Application Note #2

Transmitter Two Tone Test

How to measure amplifier non-linearity

How can the ham make practical amplifier measurements to check for splatter, IMD products and unwanted harmonic content? While it is helpful to understand the theory and math behind amplifier non-linearity's, all that is required is to make accurate measurements minimizing splatter and distortion is an understanding of the basic concepts.

Basically there are three methods to measure non-linearity and IMD products; Spectrum analyzer, Trapezoid test and the Two Tone test. Each has its advantages and disadvantages.

Two tone signal test using an oscilloscope

The Two Tone, third-order intermodulation distortion (IM) test measures the degree of nonlinearity of an electronic device with a definable dynamic range, such as an amplifier**.** Nonlinear RF Amplifiers may spread signals into adjacent channels, and or frequencies, which can cause Cross Modulation. This is based on the same phenomena as third order intermodulation for nonlinear amplifiers with two-tone inputs. Fortunately, when making a Two Tone test, the signal distortion is relatively easy to spot. Testing ham radio HF linear amplifiers can be done by injecting a two tone test signal (usually 700 Hz and 1900Hz) into the amplifier input and observing the modulation envelope with an oscilloscope.

This test can be done by simply inputting the signal into the transceiver's mike jack from the line out of the two tone test generator, or in the alternative, using the speaker output to drive an external speaker placed close to the microphone. The drawback to using this technique is that the microphone and speaker performance may impact the test result. For this reason separate level and balance control are provided.

Fig 1. This Two Tone test generator provides a standard 2-tone (700 and 1900 Hz) audio source. This type of testing is most commonly used as a measure of transmitter linearity for amateur radio equipment.

Figure 1 The TTG1 Two Tone test generator

Results of 2-tone IMD tests can be found in every ARRL review of new transceivers and power amplifiers.

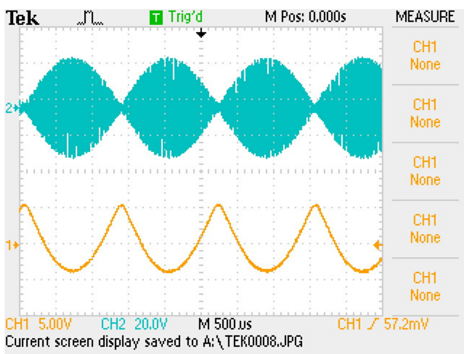


Figure 2 Scope Two Tone test display

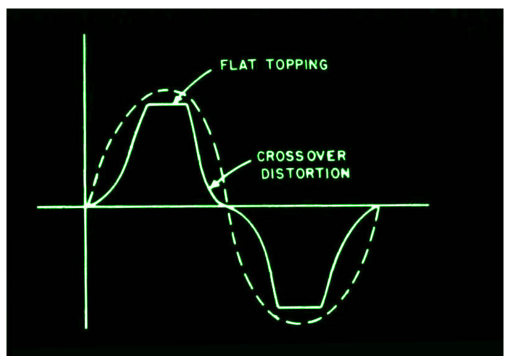
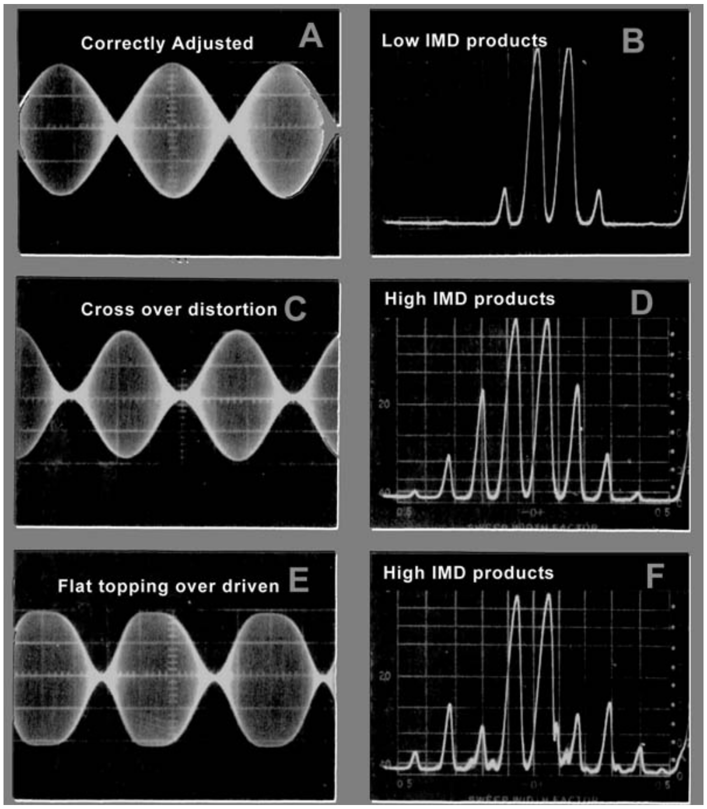


Figure 3 Two Tone test characteristics

Fig. 2 Top trace, note the lack of flat topping and or cross over distortion as when compared to the example shown in Fig 3.



A & B Properly adjusted transmitter.

C & D Crossover distortion resulting in high IMD products.

E & F Flat topping over driven modulation causing splatter and high IMD products.

