Communications
& Power Industries

‘Memory Effect’ On Usable Linear Output Power of GaN Solid State Devices/Amplifiers Used in Multicarrier Applications

Produced by: the CPI Satcom Products Group

ADVANCE SUMMARY

- **Memory Effect is a phenomenon that can negatively affect output linear RF power, primarily when GaN BUCs are used in multicarrier applications.**
- **The degree to which output power is affected is determined by tonal spacing and number of carriers.**
- **CPI has mapped this behavior using IMD sweeps and spectral regrowth charts.**
- **CPI has mitigated this effect in its own GaN-based products. Other manufacturers may or may not be aware of this issue.**

INTRODUCTION

Over the past 5-10 years, gallium nitride (GaN) technology has become an increasingly popular selection for those wishing to purchase solid state high power amplifiers for satellite uplink applications. GaN-based SSPAs have not only supplanted traditional applications dominated by their gallium arsenide (GaAs) based predecessors, such as the maritime and milsatcom markets, they have also been readily considered for wideband and multi-carrier applications long dominated by TWT-based amplifiers. This is all possible because GaN devices are capable of providing power that GaAs devices cannot, and on a more cost effective basis. However, a challenge has arisen for SSPA manufacturers selling into these new multi-carrier and wideband markets: a phenomenon which directly impacts the linear performance of SSPA transmissions, dubbed “memory effect.”

The end result of memory effect is that it impairs the expected intermodulation performance of the HPA, sometimes by as much as 10 dB. This requires the user to back off the output power by more than the expected amount, negatively impacting the link budget and/or the overall performance of the earth station. Memory effect is not necessarily limited to GaN devices. It can also affect GaAs based SSPAs. However, GaAs SSPAs are rarely used in applications where the effect manifests itself, since they are predominately used in single-carrier operations. The issue has never manifested itself in TWTAs, at least to a significant or measurable level.

HOW DOES MEMORY EFFECT OCCUR?

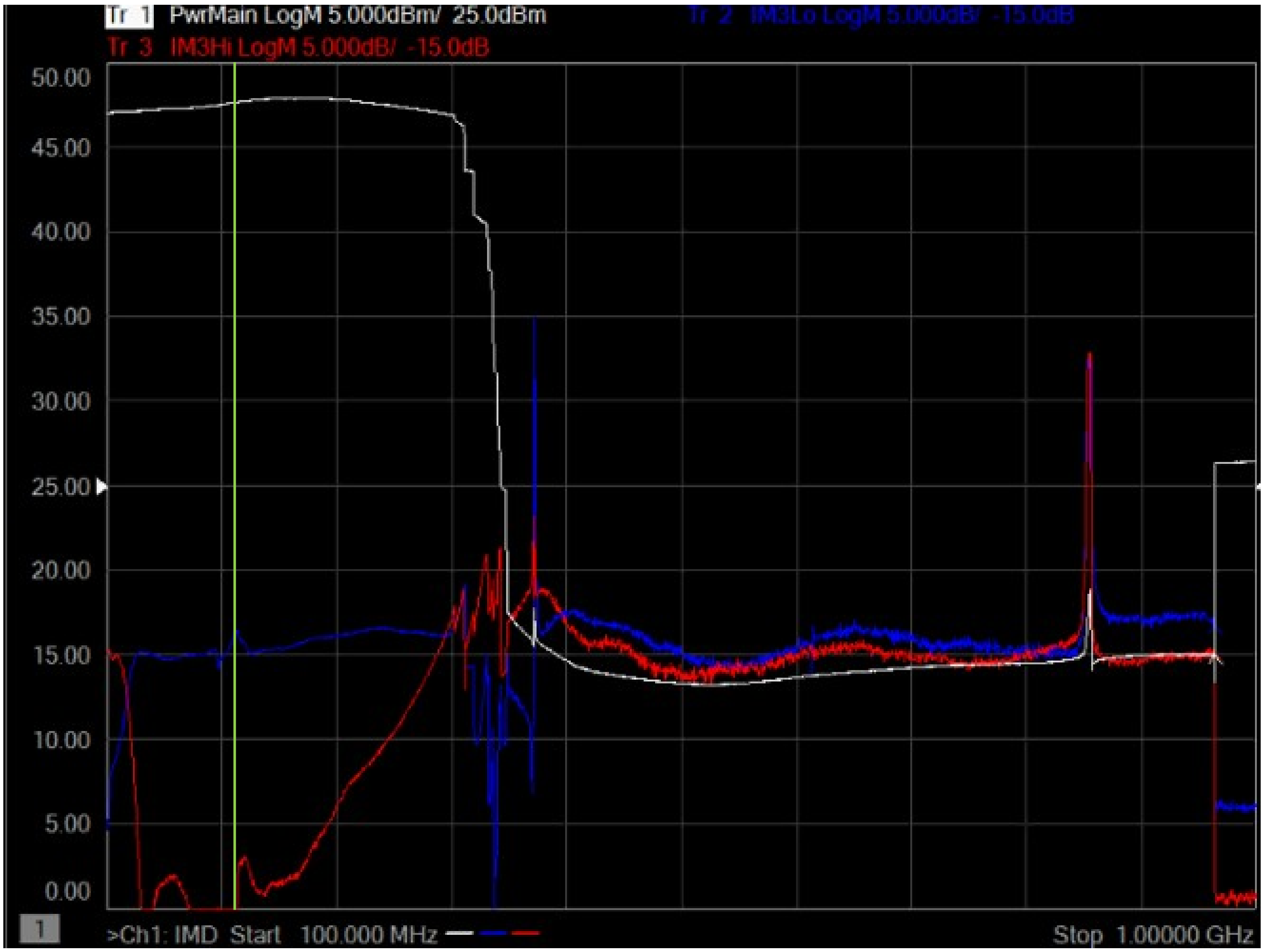
The severity of memory effect is determined by the manufacturing and biasing methods selected during the design and production of solid state devices/MMICs, and its interaction with the carrier spacing utilized in actual transmission. Carrier spacing has a significant effect on the level of the intermodulation distortion (IMD) when the bias decoupling networks are not sufficiently broadband. In addition, the addition of more carriers makes the problem worse.

