CHAPTER 8
TEST EQUIPMENT AND TECHNIQUES

1. GENERAL

When a transmitter is operated, three characteristics of the output signal are of prime importance. These are:

(1) Carrier Frequency

(2) Signal level

(3) Undesired power output

The carrier frequency is that frequency which designates the position in the spectrum occupied by the band of frequencies required to transmit the intelligence. Desired signal level is the r-f power confined to those discreet frequencies within this band that are required to transmit the intelligence. Undesired power is the r-f power at frequencies both within this band and outside it, that are not necessary to the transmission of the intelligence and, therefore, interfere with the transmitted signal as well as with other communication channels.

2. FREQUENCY MEASUREMENT

Two commonly used methods of frequency measurement are:

(1) Frequency counter and converter

(2) Receiver and frequency standard

A typical frequency counter for measurements up to 100 megacycles is the Hewlett-Packard 524B with the Hewlett-Packard 525A converter installed. Higher frequency measurements can be made with other converters which can be installed in place of the 525A. The frequency resolution of this instrument is variable by a switch on the front panel to as low as .1 cps, but in normal use, a resolution of ±1 cps is sufficient. The period of the count is the reciprocal of the resolution. For example, for a resolution of 0.1 cps the count period is 10 seconds and for a resolution of 1 cps the count period is 1 second. The readout accuracy of the counter is ±1 in the last digit so that with a resolution of 0.1 cps the accuracy of the reading displayed is ±0.1 cps and with a resolution of 1 cps the accuracy of the reading is ±1 cps. If the frequency to be counted is 10 mc and the resolution is 0.1 cps, then the readout accuracy is plus or minus 1 part in 10^8. The over-all accuracy of the measurement depends upon the accuracy of the time base standard. For example, if the oscillator producing the time base has an accuracy of 1 part in 10^8 then with a readout accuracy of 1 part in 10^8, the over-all accuracy of measurement is 2 parts in 10^8. The frequency counter is designed to count the frequency of a single sine wave of an amplitude of about 1 volt. It will not give a true indication of frequency in the presence of a complex wave since the digitalizing of the data obtained from the incoming signal is accomplished by counting the number of times the instantaneous voltage crosses a given absolute value. Short term errors existing during the period of the count are integrated by the counter, and the average error is included in the frequency display at the end of each count. The internal frequency standard which provides the time base for the count in the HP525A has a stability of approximately 1 part in 10^6 per day, but provision is made for connection of an external standard if higher accuracy is desired.

A second method of frequency measurement using a receiver and associated frequency standard is less accurate than the frequency counter method. If a receiver such as the Collins 51J is used, the internal frequency standard can be calibrated to a standard of known accuracy, and by using the bfo, the kilocycle dial can be calibrated at adjacent, integral 100 kc points on each side of the frequency at which the measurement is to be made. The accuracy of the measurement made with this receiver will be in the order of ±250 cps.

A highly accurate adjustment between two frequency standards can be made by mixing products of the two standards into a receiver and adjusting one standard to agree with the other by observing the beat frequency on the receiver S meter. Best results are obtained when the effect of the two frequencies are equal in amplitude at the detector in the receiver. Where such comparison is made between two frequency standards, the 100 kc output of one standard can be amplified to about 100 volts and applied to the calibrator crystal socket in the receiver to obtain strong 100 kc points throughout the range of the receiver. A transmitter whose frequency standard is to be trimmed is tuned to an integral 100 kc point; the receiver is tuned to that frequency, and the beat between the two observed on the receiver S meter. The level of input to the receiver from the transmitter is adjusted for maximum swing on the S meter and then the transmitter standard is adjusted for zero beat. When using frequency standards with stabilities of 1 part in 10^8 per day or better, beats having periods of approximately 20 seconds can be obtained when comparing signals at 30 mc.

Since the frequency counter will not give an accurate measurement of frequency in the presence of a complex wave, and since measurements of frequency by means of a receiver are confused in the presence of additional signals, it is necessary to disconnect modulation from the transmitter and make all frequency measurements on the reinserted carrier, or on a single tone of known frequency and stability equal to that of the equipment under test.

3. SIGNAL LEVEL

Most measurements of power output presume that the level of undesired power output is small compared to the accuracy required of the measurement of desired power output. Normally, the rms sum of undesired power output will be in the region of 35 to 40 db below desired power output, or about 1% of desired power. If a suitable resistive load is available to terminate the r-f output circuit, a vacuum-tube voltmeter such as the Hewlett-Packard 410B will give a reading of voltage across the load which is reasonably accurate for power computation. This meter is a negative peak reading meter calibrated in terms of rms. It has a very high impedance a-c probe which will not change the reactive characteristics of a 50 ohm line, provided that the meter probe is connected across the line with a minimum of additional shunt capacity or series inductance. When using this method for measuring power, the accuracy of voltage measurement is important since the effect of any error is squared when computing $P = \frac{E^2}{R}$. The most accurate measurement available with the Hewlett-Packard 410B is made with a single tone, although experience has shown that measurement of two equal tones on the r-f output line will give a voltage indication for computing peak envelope power to an accuracy varying between 5 and 10%, the higher accuracy being obtained on the higher ranges of the meter. Table 8-1 and figure 8-1 show comparative measurements made with a vu meter which reads slightly above the average value of the applied signal, a Ballantine 310A which reads the average value, a Ballantine 320 which reads true rms, a Hewlett-Packard 410B which reads negative peaks but is calibrated in rms, and an oscilloscope which was used to obtain the peak to peak voltage of the signal. Measurements were made on a signal containing from 1 to 16 equal audio tones. In table 8-1 the output level of the amplifier was reset for each reading so that the maximum reading on the vu meter was -3.0 vu. Since beats between tones began to effect the meter readings after more than 2 tones

TABLE 8-1. COMPARATIVE METER READINGS 1 TO 16 EQUAL TONES
AMPLIFIER OUTPUT HELD CONSTANT ON VU METER

Meter	VU		310A		320	410B			Scope
Reads	Average +		Average		True RMS	Neg Peak			P-P
Calibrated	VU		dbv		dbv	Volts rms			Volts
No. of Tones	Min	Max	Min	Max		Min	Avg	Max	Max
1		-3.0		-1.5	-1.5			0.85	2.6
2		-3.0		-1.7	-0.7			0.23	3.8
3		-3.0		-1.7	-0.8	1.3	1.4	1.5	4.5
4	-4.0	-3.0	-3.0	-1.7	-1.3	1.0	1.4	1.6	5.0
5	-4.0	-3.0	-2.7	-1.8	-1.2	1.1	1.4	1.8	5.5
6	-4.0	-3.0	-3.1	-1.7	-1.0	1.0	1.4	1.9	5.3
7	-4.0	-3.0	-3.0	-1.6	-0.95	1.1	1.5	2.1	6.0
8	-4.0	-3.0	-2.7	-1.8	-1.0	1.1	1.5	2.2	6.2
9	-4.0	-3.0	-3.0	-1.7	-1.0	1.1	1.5	2.3	7.0
10	-3.7	-3.0	-3.0	-1.8	-1.0	1.1	1.6	2.3	7.0
11	-3.7	-3.0	-3.0	-1.5	-1.0	1.05	1.5	2.4	7.0
12	-4.0	-3.0	-2.7	-1.8	-1.0	1.1	1.6	2.3	7.0
13	-3.9	-3.0	-2.7	-1.7	-1.0	1.1	1.6	2.2	7.0
14	-4.0	-3.0	-2.8	-1.8	-1.0	1.1	1.6	2.5	7.2
15	-4.0	-3.0	-3.0	-1.7	-1.0	1.1	1.6	2.5	7.2
16	-4.0	-3.0	-2.8	-1.7	-1.0	1.1	1.6	2.4	7.2

