Application Note #1

Transmitter Trapezoid Test

© Roger Stenbock W1RMS 3/3/2012

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.

Trapezoids station monitor testing

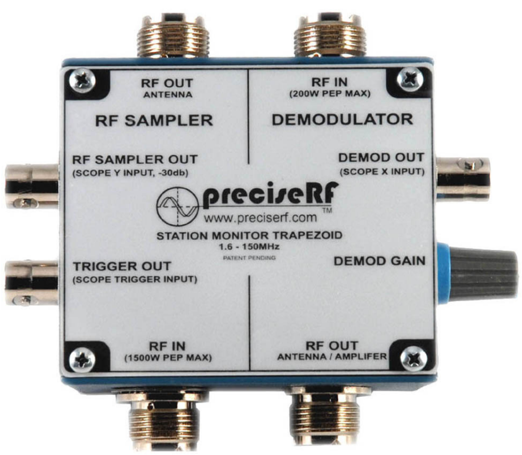

Figure 1 Station monitor

Figure 1. The station monitor provides all the components to make accurate transmitter tests. It includes a demodulator with separate level control for the scope's X input, an RF sampler for the scope's Y input, and a scope trigger output.

This station monitor allows for precise tuning of the entire transmitter chain with transceiver output of up to 100 Watts driving linear RF amplifiers. It features a wide band sampler, a high performance demodulator, a variable base band output, and an oscilloscope trigger output. A Linear RF amplifier generally amplifies an RF signal from 20-100 Watts by 20dB or more to about 500-1,500 Watts. Its performance and modulation can be characterized using a low-cost oscilloscope with a trapezoid display.

