More notes on intercept points:

11/06

Read these notes with the other related notes (intermod_notes)

1.0 Gain compression:

If a signal:

$x(t) = ACos\omega t$ is input to a nonlinear system, we get a nonlinear response. This response can be written (to the third order nonlinearity) as:

$$y(t) = \alpha 1ACos\omega t + [\alpha 2A^2] Cos^2\omega t + [\alpha 3A^3] Cos^3\omega t \qquad \text{Eqn 1.0}$$

$$= \alpha 1ACos\omega t + [\alpha 2A^2/2](1 + Cos2\omega t) + [\alpha 3A^3/4](3Cos\omega t + Cos3\omega t) \qquad \text{Eqn 2.0}$$

$\alpha 1$, $\alpha 2$, $\alpha 3$ are gains of the various order output components. A is the input amplitude.

Upon further expansion and simplification this leads to:

$$= [\alpha 2A^2/2] + [\alpha 1A + \{3\alpha 3A^3/4\}] Cos\omega t + [\alpha 2A^2/2] Cos2\omega t]+ [\alpha 3A^3/4]Cos3\omega t \qquad \text{... Eqn 3.0}$$

Here:

$[\alpha 2A^2/2]$	is the DC component	Eqn 4.0
$[\alpha 1A + \{3\alpha 3A^3/4\}] Cos\omega t$	is the fundamental component	Eqn 5.0
$[\alpha 2A^2/2]Cos2\omega t\}$	is the second order component	Eqn 6.0
$[\alpha 3A^3/4]Cos3\omega t$	is the third order component	Eqn 7.0

Even order harmonics (with αj, j even) = 0.0 when system or device has odd symmetry. i.e, differential system.

In a practical system some even order products result from mismatches etc. These are proportionally small.

The nth harmonic consists of terms with A^n and other terms with higher powers of A.

When a device or system is driven with an input signal of the form given above, at first its output increases as the input increases. However, a point is reached when the output start compressing, i.e. failing to increase proportionally to the input signal. At this point its *small signal* gain decreases with increasing signal. When its gain decreases by 1 dB with respect to the uncompressed gain, *the input signal* which causes this to happen is the 1 dB compression point of the device. See figure 1 below