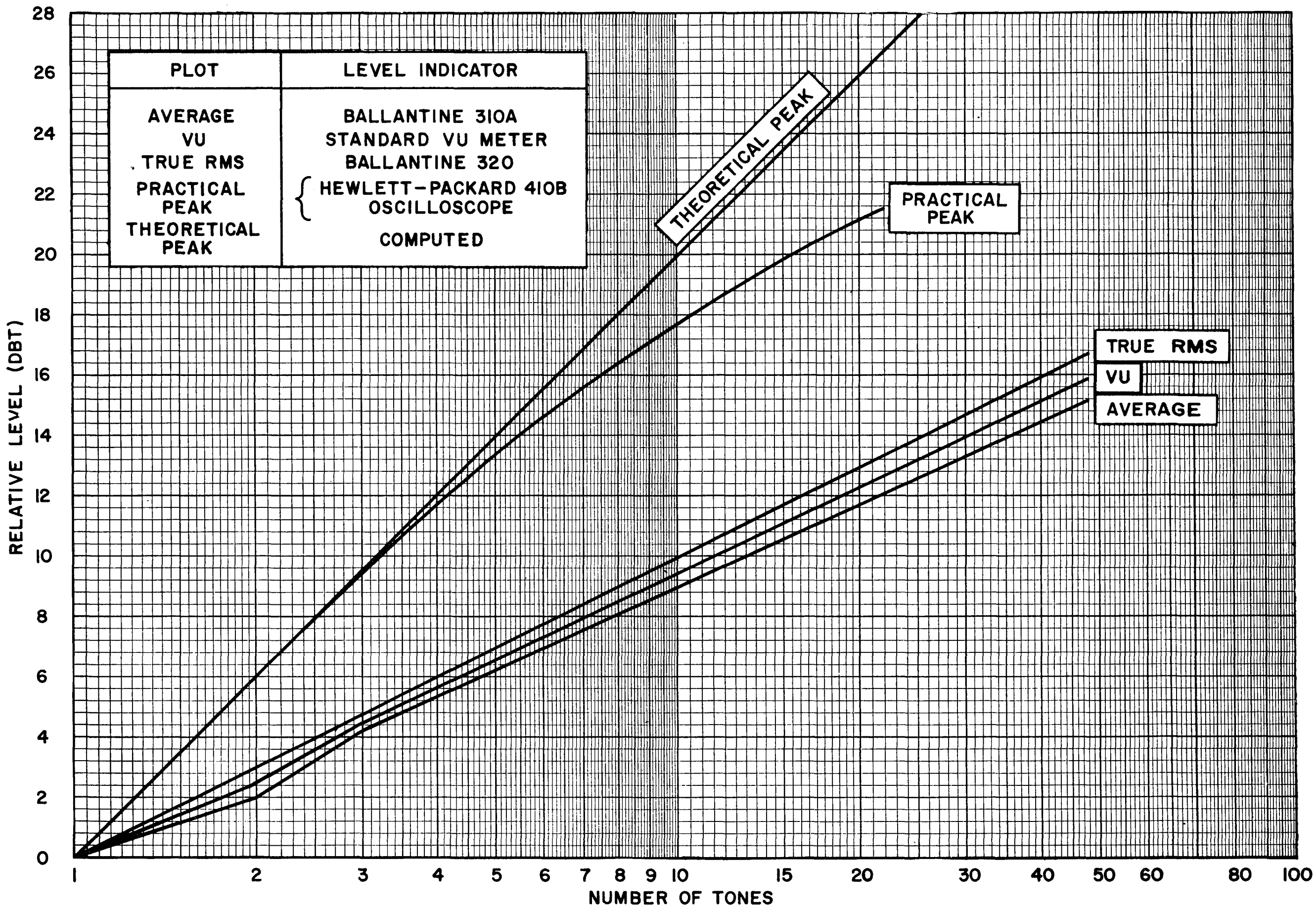


Figure 8-1. DB Level Versus Number of Equal Amplitude Tones for Various Types of Level Indicators

were combined, the minimum and maximum readings were taken each time. Where average readings are given, they are the value indicated by the meter for a major portion of the period during which each reading was taken. Similar readings were taken for figure 8-1. A signal composed of 16 tones of equal amplitude was adjusted to indicate full scale maximum on the vu meter. Then the tones were dropped one at a time and the maximum readings were taken without further level adjustment. All readings were converted to DBT (decibels with 0 db equal to the indication for a single tone on each type of indicator).

The theoretical peak was computed on the basis of a 6 db increase each time the number of tones is doubled and is indicative of theoretical peak envelope power. The true rms indication increases 3 db each time the number of tones is doubled and is indicative of true "heat" power. Statistically, the possibility of the practical peak indication approaching theoretical peak during a given time interval may be computed. The Hewlett-Packard 410B and the oscilloscope agree within a few tenths of a decibel when read for maximum peak indication over a one minute interval, yielding the practical peak curve of figure 8-1 which is indicative of practical peak envelope power. Note the double inflection in the vu and average curves at the two-tone and three-tone points, the divergence of the vu and average curves from true rms above three tones, and the fact that the vu indication remains almost exactly midway between average and rms throughout the graph.

The Ballantine 310A is an average reading vacuum-tube voltmeter calibrated in terms of rms but does not have as high an input impedance as the Hewlett-Packard 410B probe and has a cutoff frequency of about 2 mc. However, since its sensitivity extends to less than 100 microvolts, it is useful for measuring low signal levels at i-f frequencies. Dummy loads such as those manufactured by the Bird Electronic Corporation exhibit resistance tolerance of the order of ±0.5 ohm and present very little reactance to the signal source. Most of these loads are good for measurements into the hundreds of megacycles. If a resistive dummy load is not available, the measurement of voltage or current will not give an accurate indication of power. In these circumstances the calorimetric method of measuring power will give a more accurate indication. The flowmeter and thermometers may be calibrated separately to high accuracies and errors in reading of the flowmeter or thermometers do not appear in a squared term in the calculation of power as do the errors in voltage or current readings. The accuracy of the temperature readings, however, is affected by the temperature at which the calorimeter is operated with respect to the ambient temperature.

Another device for measuring power, which does not require a special load and which can be used while feeding an antenna, is a directional wattmeter. Figure 10-29 is a chart showing the relationship of the standing-wave ratio to forward and reflected power. The wattmeter will measure average power integrated as affected by the time constant of the metering network, and if both forward and reflected power are measured instantaneously, the chart will hold for multiple tones. An envelope detecting voltmeter will read 45% of peak voltage when a two-tone r-f signal is applied. This presumes that the voltmeter reads the average of the r-f and the rms of the envelope. Thus 0.707 of 0.637 is 0.45 or 45% of peak envelope voltage. A modification of directional wattmeters to approach a measurement of peak envelope power is useful for speech and other complex single-sideband signals, since these quantities are of greater importance in single-sideband equipment than average power. With extra capacity to lengthen the time constant of the voltmeter circuit, it is possible to make the meter read approximately 0.8 of the peak envelope power so that it will follow speech peaks more closely.

4. UNDESIRED POWER OUTPUT

Two types of undesired power may be present in the output of a transmitter. These are:

(1) Spurious responses outside the passband

(2) Intermodulation and incidental amplitude and angle modulation products in or near the passband

Spurious responses outside the passband consist mainly of harmonics of the desired output frequencies, products of frequency synthesis, and broadband noise from lower level stages amplified by the power amplifiers. The most direct method of measurement of this type of undesired response is the receiver/signal generator substitution method shown in the block diagram of figure 8-2. A portion of the transmitter output is sampled to provide approximately 1 or 2 volts r-f at desired signal frequencies through a 50 ohm attenuator to a 50 ohm load. When measurements are to be made, the transmitter is operated to provide carrier only or one sideband of modulation by a single tone of known frequency. The receiver is tuned to the transmitter output frequency and the 50 ohm attenuator is adjusted to obtain a convenient reference point on the receiver level indicator. The signal generator is then substituted for the transmitter and tuned for maximum indication on the receiver level indicator. Then the signal generator output, the 50 ohm attenuator, or both are adjusted to obtain the same indication on the receiver level indicator as was obtained with the transmitter. The reading on the signal generator level indicator, corrected to compensate for the attenuator setting, is the amplitude of the signal across the 50 ohm load which was equivalent to that obtained from the transmitter, and is the reference or zero decibel indication for measurements of spurious products. The transmitter is then reconnected to the attenuator and operated exactly as before, but the receiver is

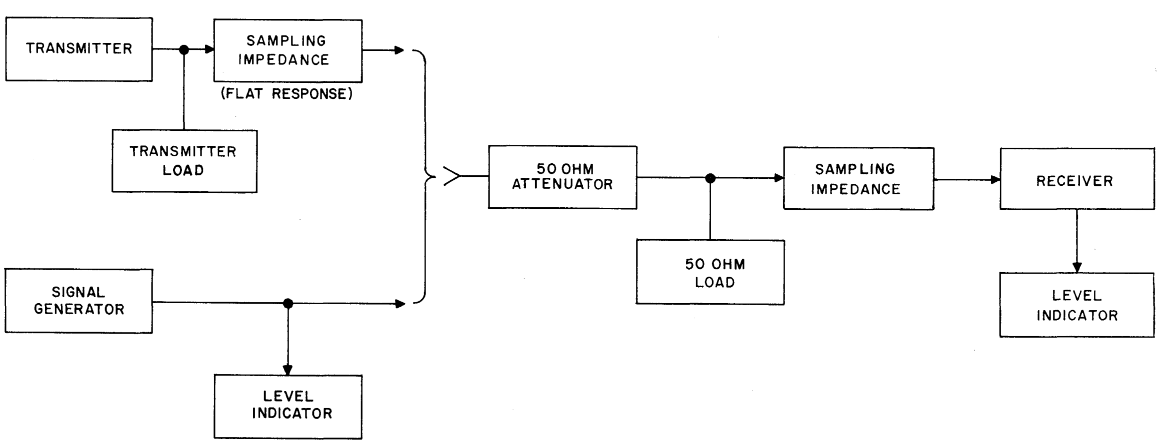


Figure 8-2. Receiver/Signal Generator Substitution, Block Diagram

tuned to a known point in its frequency range where a harmonic would appear, or a search for a spurious response is made. After the receiver is tuned for maximum level indication at a spurious response, the attenuator is adjusted to obtain a convenient reference point on the receiver level indicator. Once again the signal generator is substituted for the transmitter and tuned for maximum indication on the receiver level indicator at the frequency where the spurious response was found. The signal generator and attenuator are adjusted to obtain the same level indication at the receiver as produced by the spurious response and the voltage output of the signal generator, corrected to include the attenuator setting, provides a second reading of amplitude across the 50 ohm load. Comparison of the two readings gives the relative amplitude of the undesired response with respect to the desired signal. The accuracy of these measurements is determined by the accuracy with which the amplitude indication at the receiver level indicator is duplicated when the signal generator is substituted for the transmitter. If the receiver and signal generator are suitably isolated from any interconnecting paths such as the power line, are suitably shielded from each other, and the transmitter is shut down completely when measurements are made with the signal generator, it is possible to obtain reliable and repeatable measurements about 120 db below the desired output of the transmitter.

Since it is most practical to generate single sideband by initially generating the sideband frequencies at an intermediate frequency and subsequently heterodyning these signals to the desired r-f output frequency, products of output frequency synthesis may appear at the output of the transmitter. These products may be the actual heterodyning frequencies used to translate the intermediate frequency single-sideband signal to the r-f output frequency, or they may be mixer products of this process. Normal equipment specifications for these products are that they shall be from 70 to 80 db below the desired output of the transmitter. Low order harmonics of the output frequency are often specified 50 to 60 db below the desired output.