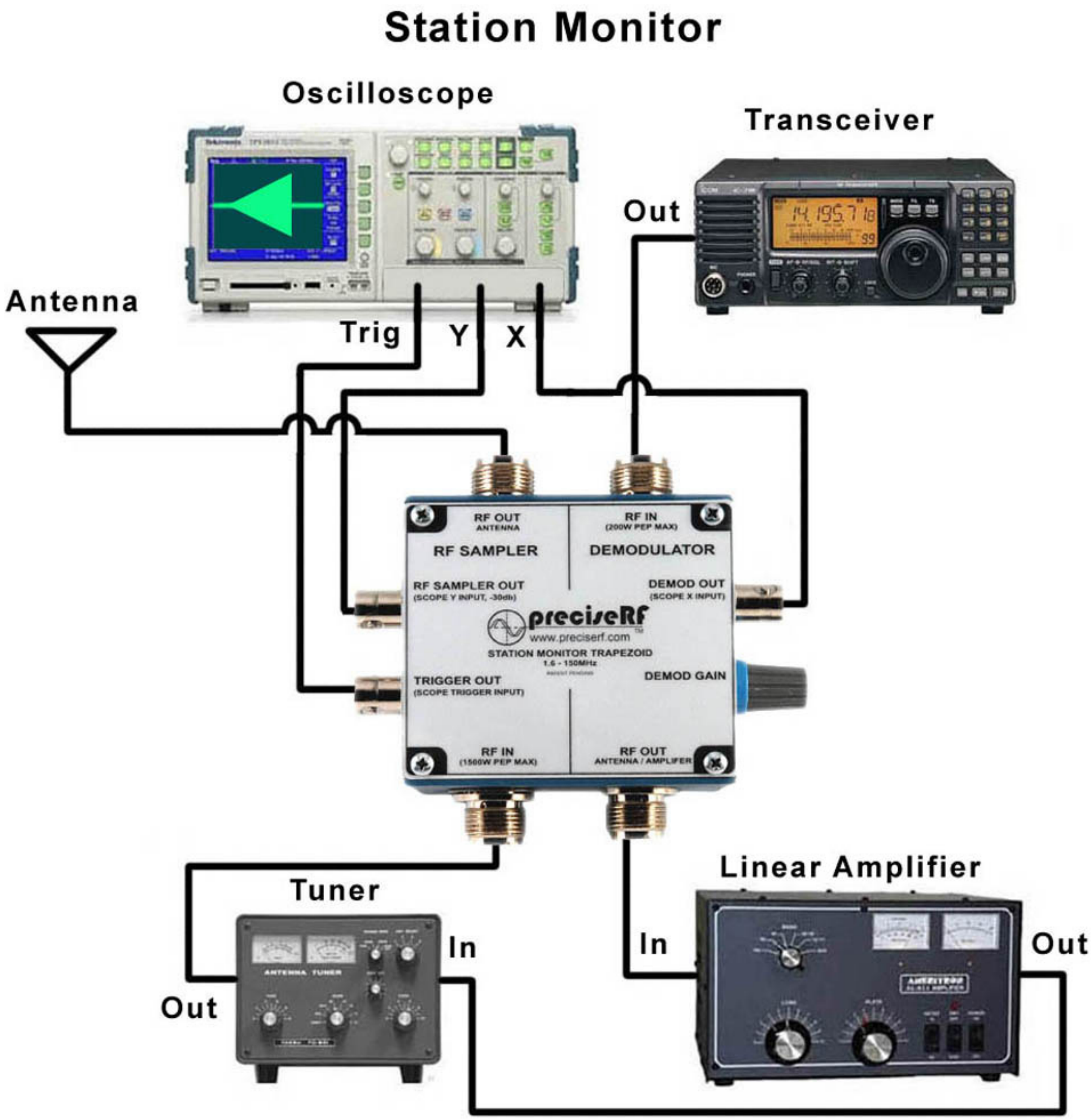

Figure 2 Block diagram station monitor

Figure 3. The RF signal is sampled and demodulated by the station monitor. The outputs are connected to the scope's X and Y inputs and external trigger input for monitoring the signal quality.

Figure 3 Station monitor connection

This is done by sampling the amplifier's output by using an RF sensor. This sensor is connected to the oscilloscope's vertical (Y) input. See the Figure 2. block diagram..

The input of the amplifier is driven by a transceiver which usually outputs less than 100W. Its output drives the input to the amplifier and also a wide band demodulator which extracts the baseband from the modulated carrier. It is this baseband that is connected to the oscilloscope's horizontal (X) input. This display yields a trapezoid pattern. This pattern compares the transceiver's output to the amplifiers output.

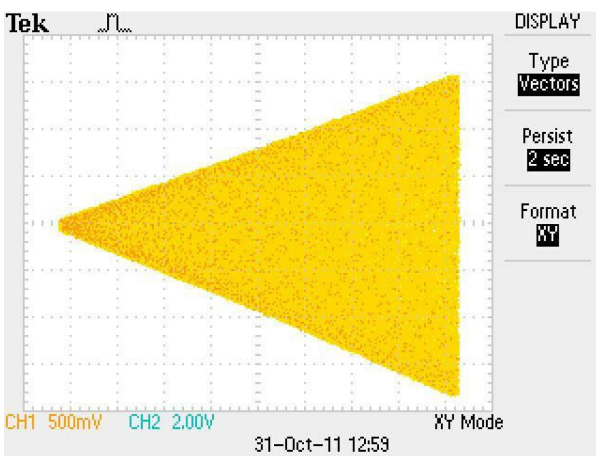

Figure 4. Shown here is the amplitude of the modulated RF increasing in a linear fashion, from minimum at left to maximum at right. When the demodulated horizontal (X) is reversed the trapezoid will be reversed seen here.

Figure 4 Station monitor display

If the amplifier is linear without any distortion and not overdriven, the trapezoid pattern will be a linear undistorted triangular waveform. To rely on such a measurement, the demodulator and signal samples must be linear and free of distortion.

