SATCOM For Net-Centric Warfare — February 2013

MilsatMagazine

Military Communications

Wideband Global SATCOM artistic rendering, courtesy of United States Strategic Command

The introduction of Ka-band satellite communications (SATCOM) has changed MILSATCOM forever—and influenced commercial SATCOM as well! A major ground system component that has been dramatically affected by the advent of Ka-band is the *high power amplifier* (HPA).

Photo of SATCOM-On-The-Move (SOTM) product. Courtesy of Boeing Defence Australia.

Some of the key changes in HPA requirements due to the introduction of Ka-band include: the necessity of locating the transmit amplifier even closer to the feed; transitioning from multi-band capability in a single amplifier to use of separate, interchangeable amplifiers for each band; and the move to making linear output power the key amplifier requirement.

With MILSATCOM frequencies in X-band, the loss encountered in the waveguide runs from a transmit amplifier located a few feet from the feed, or even farther, could be accommodated in typical link budgets without too much difficulty. The commercial C-band SATCOM band has similar low waveguide loss. *Figure 1* shows the loss in dB/meter of straight waveguide at each transmit band frequency for X-, Ku- and Ka-bands.

As the military transitions to using large amounts of commercial Ku-band SATCOM capacity, a drive was initiated to place the transmit amplifier closer to the antenna feed, as the Ku-band waveguide loss is 1.7x the loss at X-band. Moving to Ka-band increases the waveguide loss of any runs to the feed by a factor of 6, and the cost/watt of Ka-band RF power is also higher. This has meant that system integrators have been under great pressure to put the Ka-band HPAs as close to the feed as possible, often complicating other system aspects to make such happen.

In order to move the Ka-band HPAs close to the feed, amplifier size, weight, and power consumption have all had to be dramatically reduced. The HPA weight can be critical in allowing the antenna to meet tighter pointing requirements at Ka-band, and many mounting configurations demand small HPA size to reduce or eliminate blockage.

This has been accomplished with a range of technology and design adjustments, resulting in higher power available from smaller units in the band than ever before possible. An example of this is the reduction in SWP made when transitioning from a standard size 250W rated Ka-band HPA, which provided about 100W of linear power for fixed Earth station applications, to a compact, ruggedized, HPA that is suitable for transportable *on-the-halt* (**OTH**) terminals while providing 110W of linear power at Ka-band over the challenging environment seen by these terminals.

Figure 2 shows that similar linear power provided by the 48lb. fixed Earth station unit can now be provided by the much smaller 30lb. transportable unit without surrendering any capability. An additional factor at Ka-band is that, due to the higher waveguide losses, the upconverter can no longer be located remotely from the amplifier, even for larger systems. This means that all Ka-band HPAs come with the option of including the upconverter inside the unit—almost all military applications do so.