Since the Q of the output circuits of a reasonably efficient r-f power amplifier will be in the vicinity of 10 to 12, broadband noise generated in or amplified by the r-f power amplifier stages will not be affected appreciably by the selectivity of the output tank circuits. In a linear power amplifier with three or four stages, this noise will be due primarily to thermal and shot noise in the lower level stages. The effects of this noise may be observed on a spectrum analyzer or on a highly selective receiver. It is not normal for this noise to interfere with communication on the channel of the transmitter causing the noise, however, if the noise is particularly severe, its broadband nature may cause it to interfere with adjacent channels several channel widths removed.

The second type of undesired power output includes those spurious responses inside or very near the passbands of frequencies including the intelligence to be transmitted. These in-band spurious products are caused by:

(1) Intermodulation distortion resulting from operation of mixers or amplifiers beyond their capabilities.

(2) Amplitude or angle modulation resulting from imperfect stabilization of the oscillator or synthesizer from which translating frequencies are derived.

In addition, the following characteristics are important to a good single-sideband signal:

(1) Suppression of opposite sideband

(2) Suppression of carrier

(3) Minimum compression of desired signal due to power amplifier loading

Two equal amplitude audio tones have become a standard test signal for distortion measurements because:

(1) One signal is insufficient to produce intermodulation.

(2) More than two signals result in so many intermodulation products that analysis is impractical.

(3) Tones of equal amplitude place more demanding requirements on the system than it is likely to encounter in normal use.

Any two tones will serve for this test but with many frequency relationships, intermodulation products and harmonics tend to merge making identification of these products impossible. A 3 to 5 frequency ratio is the simplest that will alleviate this problem. Tones having a more complex ratio may produce products with frequency relationships more suitable to certain tests, but these products will be more difficult to identify than those of the simpler ratio. The following chart shows the relationships between products produced by distortion of the upper sideband of 300 kc modulated by 3 kc and 5 kc tones.

TABLE 8-2. SINGLE-SIDEBAND DISTORTION PRODUCTS

Frequency (kc)	Order of Products							
		7	6	5	4	3	2	1
295								OSB
296								
297		IM						OSB
298								
299				IM				
300								Car
301				AIM		IM		
302			AIM				AD	
303		AIM						3 kc DT
304					AIM			
305		AIM						5 kc DT
306			AIM				AH	
307				AIM		IM		
308							AS	
309				IM		AH		
310			AIM				AH	
311		IM						
312					AIM AH			
313		AIM						
314			AIM					
315				AH		AH		
316					AIM			

Legend:

A = Audio
AD = Audio Difference
AH = Audio Harmonic
AIM = Audio Intermodulation
AS = Audio Sum
Car = Carrier
DT = Desired Tone
IM = Intermodulation
OSB = Opposite Sideband

The idealized spectrum analyzer pattern for a two-tone single-sideband signal will consist of three discreet frequencies as illustrated in figure 8-3.

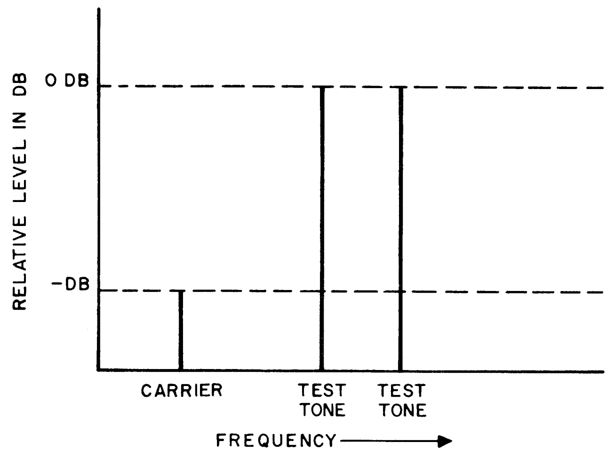


Figure 8-3. Idealized Spectrum Analyzer Pattern

These are the frequencies of each of the two audio test tones translated to the desired r-f output frequency and the carrier, which should be suppressed to the required level. The amplitudes of all undesired products and the carrier are measured in terms of decibels below either of the two equal amplitude test tones. Practical circuits always have some degree of intermodulation distortion which appears in the form of new discreet frequencies above and below the two test tones as illustrated in figure 8-4. The spacing

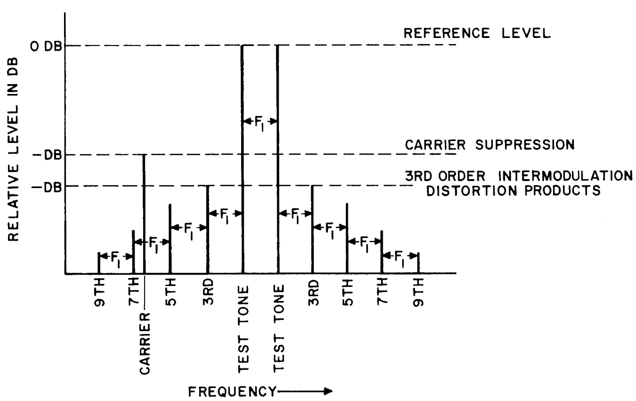


Figure 8-4. Practical Spectrum Analyzer Pattern

between each tone and the adjacent intermodulation products and the spacing between subsequent intermodulation products are equal to the spacing, F_1, between the two tones. The intermodulation products first adjacent to the desired tones are the third-order intermodulation distortion products; the next pair of products are the fifth-order intermodulation distortion products spaced equally outside the third-order intermodulation products; the next pair are the seventh, then the ninth and so on. The order of a distortion product is the sum of the coefficients in the frequency expression. For example, the third-order intermodulation products will be two times the frequency of one desired tone minus the frequency of the opposite tone. The fifth-order product is three times the frequency of one tone minus two times the frequency of the other. The odd-order products fall in or near the desired transmission band and are, therefore, the most objectionable because once generated they cannot be eliminated by either the transmitter or receiver. The signal to distortion ratio is the ratio of either of the two desired test tones to the largest undesired product expressed in decibels. A signal to distortion ratio of 40 db is usually acceptable for high-frequency communication systems when the equipment is tested on a two-tone basis. Unless unusual cancellation exists in the power amplifier, the third-order intermodulation products will be largest and the higher order products will be progressively smaller.

Over-all distortion resulting from several cascaded stages of amplifiers, modulators or mixers may be computed if the distortion of each stage is known. It is useful to note that each "stage" may be a "black box" actually composed of multiple stages, and one of the black boxes may be the distortion analysis equipment itself.

To obtain the over-all distortion in a system composed of several cascaded stages the following formula applies:

$$db_t = 10\left\{10-\log\left[\log^{-1}\left(10-\frac{db_1}{10}\right) + \log^{-1}\left(10-\frac{db_2}{10}\right) + \ldots\ldots + \log^{-1}\left(10-\frac{db_n}{10}\right)\right]\right\}$$

where db_t = Total or over-all signal to distortion ratio in db

db_1 = Signal to distortion ratio of 1st stage in db

db_2 = Signal to distortion ratio of 2nd stage in db

db_n = Signal to distortion ratio of nth stage in db

log = logarithm with a base of 10

$\log^{-1}$ = antilogarithm with a base of 10

This equation yields the following typical results from two stages:

Difference between signal to distortion ratio between the two stages in db	Amount by which the overall signal to distortion ratio is degraded beyond that of the poorer stage in db
0	3.0
3	1.8
6	1.0
10	0.4

Any of the oscillators in a transmitter, receiver, or in an analyzer may have amplitude or angle modulation caused by such deficiencies as power supply ripple, alternating currents in tube heaters, mechanical vibration, or strong electric or magnetic fields in the vicinity of the oscillators or their control devices. This incidental modulation causes new sidebands to be produced by the transmitter. These may be observed on the spectrum analyzer display as responses symmetrically located on either side of all desired tones. Each distortion product will also exhibit these sidebands. When the oscillator that is used in the frequency scheme of a transmitter is modulated, the sidebands produced thereby are often unequal in amplitude because of simultaneous angle and amplitude modulation. An analysis of this phenomenon is summarized in the article entitled "Linearity Testing Techniques for Sideband Equipment" by Icenbice and Fellhauer in The Proceedings of the IRE, December, 1956. Phase modulation distorts the amplitude symmetry of the two sidebands produced by a single sine wave simultaneously angle and amplitude modulating a carrier or other desired output signal by subtracting a component from one sideband and adding it to the other.

5. SPECTRUM ANALYZER 478R-1

The most informative and universal method of measuring in-band spurious is by means of a spectrum analyzer such as the Collins 478R-1 Spectrum Analyzer. In this analyzer, a complete picture of the spectrum in the vicinity of the intelligence passband is plotted directly on an oscilloscope screen or may be recorded by means of a two-axis recorder. The problem of construction of this equipment was primarily to reduce intermodulation within the analyzer to a level appreciably below that to be measured. Although the analyzer is large and complex, the signal under test passes through only two tubes before detection by the narrow-band selective amplifier. These two tubes are both mixers, and much of the remainder of the equipment is devoted to insuring that the injection or translating frequencies applied to these mixers are sufficiently free from noise, distortion, and incidental angle modulation.

The basic circuit of the Spectrum Analyzer is that of a wave analyzer for measuring frequencies generated by signals passing through an amplifier or mixer or other system with an unknown amplitude transfer characteristic. Figure 8-5 is a block diagram of the 478R-1. Additional selectivity, variable sweep width, and other features permit accurate and simultaneous measurements of level in decibels versus frequency of distortion, hum, noise, and other spurious products in a direct plot on the analyzer screen or on a two-axis recorder. Included in the analyzer is a two-tone audio generator consisting of two audio oscillators and a filter-mixer panel. This portion of the analyzer generates a two-tone audio test signal for use as an audio input for intermodulation distortion measurements of the equipment under test.

