Communications & Power Industries
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UNDERSTANDING THE LANGUAGE OF INTERMODULATION SPECIFICATIONS IN HPA DATA SHEETS

High power amplifiers (HPAs) are a critical component in the uplink earth station RF chain and are generally the most expensive components, after antennas, in that chain. For this reason, integrators or users in the market for HPAs must take great care to ensure that like-for-like comparisons are made when evaluating HPAs.

Typically, linear output power and power consumption are two of the most important specifications for HPA comparison in the industry. The comparison of linear power is not which amplifier provides more of it --- rather it is the point from which a valid comparison can be made. A diligent consumer might think it obvious, therefore, to simply collect different manufacturers' data sheets on HPAs that meet the link budget's linear power requirement and then make a comparison of each manufacturer's key specifications, such as power consumption, weight, heat loss, size, other features, and price. However, this comparison is much easier said than done.

Unfortunately, comparing "linear power" is not that straightforward, even with data sheets (some might say *especially* with data sheets!). The reason stems from the different methods used to measure linearity that developed first in private industry and then in the U.S. military. In the 1960s, engineers were concerned with linearity in the radio broadcast industry and used a method of measuring against a single carrier in an equal two-carrier setup. As standards for the satellite industry developed, this method naturally extended to evaluating uplink traveling wave tube and klystron amplifiers; in fact, this method of measuring linearity continues to be used to this day. In the past, industry data sheets have typically stated this method of measurement as:

> "-23 dBc or better with two equal carriers at total output power 7 dB below rated single-carrier output."
> *Anywhere from -18 dBc to -28 dBc is typically provided as the testing point, and the actual power in watts or dBm is often used in place of how much backoff is required.*

Over time, separate military standards were also developed and then formalized in 1989. The United States specification standard MIL-STD-188-164 has historically defined linearity as meeting both a spectral regrowth and an intermodulation requirement. The intermodulation requirement is as follows:

> "The maximum combined transmit power of two equal amplitude continuous wave (CW) carriers, when the third order intermodulation product power is -25 dB relative to the combined power of the two CW carriers."

The spectral regrowth specification is as follows:

> "The single carrier maximum-linear power equals the carrier power when the power spectral density in the modulated carrier sidelobes, 1.5 times symbol rate removed from the carrier center frequency, is -30 decibel (dB) relative to the power spectral density at the carrier center frequency."

The military standard for intermodulation in the United States is measured against the sum of two carriers, rather than against a single carrier. Thus, the military and commercial comparisons are

different: the same amplifier that meets -25 dBc at a certain power level with regard to two carriers (the military method) typically only meets -22 dBc with regard to either of two equal carriers (the commercial method). In order for this amplifier to meet -25 dBc with regard to each of two carriers, output power would have to be lowered about 1.5 dB, since there is roughly a 1:2 ratio of increase in power versus increase in intermodulation products.

Coincidentally, in the late 1980s and early 1990s, solid state HPA (SSPA) manufacturers had also started to introduce HPAs to compete against the already-established TWTAs. Since early SSPAs could not compete with TWTAs for total output power, and because SSPA manufacturers identified the U.S. military as a major potential market, SSPA manufacturers tended to adapt the military intermodulation standard. SSPA data sheets typically stated intermodulation as follows:

> "-25 dBc or better at 3 dB output backoff from P1dB with two carriers"

Some SSPA manufacturers then began to claim that linear power was achieved in their products at a much higher output power level than TWTAs could provide. This claim was technically correct, but also a bit misleading. For instance, a 400 W TWTA provides 350 W of CW output power at the flange (55.44 dBm). Using the traditional commercial method of stating intermodulation, this amplifier meets the -23 dBc threshold for output linearity at 78 watts. SSPA manufacturers could point to this measurement and claim that their 200 watt (Psat) amplifier achieves linear power at 78 watts. But in fact, this TWTA produces 95 watts of linear power when using the military method of measuring intermodulation, and 190 watts of linear power with another technological advancement, the TWTA linearizer.

