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MEASURING THE INTERMODULATION DISTORTION OF LINEAR AMPLIFIERS

Prepared by: Helge Granberg
Circuits Engineer, SSB

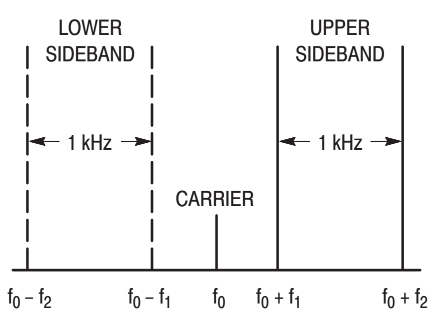
The measured distortion of a linear amplifier, normally called Intermodulation Distortion (IMD), is expressed as the power in decibels below the amplifier's peak power or below that of one of the tones employed to produce the complex test signal.

A signal of three or more tones is used in certain video IMD tests, but two tones are common for HF SSB. The two-tone test signal provides a standard, controlled test method, whereas the human voice contains an unknown number of frequencies of various amplitudes and couldn't be used for accurate power and linearity measurements. Separation of the two tones, for voice operation equipment, may be from 300 Hz to 3 kHz, 1 kHz being a standard adopted by the industry.

Generation of the Test Signal

The two-tone IMD test signal can be generated by a number of means of which the following three are the most common:

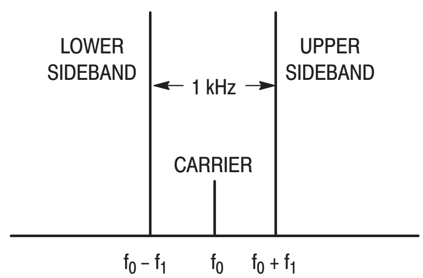
System A — A two-tone audio signal is formed by algebraically adding two sine wave voltages of equal amplitude which are not harmonically related, e.g., 800 Hz and 1.8 kHz. This two-tone audio signal is fed into a balanced modulator together with an RF carrier, one sideband filtered out, and the resultant further mixed to the desired frequency and then amplified. The system is useful in testing complete SSB transmitters. A commercial transmitter can also be used as a signal source for testing linear amplifiers.



SYSTEM A

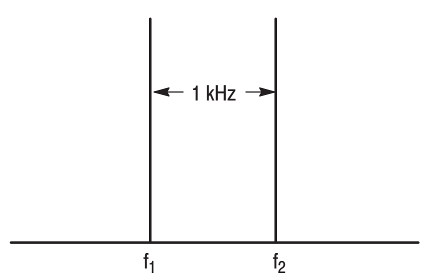
System B — In this method, a signal of approximately 500 Hz is fed into a balanced modulator together with an RF carrier and amplified to the required power level.

The resultant is a double-sideband signal that resembles a single-sideband signal generated under two-tone sine wave conditions. Viewed on a scope screen, the envelope produced by this method appears the same as a SSB twotone pattern. However, unlike the System A test signal, there is a controlled and fixed phase relationship between the two output tones. This system is widely employed to generate the test signal for linearity measurements.



SYSTEM B

System C — Two equal amplitude RF signals, separated in frequency by 1 kHz, are algebraically added in a hybrid coupler. The isolation between input ports must be high enough to avoid interaction between the two RF signal generators. Short-term stability (jitter) should be less than one part per million at 30 MHz. The carrier is nonexistent as compared to A and B, and the two-tone signal is generated as the RF voltages cancel or add at the rate of their difference frequency according to their instantaneous phase angles. Because no active components are involved, very low IM distortion is achievable. This system is useful in applications where low distortion and low power levels are required.