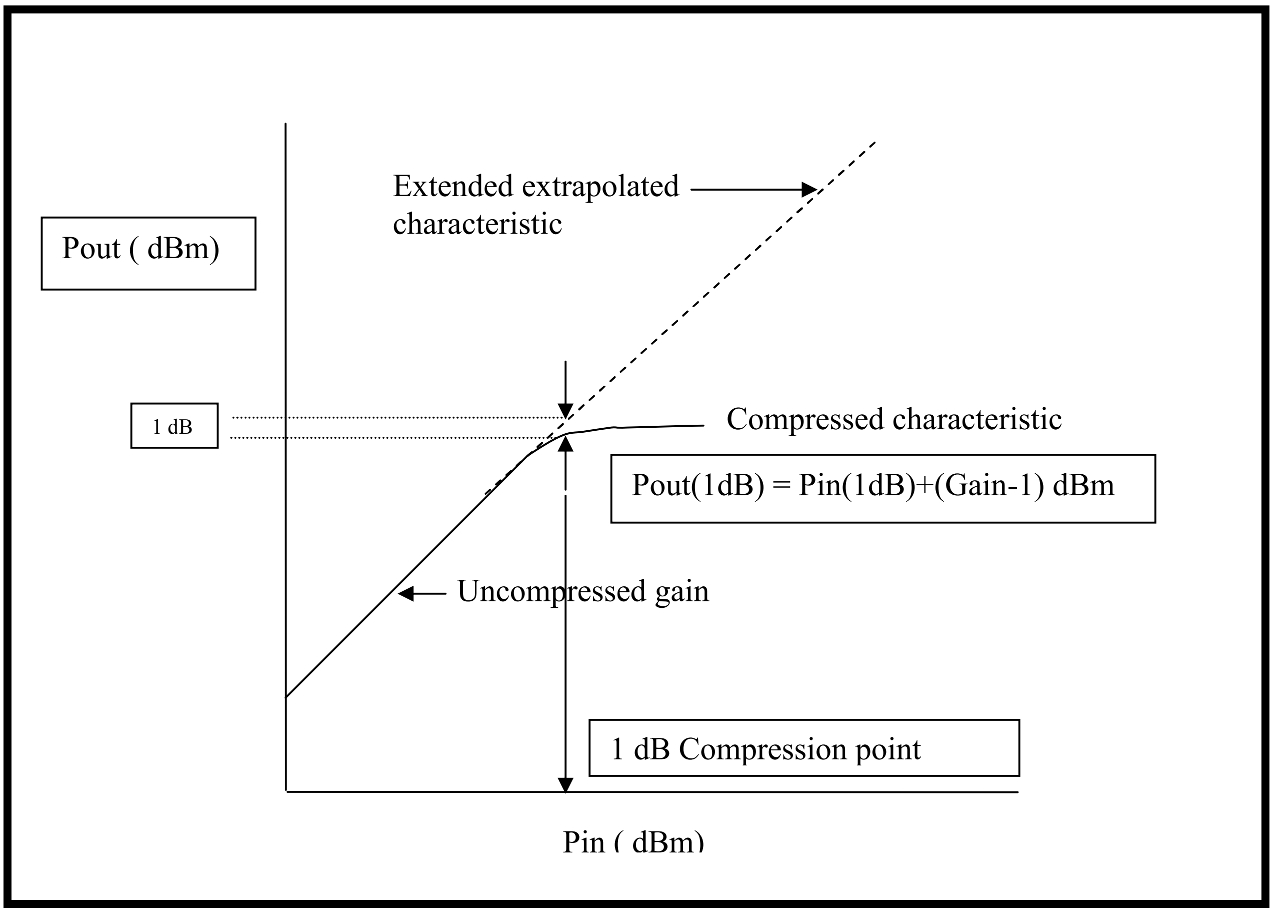


Figure 1.0. 1 dB Compression point

What is the significance of this point? It is this:

As long as the device (amplifier, mixer etc) is driven with an *input* signal that is less than its 1 dBCP, the output will be proportional to the input. As soon as the 1dBCP is exceeded, it will start distorting the signal and generating multiple order spurious signals or INTERMODULATION products. Of these the *third order nonlinearity* or IM3 product is the most critical as explained below.

Why is the third order non linearity so critical?

First of all, if two signals with frequencies $\omega 1$ and $\omega 2$ are applied to the system or device the third order products *of concern* are those that have frequencies of:

$$2\omega 1 - \omega 2 \qquad \text{Eqn 8.0}$$

and

$$2\omega 2 - \omega 1 \qquad \text{Eqn 9.0}$$

Usually these frequencies are spaced close to one another. In a compressing or non linear system these two frequencies generate Inter-modulation products that lie close to the original signals at $\omega 1$ and $\omega 2$. This leads to problems such as distortion. Also if a weak input signal is accompanied by two strong interfering signals then one or more of the IM products from these stronger signals can fall in the band of interest and corrupt the desired (weaker) signal. In receivers this strong IM product can cause "blocking" or in-sensitization of the receiver to the weaker desired signal.

The third order intercept points, both input, IIP3 and output, OIP3 are measures of these deleterious effects and will be further described below. The second order product IIP2 and OIP2 are also important and will be dealt with here.

Please see the html file intermod_notes.htm for background on these important measures.

2.0 Analytic discussion:

Without proof:

The amplitude of 1 dB gain compression is:

$$A1dBCP = \sqrt{[0.145\ |(\alpha 1/\ \alpha 3)]} \qquad \text{Eqn 10.0}$$

Usually a graphic technique is used for IP3. However the following treatment shows an analytic technique to estimate both input and output IP3.

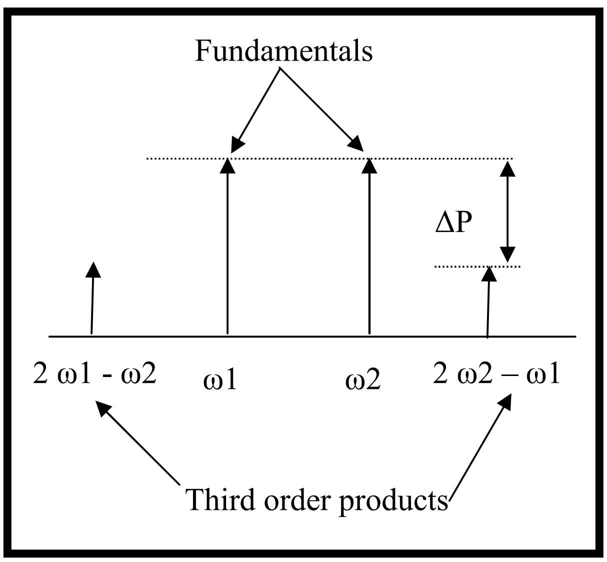
Assume that:

Ain	= Amplitude if input signal at any frequency	Eqn 11.0
$A\omega$	= Amplitude of IM3 products at both frequencies	Eqn 12.0
AIP3	= Amplitude of input IP3	Eqn 13.0
AIM3	= Amplitude of output third order IM products	Eqn 14.0

Then,

$$20\log AIP3 = 0.5[20\log A\omega - 20\log AIM3] + 20\log Ain \qquad \text{Eqn 15.0}$$

The following figure shows this equality graphically.



IIP3(input IP3) (dBm) =

$[\Delta P/2(dB)]/2$ + Pin(dBm).