The two-tone mixer panel satisfies several requirements for minimizing harmonic and intermodulation products in the two-tone audio test signal. One such requirement is sufficient isolation between the two audio signal generators to reduce intermodulation distortion in the output tubes of one generator because of coupling to the output of the other. This isolation is provided by pads in the output of each generator ahead of the mixing circuit. Second and higher order harmonics in the output of the generators are attenuated by plug-in low-pass filters selected to have cutoff frequencies between the fundamental frequencies and the second harmonic frequencies of their respective generators. Second-order intermodulation distortion which appears to be third-order intermodulation results from direct mixing of the second harmonic output of one audio generator with the fundamental of the other. This effect also is minimized by the low-pass filters. The difficulty of mixing the output of two signal generators so that they do not modulate each other is illustrated in figure 8-6. Both circuits A and B have the same output level but circuit A has approximately 50 db more isolation between the oscillators. The level of third-order intermodulation products is approximately 20 db higher in circuit B than in circuit A. While the attenuation of the audio output signal from oscillator no. 1 is affected primarily by the output series resistor and the 560 ohm load, the attenuation between audio oscillator no. 1 and no. 2 is affected by the output series resistor of oscillator no. 2 and the internal generator impedance of oscillator no. 2 as well as the attenuation between oscillator no. 1 and the output.

During spectrum analysis of a transmitter, products observed by the analyzer can be more readily identified by removing one or the other of the audio tones and observing the effect on the intermodulation products of interest. The ON-OFF switches in the two-tone audio generator are provided with dummy loads in the OFF position to preserve the impedance termination on the audio mixing circuit and thereby prevent a change in the amplitude of the remaining tone when

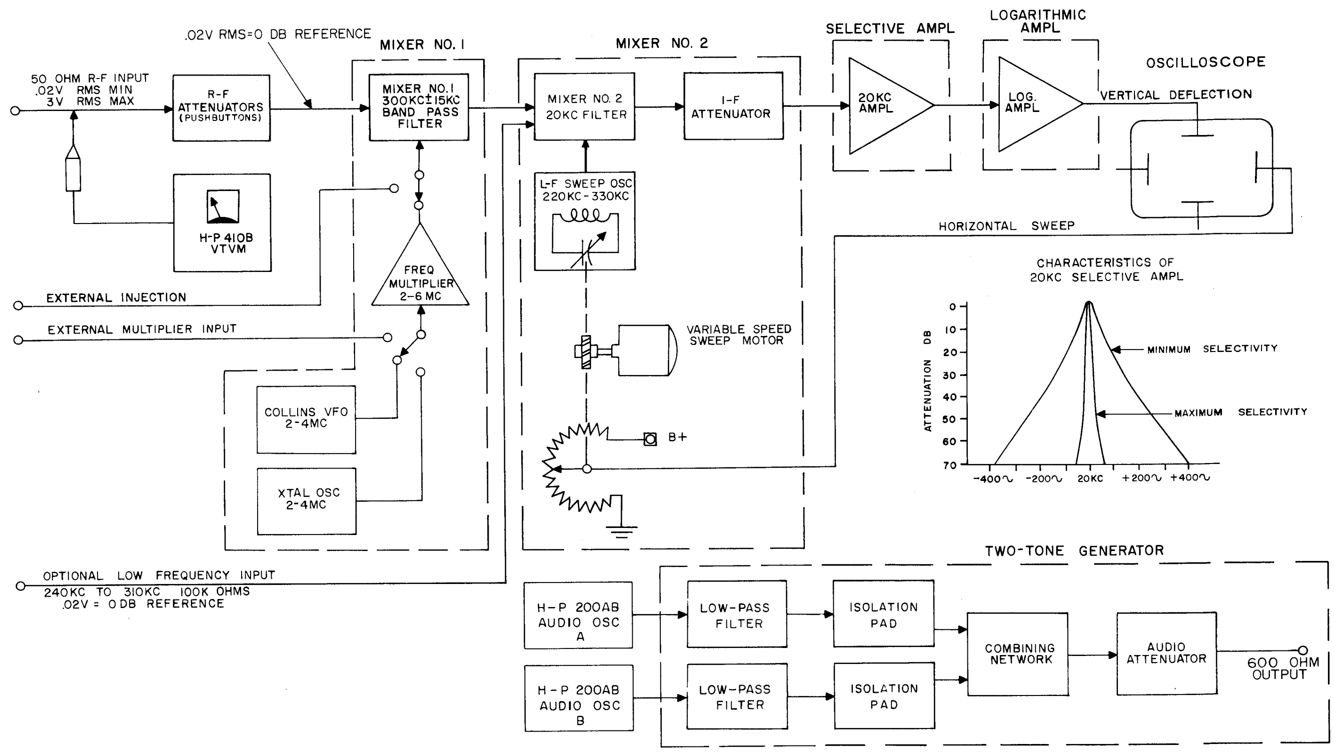


Figure 8-5. Spectrum Analyzer 478R-1, Block Diagram

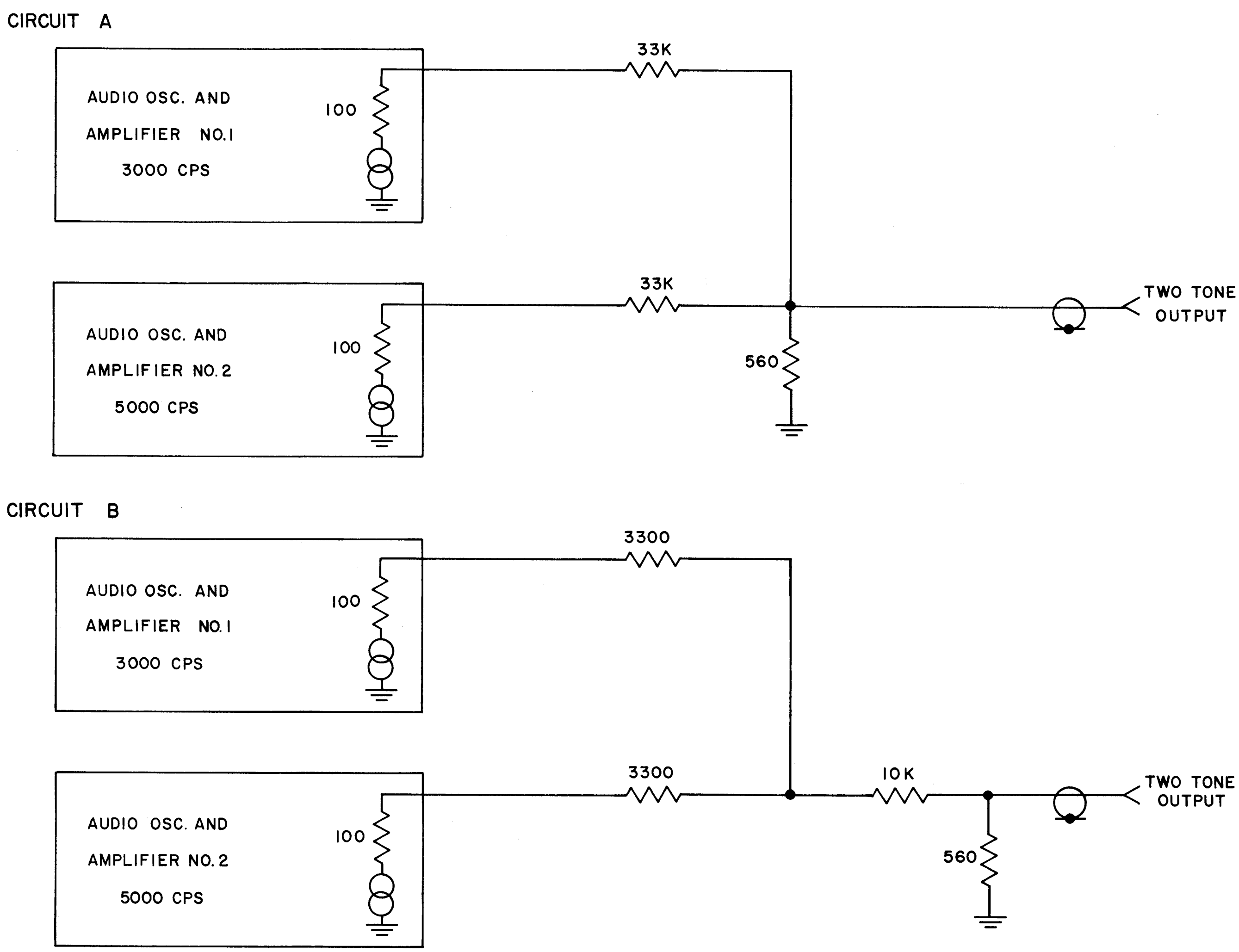
one tone is switched off. The audio filters may be switched out of the circuit to allow the use of audio frequencies beyond the range of the filters, and a set of decade attenuators is provided to enable rapid and accurate testing of equipment with different amplitudes of audio input.

The dynamic range of the analyzer is 70 to 80 db, displayed on one scale to an accuracy of ±1 db. Continuous metering circuits are provided on the front panel to insure correct mixer injection level. The analyzer will accept a frequency spectrum with a center frequency from 1.7 mc to 64.3 mc and from 240 kc to 310 kc without additional coils or test equipment. The spectrum display is on a 17 in. cathode ray tube. Signal to be analyzed is fed into the precision attenuator panel where it may be monitored by the internal vacuum-tube voltmeter, Hewlett-Packard 410B. The attenuator is adjusted to the proper level and the attenuated signal is applied to mixer no. 1 which converts the signal to the 300 kc i-f. The output of mixer no. 1 passes through a 300 ±15 kc band-pass filter to mixer no. 2 where it is converted to 20 kc. Mixer no. 2 can accept directly any frequency from equipment under test between 240 kc and 310 kc. The tuning capacitor of the injection oscillator for mixer no. 2 is rotated by a variable speed motor to sweep the frequency of this oscillator through the required range.