The real world impact is that when reviewing an IMD specification on a product datasheet, the general statement of compliance to "below -25 dBc" up to the specified Plinear operating pointappears to show compliance because it assumes a very "coarse" IMD product. However, during these resonance events, the increase in IMD is typically sharper, thus ending up in poor linearity performance, requiring further backoff to compensate.

The parasitics in the capacitors, resistors and inductors used in the bias decoupling network can cause series and parallel self-resonant frequencies where filtering/bypassing is inadequate.

The following are actual snapshots of two IMD sweep tests performed on a 160 W Ka-band GaN-powered BUC: one taken prior to memory effect mitigation (Exhibit 1 and 2, 5 and 6, 8), and the other taken after steps have been taken to mitigate memory effect (Exhibit 3 and 4, 7)

Exhibit 1: PNA-X IMD sweep, two tones from 100 to 1000 MHz spacing
BEFORE mitigation,
X-axis: tone spacing 200 MHz apart
Y-axis: dBm (output power) and dBc (intermods)
white trace: amplifier output power
blue and red traces: left and right intermods
(Note each horizontal division represents 90 MHz)



The green line indicates the sweep when the tones are about 200 MHz apart. The Y axis labels are set to show the output power in white (dBm). For the sake of scaling the graph, the IMD products (dBc) are actually 10 dB lower than the labels on the Y-axis. For instance, where tones are 100 MHz apart on the far left, IMD = -25 dBc, not 15 dBc. At this point in the sweep, usable linear power is still acceptable (around 47 dBm, or 50 W), however the left intermod IMD has crept just above -25 dBc while the right intermod is very low. Exhibit 2 on the next page shows how the 200 MHz spacing is manifests itself in the spectrum analyzer view. Note that IMD is output power minus peak intermod.

