



Wideband Global Satcom (WGS)
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Selecting a Ka-band Linear Amplifier for Wideband Global SATCOM

White Paper *Created November 2008*



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Selecting a Ka-band Linear Amplifier for Wideband Global SATCOM

Military Satcom network engineers need to consider non linear effects of transmissions where signal levels are low or multiple carriers occupy a narrow bandwidth. Non linear characteristics of some Ka-band amplifiers behaviour differently to Ku-band and X-band amplifiers, and therefore there is a need to carefully measure the performance of Ka-band amplifiers when selecting for use on Wideband Global SATCOM (WGS).

This Paper discusses the importance of linearity in SATCOM amplifiers by addressing:

1. *Why Amplifier Linearity is Important,*
2. *How Linearity is Defined for FET Technology,*
3. *How Linearity is Defined for MMIC Technology,*
4. *Measuring Linear Power of MMICs,*
5. *Using a Lineariser with MMIC Technology, and*
6. *Measuring Linear Power where a Lineariser is used*

1. Why Amplifier Linearity is Important?

Ideally the amplifier output signal should be identical to the input signal. However the signal amplitude will be larger, and there is a time delay due to time taken for the signal to travel through the physical length of the amplifier. An amplifier that behaves in this way, or to a very good approximation, is referred to as a linear amplifier.

In practice all amplifiers will exhibit some deviation from this ideal linear response and the extent of this deviation, which usually increases as the output power level approaches the maximum power available, determines the non linearity of the amplifier.

If the signal is a pure tone, that is a single frequency, then the non linear distortion can be determined from the power levels in the second and higher order harmonics. In the frequency domain, the power in these harmonics is the main manifestation of the amplifier non linearity. If the signal is a modulated one, then the non linearity will be seen not only as harmonics, but also as amplitude and phase distortion of the modulated signal. This is due to the power appearing at other frequencies outside the spectral bandwidth of the input modulated signal.

With digital signals, the amplifier non linearity degrades the Bit Error Rate (BER) of the signal and adds noise into other channels so degrading the BER of other signals. Consequently, it is necessary to set specifications for non linear behaviour to guarantee the BER performance of the wanted signal and to avoid degrading the performance of other signals.

2. How Linearity is Defined for FET Technology

There are a number of ways to specify the non linear behaviour of an amplifier and over time a number of short hand parameters have been adopted as de facto standards. MIL-STD-188-164 is now widely being used as the industry standard, and this follows a long history of trying to succinctly define linearity. At RF frequencies, adequate information used to be contained in an imaginary point called the third order intercept point. This is the projected power level, where the extrapolated lines of the main power and intermodulation power, as functions of input power, intersect. If an amplifier was operated at a given level below this third order intercept point, then its linear performance was considered adequate.

At microwave frequencies, particularly for solid state amplifiers, it was found that the P1dB point which is the power where the gain drops by 1dB compared to the linear gain was a more realistic way to compare amplifiers. This was reasonable when solid state microwave amplifiers were designed with individual FETs as the basic building block. The P1dB point was typically a fixed value below the third order intercept point. At higher frequency bands it was noted that this nominally fixed value tended to decrease. At 6GHz for example, the P1dB point might be 9dB below the third order intercept point but at 14GHz the difference might be only 7dB. This is one reason that adequate information for comparison reasons is not contained in the third order intercept point.

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With the move to MMICs (monolithic microwave integrated circuits), the frequency increased up into millimetre bands (greater than 20GHz), and with the wide diversity of modulation methods, the P1dB point is no longer a sufficiently accurate predictor of the amplifier performance in a system.

3. How Linearity is Defined for MMIC Technology

One way to make a comparative analysis between amplifiers as comprehensive as possible is to specify a wide range of non linear parameters and to set a limit on each. This typically involves specifications on the harmonic levels, and amplitude and phase deviations; when the amplifier is driven by a single tone and on the levels of intermodulation products generated when the amplifier is driven with two or more tones. Limits on the distortion of a modulated signal and the power levels generated in other channels by the effect of the non linearity on the modulated signal are also often added to the specification list.