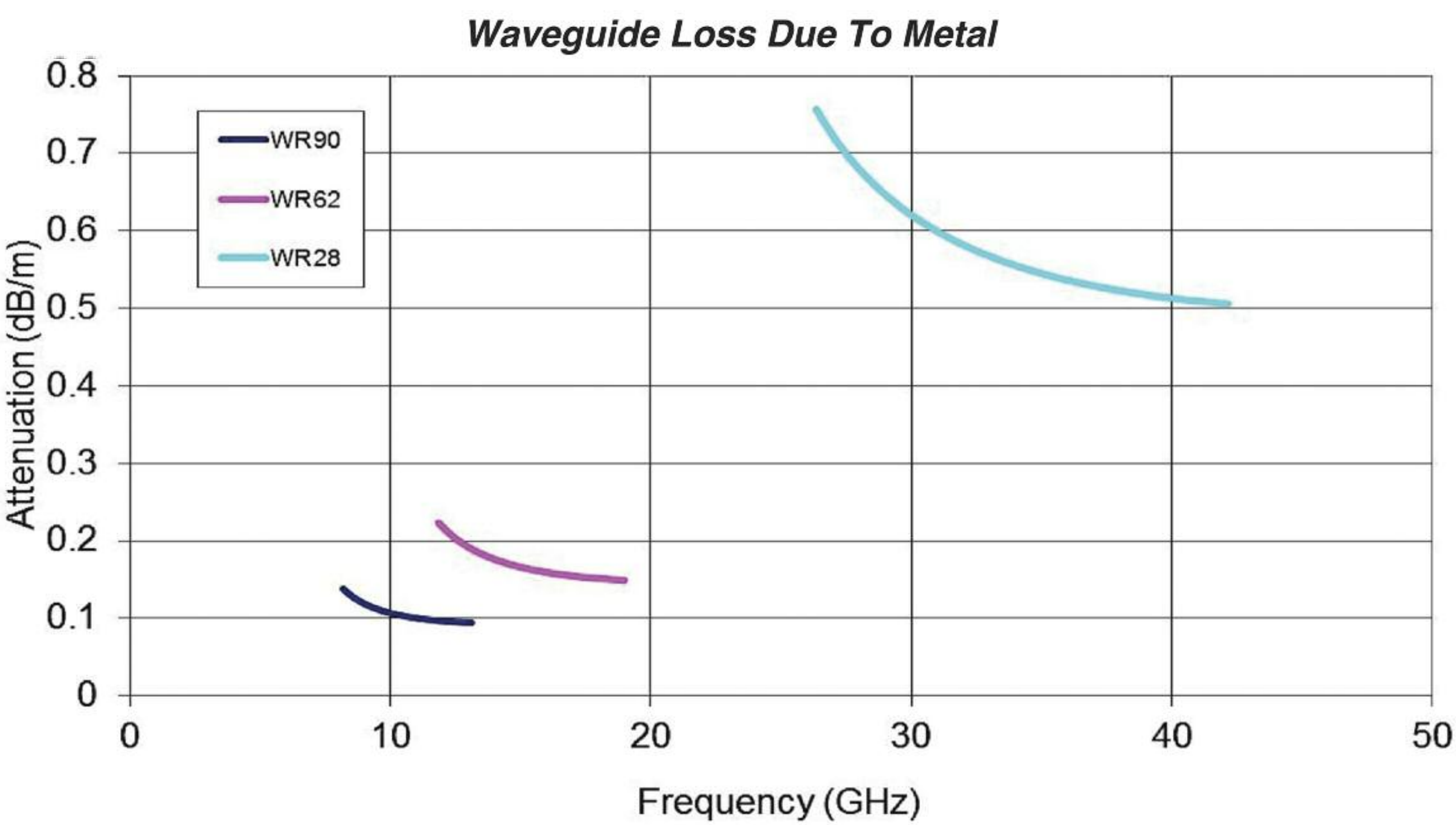


Figure 1. Waveguide Loss at Standard SATCOM Frequency Bands — Source: Microwaves101.com

	250W HPA	110W linear HPA	% Change
Linear Power:	100 W	110 W	+10 %
Volume:	1948 cu in	1146 cu in	- 41 %
Weight:	48 lbs	30 lbs	- 37 %
Prime Power:	800 VA typ	850 VA typ	+ 6 %
Linear Power Density:	0.051 W/cu in	0.096 W/cu in	+ 88 %

Figure 2. Smaller, Rugged Ka-Band HPAs Enable Mounting at the Feed

The wide frequency gap between Ku- and Ka-band makes it prohibitive to build an amplifier that can cover both bands, much less one that includes X-band. The result is that multi-band terminals that used to include a tri-band C-, X- and Ku-band transmit amplifier must now take another approach.

Some existing terminals have opted to retain the older tri-band HPA and add a Ka-band one to be switched in as needed for Ka- operation. However, many newer terminals, especially smaller, tactical terminals, have incorporated a modular band switching capability that allows the user to reconfigure for a different band in the field.