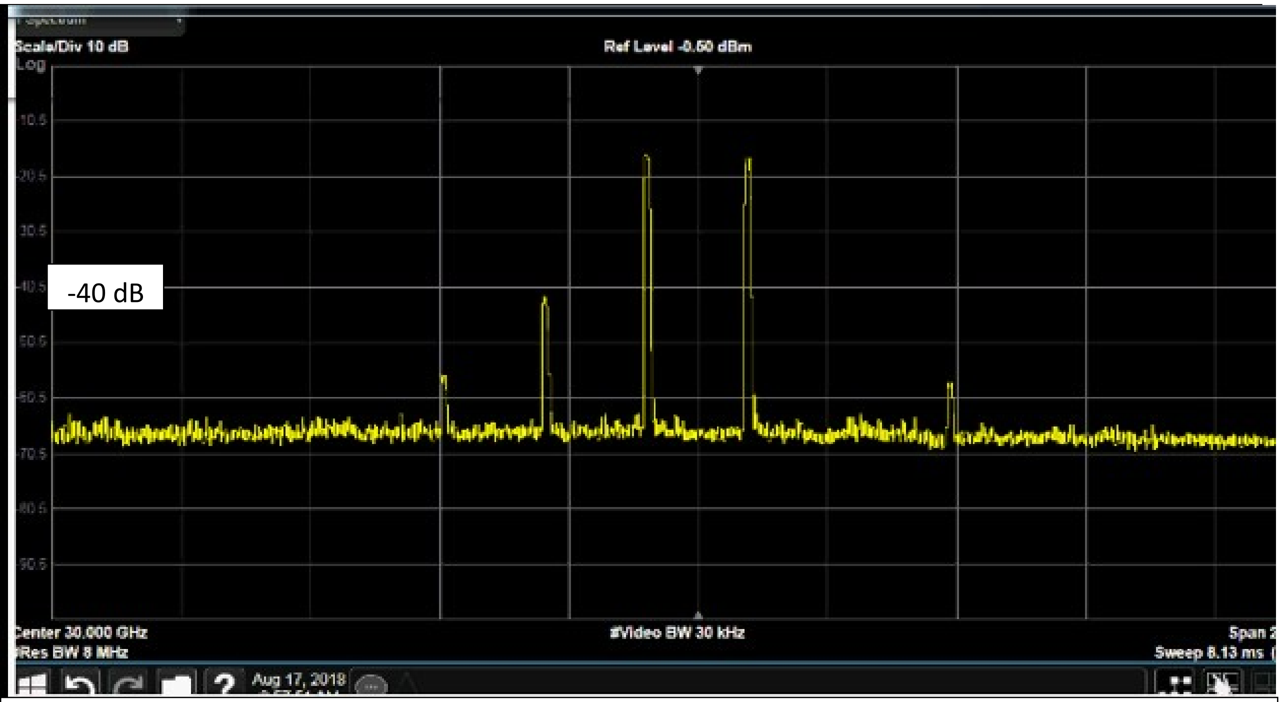
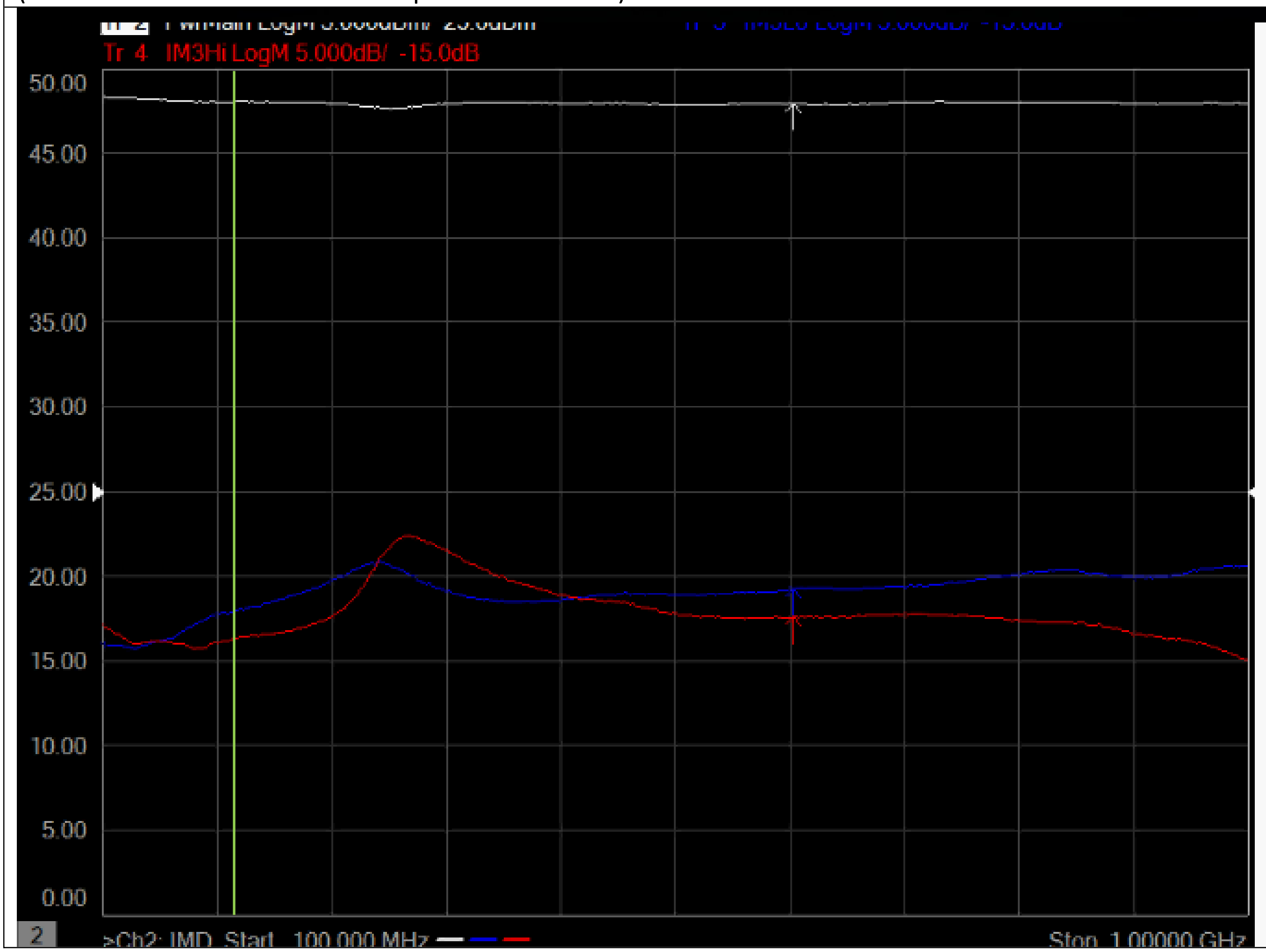


