

APPLICATION NOTE 3902

Adjacent Channel Leakage Ratio (ACLR) Derivation for General RF Devices

Abstract: The adjacent channel leakage ratio (ACLR) of any general purpose RF device, whether a mixer, amplifier, isolator, or other device, is frequently dominated by the 3rd-order intermodulation distortion (IM3) of the device. The relationship between the IM3 performance and the output intercept point (OIP3) parameter of the device can be derived. A formula for the prediction of the ACLR performance as a function of this IM3 performance parameter is derived in the following paragraphs.

ACLR/IMD Model

A convenient way to look at the source of ACLR degradation in an RF device is to model the wideband carrier spectrum as a collection of individual CW subcarriers. Each of these subcarriers would carry a fraction of the total carrier power. The following figure illustrates such a model. The continuous RF carrier is modeled in this case by four individual CW subcarriers, each of which has one-quarter of the power of the total broadband carrier. The subcarriers are distributed in equal intervals across the carrier bandwidth.

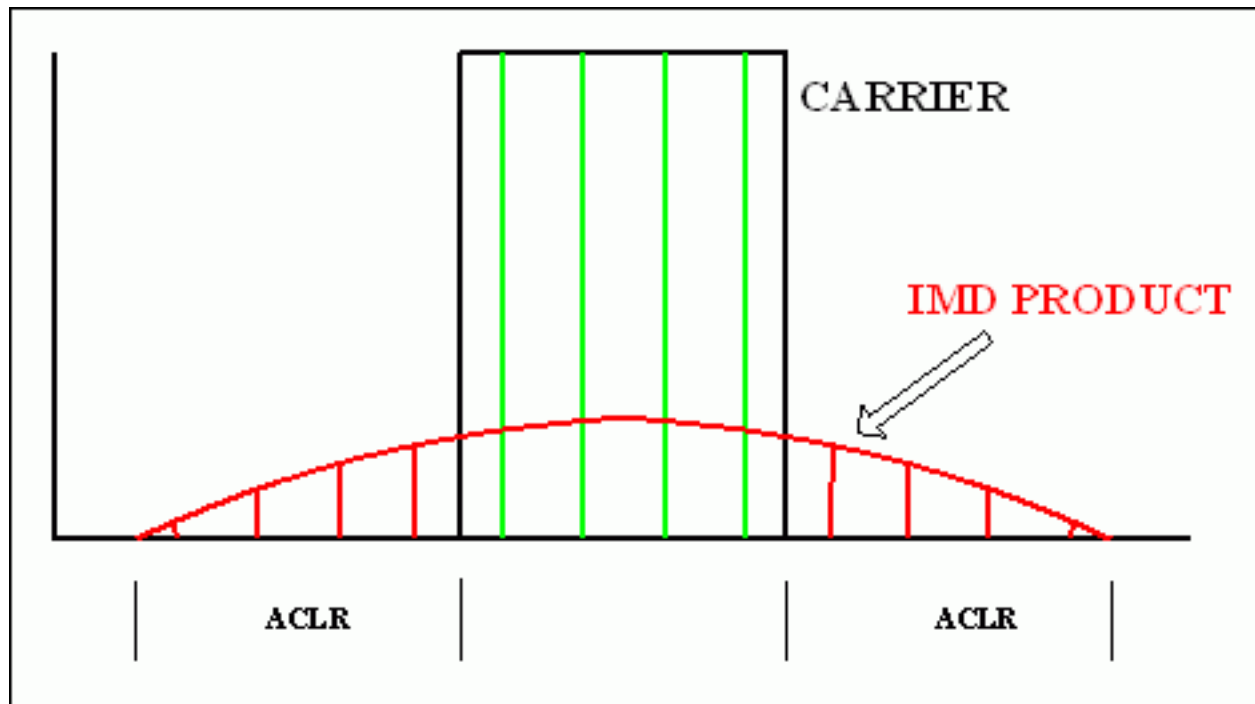


Figure 1. Subcarrier model of a broadband carrier signal.

The green lines in **Figure 1** are called subcarriers 1, 2, 3, and 4 from left to right. If we look at just the two subcarriers on the left (1 and 2), we can consider the 3rd-order IMD products that would result from any IMD3 distortion in the RF device. This 3rd-order distortion would manifest itself as low level subcarriers on either side of the two subcarriers themselves. The first "red" distortion product to the left of the two "green" subcarriers is the result of the IMD3 distortion from these two subcarriers.

The IMD3 component from subcarriers 1 and 3 has an IMD3 distortion product at an equal frequency spacing from carrier 1. This generates the second "red" IM product to the left of the carrier spectrum. Similarly, the

IMD3 from subcarriers 1 and 4 produces a distortion product farther out from the carrier edge.

It is useful to note that there also are other IMD products present here. Subcarriers 2 and 4 produce IM3 products, which fall directly on top of the IMD product from subcarriers 1 and 2. This summation effect forces the IMD products closer to the edge of the RF carrier to be higher in magnitude than those IMD products farther away from the edge of the RF carrier, producing the characteristic "shoulders" that appear in an ACLR distortion spectrum. A paper by Leffel¹ details this summation of IMD products from multiple subcarriers.