Examples of this type of terminal are shown in *Figure 3*; the terminal can be configured for X-, Ku- or Ka-band by simply removing the feed, BUC and HPA (a single feed-boom assembly) and installing one of a different band. This approach is, again, made possible by smaller and lighter transmit amplifiers that mount on the feed boom.

Figure 3. Modular Frequency Band Switchable Terminals. Source: http://www.globalcoms.com/Hawkeye_III.asp

Traditionally, transmit amplifiers have been specified by their highest guaranteed output RF power, either as a saturated power or a 1dB compressed power (see *Figure 4*). Communication systems don't generally operate the HPAs at these power levels, as the distortion caused by the non-linearities of the amplifier at those levels would create too much interference, either in-band or out-of-band for low error rate performance.

Most amplifier specifications also included one or more linearity requirements. These could be specified in varying ways and applied at a reduced or "*backed-off*" power level relative to the rated power. The *backed-off-from-rated power level* necessary to meet the linearity or distortion requirements and ensure that it is not interfering with transmission of in-band or out-of-band signals over the satellite is called the linear output power (again, *Figure 4*).

In the past, most HPAs were specified and procured according to the "rated" or highest guaranteed output power. With the ***WGS*** (**Wideband Global SATCOM**) emphasis on specifying linear power, the "rated" power (either saturated or P1dB) is not specified at all as it is irrelevant. Only the linear power at which the amplifier will actually operate is of interest.