Exhibit 2. Spectrum Analyzer, unmitigated HPA, tones 200 MHz apart. The two tallest spikes are usable output power, which is very much acceptable, while the nearest left spike shows the intermod (also shown in Exhibit 1, in blue). The right intermod (which is in red in exhibit 1) is in the noise on the sweep here. The difference between the signal and the left intermod is around -25 dB.

Exhibit 3. PNA-X IMD sweep, two tones swept from 100 to 1000 MHz apart
AFTER mitigation
X-axis: tone spacing 200 MHz apart
Y-axis: dBm (output power) and dBc (intermods)
white trace: total HPA output power
blue and red traces: left and right intermod, respectively
(Note each horizontal division represents 90 MHz)



The beginning of this sweep shows the Ka-band HPA AFTER memory effects have been mitigated, when the tones are 200 MHz apart (indicated by the green vertical line). The intermods are much closer in behavior, and while slightly higher than the first example, so is the output power. On the spectrum analyzer view (Exhibit 4), one can now see both intermods behaving in an expected fashion.

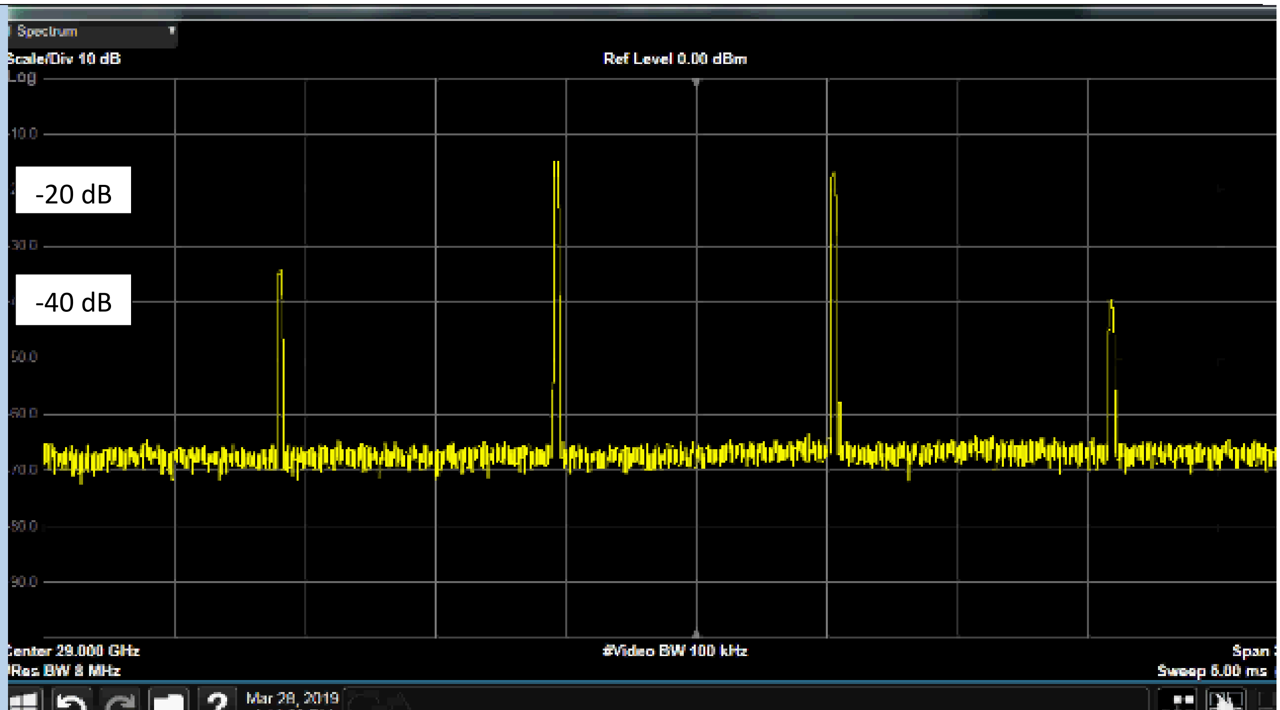
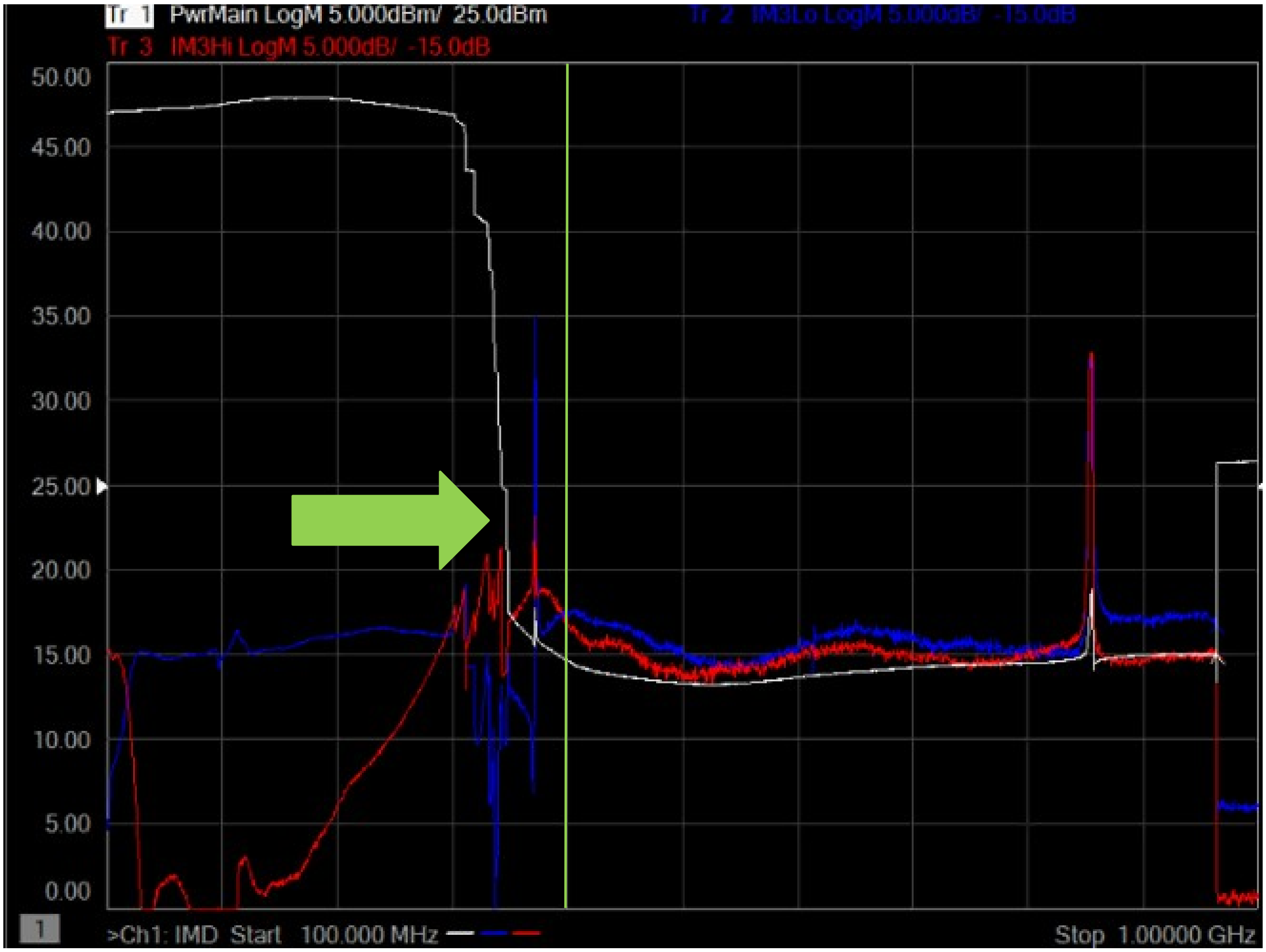


Exhibit 4. In the improved HPA, the two carriers show acceptable power, and the two intermods are reasonably close to each other in output. Difference between the signals and intermods is around -22 dBc.