Figure 4 Tow Tone test, left column scope display, right column spectrum analyzer display

HF amplifier distortion measurements

Linear RF Power Amplifiers are used in a wide variety of ham radio stations. The output power of these linear amplifiers can range from a few watts to several thousand watts. FCC regulations limit the maximum power to 1,500 peak envelope power (PEP). When adjusted properly and operating in their linear region, these amplifiers do exactly that, they amplify RF energy without adding any significant additional distortion products.

However, if overdriven or not properly tuned, the potential distortion products can cause severe problems such as unintelligible modulation. RF power being transmitted out of band, thus causing interference with other radio communications. The interfering signals are the result of harmonic and intermediation products – sometimes referred to as “splatter”.

Efficiency

Another byproduct of improper linear amplifier operation is inefficiency. Power that is not converted to a useful signal is dissipated as heat. Power Amplifiers that have low efficiency have high levels of heat dissipation, which could be a limiting factor in a particular design. This can have an adverse effect on the components, particularly the final output tubes or transistors.

Instability

Another undesirable amplifier phenomenon is instability. Instability in RF amplifiers may manifest itself as oscillation at almost any frequency, and may damage or destroy the amplifying device. This unwanted RF energy is called spurious oscillation.

These spurious oscillations can arise at specific or very wide ranging frequencies and over a particular bias, drive level, temperature or output load impedance.

Responsibility

In the amateur radio service, the control operator (i.e. ham) is responsible for ensuring that all emitted signals including RF linear power amplifiers are operated in accordance with those prescribed by their license privileges and do not exceed the maximum allowed distortion by the FCC.

Some practical theory

In practice and to ensure efficiency, many linear amplifiers operate as Class B. In Class B the conduction angle for the amplifying device (tube or transistor) is approximately 180°. Thus, the amplifying device conducts only half of the time, either on positive or negative half cycle of the input signal.

The same as in Class A, the DC bias applied to the amplifying device determines the Class B operation. Class B amplifiers are more efficient than Class-A amplifiers. The instantaneous efficiency of a Class-B PA varies with the output voltage and for an ideal PA reaches $\pi/4$ (78.5 %) at PEP. However they are much less linear. Therefore a typical Class-B amplifier will produce quite a bit of harmonic distortion that must be filtered from the amplified signal.

PDC = (2*VCC*V) / (Π*R);

PLOAD = V2 / (2*R);

η (Efficiency Class-B) = (Π*V) / (4*VCC)

A common configuration of Class B amplifiers is push-pull. In this configuration, one amplifying device conducts during positive half cycles of the input signal and the second transistor conducts during the negative half cycle. In this way, the entire input signal is reproduced at the output. In the push-pull arrangement, the DC components and even harmonics cancel, (but odd harmonics add), thus the output contains the fundamental signal only. Note that the cancellation of odd harmonics is only valid if the amplifier is not driven hard.

Power amplifier linearity

When two or more signals are input to an amplifier simultaneously, the second, third, and higher-order intermodulation components (IM) are caused by the sum and difference products of each of the fundamental input signals and their associated harmonics. The rated PEP of a Power Amplifier is the maximum envelope power of a two-tone signal for which the amplifier intermodulation level is -30dBc. When two signals at frequencies f1 and f2 are input to any nonlinear amplifier, the following output components will result:

Fundamental: f1, f2

Second order: 2f1, 2f2, f1 + f2, f1 - f2

Third order: 3f1, 3f2, 2f1 ± f2, 2f2 ± f1,

Fourth order: 4f1, 4f2, 2f2 ± 2f1,

Fifth order: 5f1, 5f2, 3f1 ± 2f2, 3f2 ± 2f1, + Higher order terms

The odd order intermodulation products (2f1-f2, 2f2-f1, 3f1-2f2, 3f2-2f1, etc) are close to the two fundamental tone frequencies f1 and f2.

The nonlinearity of a Power Amplifier can be measured on the basis of the generated spectra (i.e with a spectrum analyzer) than on variations of the fundamental waveform (i.e. oscilloscope). The estimation of the amplitude change (in dB) of the intermodulation components (IM) versus fundamental level change, is equal to the order of nonlinearity.

For a one dB increase of fundamental level (f1 and f2), the level of IM2 will go up by 2dB, the level of IM3 will go up by 3dB, and so on. As a relation between the degree of nonlinearity (third, fifth, etc) and the frequency of the side tone (such as IM3, IM5, etc). It can be mentioned with the IM5 tones are not affected by third-degree nonlinearities, but IM3 tones are functions of both third- and fifth-degree (and higher) nonlinearities. That means at low signal amplitudes, where the fifth-order distortion products can be neglected, the amplitudes of the IM3 tones are proportional to the third power of the input amplitude (see below).

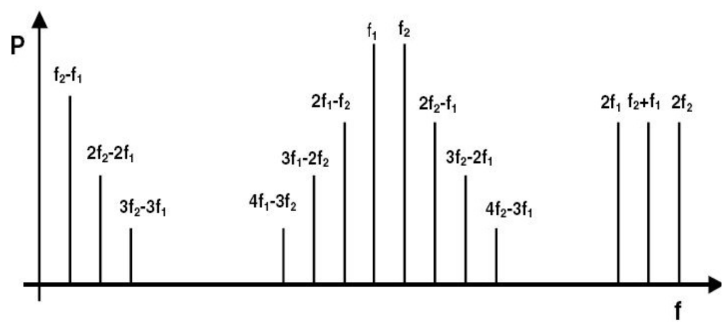


Figure 5 Spectrum of IMD products

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