Sweep widths of 4 kc, 8 kc, and 16 kc are available. The output of mixer no. 2 is fed through a precision attenuator with 0.1 db steps to a narrow-band 20 kc selective amplifier. The half bandwidth of the selective amplifier at 40 db below maximum response is variable from 30 to 145 cps by a control on the front panel. The output of the 20 kc selective amplifier is fed to a logarithmic amplifier. The output of this amplifier is a d-c voltage that is a logarithmic function of the input over a 70 db dynamic range. The calibrated attenuator between mixer no. 2 and the 20 kc selective amplifier provides for checking the linearity of the logarithmic amplifier and the oscilloscope to insure an accuracy of ±1 db throughout the 70 db dynamic range of the analyzer. The varying d-c output from the logarithmic amplifier is applied directly to the vertical deflection amplifier of the oscilloscope or to an external recorder. Synchronized horizontal sweep voltage is provided by a potentiometer ganged to the oscillator sweep tuning capacitor.

The signal path in the analyzer includes only three nonlinear devices ahead of the 20 kc selective amplifier after which nonlinearity causes no further intermodulation. The first nonlinear device in the signal path is the Hewlett-Packard 410B vtvm probe, but the loading of this high-impedance probe on the 50 ohm circuit is so slight that negligible intermodulation distortion results. Mixer no. 1 and mixer no. 2 consist of only one tube each and their operating characteristics have been very carefully selected to minimize intermodulation distortion. Microammeters on the mixer front panels provide continuous monitoring of injection grid current to insure that the mixers are always operated under optimum injection level conditions.

An ideal panoramic display of a constant carrier with no modulation would appear as a single line at right angles to the frequency axis. However, in practical equipment this display is a single plot of the selectivity of the analyzer. If the selectivity of the analyzer is changed, the displayed shape of the same carrier under test will change to the new shape of the selectivity curve of the test equipment. Signals under test which have sidebands or intermodulation products to be observed by the analyzer will produce individual responses corresponding to each of these sidebands, or products, together with the desired responses themselves and each response will be



CIRCUIT	FREQ (CPS)	3RD ORDER LEVEL (DB)
A	1000	> 75
	7000	75
B	1000	52
	7000	58

GOV'T NO. | COLLINS NO.
USED ON ASSEMBLY
[redacted]
WEIGHT
LBS.
UNLESS OTHERWISE SPECIFIED:

Figure 8-6. Two-Tone Generator, Source Isolation basically the shape of the analyzer selectivity curve, each with it own maximum amplitude. The maximum response from each discreet frequency is the required measurement. When these discreet frequencies or sidebands are spaced only a few cps apart, such as may be encountered with hum modulation, their corresponding responses on the analyzer screen tend to merge into each other. The responses, for example, of hum modulation will appear on the skirt of the response to the carrier for that modulation. The ability to separate such discreet frequencies is known as the resolving power of the analyzer. Maximum resolving power is attained when the equipment is operated with minimum sweep width, minimum sweep speed, and maximum selectivity. Since this mode of operation reduces the speed with which data may be obtained, provision is made for varying all three parameters so that data requiring less resolving power may be obtained more rapidly. With maximum selectivity, the speed of the sweep and the sweep width may be adjusted so that the frequency is swept through the response frequency of the analyzer so rapidly that the effective Q or selectivity of the analyzer will not allow the signal to build up to its peak amplitude before the sweep has passed this frequency. This error is always present with any reasonable amount of selectivity, but the effect will be negligible if the sweep width and sweep speed used are commensurate with the selectivity to which the analyzer is adjusted. The easiest check to insure a safe sweep speed is merely to reduce speed about one half and note whether the amplitude increases. If the peak amplitude increased more than 1 db, the original speed was too fast.

When single-sideband suppressed carrier equipment is under test, it is helpful to take the intermodulation distortion test data in steps of about 3 db. This is accomplished by inserting 3 db of attenuation in the output of the two-tone mixer by means of the audio attenuators and removing 3 db of attenuation from the r-f input to the analyzer by means of the r-f attenuators. This preserves the same amplitude of desired tones on the analyzer thus allowing observation to be concentrated on the changes in the intermodulation products. In this way, the point on the distortion versus signal curve, at which the equipment under test should be operated, can be established rapidly. The intermodulation products will increase relative to the desired output signals at an ever increasing rate, as the rated signal level of balanced modulators, mixers, or amplifier stages in the r-f equipment is approached. Near the overload point, intermodulation products commonly increase at a rate 2 or 3 db faster than the desired output signals. Beyond this point the rate of increase of the ratio of intermodulation distortion products to desired output signals becomes much more rapid. If the audio input signal level is reduced well below the normal level, the rate of increase of intermodulation distortion products' amplitude will be reduced until at very low levels the intermodulation distortion products will change imperceptibly with respect to the desired output signals.

6. ANGLE MODULATION MEASUREMENTS

In order to make use of the resolution available from the selectivity of the 478R-1 Spectrum Analyzer in measurements of hum phase modulation sidebands, special precautions were taken to minimize hum phase modulation on the injection oscillators and in the signal path through the analyzer. Electronically regulated power supplies were used to reduce hum ripple on the plate voltages to less than 1 millivolt, wherever possible cathodes were operated at ground potential, and plate circuits were either shunt fed or a pair of tuned circuits were coupled to insure that the grids of the following stages were grounded with respect to hum frequencies. In critical circuits, such as in the variable frequency oscillator, where the preceding methods were not applicable, filaments were supplied with direct current, circuits and components were selected to minimize microphonic pickup, and the Sola regulating transformer was housed in a special case to reduce magnetic fields at harmonics of the 60 cps line frequency.

When angle modulation is analyzed on a spectrum basis, only a simple amplitude detecting rectifier circuit is required in addition to the analyzer selectivity. Since the selectivity of the analyzer can slope detect angle modulation, it is necessary to integrate the output of the detector rectifier because the slope detection is a function of the analyzer selectivity and will not truly represent the spectrum of the equipment under test. On the 478R-1 analyzer, an external plug-in capacitor of several microfarads may be placed across the oscilloscope deflection input terminals to perform this integration and eliminate the slope detection.

A sinusoidally modulated FM wave has a spectrum which contains not just two side frequencies as in AM, but an infinite number of side frequencies spaced equally from the carrier by intervals equal to the modulating frequency. When the angle modulation level is very low, the amplitudes of the higher order sidebands drop very rapidly. When the modulation level is high the amplitude of the carrier may be lower than some of the sidebands, and the sidebands will extend over a much larger band of frequencies. A qualitative check of the effect of low-level incidental angle modulation on a carrier may be obtained by slope detection in a receiver which has a relatively high degree of selectivity, such as the 51J or R390. The receiver is tuned to one side of the carrier signal so that the S meter indicates 1/2 or less of the maximum deflection obtained when peaked exactly on the signal. If no hum or other tone is heard in the receiver as the avc allows the sensitivity of the receiver to increase and the noise to rise, it may be assumed that closely spaced discreet angle modulation spectra are below the noise level.

7. COMPRESSION MEASUREMENT

An additional characteristic of power amplifiers known as compression is often measured as an indication of capability of the power amplifier and its power supply. Compression of the output signal may result from less than optimum d-c regulation of the power supply for the power amplifier plate, screen and bias voltages and may serve as an indication of intermodulation in the power amplifier when subjected to close spaced tones. Since the power amplifiers are normally operated in class AB_1, or some other mode of class B operation with respect to plate current, the load on the power supply varies with the instantaneous amplitude of the signal envelope. Compression results when, in the presence of one signal which does not utilize full peak envelope power capability, a second signal is applied which approaches full peak envelope power. The amplitude of the first signal is compressed by an amount which is a function of the variation in the power supply output voltage as a result of the additional loading demanded by the second signal. Measurements of compression must be conducted with selective equipment which is capable of observing the amplitude of one continuous signal as a second signal is varied in amplitude. Such measurements are usually obtained with spectrum analysis equipment by observation of a continuous desired signal 10 to 20 db below peak envelope power while a second signal which demands approximate peak envelope power is switched on and off. The effect on the fixed amplitude tone is plotted in terms of decibels versus the number of decibels by which peak envelope power is approached or exceeded. The 478R-1 analyzer is particularly adaptable to this type of measurement in that its decibel scale may be expanded 10 to 1 so that each inch of oscilloscope scale equals 1 db, and the accuracy of the measurement is then ±.1 db. Such measurements may be conducted using the same tones as are used with the standard two-tone test signal and stopping the sweep motor so that the amplitude of one tone is continuously monitored while the other tone is switched on and off. Intermodulation distortion may be produced by the r-f power amplifier when operating with close spaced tones if the low-frequency a-c impedance of the power supply is too high. The screen voltage supplies for pentode power amplifiers often present stringent requirements because such amplifiers are sensitive to screen voltage changes.

8. INTERMODULATION MEASUREMENTS WITH BUILT-IN MONITOR

Intermodulation distortion in a transmitter may be tested by means of a monitor which uses the same frequency scheme as the transmitter, but operating in reverse to translate the r-f output signal back to audio or some convenient fixed intermediate frequency. In this manner, spectrum analysis can be made and compared with analysis of the original audio signals applied to the transmitter. The monitor itself must be carefully designed so that its intermodulation is lower than that of the transmitter to be tested. For example, if the level of intermodulation distortion products are 40 db below desired output signals, and the intermodulation within the test equipment is 46 db below desired output, then the resulting intermodulation distortion measurement will be in error by approximately 1 db. Therefore, the result of the measurement will indicate intermodulation products 39 db below desired output rather than the actual 40 db figure. These relationships represent normal conditions but do not guarantee this result for every situation.

Measurements made by means of such a monitor, however, will not show incidental angle modulation since use of the same translating frequency sources for both the transmitter under test and the monitor will tend to cancel the effect of such incidental angle modulation. Separate translating frequencies for the test equipment must be used to measure spurious sidebands caused by incidental angle modulation.