SYSTEM C

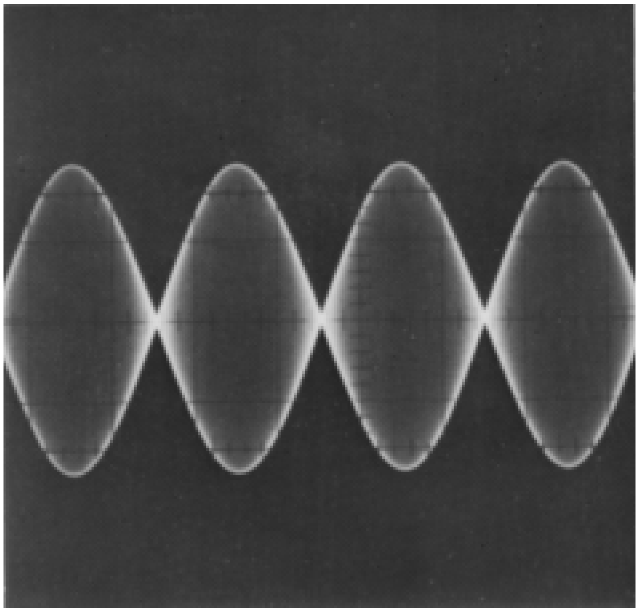


Figure 1. Two-Tone Test Pattern Generated by A, B, or C

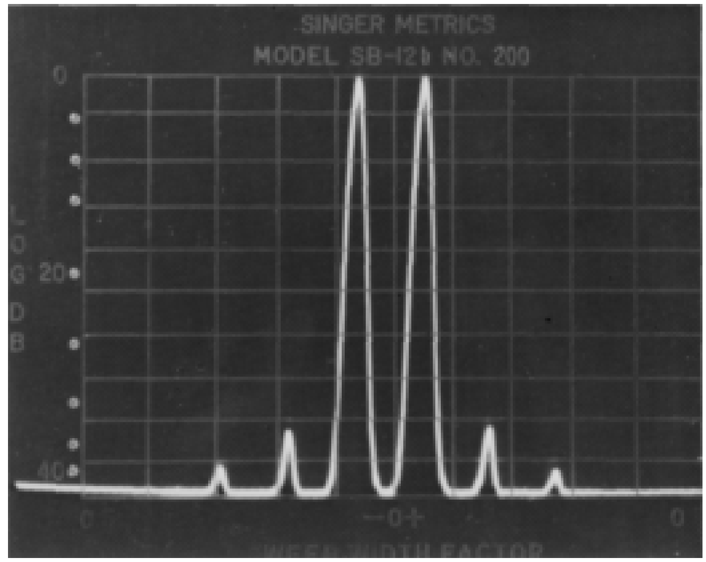


Figure 2. Test Signal of Figure 1 Displayed by a Spectrum Analyzer. 3rd and 5th Order Distortion Products Are Visible

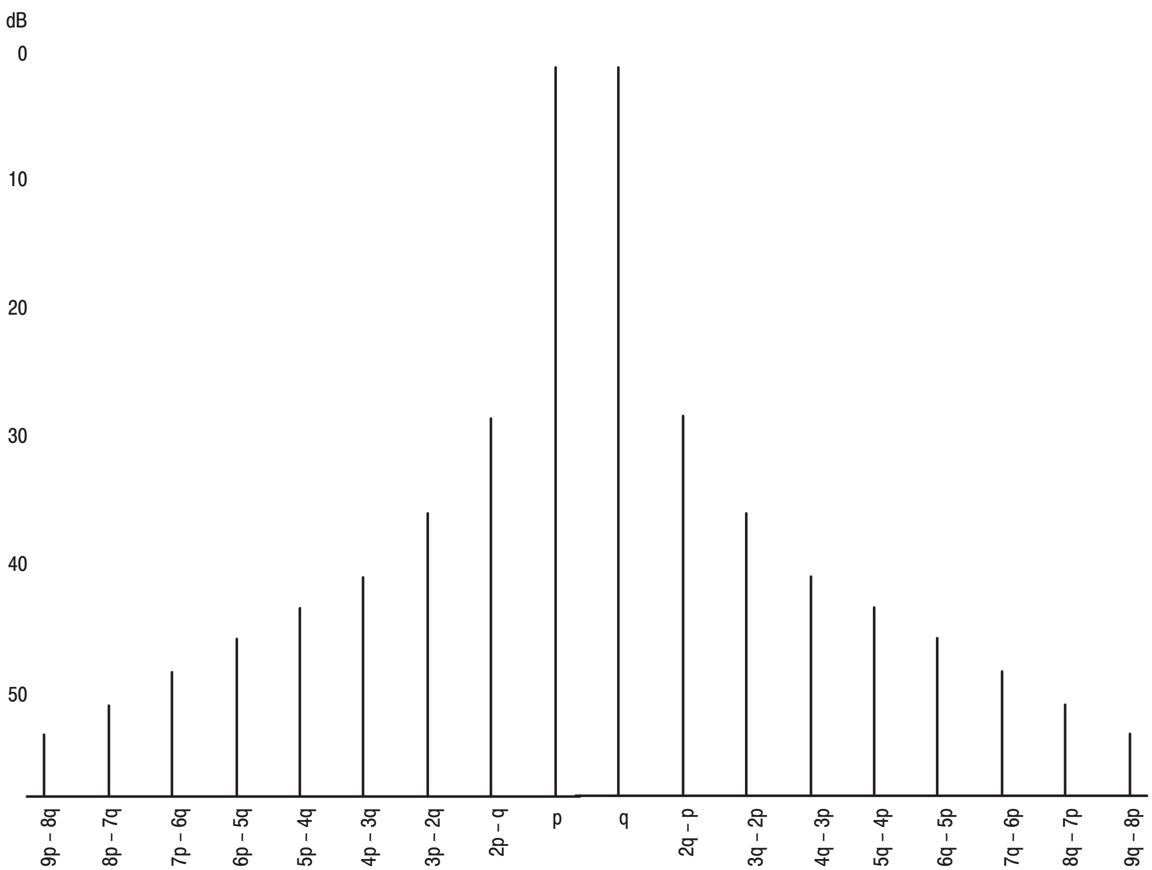


Figure 3. Typical Distribution of Distortion Product Amplitudes Compared to the Two Fundamental Frequency Components