For manufacturers of these devices and the power amplifiers, it is often necessary to test all these non linear characteristics and the relationships between them. This helps to understand the amplification process at the device and circuit level, and to improve and optimise performance. However, for potential users of this type of amplifier it may be confusing. Network designers may prefer one or two standard tests as an overall performance summary which would indicate what application the amplifier best suited, or how it compared to similar amplifiers.

3. How is Linear Power Defined (cont)

A simple way to improve the linear performance of an amplifier is to operate it further backed off from the defined non linear point. If the system operation requires a given power level, then this means that a higher power amplifier is required. Increasing the power level, particularly at millimetre wave frequencies can be expensive in financial, thermal and reliability terms, and in general millimetre wave devices will exhibit more pronounced non linear characteristics than microwave devices for the same relative back off levels.

The concept and definition of linear power is a useful alternative to previous ways of trying to summarise non linear performance in one or two terms. The linear power is defined from the power levels as described below.

3.1 Non Modulated Signal Definition

The linear power is defined as the total output power in two equal tones when the power in one of the third order intermodulation products is 25dB below the total power in the two tones. That is the intermodulation relative level (IMR) is 22dBc below the tone power level for both the upper and lower product. This is illustrated in Figure 1.

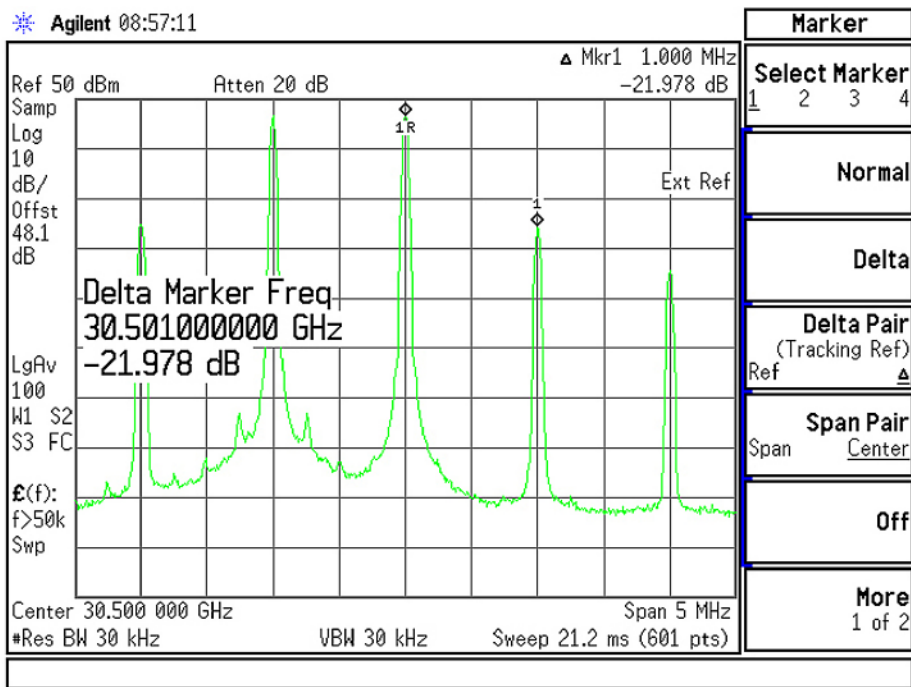


Figure 1. Two Tone IMD as displayed on a Spectrum Analyser

3.2 Modulated Signal Definition

This linear power is defined as that level when, for a specific modulated signal, the peak power in the sidelobes does not exceed -30dBc with respect to the peak power in the modulated signal at a specific frequency offset. This is illustrated in Figure 2. (symbolmod-2.gif, note top cropped to remove date) Typically the modulation is defined as OQPSK signal with 1/2 rate forward error correction and the offset is 1 symbol rate from the centre frequency of the carrier.