Exhibit 5. PNA-X IMD sweep, two tones swept from 100 to 1000 MHz apart
BEFORE memory effect mitigation
X-axis: tone spacing 460 MHz apart
Y-axis: dBm (output power) and dBc (intermods)
white trace: Total HPA output power
blue and red traces: left and right intermod
(Note each horizontal division represents 90 MHz)



Now observe the middle of the sweep (indicated by the green line) for the unimproved amplifier (Exhibit 5 above). Between the 3rd and 4th horizontal division (~400MHz) there is a big event (indicated by the green arrow) which one can refer to as “the resonance.” The IMD spikes up quite sharply, almost to the same level as output power, demanding a huge change in power from the power supply and bias circuitry, which causes the device to protect itself. Some of the FETs turn off during this event, thus the output power (white trace) has dropped significantly.

Exhibit 6. For the unimproved HPA, the spectrum analyzer shows the smaller differences between the signals and the intermods.

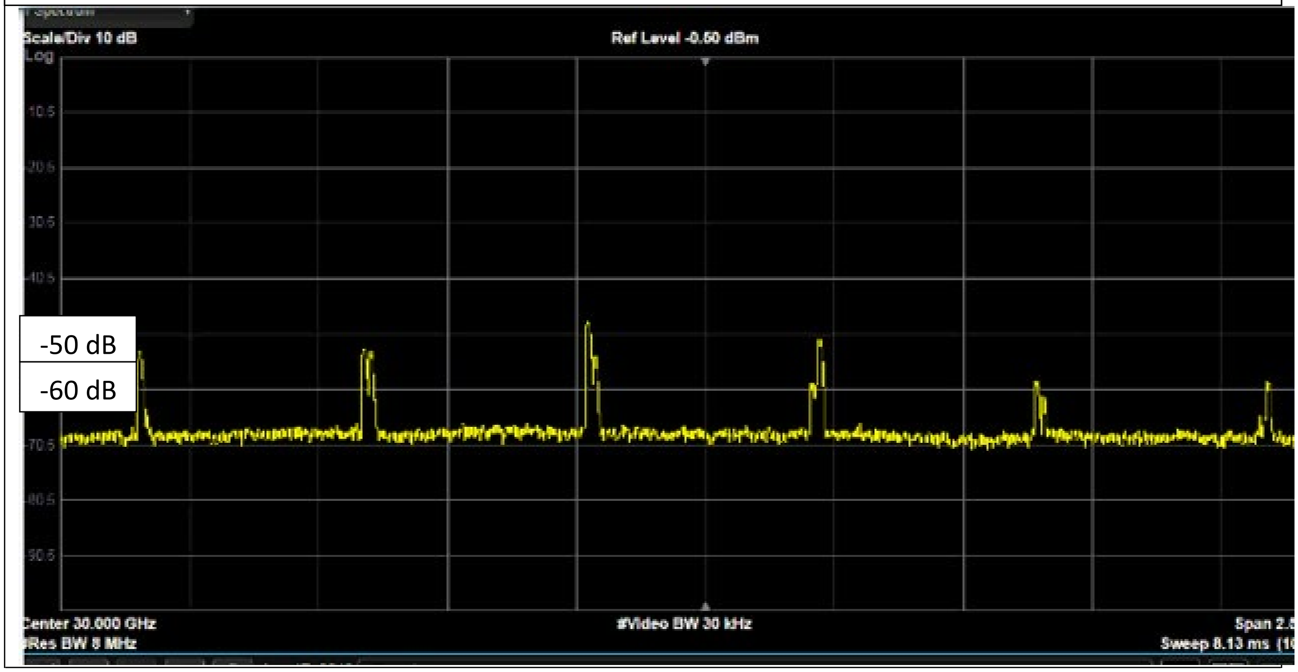


Exhibit 7. PNA-X IMD sweep, two tones from 100 to 1000 MHz apart
AFTER memory effect mitigation, middle of sweep
X-axis: tone spacing
Y-axis: dBm (output power) and dBc (intermods)
white trace: amplifier output power
blue and red traces: left and right intermod
(Note each horizontal division represents 90 MHz)

