



Understanding power linearity and its importance in amplifier specification for satellite uplinks

Transmitting clear, strong and undistorted communications signals from the ground to orbiting satellites requires amplifiers with high power output, and excellent linearity. Specifying the right amplifiers for demanding, multi-channel satellite uplink applications requires an understanding of power saturation, power linearity and compression and how this affects digitally modulated signals.

In this white paper, we explore power linearity in high-power satcom applications, how it is measured and how it is delivered by the two main amplifier technologies: travelling wave tubes and solid-state power amplifiers.

Power linearity is critical in satellite communications because it determines the ability of an amplifier to increase the signal level without creating distortion. Linearity can be described as the degree to which an amplifier's output is an accurate, undistorted representation of its input signal. The power linearity (P_{lin}) of an amplifier is different to its power saturation (P_{sat}), which is the maximum power output the amplifier can produce. At the saturation point, linearity is severely compromised and output signals are highly distorted.

Why linearity matters for satcom signal amplifiers

With digital signal modulation, it's vital to keep signals as linear as possible throughout the transmission chain, for both the uplink and downlink to and from the satellites. That means ensuring amplifiers or any other devices in the chain are not operated under compression. To avoid compressing signals, amplifiers must be operated at a level below their power saturation point (backed off) so that linearity is maintained and signals are not distorted.

Assessing the power linearity (P_{lin}) of amplifiers is not always straightforward, given that the stated power rating for amplifiers usually relates to saturated power (P_{sat}). While P_{sat} is an important specification, a more practical measure of useable power is often the P_{1dB} point, where gain drops by 1dB from its constant value and signals are more linear and less distorted. This is the point that marks the boundary between an amplifier's linear and non-linear operational regions.

The extent to which power needs to be backed off from the saturation point to achieve linearity differs between the two main amplifier technologies – travelling wave tube amplifiers (TWTAs) and solid-state power amplifiers (SSPAs). We'll explore these differences later, but first it's useful to understand the different ways power linearity is calculated for amplifiers handling multiple signals, to help specifiers make well-informed, like-for-like comparisons when reviewing amplifier capabilities.



FILTRONiC

Useful definitions

Power saturation (P_{sat}) is the maximum power output of an amplifier. It is the point at which the amplifier is saturated and can no longer increase its output power, even if the input power is further increased.

P1dB is the compression point of an amplifier at which its output power is 1dB less than it would be under ideal linear conditions. It's a specification that indicates the upper limit of an amplifier's linear operating range, where the gain begins to compress and the output power no longer increases in direct proportion to the input power.

Power linearity (P_{lin}) is the ability of an amplifier to increase the power of a signal without distortion. A perfectly linear amplifier will increase the power of the output signal in direct proportion to the input power. If there is just one signal (or carrier) within an amplifier, the maximum power linearity can be the same as P1dB. However, for amplifiers handling signals from multiple carriers, power linearity can be defined in three different ways: spectral regrowth, 3rd order intermodulation (IM3) or noise power ratio (NPR).

How to measure power linearity (P_{lin}) for satellite communications

For satellite communications, specifiers need to understand the differences between saturated power and linear power, and the relationship between linear power and P1dB to ensure the most appropriate amplifier technology is chosen. For amplifiers carrying multiple signals, there are three different ways to measure power linearity:

1. Single modulated carrier – spectral regrowth

This method of defining linearity is typically used for a digitally modulated single carrier being transmitted through a high-power amplifier (HPA). This definition is commonly used when multiple transmitters from different sources are transmitting to the same satellite, with each transmission having a defined bandwidth in which to operate. The aim is to prevent interference in adjacent channels. Outside of each defined bandwidth there is a maximum stated level at which the modulation energy (spectral regrowth) is observed. This is particularly visible for a QPSK carrier, but harder to see for higher order modulations.

Satellite operator Eutelsat established the original spectral regrowth specification, for situations where multiple carriers were sent to a satellite transponder split into 28 MHz wide (or narrower in some cases) channels for direct-to-home (DTH) broadcast TV. This specification stated that the out-of-channel modulation should be less than 26dBc. It meant that amplifiers had to be operated considerably below their power saturation point to meet the 26dBc linearity specification. Operating an amplifier beyond this level causes the spectral regrowth to be at a higher level in the adjacent channel, thereby causing interference.