Agilent 10:08:35 Jan 1, 1970

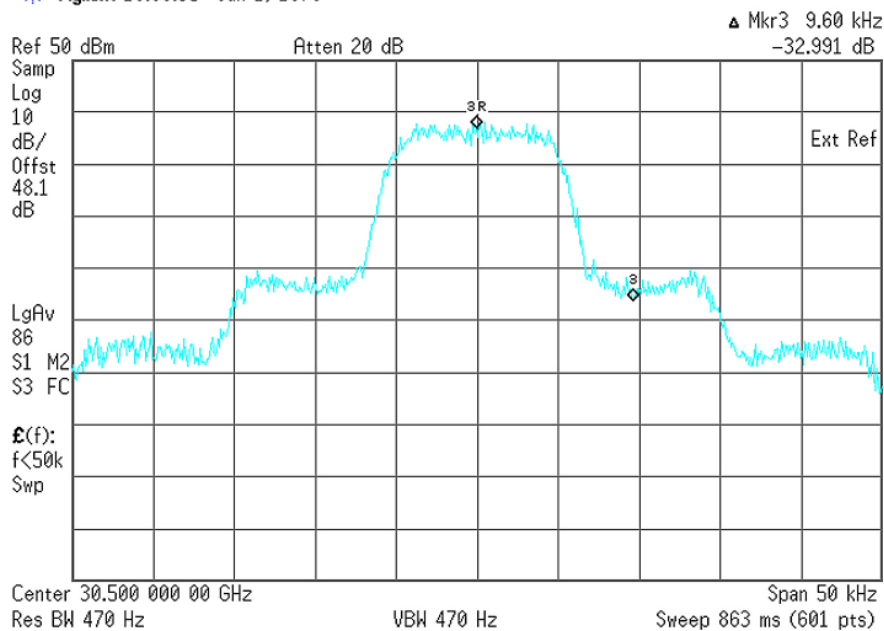


Figure 2. Spectral Regrowth of a 9.6kBPS OQPSK signal with 1/2 rate error correction.

For an amplifier the linear power is formally defined as the smaller of the power levels as described above. This definition is a very useful shorthand description for evaluating power amplifiers for SATCOM operations. It is also used to set the measurement point where other non linear characteristics such as AM/PM, AM/AM, harmonics etc can be measured.

4. Measuring Linear Power of MMICs

4.1 Non Modulated Linear Power

Until recently, the Spectrum Analyser (SA) method was the most useful technique for measuring intermodulation (IM) levels and hence linear power. Vector Network Analyser (VNA) techniques have now been expanded to measure IM and these offer the advantage that the IM levels can be seen in real time.

Since the operational power levels in SATCOM systems must be known precisely to realise a specified performance, the power meter is used for both SA and VNA measurements as the reference calibration device.

4.1.1 Spectrum Analyser Method

This method is quite simple in practice although considerable care in the test set up and in the technique is required for accurate results. Two tones at a specified frequency spacing are applied to the amplifier and the output levels set equal on the SA display. The output power in the tones is increased until the upper and lower IM products which should be equal are each 22dB below the adjacent tone.

The power level is then measured with a power sensor (or with the SA if it has just been calibrated against the power sensor) and this power is defined as the linear power.

4.1.2 Vector Network Analyser Method

The output power of a 4 port VNA, or a 2 port VNA with an additional frequency synthesiser, is calibrated against the power sensor at each tone frequency and set equal. Both signals are fed into the amplifier and the output of the amplifier is connected via a suitably calibrated coupler into the second port of the VNA. The VNA display is then selected to display the power in one of the main tones and in either or both of the IM products and the power swept over the required range. The VNA display will show the main power and the IM power as a function of input power. Markers or a VNA trace equation can be used to define the 22dBc difference position and the output power level at this position measured with the power sensor.

The advantage of this technique is that amplifier parameters (eg bias conditions, RF tuning, tone spacing, lineariser settings etc.) can be varied and the effects on IM seen immediately, over the selected power range, and at a number of frequencies. Refer Figure 4.