9. LINEARITY MEASUREMENT WITH NOISE LOADING

Intermodulation distortion measuring equipment using two tones is very versatile for identification of linearity characteristics. However, measuring equipment using noise as the input signal has the advantage that the test signal more nearly simulates the complex signal typical of voice or multiple tone modulation.

If band limited noise is introduced into a system under test, linearity of the system may be partially described in terms of the noise outside the original band limits. If the output of a random noise generator is fed into a band-pass filter which equally passes all noise frequencies in the passband to be tested except for a small portion at the upper and lower extremes, the noise loads all but a few cycles of the transmission band to any degree of modulation desired. At the receiving end of the system, three band-pass filters with equal bandwidth and insertion loss are used for measurement purposes. One such filter is selected near the center of the transmitted noise passband, and a true rms noise voltage from this filter is used as a reference signal level. The other two filters pass the distortion sidebands just outside the intended noise passband. The output of these two filters are measured separately with the true rms voltmeter, and these levels in decibels below the reference voltage represent the intermodulation distortion generated at the low- and high-frequency ends of the loaded passband. Noise generators for this purpose are commercially available and the band-pass filters may be selected to satisfy the requirements of the equipment under test.

As indicated in figure 8-7, a transmitter loaded with noise signals over a discreet bandwidth, B, will have all third-order intermodulation products appearing in a band equal to three times the desired bandwidth and with the same center frequency. All fifth-order

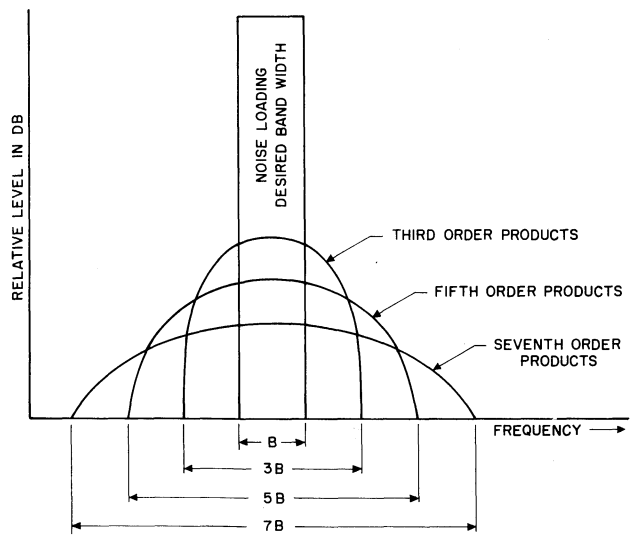


Figure 8-7. Intermodulation Products in a Noise Loaded System

intermodulation products will fall inside a bandwidth five times the width of the desired band and having the same center frequency. All seventh-order products will fall inside a band having seven times the width of the desired band and having the same center frequency and so on. Since the amplitude of the intermodulation distortion products are usually in approximate inverse proportion to the order of the product, the shape of the curves describing the amplitudes of the products may be predicted. If a two-tone test signal is employed, the discreet frequency relationships between the desired signals and the intermodulation products will be known or may be computed. When these are superimposed upon the curves of the intermodulation products for a noise loaded system (figure 8-6), an approximate plot of the entire spectrum resulting from the two-tone test signal may be predicted.

The Collins 478R-2 Baseband Spectrum Analyzer may be used in the same manner to test intermodulation distortion in a noise loaded system or in one employing. multiple discreet frequencies. Only one filter is necessary at the receiving end of the system and a sweeping frequency scheme is employed to allow a panoramic plot on an oscilloscope or on a recorder of the responses throughout and beyond the system bandwidth. This equipment permits simultaneous observation of a range of audio and video signals from 3 kc to 2 megacycles. The plot on the oscilloscope or recorder is in terms of decibels plotted on the Y axis against frequency in kilocycles on the X axis, as in the 478R-1 Spectrum Analyzer. The sweep width is variable from 0 to 70 kc, and the main tuning dial is detented to position the center frequency at 50 kc intervals over the 3 kc to 2 mc range so that the complete frequency range may be examined accurately and rapidly in 50 kc increments. This equipment is particularly suited for portable and field use when used with a portable two-axis recorder.

10. DELAY DISTORTION

A transmitter which has delay distortion but negligible nonlinear distortion will not cause the production of new output frequencies. The amplitude of the output components are not affected by delay distortion; therefore, the existence of delay distortion within the transmitter will not influence the results of measuring nonlinear distortion by either multisignal loading or noise loading methods if the delay distortion does not vary with time. Phase always varies with frequency in a reactive network, but phase distortion is not necessarily produced. Instruments for the direct measurement of phase of audio frequencies are commercially available. When a plot of the phase measurements against frequency is differentiated with respect to frequency, the derivative is the envelope delay. Phase delay is defined as the ratio of the phase with respect to frequency and approaches the value of the envelope delay expression, namely, the derivative of phase with respect to frequency, when the phase-frequency plot approaches a straight line. The perfect system is never available in practice, so the phase delay is never exactly equal to the envelope delay. Delay distortion measurements may be obtained by passing a modulated signal through a network and measuring the resultant modulation envelope phase shift caused by the network under test. Time delay may then be computed by using $T_d = \Theta/360f_m$, where T_d is the delay in seconds; Θ is the phase shift of the modulation envelope in degrees, and f_m the frequency of modulation in cps. Systems in which delay distortion can seriously affect or completely destroy the useful characteristics of the desired signal must be tested using equipment designed for this particular purpose, the common method being the measurement of envelope phase shift.

11. FIELD TEST SET FOR INTERMODULATION DISTORTION MEASUREMENTS

A smaller portable spectrum analyzer would be useful for field test purposes. Such a unit could serve as a transmitter monitor as well as an intermodulation distortion analyzer. The following measurements could be provided by this equipment:

(1) Linearity or intermodulation distortion in a transmitter, receiver, or audio amplifier.

(2) Carrier leak or suppression

(3) Alignment checks

(4) Low-level r-f voltage measurements

(5) Transmitter monitoring

The basic technique of such a distortion analysis field test set would be to translate the r-f signal through low-distortion mixers to audio and separate the signals and distortion products with audio filters. The relative amplitudes of the intermodulation products with respect to desired signals would be obtained from attenuator readings and would be limited to about a 50 db range. When measuring intermodulation distortion in a transmitter or in a receiver, a study of relative magnitudes of the intermodulation distortion products, combined with familiarity with the frequency scheme, will usually isolate a malfunction with respect to the r-f, i-f, or audio section of the equipment under test. Such an analyzer would not indicate r-f signal levels directly in volts; however, it would indicate whether the same readings prevail that existed during a previous test. This function would be especially useful for trimming tuned circuits that operate at levels below normal vtvm sensitivities. The monitor portion of the test unit would allow aural checks with the equipment in operation to determine if speech or multiple-tone data circuits sound normal. When the equipment is used for monitoring purposes either or both sidebands, as transmitted, would appear in the audio output without separation.

The field analyzer would consist of three basic units:

(1) An audio two-tone test signal generator

(2) An audio distortion analysis filter

(3) An r-f to audio converter

For monitoring purposes, a fourth unit consisting of an audio amplifier with provisions for headphones or loudspeaker could be used.

a. AUDIO TWO-TONE SIGNAL GENERATOR

The audio two-tone signal generator (figure 8-8) would consist of two oscillators whose frequencies would be controlled by audio resonators such as are provided in Kineplex* equipment. Each oscillator