Where there are no adjacent carriers, an amplifier can be operated above this P_{lin} level – typically to around the P1dB point, after which the signal tends to distort itself.

2. Two-tone or 3rd order intermodulation (IM3)



FILTRONiC

This is probably the most common method of specifying the power linearity of amplifiers marketed for satellite communications. It is typically specified where two or more carriers are being transmitted through an amplifier. It is directly related to the 3rd order intercept point of the amplifier. This intercept point is a mathematical concept and does not correspond to any practically occurring physical power level.

The specification required by most satellite operators is that the 3rd order intermodulations of two unmodulated tones of equal level spaced relatively close to each other (typically 10MHz spacing) should be no higher than 25dB below the level of those two unmodulated tones (or 28dB below the sum of the two tones).

3. Noise power ratio (NPR)

This method of quantifying amplifier linearity originated in the world of telecommunications. It tends to be used in satellite communications to define the required linearity of an uplink, or gateway, where the amplifier is transmitting a very wideband (typically 16-128APSK) carrier or multiple carriers of low level.

NPR is calculated as the ratio of the power in a wideband signal with a notched-out frequency band, to the power of the noise that fills that notch after the signal has passed through the amplifier. Essentially, a high NPR indicates better performance, as it means less noise has entered the notched-out frequency band due to non-linear distortion. Using this method, the Plin is typically specified as the power level at which 19dB NPR is achieved. It is usually a similar figure to the Plin level calculated using the two-tone method.

How does linearity vary between amplifier technologies?

A knowledge of these definitions of power linearity is helpful when it comes to assessing the performance of amplifiers for satellite applications. The calculation of power linearity and its relationship with power saturation is further complicated by the differences between TWTAs and SSPAs, their performance at different power and frequency levels, and the way power ratings are usually specified for these devices.

TWTAs were the original amplifier technology used in RF communications. They are well established, reliable and still widely used. TWTAs are structurally complex, vacuum-based electronic devices that are time-consuming and expensive to manufacture. The challenger technology is the SSPA. These semiconductor-based devices can be produced quickly and in high volumes, at dramatically lower cost than TWTAs.

Broadly speaking, SSPAs offer better power linearity than TWTAs. Tube-based amplifiers had traditionally been recognised as having excellent amplification qualities with very low distortion. But as the number or power of signals passing through amplifiers increased, TWTAs performed less reliably and needed to be backed off considerably from their power saturation point. SSPAs, by contrast, can be operated much closer to their power saturation point while maintaining linearity.

The first TWTAs operating in the satellite bands (C, Ku, Ka) needed to be backed off from their saturation point by around 7dB to achieve the required linearity. The first SSPAs, using gallium arsenide (GaAs) semiconductors, were inherently linear in operation and only



FILTRONIC

needed to be backed off from saturation point by 3dB. That meant they delivered a much better like-for-like linear performance than TWTAs.

Subsequently, linearisers were developed for use with TWTAs, which improved their linear performance and meant they only had to be backed off by 4dB or 5dB. Although this didn't quite match the linear performance of SSPAs, TWTAs remained the amplifier technology of choice for higher-power, higher-frequency operations due to their superior efficiency. GaAs amplifiers consume around three times as much power as TWTAs when used for high-power satellite communications. Consequently, SSPAs tended to be used primarily for lower power applications.

GaN levels up power efficiency for SSPAs

The advent of gallium nitride (GaN) semiconductors for SSPAs introduced more efficient and more reliable operation at higher frequencies. While GaAs SSPAs require low-voltage, high-current power supplies, GaN amplifiers require higher-voltage, lower-current supplies, and so offer improved efficiency and reliability.

However, unlike GaAs amplifiers, the first GaN amplifiers were not inherently linear. At a point well below power saturation, GaN-based amplifiers produced a deviation or 'kink' in the response between input power and output power, where an increase in input power did not correlate with a proportionate increase in output. This impaired linear operation and gave GaN amplifiers a shallower slope towards Psat, which meant they did not have a P1dB point. See figure 1 (green line).