4.2 Modulated Linear Power

Since SATCOM networks typically use QPSK or variants of QPSK as the modulation method, the linear power for a modulated signal is defined with a QPSK signal. This could be extended to other modulation types if necessary but QPSK, or rather the variant OQPSK serves as a useful reference.

The technique is straightforward at the conceptual level. The modulated signal is applied to the amplifier and the spectrum displayed on the SA as the power level is increased. When the power in either sidelobe at the specified offset reaches a level 30dB below the peak power in the main signal, the total power is measured and this is the linear power as defined by this technique.

Since a QPSK signal can have different bit rates and error correction coding which may affect the results, it is necessary to further constrain the measurement. The point in the sidelobe where the relative power is measured is defined by the bit rate for a specific coding rate as shown in Figure 2 where the modulated signal is a 9.6kBPS QPSK signal with 1/2 rate error correction.

The linear power is defined as the lower value of the above two results. In general, the linear powers measured with both techniques will be quite similar but there may be differences of around 1-3dB which can vary with bias and other conditions of the amplifier.

5. Using a Lineariser with MMIC Technology

Linearisers, which reduce the level of the non linear characteristics, may therefore be a realistic alternative to increasing the power level but the inclusion of a lineariser may further complicate the specifications for non linearity. Typically, linearisers will improve the non linear behaviour over a certain power or frequency range but may degrade it outside these boundaries.

It is instructive to compare the approximate differences in linear power relative to the maximum output power between typical Ku and Ka band SSPAs. At Ku band, the linear power as defined by the two tone method has been measured to be typically 3-4dB below the saturated power level for SSPAs in the 100W power range. The linear power is therefore around 40-50W.

5. Using a Lineariser with MMIC Technology (cont)

At Ka band, the linear power as defined by the two tone method has been measured to be typically 7-8dB below the saturated power level for SSPAs in the 40W power range. The linear power is therefore only around 8W.

The difference in linear power compared to the saturated power between Ku and Ka band SSPAs is primarily related to the performance of the devices currently available in each band. Consequently, if a typical Ka band amplifier is linearised to increase the linear power to say 3dB below the saturated level, then the operational power can be increased from 8W to around 20W. This is a major improvement. At Ku band, a lineariser will also give an improvement but the effect is not as significant and it is also cheaper to add 3dB more power at Ku band than it is at Ka band.

6. Measuring Linear Power where a Lineariser is used

The two tone method of measuring linear power needs to be applied with some caution to Ka band SSPAs especially if a predistortion lineariser is included with the SSPA circuit. Firstly, the non linear performance may not be the same across the operational frequency band so measurements should be made at several frequencies across the band. Frequency sensitivity is expected to decrease as the upper frequency limit of available MMIC devices increases well beyond the 31GHz mark.

A predistortion lineariser can be considered to operate by compensating the amplitude and phase distortions generated at higher output power or equivalently generating out of phase IM products to cancel the IM products generated in the final stages of the SSPA. These two concepts are illustrated in Figure 3.