This approach can be quantified to predict the actual levels of the individual IMD3 distortion products. The model can also be extended by increasing the number of individual subcarriers used in the model, which helps increase its accuracy.² The ACLR performance of multiple wideband carriers look much like the ACLR from this model, where each individual wideband carrier occupies a fraction of the total wideband carrier bandwidth. The ACLR for a carrier adjacent to the last carrier in the contiguous collection of wideband carriers rides on the high shoulders of the IMD3-induced distortion response. This causes the ACLR for a multicarrier case to be considerably worse than that for a single-carrier system. Again, this effect can be quantified and used to accurately predict the ACLR performance of single or multiple wideband carriers. This basic approach is used to predict the ACLR performance RF devices from the OIP3 specification alone.

Basic Relationships

The relationship between the 3rd-order intermodulation products of a device and the 3rd-order intercept point of that device is as follows:

$$\text{IMD3} = (3 \times P_m) - (2 \times \text{OIP3})$$

where:

P_m = Power per tone in a two-tone test case

IMD3 = 3rd-order IM3 in dBm, in absolute power

OIP3 = 3rd-order intercept point, in absolute power

For convenience, this formula can be rewritten as relative IMD3, which is the IM3 performance relative to the power level (P).

$$\text{IMD3} = 2 \times (P_m - \text{OIP3})$$

where:

P_m = Power per tone in a two-tone test case

IMD3 = 3rd-order IM3 in dBc, in relative power

OIP3 = 3rd-order intercept point, in absolute power

Example 1

Consider a PA with a total output power (P_{tot}) of +30dBm, and OIP3 of +45dBm. The relative IMD3 of such a PA can be derived by use of the above formula. However, the output power of each of the two tones in the IM3 test case would be 3dB lower than the total output power of the PA, or +27dBm each tone. We therefore use these values for computing the IMD3 for this PA:

$P_{tot} = +30\text{dBm}$ for total PA

$P_m = (+30\text{dBm} - 3\text{dB}) = +27\text{dBm}$ per tone

OIP3 = +45dBm

$$\text{IMD3} = 2 \times (27 - 45) = -36\text{dBc}$$

ACLR Relationships to IMD3

The ACLR of a wideband carrier can be related to the two-tone IMD3 performance by a correction factor. This correction is due to the fact that the ACLR performance is degraded by the IMD3 performance. This degradation is itself due to the effects of the various intermodulation products that form from the spectral density of the spread-spectrum carrier. A useful relationship for ACLR to IMD3 is as follows:

$$\text{ACLR}_n = \text{IMD3} + C_n$$

where C_n is from the following table:

No. of Carriers	1	2	3	4	9
Correction C_n (dB)	+3	+9	+11	+12	+13

We can now combine the above relationships for IMD3 and ACLR_n into one unified expression to derive the ACLR for a number of spread-spectrum carriers from the basic performance parameters of the RF device.

$$\text{ACLR}_n = (2 \times [(P - 3) - (\text{OIP3})]) + (C_n)$$

where:

P_{tot} = total output power for all carriers, in dBm

OIP3 = OIP3 of the device, in dBm

ACLR_n = ACLR for "n" carriers, in dBc

C_n = value from the above table

Example 2

Let us repeat our numeric example, now assuming that the power amplifier must generate four carriers of 250mW each, for 1W total output power.

P per carrier = +24dBm

P_{tot} = +30dBm total

OIP3 = +45dBm

$$\text{ACLR}_n = 2 \times ((30 - 3) - (45)) + 12$$

$$\text{ACLR}_n = -36\text{dBc} + 12\text{dB}$$

$$\text{ACLR}_n = -24\text{dBc}$$

The formula can be rearranged to derive the OIP3 requirements for a desired ACLR. The rewritten formula then becomes as follows:

$$\text{OIP3} = 0.5 \times ([2 \times (P - 3)] - [\text{ACLR}_n] + [C_n])$$

where:

P = total output power for all carriers, in dBm

OIP3 = OIP3 of the device, in dBm

ACLR_n = ACLR for "n" carriers, in dBc

C_n = value from the above table

Example 3

Let us repeat our example, now with a four-carrier ACLR target of -50dBc for this power amplifier.

P per carrier = +24dBm

$P_{\text{tot}} = +30\text{dBm}$ total

$\text{ACLR}_n = -50\text{dBc}$

$\text{OIP3} = 0.5 \times ([2 \times (30 - 3)] - [-45] + [12])$

$\text{OIP3} = +55.5\text{dBm}$

Conclusion

The relationship between carrier power level, OIP3 specification, and single-/multicarrier ACLR performance has been derived for a general RF device. This relationship holds for RF devices whose performance is dominated by 3rd-order distortion products. This includes many common RF devices, when not driven too close to their saturation level. The accuracy of the model has been observed to be approximately $\pm 2\text{dB}$ for ACLR prediction.

References

1. Michael Leffel, "Intermodulation Distortion in a Multi-signal Environment," *RF Design Magazine*, June 1995, pp. 78-84.
2. Nuno Borges Carvalho and Jose Carlos Pedro, "Compact Formulas to Relate ACPR and NPR to Two-Tone IMR and IPE," *Microwave Journal*, December 1999, pp. 70-84.

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