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MATRIX
TECHNICAL NOTES
MTN-109

THE RELATIONSHIP OF INTERCEPT POINTS COMPOSITE DISTORTIONS AND NOISE POWER RATIOS

Amplifiers, mixers, diode attenuators, and some passive devices can generate intermodulation distortion. These distortion products are a result of a nonlinear transfer characteristic.

A common specification, related to distortion, for amplifiers and mixers is the **Intercept Point.** If the input Vs output of a device is displayed graphically on a dB Vs dB scale, the slope of the linear portion will be 1. If second order distortion products are displayed on the same scale they will have a slope of 2, third order distortion products will have a slope of 3, etc. In most cases distortion products above third order are not important but these rules are still valid.

The **Intercept Point** is the point where the linear extension of the particular distortion intersects the linear extension of the input Vs output line. Usually intercept points are given in terms of output power but in some cases, for example mixers, intercept points are given in terms of input power. When making distortion calculations, it is necessary to specify, or at least be consistent, as to where (input or output) the results apply.

To be more correct the intercept point should be named the **Two Tone Intercept point** because two tones are used as the signal source. Two tones will generate third order distortion products **3A, 3B, 2A + B, 2A - B, 2B + A** and **2B - A.** This method of measuring distortion was developed so that narrow band amplifiers could be measured. The only third order products that fall in band, in narrow band amplifier, are **2A - B** and **2B - A**.

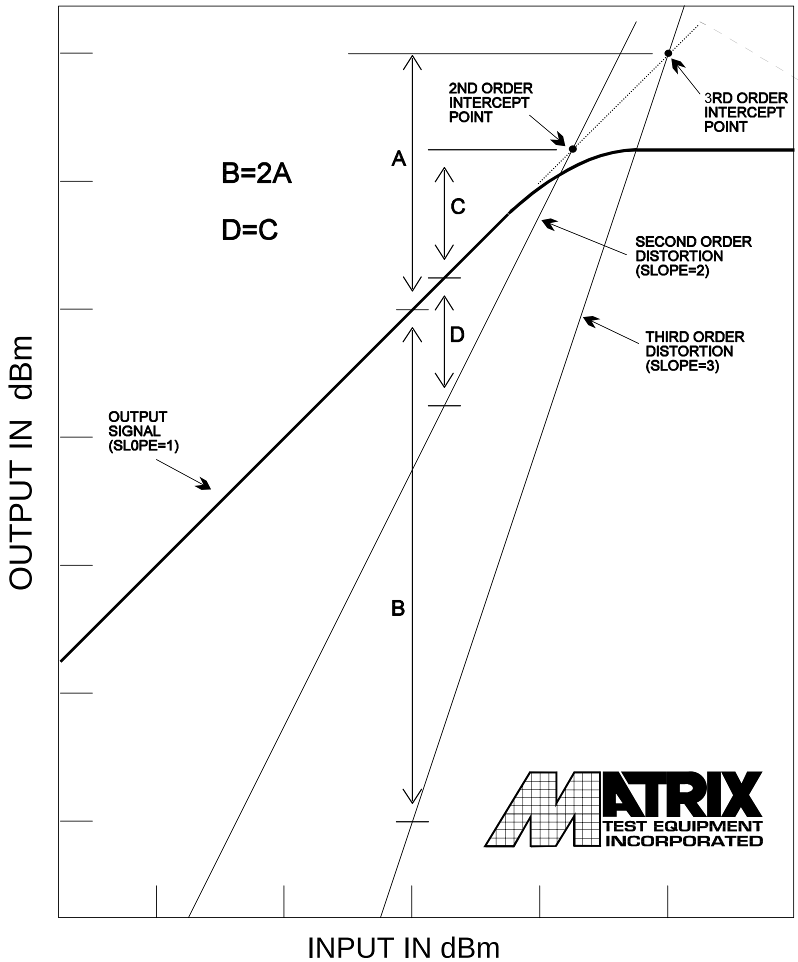

Figure 1, TWO TONE SECOND AND THIRD ORDER DISTORTION PRODUCTS. INPUT LEVEL FOR ONE TONE, VS OUTPUT SIGNALS AND DISTORTIONS RELATIVE TO ONE TONE

The method of making the measurement is to insert two closely spaced equal level carriers into the device under test. The distortion products are then measured and compared with the level of **one** of the signals.

The graphic representation of the distortions is valuable because it allows insight into the behavior of the distortion products.

If the signal levels are 20 dB below the third order intercept point, then the third order distortion will be 40 dB below the signal.

In a similar way it is obvious that if the signal levels are 20 dB below the second order intercept point, then the second order distortion will be 20 dB below the signal.