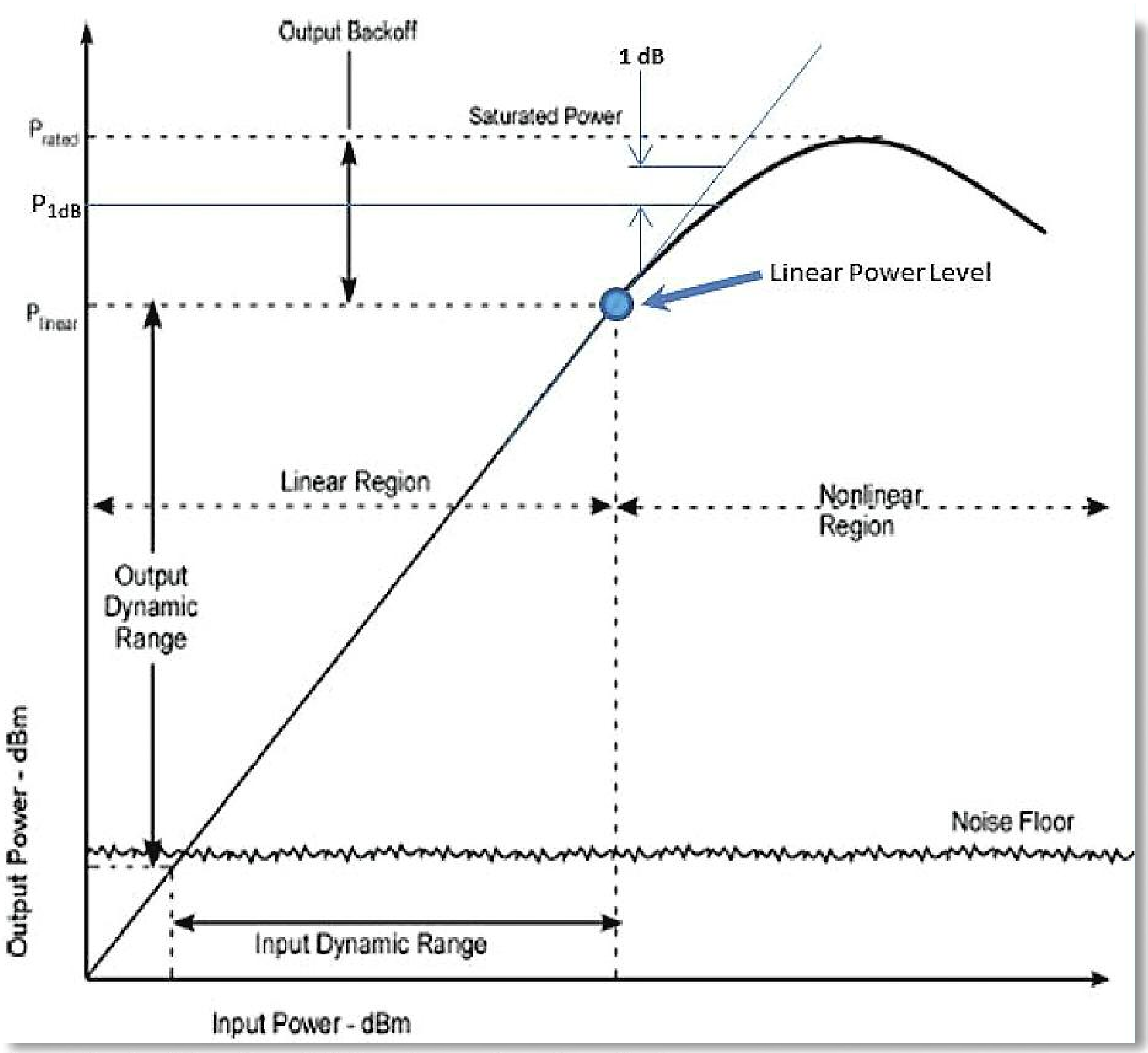


Figure 4. Rated and Linear Power Definitions Shown on Power Saturation Curve

Linear power can be different for the same amplifier if the linearity requirements are different, so it becomes critical to define linearity appropriately for the terminal and its application. Traditional amplifier linearity requirements have generally focused on *third order intermodulation* (**IM3**) products, however, for single-carrier terminals, the user does not create any intermodulation products. For single-carrier terminals, *spectral regrowth* is a better indicator of the operational linear power available.

Spectral regrowth (see *Figure 5a*) is an indicator of how much of a modulated signal's power will fall out of band and interfere in the adjacent band due to the HPA's nonlinearities. Power is typically measured relative to the in-band modulated carrier power at one symbol rate from the carrier frequency using the system's planned modulation format (*i.e.*, **QPSK**, **OQPSK**, and so on).

For systems with two or more carriers, intermodulation products—or IMs (see *Figure 5b*)—provide a good indication of the level of interference with other links using nearby frequency channels due to the interaction of the multiple carriers through the amplifier. The IMs are measured by passing two equal-powered unmodulated carriers through the HPA and measuring their output along with the levels of the mixing products created by the non-linearities in the amplifier.

In industry, these have been traditionally measured relative to the power level of a single carrier, but with ***WGS***, they are measured relative to the sum of the power of the two carriers.

A third approach to determining linear output power applies if there are many carriers, such as is often the case with hubs or teleports. In these cases, the *noise power ratio* (or **NPR**) can be used to indicate the level of distortion introduced in the channels transmitting the other carriers (see *Figure 5c*).

For this test, white noise with a large notch (typically 40dB deep) cut out of the white noise spectrum is injected into the amplifier and the output measurement shows how much distortion falls back in the notch due to the non-linearities of the HPA. *Figure 5* shows typical specification values for each of these parameters.

As transmit amplifiers cannot perform with excellent linearity all the way up to the maximum output power, communications engineers came up with the idea of accomplishing the opposite in gain and phase of what the amplifier does to the signal, so that at the output of the HPA it is much flatter in both gain and phase response. This is called a *pre-distortion linearizer*; *Figure 6a* shows an idealized gain and phase response of a TWTA and an SSPA without and with pre-distortion.

Figure 6b shows the improved power saturation curve of a linearized TWTA; the predistortion actually shifts the curve as well as the maximum location on the curve at which linear operation is achieved. SSPAs at lower frequencies typically do not require linearization as they can operate fairly close to saturation (within 3dB) while meeting key linearity specifications.