That was until a new type of corrective lineariser was developed for GaN amplifiers which ironed out this 'kink' in power output. It enabled GaN amplifiers to produce very good linear performance. Since then, GaN amplifiers have been developed that have a maximum power linearity (measured by either the two-tone or NPR method) just 3dB below power saturation. See figure 1 (yellow line).

The result is that GaN high-power amplifiers have now become the first choice for satellite communication uplinks, since they combine efficiencies approaching those of TWTAs with significantly better linear performance. These amplifiers are now making inroads into the higher frequency bands where TWTAs had previously dominated, such as Ka, V and E-band.



FILTRONiC

GaAs P1dB and Equivalent GaN Gain Response Graph

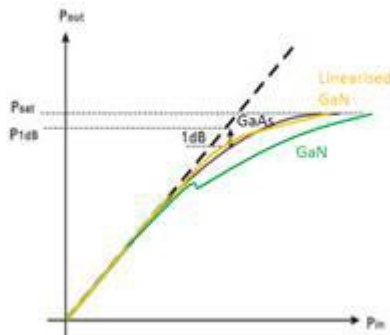


Figure 1: GaAs P1dB and equivalent GaN gain response

Ensure like-for-like comparisons between amplifiers

It's widely recognised that linearity is vital for digitally modulated signals. What is less well understood is that to achieve optimum linearity, amplifiers must be operated below their power saturation point, and often well below their 1dB compression point. This is particularly true for TWTAs, which cannot be used anywhere near their maximum power levels for communications applications.

Satcom specifiers need to be aware of which power level is being advertised on any amplifier and to understand the relationship between saturated power (P_{sat}) and useable 'linear' power (P_{lin}) for any amplifier – so that like-for-like comparisons can be made.

Many amplifier specifications refer to P_{sat} levels, and TWTA specifications traditionally describe the P_{sat} level of the tube within the device, not the final packaged device itself. The actual saturated output power of the fully packaged TWTA will be below the P_{sat} level of the tube within it. For example, a TWTA containing a tube with a P_{sat} of 200W would only have a saturated output power of around 150W when operating at high frequencies. To achieve linearity, this would have to be backed off further to around 50-60W.

By contrast, the saturated output power stated for SSPAs is the P_{sat} of the device as a whole, not any of its constituent parts. Furthermore, SSPAs require less 'back off' from P_{sat} to achieve linearity. So, an SSPA with a P_{sat} of 150W, for example, would have a maximum power linearity of at least 75W for high-frequency satellite communications.

It's also worth noting that amplifiers for lower-power applications in point-to-point terrestrial communications are marketed according to their linear operating power, and not power saturation.

Bringing clarity and new capabilities to satcom amplifiers

FILTRONIC

At Filtronic, to avoid misunderstandings, we are moving towards using power linearity (Plin) in the specification of our SSPAs. We believe that transmitters, amplifiers and other RF devices used in satellite communications should be marketed according to their useable linear power, which is the critical characteristic for undistorted signal transmission.

GaN has proved to be a game changer in delivering reliable power linearity at higher frequencies. Filtronic is at the leading edge of this push to develop GaN SSPAs for the satellite market, using our proprietary chip designs and proven expertise to develop SSPAs that are now displacing TWTA's at higher-power levels in the higher frequency bands such as Ka, V, E and even W band

As demand for more and faster data accelerates, so the deployment of satellite constellations and their enabling technologies needs to keep pace. Legacy TWTA technologies will not be able keep up. TWTA's are complex and time-consuming to manufacture, particularly at scale, and there are a limited number of TWTA manufacturers worldwide, resulting in long lead times.

The emergence of semiconductor-based SSPAs that can be manufactured consistently at scale and can now outperform TWTAs for efficiency and power linearity at higher frequencies, is a game changer. It gives satellite companies the chance to acquire the volume of amplifiers they need to expand satellite deployment in line with fast-growing global demand.