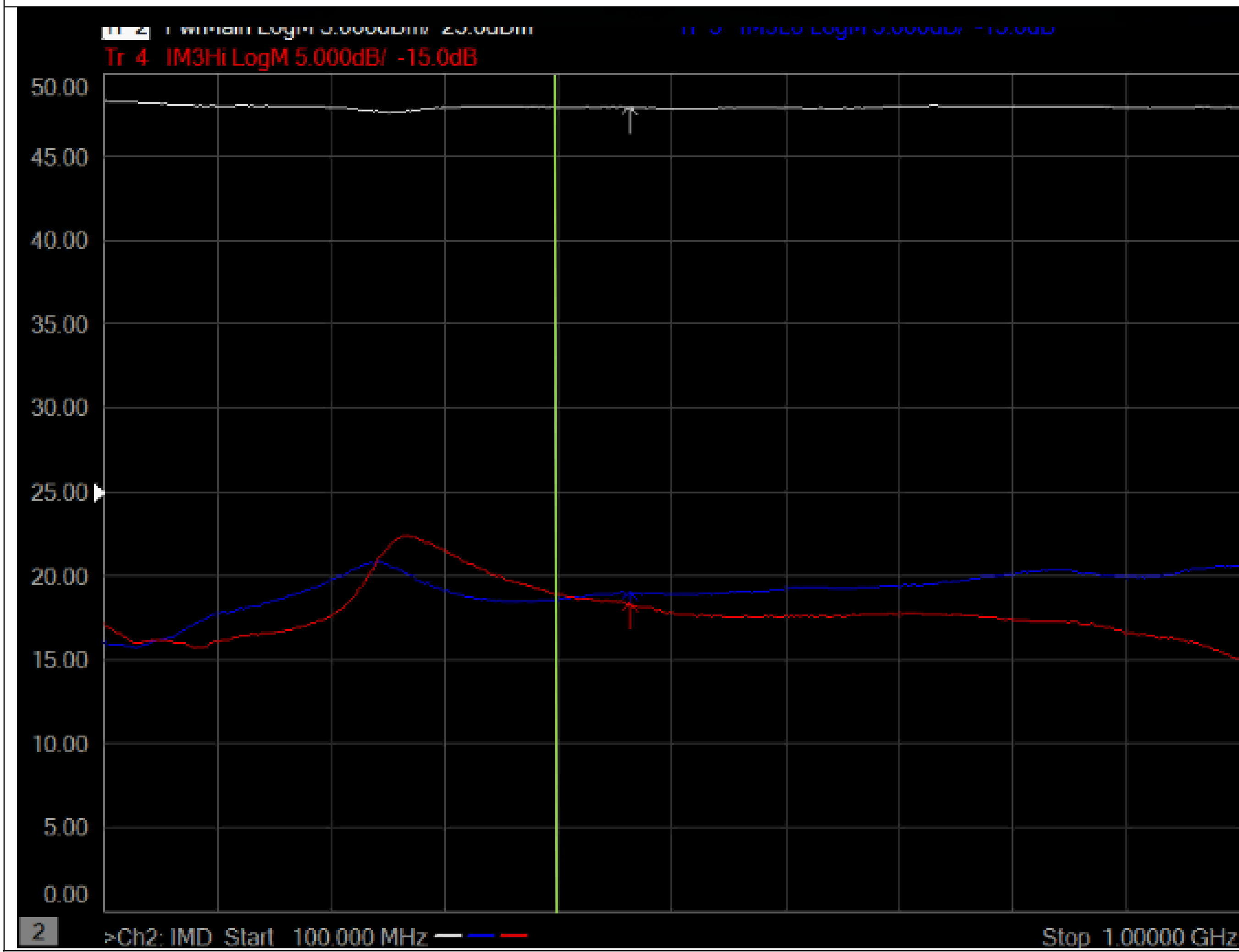
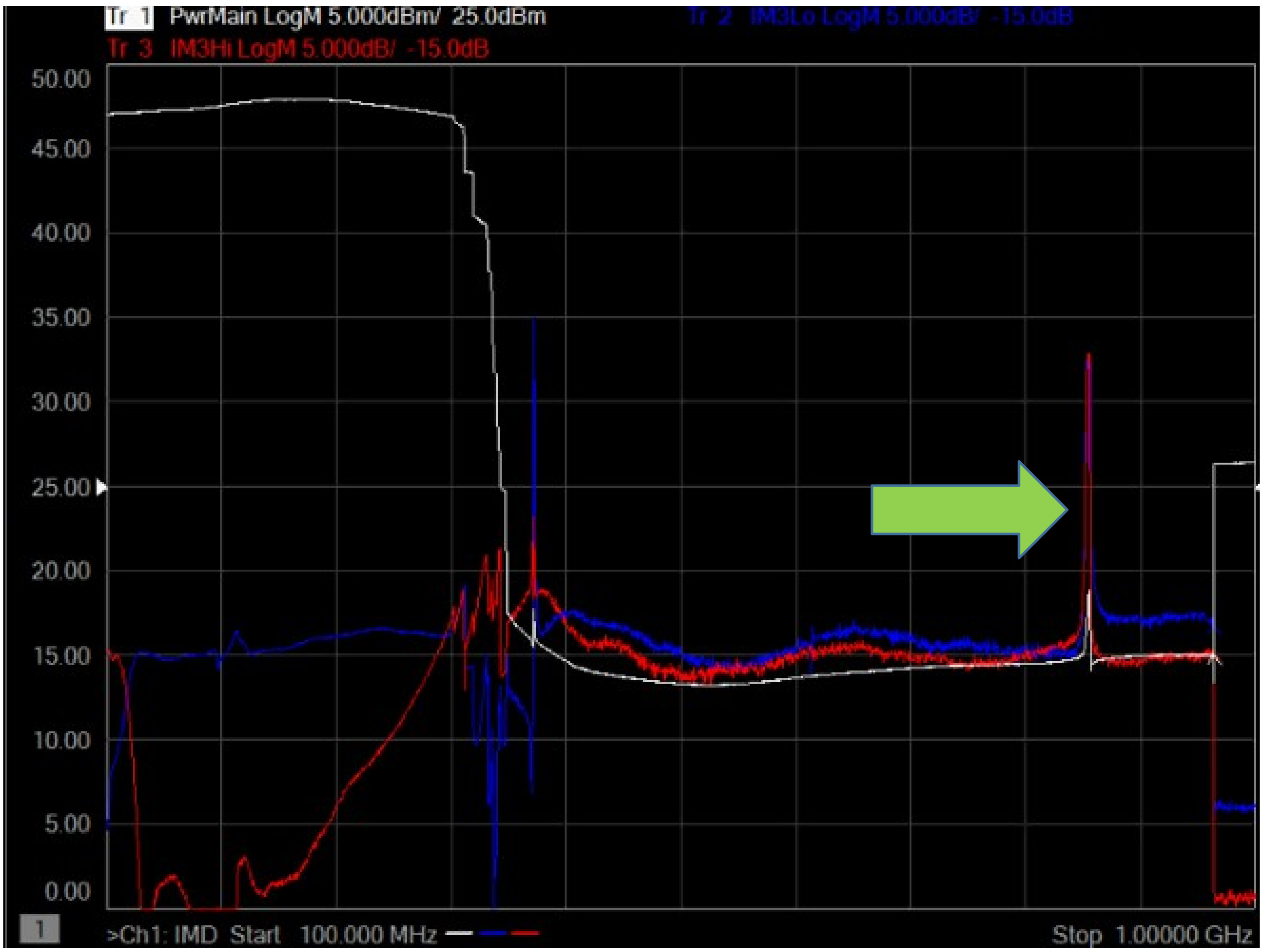