However, at Ka-band most of the high power chips available for use in power combined HPAs do not have as good of linearity as those at Ku-band and below, making linearization of SSPAs a real option. Linearizers have played a key role in achieving the power levels needed for military

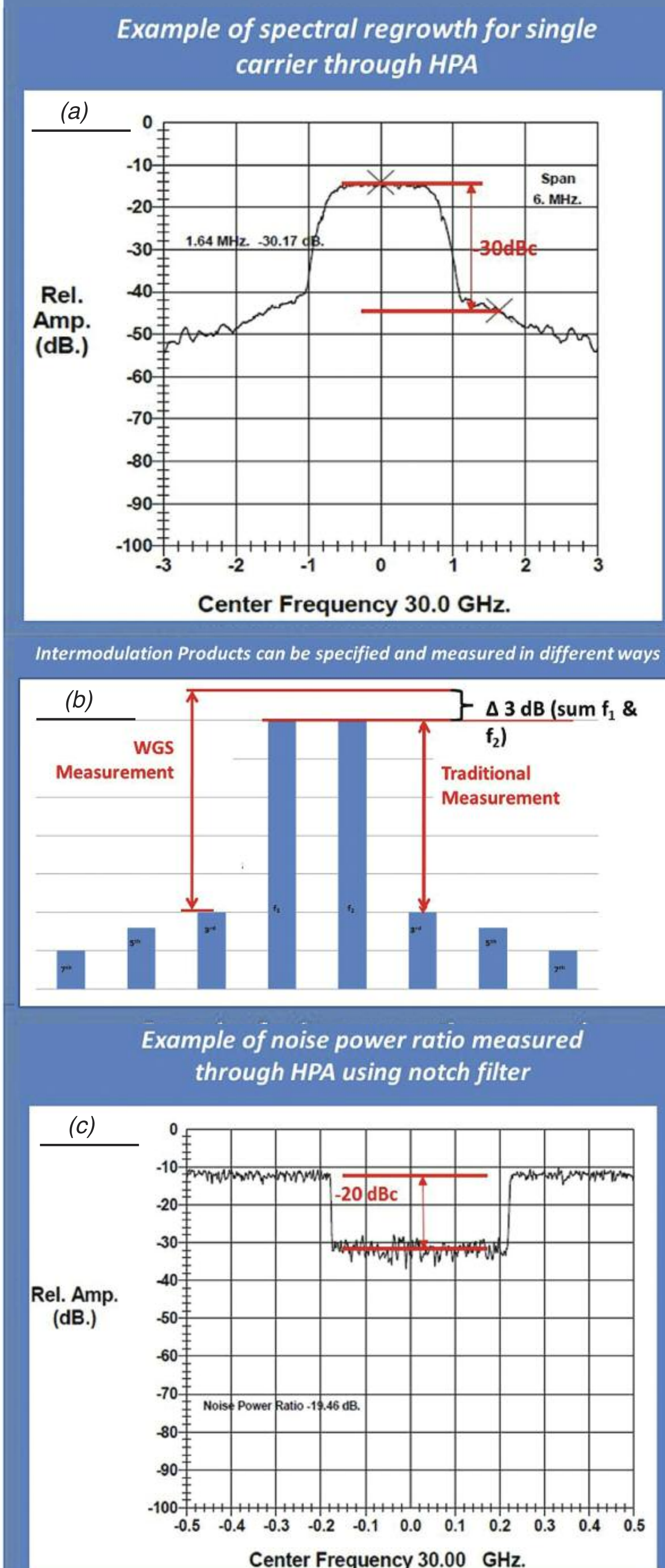
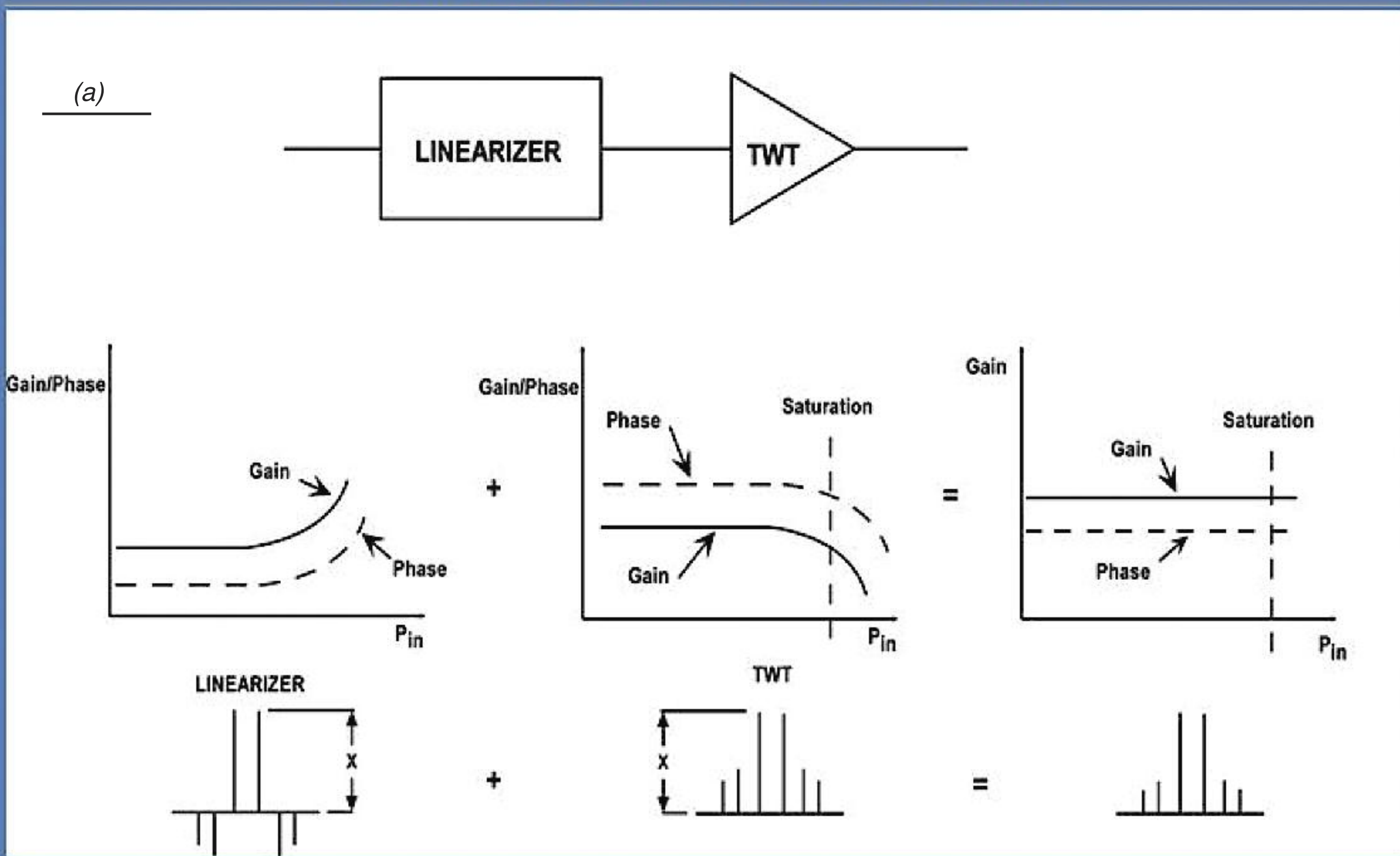