Fortunately, both TWTA and SSPA manufacturers have begun to make themselves more consistent and clear in what their linear output power measurements mean. Although some SSPA manufacturers simply state that their products conform to MIL-STD-188-164B at a given level of output power, others do spell it out more clearly:

> "PLINEAR is the power at which the IMD=-25 dBc for two CW signals 5 MHz apart and the spectral regrowth is <-30 dBc @ 1.0 x symbol rate for a single QPSK/OQPSK/8PSK signal"

In theory, this is quite straightforward. For practical purposes, however, it is really just a spectral regrowth measurement at -30 dBc, since the spectral regrowth value is almost always more difficult to meet than the -25 dBc intermodulation specification. Thus, the diligent consumer has to go through an extra calculation to figure out at what power the HPA achieves linear power in terms of intermodulation products. Typically, he or she can estimate the power level simply by either adding 0.5 dB to this number to achieve linearity when defined, as with regard to the sum of two carriers, or decreasing output power by 1 dB to achieve linearity with regard to of two carriers.

TABLE 1 – HPA DATA SHEET: WHAT IT SAYS, WHAT IT MEANS, AND WHAT YOU NEED TO DO

WHAT IT SAYS	WHAT IT MEANS	WHAT YOU NEED TO DO
100 W Plin, meets spectral regrowth (SR) -30 dBc and -25 dBc for two CW signals 5 MHz apart.	Meets the MIL-STD-188-164 SR spec at 100 W, but does not provide a precise output power for the intermod spec because it is typically less stringent for these products.	Add 0.5 dB to find the typical output power with regard to the sum of 2 carriers (112 W), or subtract 1 dB to find the typical output power with regard to each of two equal carriers (78 W)
Intermods: meets -25 dBc at 100 watts with regard to each of two equal carriers	This HPA is using the more stringent commercial measurement	Add 1.5 dB to linear power to compare with HPAs using the military method (141 watts), or subtract dBc by 3 dB (-28 dBc at 100 watts).
Intermods: meets -25 dBc at 100 watts with regard to the sum of two carriers	This HPA uses the less stringent military measurement.	Deduct 0.5 dB to estimate spectral regrowth (89 watts), or 1.5 dB to estimate output power using the commercial method (71 watts)
Intermods: meets -23 dBc at 4 dB backoff, with regard to each of two carriers, from rated output power.	This amplifier is likely a TWTA, and has a linearizer. -23 dBc is used as the measurement point, and you have to adjust it to make a like for like comparison if you want to compare it to an amplifier measured at -25 dBc.	First, figure out what 4 dB backoff is. If this is a 225 watt amplifier which makes 53 dBm (200 watts) at the flange, 4 dB backoff from there is 49 dBm (79 watts). To get to the military intermod spec, add 1.5 dB (50.5 dBm, or 112 watts) and then deduct 1 dB to compare at -25 dBc (89 watts) --- the rule is to subtract 1 dB of power for each 2 dB reduction in dBc, so changing the test point from -23 dBc to -25 dBc requires a 1 dB power reduction
100 watts at -25 dBc with two equal carriers	Vague – does not mention which method is used to calculate intermod	Contact manufacturer to explain.
-25 dBc two signal 5 MHz apart at 100 watts relative to total power	Probably uses the military calculation (sum of 2 carriers), but not certain	Contact manufacturer to be certain.

Disclaimer: The figures and calculations used here are general rules of thumb, and characteristics may change from HPA to HPA. Contact the manufacturer for detailed explanations, and for numbers that are based on actual test data. Most manufacturers can also provide spectral regrowth numbers based on test data, and many can also provide the noise power ratio (NPR) for their amplifiers.

If you are in the market for an uplink TWTA, SSPA or klystron amplifier, contact a CPI expert today <link to www.cpii.com/satcomsales> and we'll be happy to help you with any questions you might have.