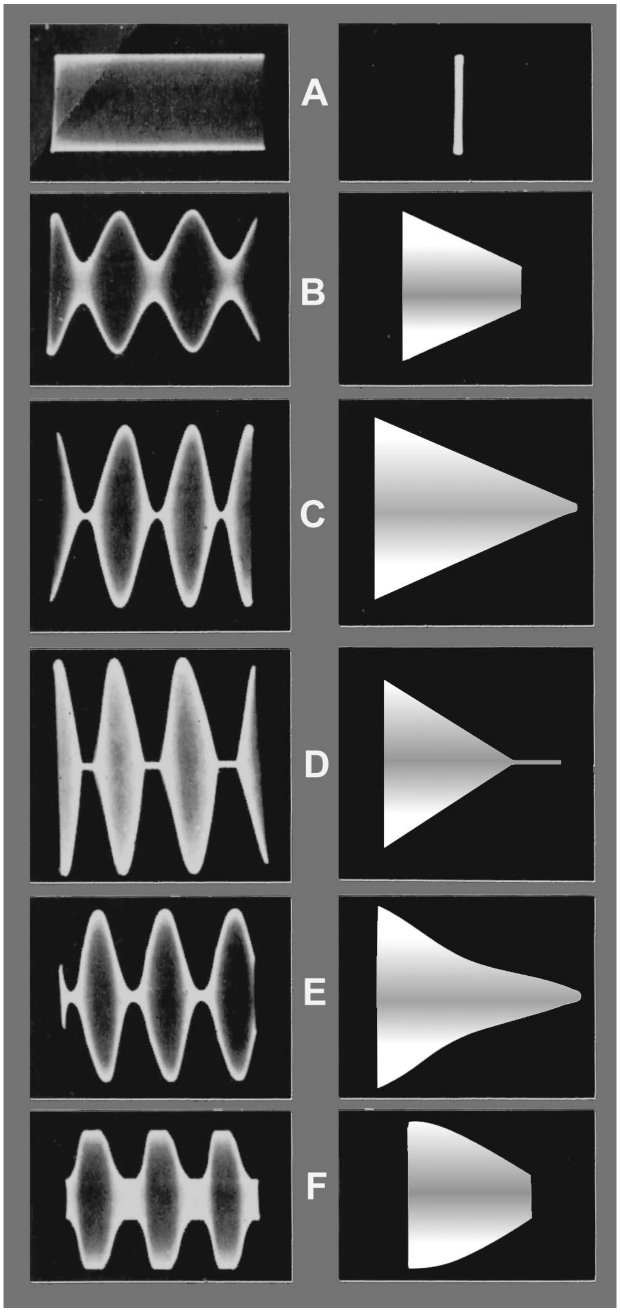

Figure 5 Oscilloscope patterns showing various forms of modulation of an RF amplifier

Figure 5. Wave-envelope patterns; with their corresponding trapezoidal patterns. The wave envelope patterns were obtained with a linear oscilloscope sweep having a frequency one-third of sine-wave audio modulating frequency, so that three cycles of the modulation envelope may be seen.

A. Unmodulated carrier

B. Approximately 50% modulation

C. 100% modulation

D. Shows modulation in excess of 100%

E. Modulation improper transmitter adjustment

F. Indicates improper modulation, incorrect bias, and clipping

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 π/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).

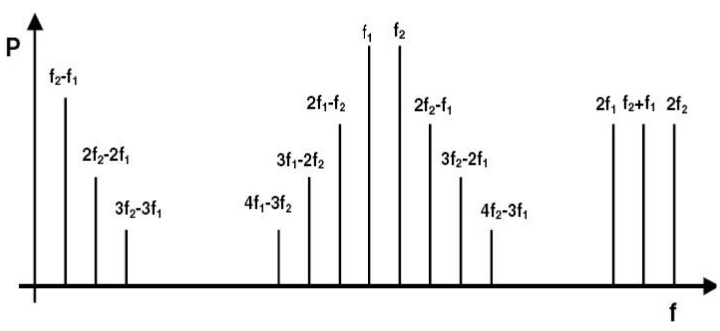

Figure 6 Spectrum of IMD products

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