* Registered in U.S. Patent Office

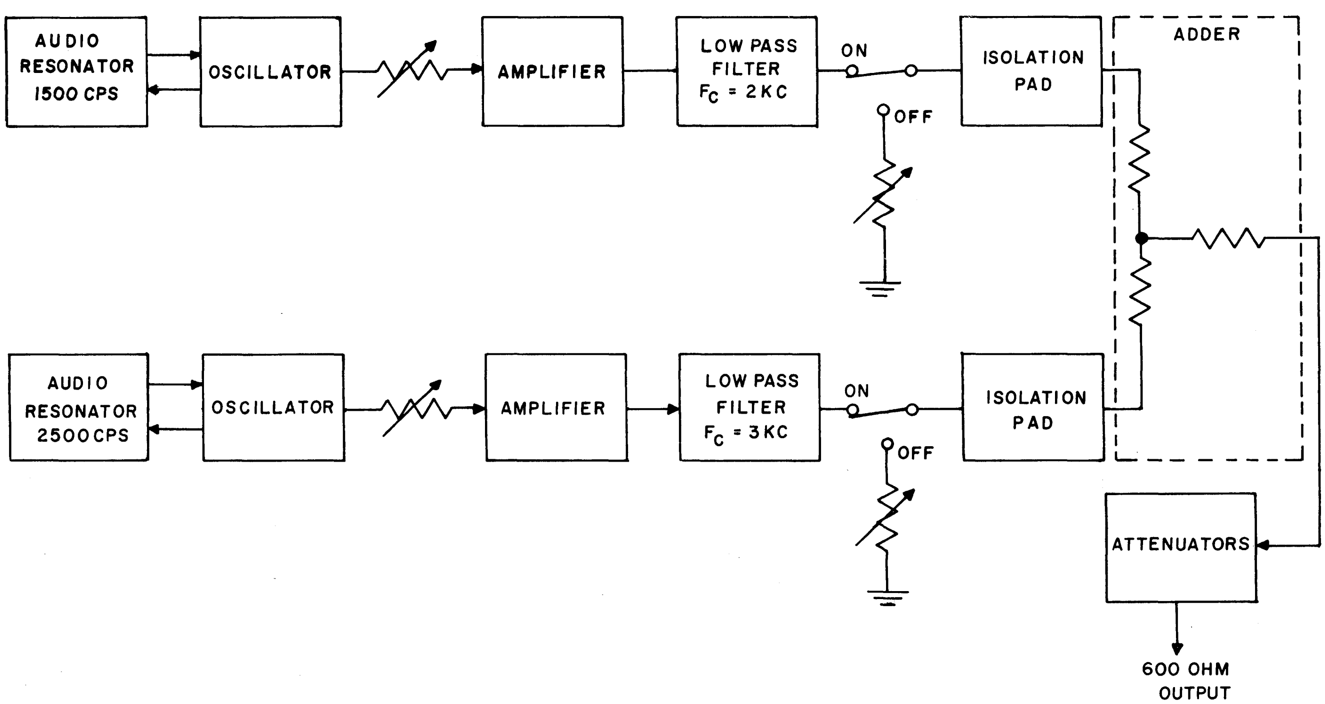


Figure 8-8. Audio Two-Tone Test Generator, Block Diagram

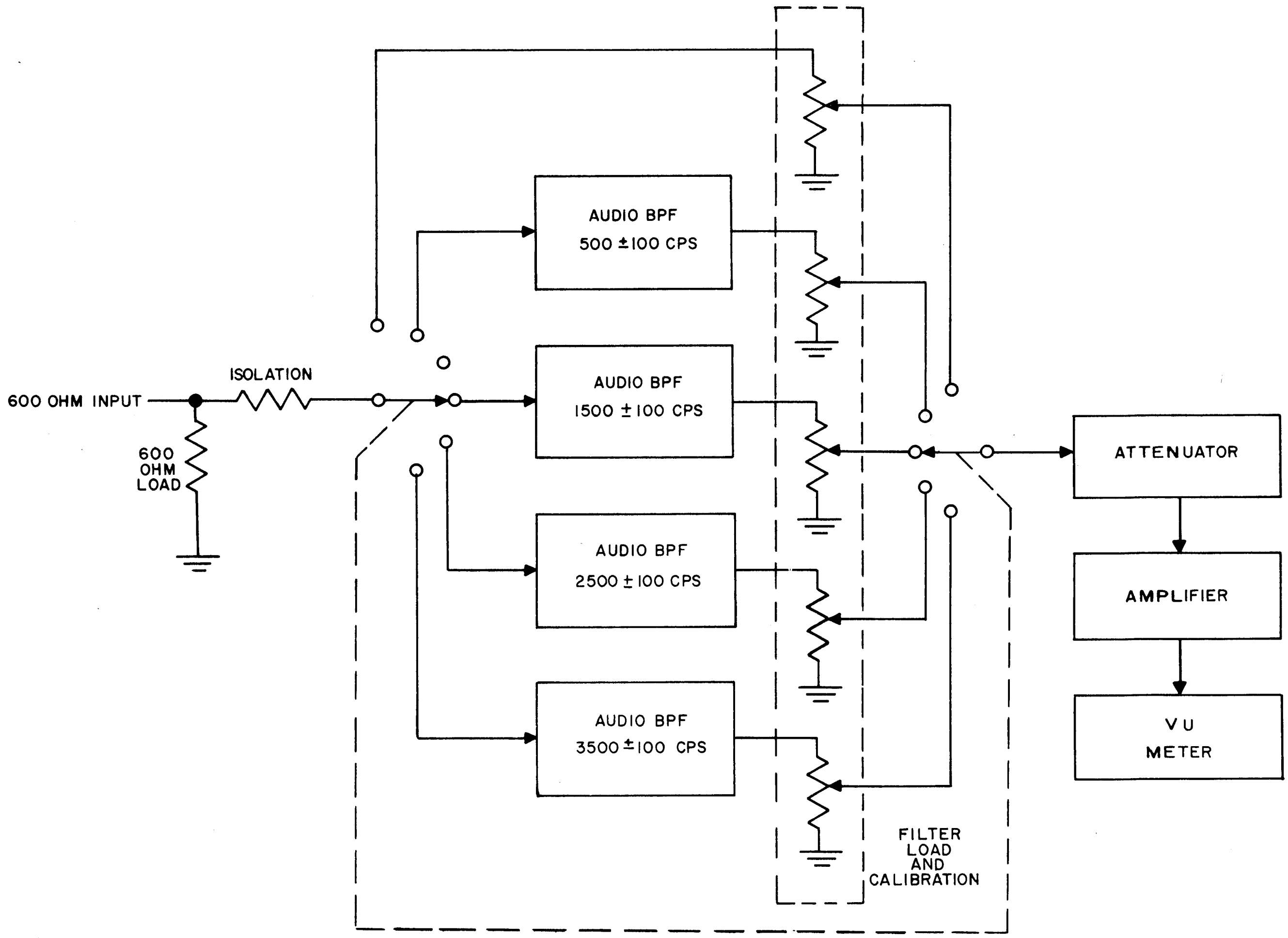


Figure 8-9. Audio Distortion Analysis Filter, Block Diagram

would be provided with a level control, its own amplifier, and a low-pass filter with the cutoff between the fundamental and second harmonic of its respective oscillator. On - off switches would be provided for each tone to enable identification of intermodulation distortion products. Isolation pads in each signal path plus the additional isolation afforded by the resistive adding network and isolation due to the presence of the low-pass filters would minimize intermodulation between the two audio amplifiers to a practical level. One and ten decibels per step attenuators in the combined output signal path would provide for intermodulation distortion measurements yielding a curve of intermodulation distortion versus audio input amplitude. The output impedance of the test generator would be 600 ohms, with an output signal level variable by means of the attenuators from approximately 3 volts per tone to 100 db below this level, approximately 30 microvolts.

b. DISTORTION ANALYSIS FILTER

Although audio analysis may be performed with commercial wave analyzers, the process is slow and commercial units for this purpose are expensive and impractical for field use. The audio distortion analysis filter (figure 8-9) for this field test set would have a 600 ohm input termination, suitable isolation of the internal audio band-pass filters from the 600 ohm input, and a selector switch for inserting any one of four audio band-pass filters or an unfiltered circuit in the path to the indicating meter. Each band-pass filter would be wide enough to pass only one of the discreet audio frequencies of interest, allowing for approximately 50 cps error in tuning of the vfo in the r-f to audio converter. Two of the filters normally would pass the desired two-tone test signals, and the other two filters would pass the third-order intermodulation distortion products resulting from the two desired test tones. The unfiltered circuit would provide measurement of signal levels under normal operating conditions of the equipment monitored. Fifth-order products in a transmitter could be measured by tuning the r-f to audio converter to one side so that the desired two tones fall on the frequencies of the first and second filters. Then the third-order intermodulation distortion product would appear in the third filter and the fifth-order intermodulation product in the fourth filter. Seventh-order products could be measured by side stepping the tuning of the r-f to audio converter one additional slot so that the higher of the two desired test tones falls on the frequency of the first filter. Then the third, fifth, and seventh-order products would fall on the second, third, and fourth filters, respectively. Provision would be made for compensating for the insertion loss of the various filters individually, and a second gang on the selector switch would connect the attenuator, amplifier, and level indicating meter to the filter circuit to which the input was switched. With a 10 db per step attenuator and a level indicating meter calibrated in decibels over a 1 to 10 db range, signals could be measured with an accuracy of ±1 db, while the dynamic range requirements on the meter amplifier would be only 10 db and, since it would pass only one frequency at a time, its distortion requirements would be negligible.

c. R-F TO AUDIO CONVERTER

The r-f to audio converter (figure 8-10) would consist of three mixers. Only fixed tuned low-pass and band-pass filters would be used in the signal path of the converter to eliminate the necessity for tracking tuned circuits. The first mixer input might be switched to either a high-impedance input through a potentiometer or to a 50 ohm calibrated r-f attenuator. A limited range of input level control would be obtained thereby to allow setting input signals at optimum mixer operating levels. There would be no internal gain controls. If required, additional attenuation could be obtained before the signal is applied to the converter by means of sampling impedances in the external isolating circuits. Transmitters and other equipments under test should have suitable test points provided for monitor pickup.

The first mixer of the converter would obtain translating signals from a multiple crystal oscillator and multiplier to heterodyne the r-f input to a range of 1.7 to 4.3 mc. Since the output of the vfo need not be