Except for the position of the carrier in respect to the two tones, displays of the signals produced by systems A, B and C appear identical on a spectrum analyzer screen. Sometimes, however, the suppressed carrier may remain below the noise level of the instrument. Any spectrum analyzer used for SSB linearity measurements must have an IF bandwidth of less than 50 Hz to allow the two closely spaced tones to be displayed with good resolution. Figure 1 shows a low distortion, two-tone envelope displayed on a scope screen. On a spectrum analyzer screen the same signal displays as two discrete frequencies separated by the difference of the audio frequency or frequencies. See Figure 2. The display represents the rate at which peak power occurs when the two frequencies are in phase and the voltages add. Thus, one peak contains one-fourth (– 6 dB) of the peak envelope power (PEP). An average reading power meter would read the combined power of the tones, or half the PEP, assuming the envelope distortion is negligible. The third order distortion products (d_3), fifth order (d_5), etc., can be seen on each side of the tones. The actual power (PEP) of each distortion product can be obtained by deducting the number of decibels indicated by the analyzer from the average power. This value may be useful in determining the linearity requirements of the signal source. While the maximum permissible distortion levels of the driver stages in a multi-stage amplifier may be difficult to specify, a 5- to 6-dB margin is usually considered sufficient.

Types of Distortion

The nonlinear transfer characteristics of active devices are the main cause of amplitude distortion, which is both device and circuit dependent. On the other hand, harmonic and phase distortion, also present in linear amplifiers, are predominantly circuit dependent. Even order harmonics, particularly noticeable in broadband designs, cause the harmonic distortion. Push-pull design will eliminate most of the even-order-caused harmonic distortion and the driver stages, where efficiency is of less concern, can be biased to class A.

Phase distortion can be caused by any amplitude or frequency sensitive components, such as ceramic capacitors or high-Q inductors, and is usually present in multi-stage amplifiers. This distortion may have a positive or negative sign, resulting in occasions where the level of some of the final IMD products (d_3 or d_5, or both) may be lower than that of the driving signal, due to canceling effects of opposite phases. Actual levels depend on the relative magnitude of each distortion product present.

From the above it is apparent that the distortion figures presented by the spectrum analyzer represent a combination of amplitude, harmonic and phase distortion.

Measurement Standards

As indicated earlier, there are two standard methods of measuring the IM distortion:

Method 1 — In military standard (1131 A-2204B), the distortion products are referenced to one of the two tones of the test signal. The maximum permissible IMD is not specified but, numbers like – 35 dB are not uncommon in some equipment specifications. However, when this measuring system is employed in industrial applications, the IMD requirement (d_3) is usually relaxed to – 30 dB. Figure 3 shows the frequency spectrum of IM distortion products and their relative amplitudes for a typical class AB linear amplifier. Biasing the amplifier more toward class B will cause the lower order distortion products to go down and the amplitudes of the higher order products to increase. There is a bias point where the d_3 and d_5 products become equal resulting in 2 – 5 dB improvement in the lower order IMD readings.

Method 2 — In the proposed EIA standard, the amplitude of the distortion products is referenced to the peak envelope power, which is 6 dB higher in power than that represented by one of the two tones. The amplifier or device indicating a maximum distortion level of – 30 dB in Method 1 represents – 36 dB with the EIA proposed standard. Conversely, a – 30 dB reading with EIA's PEP reference would be – 24 dB when measured with the more conservative military method. In practical measurements, the two tones can be adjusted 6 dB down from the zero dB line, and direct IMD readings can be obtained on the calibrated scale of the analyzer. Alternatively, the tone peaks can be set to the zero dB level and 6 dB deducted from the actual reading.

The military standard, with the relaxed –30 dB IMD specification, is employed by most manufacturers of high power commercial transmitters and marine radio base stations. *The EIA measuring method is used by the majority of ham radio equipment and CB radio manufacturers. It is also used to measure IMD in various mobile radio applications operating from a 12.5 V nominal dc supply.

Because of the importance to your design, data sheets of the newer generation Motorola devices specify linearity tests appropriate to the expected application of the particular device and test conditions are always indicated.

REFERENCES:

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2. *William I. Orr,* "*Radio Handbook," 18th Edition, Editors and Engineers, Ltd.*
3. *Stoner, Goral,* "*Marine Single-Sideband," Editors and Engineers, Ltd.*
4. *Hooton,* "*Single-Sideband, Theory and Practice," Editors and Engineers, Ltd.*

* FCC specifications are now in effect covering maximum permissible distortion up to the 11th order products.

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