It is also possible to measure the third order intercept point by using 3 frequencies instead of 2. Actually there are advantages to using 3 frequencies because the products will be stronger by 6 dB.

If third order measurements are made using 3 frequencies, the magnitude of the products must be reduced by 6 dB in order to agree with the common definition of “Third Order Intercept”.

MULTIPLE CARRIERS

If we now consider the case of many carriers in a broadband system, the problem becomes more complicated. Consider a CATV system with many equally spaced carriers. Now we note that the distortion products **2A - B** and **2B - A** are no longer important. This is because there are fewer of them and they are one half the amplitude (- 6 dB) of the now dominant distortion products, **A + / - B + / - C, where A < B < C**.
(See MATRIX TECHNICAL NOTE MTN-108) These beats are referred to as COMPOSITE TRIPLE BEAT or COMPOSITE THIRD ORDER distortions. They are named composite distortions because they are made up of a composite of discrete distortions. They fall in a narrow range of frequencies near the carrier frequency and are measured as a group. The carriers are assumed spaced by some frequency (usually 6 MHz) and are not coherent. If they were coherent (or phase locked) the beats would also be coherent. The frequency variation of the carriers, which is on the order of a few KHz, causes the beats to have a band-spread of about 20 KHz. The spectrum of the beats resembles noise because it is made up of many carriers. In general the power in the composite of the beats is the sum of all the power in the individual beats. It is only necessary to find the power on one distortion beat and the total number of beats to determine the composite beat.

COMPOSITE THIRD ORDER DISTORTION

For equally spaced carriers, the total number of composite distortion products of the **A +/- B + /- C** variety can be closely approximated by;

Number of beats (mid band) = $3N^2/8$

Number of beats (band edge) = $N^2/4$

The beats that dominate multiple channel systems are the **A +/- B +/- C** beats because these beats are 6 dB stronger than the **2A - B** and **2B - A** beats.

Consider the following example, an amplifier is operating with 20 channels with the level of each carrier 40 dB below the intercept point. We know from our definition of intercept point that the **2A - B** distortions must be 80 dB below carriers and the **A +/- B +/- C** distortions must be –80+6 = –74 dB or 74 dB below the carrier. We also know that in the middle of the band, there are $3N^2/8$ distortion beats.

For example if: N=20

Number of beats (mid band) = $3N^2/8$ = 150 = 21.76 dB (in terms of power ratio)

We can assume that all the distortion beats have the same amplitude and will add as powers. In the example above the **A +/- B +/ - C** products were 74 dB below the carrier but we have 150 of them and if they add as powers then the CTB will be – 74 + 21.76 = – 52.24 dB, this is 52.24 dB below the carrier.

In general:

(1) $CTB(dB) = -2(P_i - P_s)dB + 6dB + 10\ LOG\ (3N^2/8)dB$ Mid band

This can also be written as:

(2) $CTB(dB) = -2(P_i - P_s)dB + 1.74dB + 20\ LOG(N)dB$ Mid band

(3) $CTB(dB) = -2(P_i - P_s)dB + 20\ LOG\ (N)dB$ Band edge

CTB = Composite third order distortion (dB)
P_i = Power level at the third order intercept point (dBm)
P_s = Power level of each carrier (dBm)
N = Total number of carries

COMPOSITE THIRD ORDER DISTORTION AND TOTAL SIGNAL POWER

At times it will be useful to calculate CTB products considering the total signal power input as opposed to the single carrier power.

We may write:

(4) P_T = Total Power = P_sdBm + 10 LOG (N) dB

(5) $P_s = P_T$ - 10 LOG (N) dB

From (2) we may write:

(6) CTB(dB) = -2(P_i +P_T – 10 LOG(N)dB + 1.74dB + 20 LOG (N)dB
For a flat input spectrum

(7) CTB(dB) = -2(P_i - P_T)dB + 1.74 dB Band Center

and

(8) CTB(dB) = -2(P_i - P_T)dB Band Edge

We note that the CTB is independent of the number of carriers but related only to the total power of the carriers.

EXAMPLES

For CW signals:

Number of CW carriers	100
Power of each carrier	-25 dBm
Third order Intercept Point	+20 dBm

With 100 carriers each with –25 dBm, the total power is:

(9) $P_T = -25dBm + 10\ LOG\ (100)$

(10) $P_T = -5\ dBm$

From (7) the CTB at Mid Band would be:

(11) $CTB(dB) = -\ 2(P_i\ -\ P_T)dB + 1.74dB$

(12) $CTB(dB) = -2(20 - (-5))dB + 1.74dB = -\ 48.26$ Mid Band

NOISE POWER RATIO

Noise Power Ratio is a method of measuring the intermodulation distortion by using shaped high level noise as a substitute for multiple carriers. This is used in conjunction with a narrow band notch filter. Intermodulation products result in excess noise at the notch frequency. The measurement of the ratio of the flat noise to the noise in the notch is a useful measure.
If we extend the above analysis by increasing the number of carriers, the input spectrum eventually approaches the spectrum of band limited Gaussian noise. Now instead of dealing with carrier power we will use Noise Power Density (dBm/Hz).

