

Measuring the Intermodulation Distortion of Linear Amplifiers

by: **Helge Granberg**
Circuits Engineer, SSB

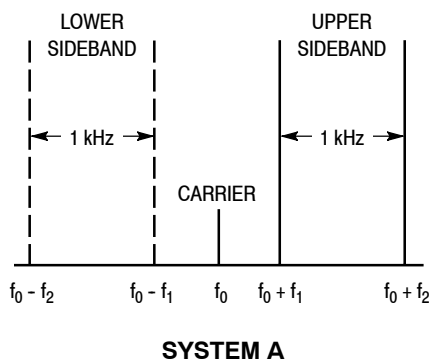
The measured distortion of a linear amplifier, normally called Intermodulation Distortion (IMD), is expressed as the power in decibels below the amplifier's peak power or below that of one of the tones employed to produce the complex test signal.

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

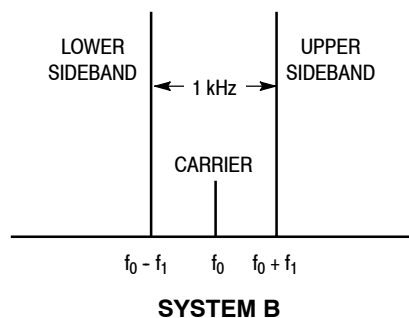
The two-tone IMD test signal can be generated by a number of means of which the following three are the most common:

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.

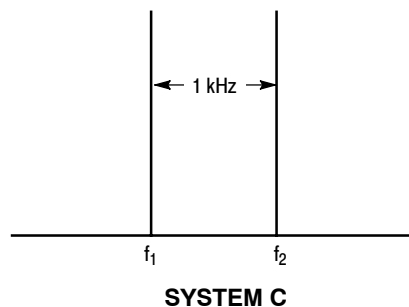


System B — In this method, a signal of approximately 500 Hz is fed into a balanced modulator together with an RF carrier and amplified to the required power level.

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 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.



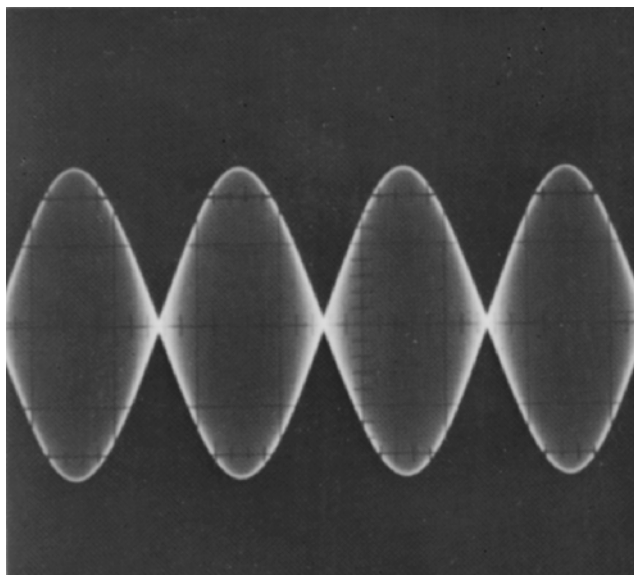


Figure 1. Two-Tone Test Pattern Generated by A, B, or C

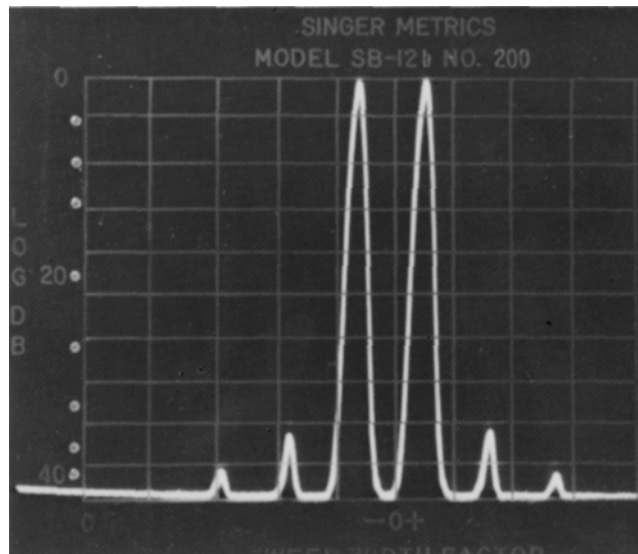


Figure 2. Test Signal of Figure 1 Displayed by a Spectrum Analyzer. 3rd and 5th Order Distortion Products Are Visible