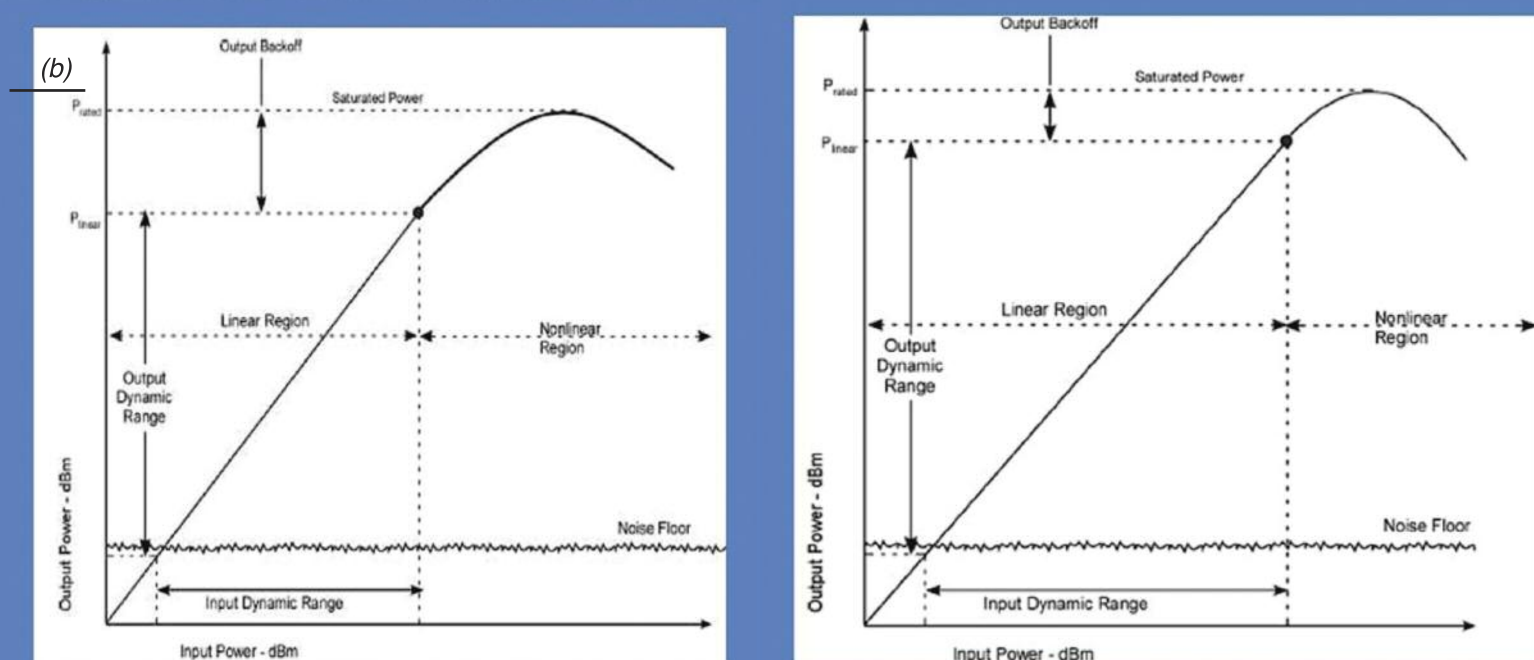
Figure 5. Linearity Can Be Specified, Based On Spectral Regrowth, Intermodulcation Products, Or Noise Ratio