Pin = Input power at point of measurement in dBm

Figure 2

<u>So measure (or simulate) the input power in dBm</u>
<u>Measure the third order output component power in dBm</u>
<u>Take the difference, divide by and add the input power to get input IIP3.</u>
<u>See below at another graphic presentation of this.</u>

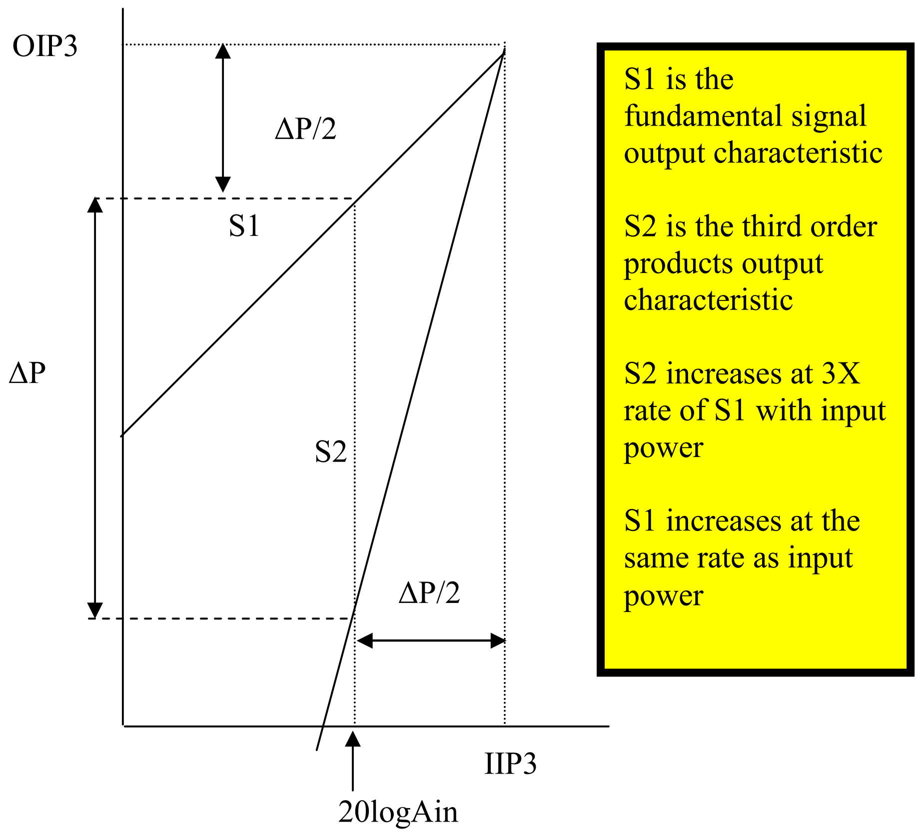


Figure 3

If input power is increased by ΔP/2 the fundamental output power increases by the same amount. Thus IIP3 and OIP3 are determined. i.e. OIP3 point is level of fundamental output power + ΔP/2 and IIP3 is starting input power plus ΔP/2.

This is a quick way to estimate these points. However, in practice accurate extrapolation should be done to get precise data.

Relationship of IIP3 to IdBCP: (Theoretical from Razawi book)

AIP3 = 9.6dB + A1dBCP (Theoretical from Razawi book) .Eqn 16.0
From surveys: AIP3 = = 12 dB + A1dBCP Eqn 16.1

For a reasonably designed device or system. *Please see the sections below on relationships between 1dBCP , IP3 and IP2 from RFCafe.com*

Input IP3 points of cascaded stages:

If one or more devices or system are cascaded the general expression of the input IP3 for the cascade is: (expression shown for 3 stages)

$[1/(AIP3)^2] = [1/(AIP3,1)^2] + [\alpha 1^2/(AIP3,2)^2] + [\alpha 1^2 \beta 1^2/(AIP3,3)^2]$ Eqn17.0

where,

$\alpha 1$ = gain of first stage
$\beta 1$ = gain of second stage

Thus is each stage has a gain larger than one, the non linearity of the latter stages becomes more and more critical because the IIP3 of each stage is *scaled down by the total gain preceding that stage.. Again this equation allows an estimate of the quantity. Precise simulations or measurements should be made for final results. (Which can be difficult!)*

The above estimate is for narrow band systems.

Relationship between (input) IP2 and IP3:

The following formulas can be used to derive this relationship.

Calculating Intercept points (Input IP): (These are formulas from ARRL)

We can calculate the second-order intercept point when you know the input power of one of the input signals and the power of the IMD product signal.

IP2 = 2PA – PIM2/(2-1) Eqn IP.1

where:

IP_2 is the second-order intercept point
P_A is the input power of one of the signals on the receiver input
P_{IM} is the power of the intermodulation distortion (IMD) product

For example, suppose that we use two tones with a strength of –30 dBm each. We measure the second-order IMD products to be –70 dBm. We want to find the second-order intercept point for this receiver. We can use Equation IP.1

PA=	-30 dBm
PIM2 =	-70 dBm
IP2 =	-60+70 = +10 dBm

There is a similar equation to calculate the third-order intercept point.

IP3 = 3PA – PIM3/(3 -1) Eqn IP.2

where:

IP_3 is the third-order intercept point
P_A is the input power of one of the signals on the receiver input
P_{IM} is the power of the intermodulation distortion (IMD) products

As an example of finding the third-order intercept point, we use the same test as above but find IP3.

IP3 = - 10dBm

From surveys the following data has been gathered about the relationship of 1 dBCP and IP3 and IP2.

IP3 = 1dBCP + 11.7 dB (sigma = 2.9 dB)
IP2 = 1dBCP + 27 dB (sigma = 8.1 dB)