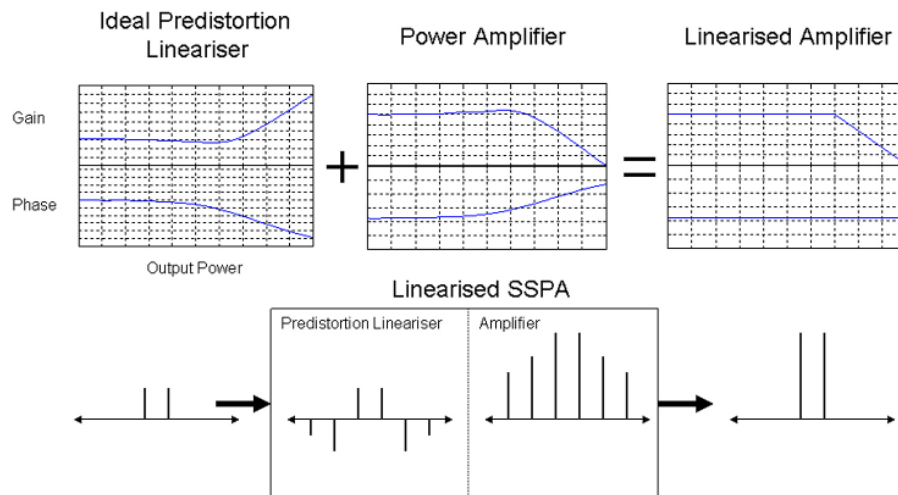


Figure 3. Ideal Predistortion Lineariser

It is a difficult challenge for a lineariser to achieve good cancellation of the IM products over wide power, frequency and tone spacing ranges and in general the lineariser will be set to maximise linear power. Some typical measurement issues to consider are listed below.

6.1 Unequal IM levels

The IM level either side of each tone should be within ± 0.5 dB if the tone power levels are accurate to ± 0.2 dB. If there is a considerable difference between the upper and lower IM levels then this will generally reduce the linear power available. A typical plot of the levels of both the upper and lower IM products is shown in Figure 4. This Figure shows the tone power in each CW Signal as measured by the VNA and the Upper and Lower IMD3 products, IMD3U and IMD3L respectively.

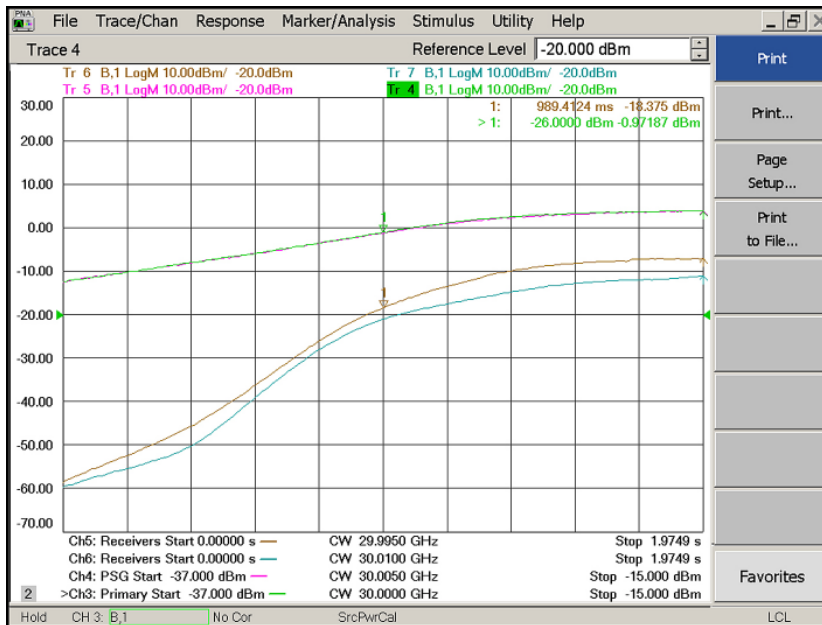


Figure 4. Unequal Intermodulation Products

6.2 Tone Spacing

Differences in upper and lower IM levels will generally increase as the tone spacing increases. Changing the tone spacing may also affect the absolute level of the IM products. Tone spacing dependent effects are usually associated with frequency dependent bias circuits or with sharp frequency sensitive circuits in the main transmission line.

Over a tone spacing range of say 1 to 20MHz, the IM levels should not change by more than ± 1 dB. A rather severe case of tone spacing dependency is shown in Figure 5 for a Ka Band SSPA. This plot shows the upper (Red) and lower (blue) IMD3 products with 1MHz (solid) and 9MHz (dashed) tone spacings at 30GHz. It is clear that linear power measured at 1MHz spacing is quite different to that measured at 9MHz.