Pre-distortion of Gain and Phase for a TWTA



Power saturation curve for unlinearized TWTA

Power saturation curve for linearized TWTA



Improvement of ~3dB in Linear Power is Typical for TWTAs with Predistortion

Figure 6. Pre-distortion Linearization Flattens Gain and Responses and Shifts the Gain Cuirve to Provide Higher Linear Power

Ka-band systems; while there is a cost for linearizers, it is almost always worth it at Ka-band.

With linear power as the key specification, being able to operate up to saturation becomes unnecessary for many communication systems, and not even allowed over ***WGS***. The output power can be limited in the amplifier design to just above the linear power, typically around 3dB below the rated power of the equivalent full power or "*CW*" tube.

In TWTAs this is called a *peak TWTA* and it allows the collector depression ratios of the traveling wave tube itself to be optimized for better efficiency over the lower total operational power range. The resulting higher efficiency and reduced power dissipation, along with the smaller power supply that only has to power the tube up to the linear power level, allow for safely reducing the heat sink size and mass.

The result is a smaller, lighter, more efficient and, yes, less expensive, TWTA. The resulting amplifier has the same RF performance characteristics as the CW TWTA, up to the point at which the power limits. *Figure 7a* shows the power saturation curves for a 400W Ku-band CW TWTA and a corresponding 400W Ku-band Peak TWTA. The plots are nearly identical, but a comparison of the two units (see *Figure 7b*) illustrates the dramatic reductions possible in size, weight and power draw.

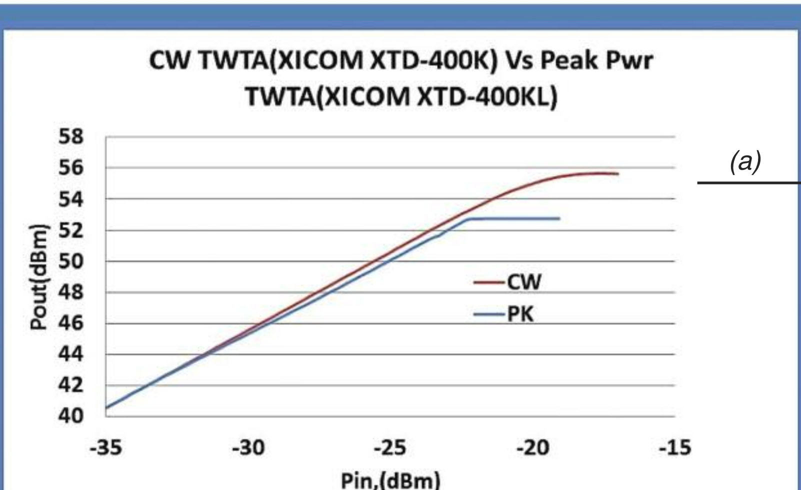
With the continued announcement of additional ***WGS*** satellites, it is clear that Ka-band MILSATCOM will be a requirement for a long period of time and will continue to drive development of new and innovative ground system solutions. The changes already occurring to the HPAs have made a significant and lasting impact on how transmit amplifiers are specified, integrated, and used for Ka-band MILSATCOM as well as in the commercial SATCOM industry.

Where they are located, what size and weight they must be, and how their linearity and linear power are specified and measured have been affected … this leave us to wonder what may be next? Commercial Ka-band has many variations, and military terminals may need to have dual-band (commercial and WGS) capability in a single package.

Incorporating more functionality into the transmit amplifier package, similar to transceivers in the past could buy some additional size and weight savings to further improve pointing. We do know that ***WGS*** Ka-band and MILSATCOM will be leading the way.

About the Author

Heidi Thelander is Director of Business Development at Comtech Xicom Technology, Inc. addressing a wide range of opportunities for the premier high power amplifier supplier in the satcom industry. Heidi has over 20 years experience in the satcom industry including satellite payload and ground-system design, program management, and new business development roles. She joined Xicom from Wavestream Corporation where she was instrumental in developing and promoting their high power Ka-band SSPA product line. Other past roles include product management and marketing for optical networking start-up Centerpoint, business development for Lockheed Martin's Western Development Labs, and a full range of engineering, management and business development positions at TRW Space & Electronics Group (now part of Northrop Grumman). Heidi has her BSEE from Marquette University and MSEE in Communication Systems from University of Southern California.



(a)

(b)

Comparison of CW and Peak Power TWTAs

Size:	10.25" x 11" x 20.5"	8.5" x 8.6" x 15.75"
Volume:	2311 cu in	1151 cu in
Weight:	55 lbs	32 lbs
Prime power:	1400 VA typical	850 VA typical

Figure 7. Peak and CW TWTAs Have Nearly Identical RF Performance—and Peak TWTAs Can Be Far Smaller and Lighter