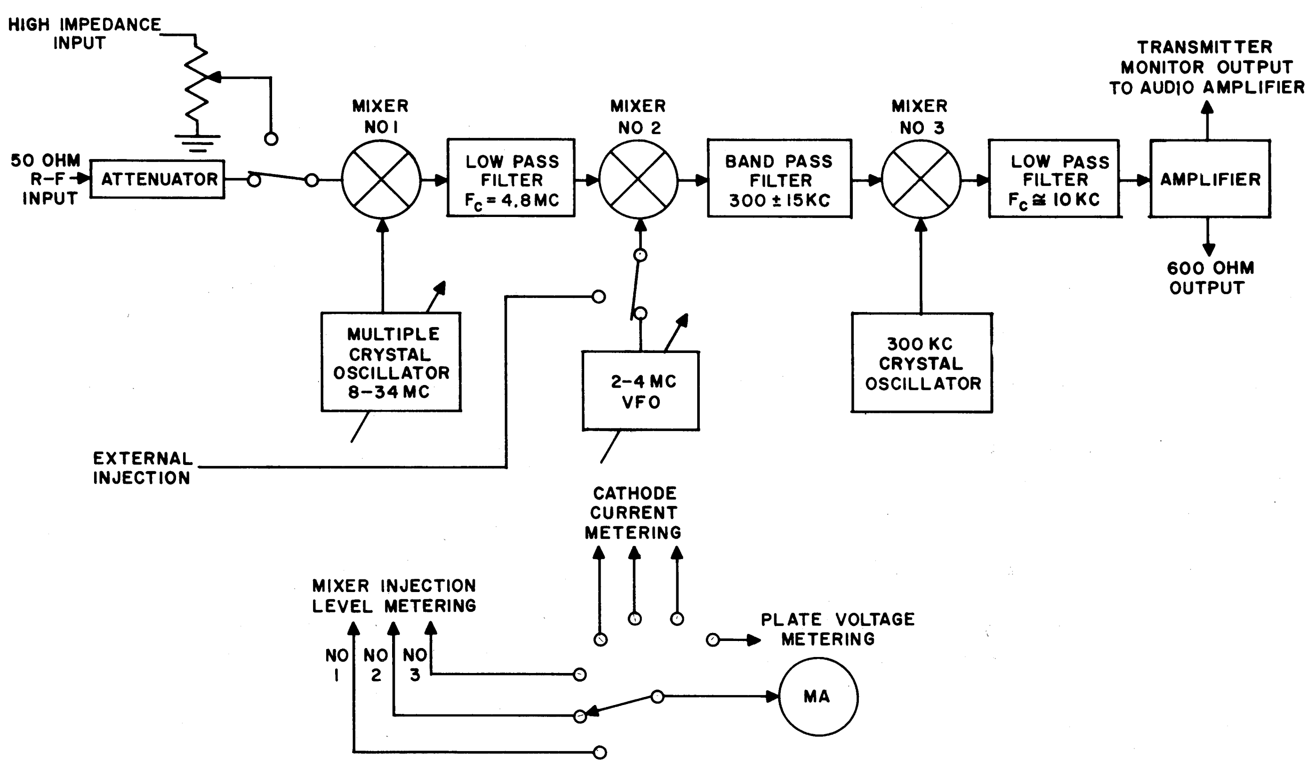


Figure 8-10. R-F to Audio Converter, Block Diagram

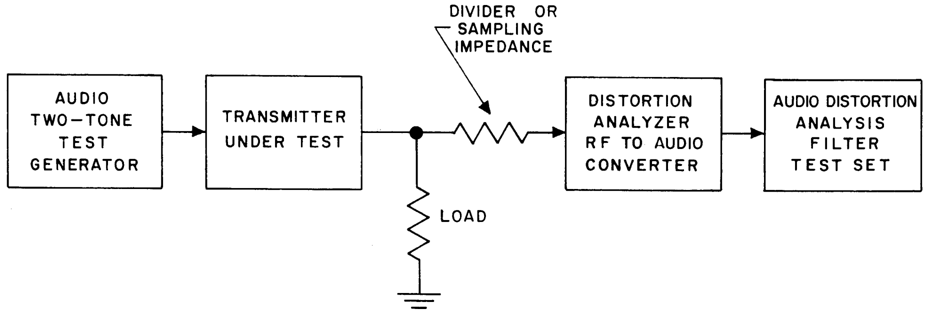


Figure 8-11. Test of Intermodulation in Transmitter

multiplied for this purpose, the stability and ease of tuning in the converter would be improved. The multiple crystal oscillator and multipliers would be provided with suitable tuned circuits for rejecting the undesired multiples where necessary. A level adjustment would be required for each range. All crystals, coils, and level controls would be selected by a range position switch. Since the output of mixer no. 1 would be filtered by a low-pass filter, signals in the range 1.7 to 4.3 mc could be applied through mixer no. 1 as an amplifier directly to mixer no. 2 without heterodyning. The second mixer would obtain a heterodyning signal from a 2 to 4 mc ten-turn variable frequency oscillator which could have a vernier control to facilitate fine tuning. If desired, the injection for mixer no. 2 could be applied externally to allow detection of signals at frequencies below 1.7 mc. The output of mixer no. 2 would be filtered by a band-pass filter approximately 30 kc wide and centered at 300 kc. Mixer no. 3 would heterodyne the signal to audio with injection obtained from a 300 kc crystal oscillator which could be provided with a trimmer for very fine tuning. The output of mixer no. 3 would be filtered to pass only the audio range after which the signal would be amplified by a low-distortion audio amplifier and made available in the form of a 600 ohm output capable of driving the audio distortion analysis filter. This 600 ohm output could be bridged with a high-impedance input audio amplifier driving headphones or a loudspeaker. If a monitor audio amplifier and speaker is used, and if the low-frequency response is adequate, the monitor would indicate the presence of hum in the transmitter. The unfiltered circuit in the distortion analysis filter could be used as an aid in rough tuning the r-f to audio converter in the absence of an audio monitor, or for measurements of the amplitudes of single signals which do not fall in the range of the filters but can be identified by audio monitoring. The latter application could implement frequency response measurements. Metering of the mixer injection

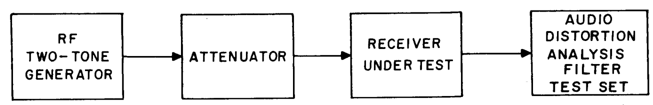


Figure 8-12. Test of Intermodulation in Receiver

levels would be provided to insure optimum mixer conversion efficiency with minimum intermodulation distortion. In addition, metering of mixer and audio amplifier cathode current and plate voltage would be provided. As in the 478R-1 Spectrum Analyzer, no preselectivity would be required and tuning of only the 2 to 4 mc vfo and selection of the proper crystal oscillator circuit for mixer no. 1 would suffice to translate the r-f signal to audio for these measurements.

The block diagrams of figures 8-11 through 8-13 demonstrate the use of the several sections of an analyzer of this type for tests of intermodulation distortion in a transmitter, a receiver or in an audio amplifier. An entire communications system could

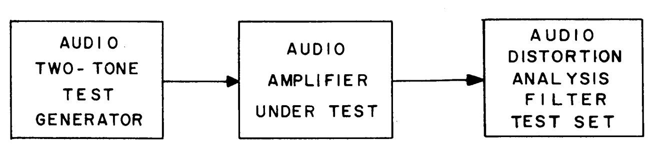


Figure 8-13. Test of Intermodulation in Audio Amplifier

be tested or the equipment could be used as a transmitter monitor as indicated in figures 8-14 and 8-15. The analyzer would be designed so that it could be used to check itself as shown in figures 8-16 and 8-17. This system would be capable of measuring intermodulation distortion products 6 db or more higher in amplitude than the indicated measurements of these products when the analyzer is used to test itself. This condition would provide an accuracy of approximately 1 db in tests of other equipment.

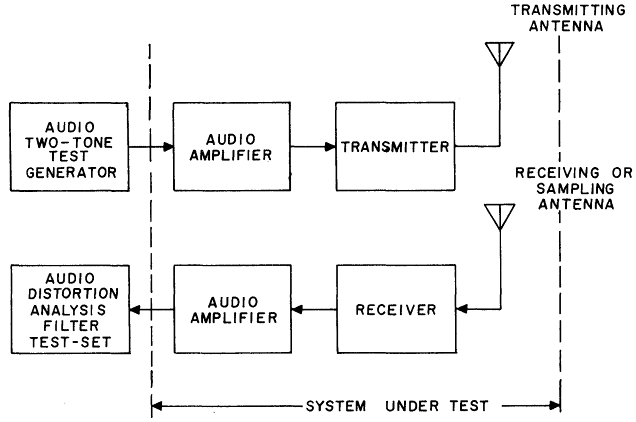


Figure 8-14. System Test for Intermodulation Distortion

12. SUMMARY

The demand for more communication channels in the high-frequency band and the large volume of information that must be carried on each channel has led to a search for a more effective and efficient method of communication. Technological advances in frequency control have made possible the use of single-sideband techniques which eliminate dependence upon a carrier for automatic frequency control at the receiver. However, to assure full utilization of the advantages of these techniques, test equipment must be provided which is capable of making measurements with a much higher degree of resolution than has been customary.

Precision frequency counters provide a convenient method of measuring frequency accuracy while spectrum analysis measures the degree of linearity and frequency stability directly in terms of bandwidth requirements. Laboratory test equipment capable of the required resolution has been built and used in the development of SSB equipment. The design and construction of precision test equipment for field use is receiving added attention as the use of SSB equipment becomes more widespread.

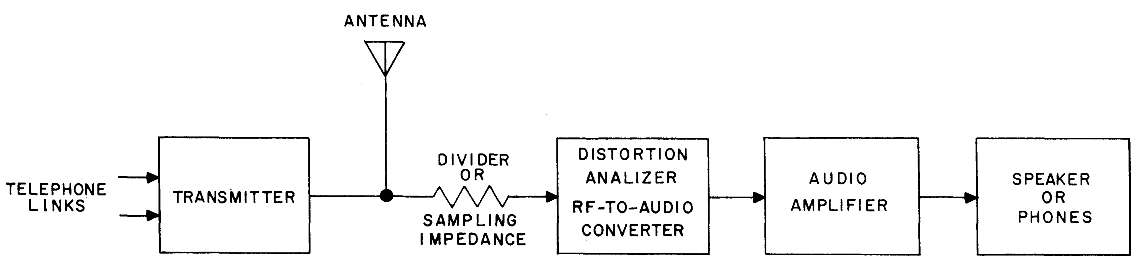


Figure 8-15. Transmitter Monitor, Block Diagram

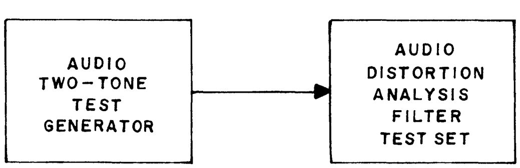


Figure 8-16. Test of Two-Tone Audio Generator

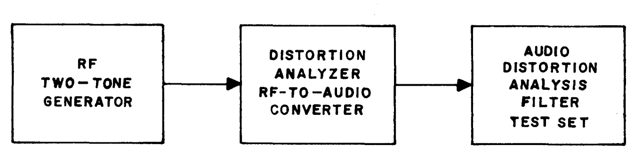


Figure 8-17. Test of Intermodulation in R-F to Audio Converter