise on the carrier shall be at least 40 db below the CW or unmodulated carrier level.

MF Range.–Carrier Noise Level – Hum, ripple, or other extraneous noise shall be at least 60 db below the 95 percent modulation level for the band of 300 to 3500 cps at zero dbm input.

HF Range.–Carrier Noise Level – Hum, ripple, or other extraneous noise shall be at least 60 db below the 95 percent modulation level for the band of 300 to 3500 cps at zero dbm input.

VHF Range.–Signal-to-Noise Ratio Per Link or Trunk.

Nominal 16-kc channel.–The rms test tone power to broadband rms noise ratio shall be at least 56 db. Test tone power may be any frequency in the pass band and shall be numerically equal to the relative transmission level at the point being measured. Noise shall be measured with a meter of flat weighting covering the entire pass band.

Nominal 48-kc channel.–The rms test tone power to broadband rms noise ratio shall be at least 53 db. Test tone power may be at any frequency in the pass band and shall be numerically equal to the relative transmission level at the point being measured. Noise shall be measured with a meter of flat weighting covering the entire pass band.

No-signal noise level (single sideband).–Hum, ripple, or other extraneous noise shall be at least 40 db below the single sideband reference level for low-performance equipment and at least 50 db for high-performance equipment.

HF Range.–Carrier Noise Level – Hum, ripple, or other extraneous noise originating within the equipment shall be at least 50 db below the 95 percent modulation level for the audio band.

VHF Range.–Carrier Noise Level – Hum, ripple, or other extraneous noise originating within the equipment shall be at least 50 db below the 95 percent modulation level for the audio band.

UHF Range.–Carrier Noise Level – Hum, ripple, or other extraneous noise originating within the equipment shall be at least 50 db below the 95 percent modulation level for the audio band.

Aircraft Systems (Surface to Air)

HF Range.–Carrier Noise Level – Hum, ripple, or other extraneous noise originating within the equipment shall be at least 50 db below the 95 percent modulation level for the audio band.

VHF Range.–Carrier Noise Level – Hum, ripple, or other extraneous noise originating within the equipment shall be at least 50 db below the 95 percent modulation level for the audio band.

UHF Range.–Carrier Noise Level – Hum, ripple, or other extraneous noise originating within the equipment shall be at least 50 db below the 95 percent modulation level for the audio band.

4-12. TELETYPEWRITER CIRCUIT PERFORMANCE.

a. OPERATIONAL STANDARDS.–In accordance with current requirements in MIL-STD-188, the following operational standards have been established for teletypewriter equipment and associated circuitry:

"*Transmitting mechanisms.* The distortion in the signals generated by the teletypewriter sending equipment shall not exceed 5 percent.

"*Receiving mechanisms.* The receiving mechanisms of teletypewriter equipment shall be capable of local operation at 60 wpm without error on signals which have 40 percent marking or spacing bias and also on signals which have 35 percent marking or spacing end distortion. At an operating speed of 100 wpm, the bias and end distortion requirements shall be 35 and 30 percent, respectively. (75 wpm operation is currently employed by many Navy circuits.)

"*Loop.* Telegraph distortion, bias or end, introduced by a loop shall not exceed 10 percent.

"All types of direct current loops shall be operated on a neutral or polar basis. (Navy utilizes neutral operation almost exclusively.)

"Neutral loops shall be operated with a steady state current flow of 20 or 65 ma plus or minus 10 percent for marking condition and a nominal zero ma for spacing condition.

"Polar loops shall be operated with a steady state current flow of 30 ma plus or minus 10 percent for marking condition and a steady state current flow of 30 ma plus or minus 10 percent in the opposite direction for spacing condition.

"Nominal steady state voltage (telegraph battery) applied to the loop shall be 125 volts.

"Maximum steady state voltage (telegraph battery) applied to the loop shall not exceed 250 volts."

b. DISTORTION.—In many Navy applications, a single teletypewriter loop is a very small component of the complete system. From end instrument to end instrument are numerous component sub-systems which may include wire and microwave link facilities, carrier systems, SSB channels, antennas, transmission lines, receivers, transmitters, and the propagation paths, each of which may contribute to the total teletypewriter signal distortion present in the loop. Theoretically, and under ideal conditions all components of the complete system would operate in such manner that no distortion is present. A measure of the distortion appearing in the receiver loop is therefore a measure of performance of the complete system, and for this reason, periodic examination of telegraph distortion in a loop serves to measure system performance. In some heavily burdened and vital circuits, continuous examination of distortion at times may be desirable.

The following definitions of distortion are contained in MIL-STD-188:

"Distortion, teletypewriter signal.—Distortion of start-stop teletypewriter signals is the shifting of the transition points of the signal pulses from their proper positions relative to the beginning of the start pulse. The magnitude of the distortion is expressed in percent of a perfect unit pulse length.

"Distortion, bias.—Bias distortion or bias of start-stop teletypewriter signals is the uniform shifting of the beginning of all marking pulses from their proper positions in relation to the beginning of the start pulse.

"Distortion, end.—End distortion of start-stop teletypewriter signals is the shifting of the end of all marking pulses from their proper positions in relation to the beginning of the start pulse.

"Distortion, fortuitous.—Fortuitous distortion of telegraph signals is the random departure from the average of the position of the transition points of a signal pulse."

Appendix XI contains a discussion of telegraph signal distortion which is of interest and useful in the application and analysis of distortion measurements as a system test procedure for teletypewriter circuits. In this discussion of distortion, the definition and treatment of "characteristic distortion" does not consider any source of "characteristic distortion" other than that introduced into a system "at the sending point, a regeneration point, or a point where the signals are converted from one code to another." Authorities differ on this definition and consider line characteristic distortion also as a part of the total characteristic distortion. This modifies the concept of characteristic distortion to include "the distortion of telegraph signals due to factors inherent in the telegraph terminal services plus that peculiar to the fixed characteristics of the transmission medium."

On a well-engineered system, characteristic distortion may be established as the circuit maintenance standard. Initial engineering to provide high-quality telegraph service plus adequate maintenance procedures to obtain optimum equipment performance are basic requirements. Distortion measurement as a system test will provide information relative to performance degradation which will help to reduce marginal operation and possible circuit outages.