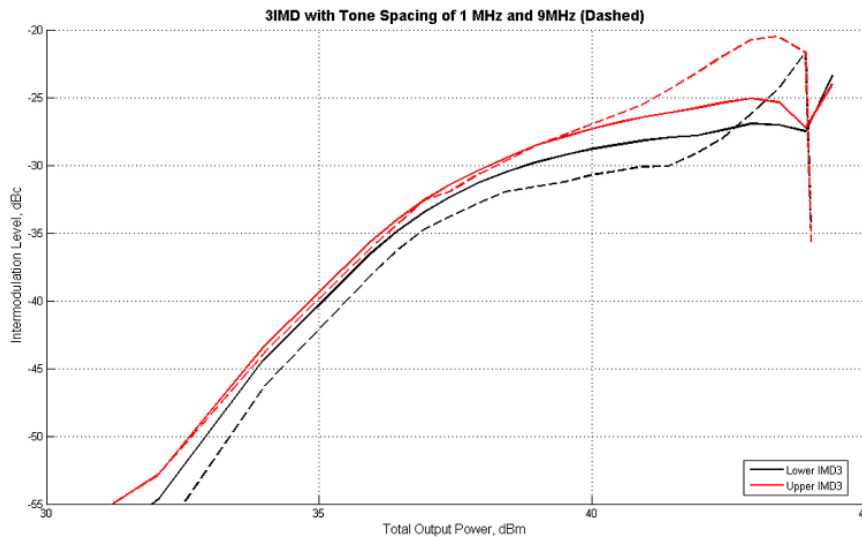


Figure 5. Tone Dependent IMD3 Products

6.3 Multiple IM Levels

For a standard SSPA, the third order IM levels are generally well above that of the higher order products so the power in these products is small even when the output power is within a few dB of the saturated power.

For a linearised SSPA, the out of phase condition of the pre distorted IM products may not hold over a wider frequency and power range. Another way to consider this is that compensation of the power dependent amplitude and phase curves will be approximate only and the curves may become non monotonic. This can be manifested as significant increases in the levels of higher order IM products which may be higher than the third order products.

This may affect the total power measurements as well as of course the performance of the SSPA in the system if there are significant power levels at 5, 7 etc times the tone spacing. A case where the upper 5th order product is greater than the adjacent 3rd order product is shown in Figure 6.

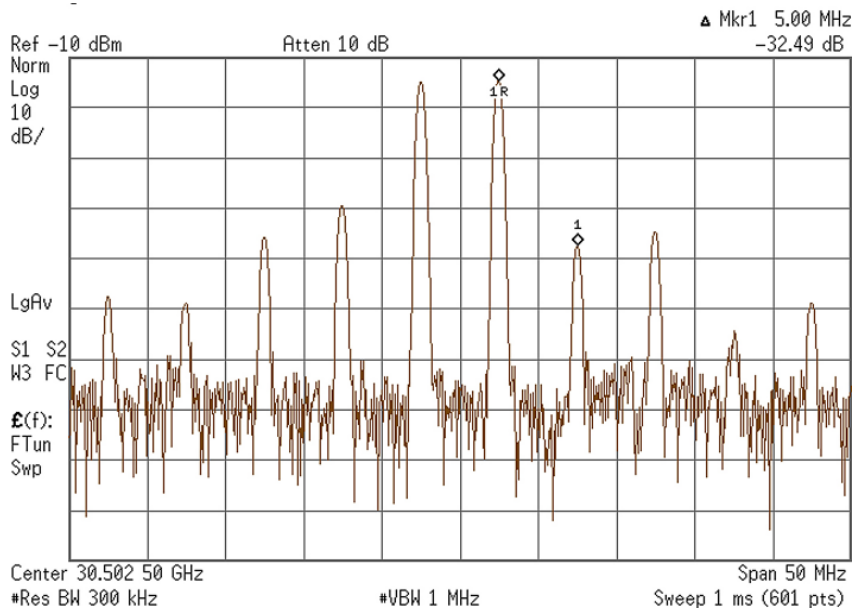


Figure 6. Higher Order IM Product Significance

6.4 Power Dependency

It is well established that the slope of the IM output level as a function of input power is about 2:1 but that this may increase before decreasing again as the power level approaches the maximum power level.