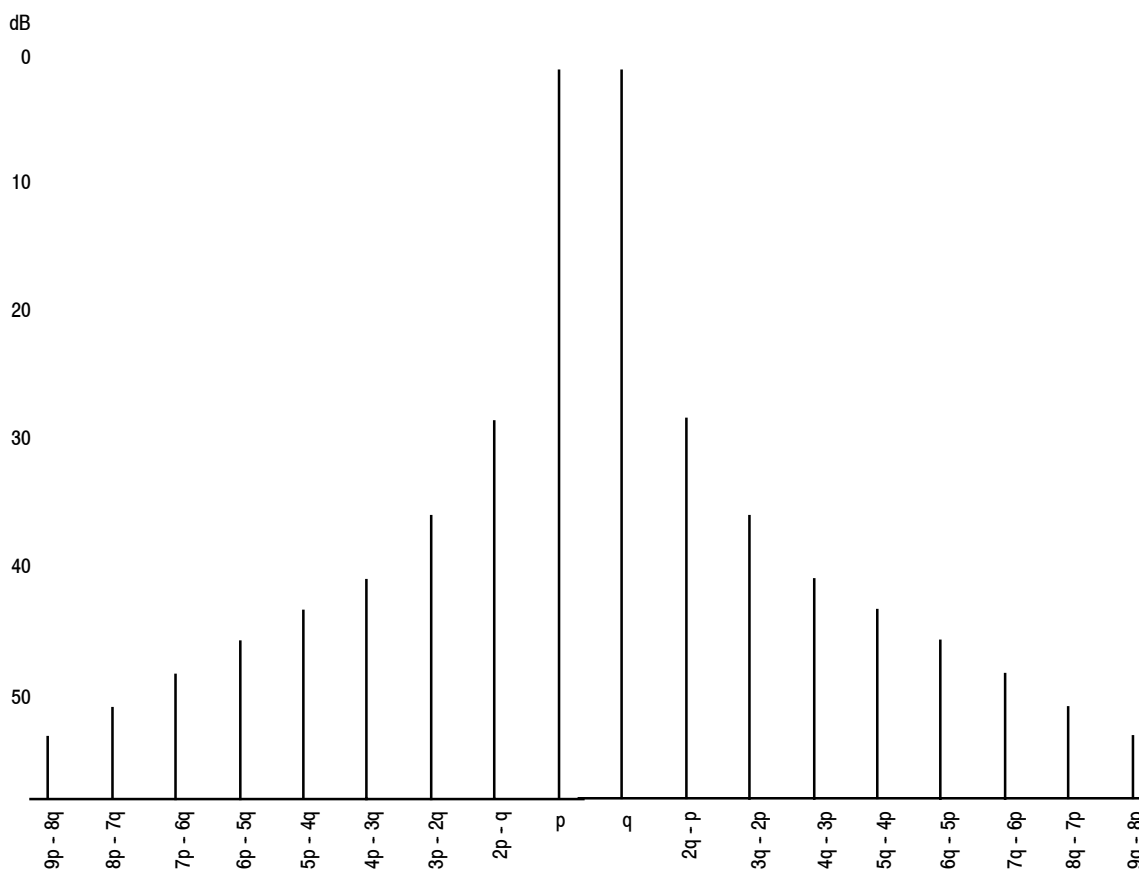


Figure 3. Typical Distribution of Distortion Product Amplitudes Compared to the Two Fundamental Frequency Components

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 Freescale devices specify linearity tests appropriate to the expected application of the particular device and test conditions are always indicated.

REFERENCES:

1. Pappenfus, Brueue & Schoenike, "Single-Sideband Principles and Circuits," McGraw-Hill.
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.

How to Reach Us:

Home Page:

www.freescale.com

E-mail:

support@freescale.com

USA/Europe or Locations Not Listed:

Freescale Semiconductor
Technical Information Center, CH370
1300 N. Alma School Road
Chandler, Arizona 85224
+1-800-521-6274 or +1-480-768-2130
support@freescale.com

Europe, Middle East, and Africa:

Freescale Halbleiter Deutschland GmbH
Technical Information Center
Schatzbogen 7
81829 Muenchen, Germany
+44 1296 380 456 (English)
+46 8 52200080 (English)
+49 89 92103 559 (German)
+33 1 69 35 48 48 (French)
support@freescale.com

Japan:

Freescale Semiconductor Japan Ltd.
Headquarters
ARCO Tower 15F
1-8-1, Shimo-Meguro, Meguro-ku,
Tokyo 153-0064
Japan
0120 191014 or +81 3 5437 9125
support.japan@freescale.com

Asia/Pacific:

Freescale Semiconductor Hong Kong Ltd.
Technical Information Center
2 Dai King Street
Tai Po Industrial Estate
Tai Po, N.T., Hong Kong
+800 2666 8080
support.asia@freescale.com

For Literature Requests Only:

Freescale Semiconductor Literature Distribution Center
P.O. Box 5405
Denver, Colorado 80217
1-800-441-2447 or 303-675-2140
Fax: 303-675-2150
LDCForFreescaleSemiconductor@hibbertgroup.com

Information in this document is provided solely to enable system and software implementers to use Freescale Semiconductor products. There are no express or implied copyright licenses granted hereunder to design or fabricate any integrated circuits or integrated circuits based on the information in this document.

Freescale Semiconductor reserves the right to make changes without further notice to any products herein. Freescale Semiconductor makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does Freescale Semiconductor assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation consequential or incidental damages. "Typical" parameters that may be provided in Freescale Semiconductor data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals", must be validated for each customer application by customer's technical experts. Freescale Semiconductor does not convey any license under its patent rights nor the rights of others. Freescale Semiconductor products are not designed, intended, or authorized for use as components in systems intended for surgical implant into the body, or other applications intended to support or sustain life, or for any other application in which the failure of the Freescale Semiconductor product could create a situation where personal injury or death may occur. Should Buyer purchase or use Freescale Semiconductor products for any such unintended or unauthorized application, Buyer shall indemnify and hold Freescale Semiconductor and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that Freescale Semiconductor was negligent regarding the design or manufacture of the part.

Freescale™ and the Freescale logo are trademarks of Freescale Semiconductor, Inc. All other product or service names are the property of their respective owners.

© Freescale Semiconductor, Inc. 1993, 2004. All rights reserved.