(13) P_T (dBm) = Input noise power density(dBm/Hz)
+10 LOG(Bandwidth in Hz)

(14) $CTB(dB) = -2(P_i\ (dBm) - P_T\ (dBm)) + 1.74dB$ Mid Band

COMPOSITE SECOND ORDER DISTORTION

It is now obvious that a similar approach can be used to calculate the composite second order (CSO) distortion from the second order intercept point.

Using the relations found in MATRIX TECHNICAL NOTE
MTN -108

Number of beats (Below carrier) = $N(1 - (f/(f_H - f_L + d)))$

Number of beats (Above carrier) = $(N - 1)(f - 2f_L - d)/(f_H - f_L - d)$

In general:

(15) $CSO(dB) = - (P_i - P_s)dB + 10\ LOG(\text{Number of Distortion products})dB$

P_i = Power level at the second order intercept point (dBm)
P_s = Power level of each carrier (dBm)
N = Number of carriers
f = Frequency of distortion product in MHz
f_H = Frequency of highest channel in MHz
f_L = Frequency of lowest channel in MHz
d = Frequency separation between channels in MHz

There are far fewer second order beats than third order beats but the magnitude of each beat may be stronger that the third order beat. In most high quality amplifiers push-pull circuits are used to reduce the second order distortion. This has the result of increasing the level of the second order intercept point but does not alter its slope.

CROSSMODULATION

X-MOD or crossmodulation is a third order distortion that is also related to the third order intercept point. It can also be considered a composite distortion similar to CSO and CTB. Here the reference calibration level is not the carrier but the level of the fully modulated sideband. Further consideration must be given to the fact that the crossmodulation distortion products are coherent and add as voltages and that each carrier generates two products. Crossmodulation, which can also result from other effects, here are assumed to be the result of only the third order nonlinearity determined by the intercept point.

(16) $$\text{X-MOD} = -2(P_i - P_s)\text{dB} + 6\text{dB} + 20\ \text{LOG}(N)\text{dB}$$

X-MOD = Crossmodulation below 100% modulation (dB)
P_i = Power level at the third order intercept point (dBm)
P_s = Power level of each carrier (dBm)
N = Total number of carriers

For comparison from (1)

(17) $$\text{CTB(dB)} = -2(P_i - P_s)\text{dB} + 6\text{dB} + 10\ \text{LOG}\ (3N^2/8)\text{dB} \quad \text{Mid band}$$

(18) $$\text{CTB(dB)} = -2(P_i - P_s)\text{dB} + 1.74\text{dB} + 20\ \text{LOG}\ (N)\text{dB} \quad \text{Mid band}$$

Note that the X-MOD distortion is independent of the carrier frequency and at band center, the crossmodulation is 4.26 higher (poorer) than the CTB. However the measured CTB will be 2.5 dB lower because of the measurement error of the spectrum analyzer. See the following paragraph.

The net result is that the measured X-MOD will measure greater that the CTB by:

2.5 dB + 4.26dB or 6.76dB.

POSSIBLE SOURCES OF ERROR

It is now important to emphasize some of the problems related to the measurement of CSO, CTB, and crossmodulation.

The common method of making composite distortion measurements uses a spectrum analyzer operating in the LOG display mode. In this mode, spectrum analyzers measure noise and noise-like signals in error. They measure noise as approximately 2.5 dB weaker than the actual power.
The spectrum analyzer method has become the "definition" of the distortion. This may result in discrepancies among the measuring methods. Great caution is required when correlating or interpreting measurements by other methods.

Crossmodulation measurements can also be a problem. Using a spectrum analyzer to measure the distortion sidebands directly can result in large errors. The desired measurement is actually amplitude crossmodulation. Many active devices generate phase crossmodulation with magnitudes that are 30 dB above the amplitude crossmodulation. The spectrum analyzer can not differentiate between the amplitude and phase sidebands and as a result great measurement errors can occur. There are several valid methods for measuring crossmodulation, one is covered in MTN-110.

The equations used for calculating the distortion products were derived by Dr. Thomas B. Warren.
Interpretations, opinions, explanations and other errors are the responsibility of Jack Kouzoujian, Matrix Test Equipment Inc.