With Ka band SSPAs, the IM levels may exhibit increased deviations from the nominal 2:1 slope even at power levels well below the linear power point. A linearised SSPA will generally make this IM power dependency more complex.

If the linearised SSPA is operated well below the linear power region, then the IM levels may actually be higher than for a non linearised SSPA. This is illustrated in Figure 7.

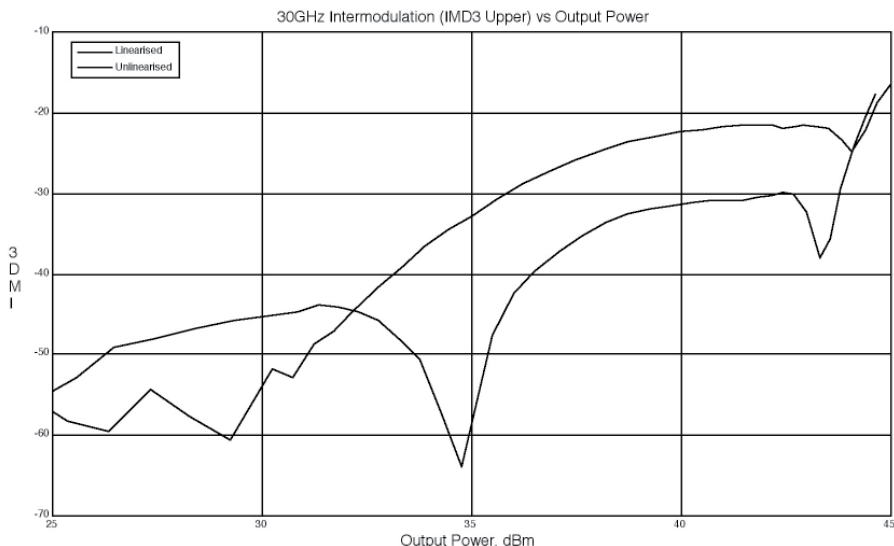


Figure 7. Intermodulation with and without a Lineariser

6.5 Modulated Signal Data Rate Dependency

Numerous modulated signals with varying data rates relevant to the particular application should be applied to the SSPA to ensure that the spectral regrowth linear power specification is not violated. An amplifier that exhibits tone spacing dependency will almost certainly display varying spectral regrowth levels for the different modulating data rates, measured at the specified offset. Similarly, if an Amplifier exhibits unequal upper and lower IM product power, the spectral regrowth will be greater on the side of the larger IM product. It may be informative to extend the modulated signal testing to multiple modulated signals input to the SSPA simultaneously.

7. Conclusion

A linearised Ka Band SSPA can offer a major improvement over a non linearised one in that the linear power level can effectively be more than doubled, that is, improved by 3dB without any significant increase in DC power consumption, heat generated, size or layout of the SSPA. There will usually be a cost increase but this will generally be relatively minor if the lineariser is fitted during manufacture of the SSPA.

However, a lineariser does add complexity and as such it usually means that there are compromises in performance when the complete power, frequency and carrier spacing ranges of operation are considered. This paper has highlighted some of these issues and what to consider when doing evaluation testing of both linearised and non linearised SSPAs particularly at Ka Band.

8. About EM Solutions

EM Solutions is a technology provider to commercial and military customers in the telecommunications sector. EM Solutions is a market leader in the supply of Ka-band products to defence and enterprise customers. Our products include LNB, BUC and SSPAs from 5W to 40W for Satcom market, and Fixed Point-to-Multipoint radios based on the WiMAX IEEE 802.16d standard. EM Solutions is also currently developing a Ka-band Mounted Battle Command On-The-Move Communications System for the Australian Defence Force. EM Solutions has developed all its products in-house, and has the organisational structure and focus to offer adaptation of core technologies and products to meet specific customer requirements.



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