Exhibit 7 above shows that linear output power is quite stable, as it has been over the entire sweep so far (here the green line indicates the same point as in Exhibit 5), while intermods are behaving as expected.

Exhibit 8. PNA-X IMD sweep, two tones ~975 MHz apart
BEFORE memory effect mitigation, end of sweep
X-axis: tone spacing
Y-axis: dBm (output power) and dBc (intermods)
white trace: amplifier output power
blue and red traces: left and right intermod
(Note each horizontal division represents 90 MHz)



The sweep for the unimproved HPA is almost complete (Exhibit 8). Once the resonance occurs in the middle of the sweep, the intermods begin to oscillate, and the growth of more intermods as the tones are spaced further and further apart keeps the HPA from operating at full linear power. Another resonance event (green arrow above) occurs when the tones are separated by about 850 MHz.

SUMMARY OF TESTING

For the improved HPA, the sweep and the spectrum analyzer continue to show expected behavior (thus we won't show it here), as in Exhibit 7.

What we see above in the PNA graphics is that for the unimproved amplifier, it behaves normally as long as the tones are close together, and the IMD (blue/red) traces are below -25 dBc on the Y-axis.

As mentioned before, the phenomenon manifests when the tone spacing is wider. On product data sheets, the general statement of compliance to "below -25 dBc" up to the specified Plinear operating point appears to show compliance because it assumes a very "coarse" IMD product. However, during the resonance events shown in this paper, the increase in IMD is typically sharper, thus ending up in poor linearity performance, requiring further backoff to compensate.

It should be noted that a similar effect could theoretically appear on VED based amplifiers if the cathode filter were not properly designed, and/or ferrites were needed on the HV wires. However, we have never seen this effect appear in TWTAs, and CPI has thousands of TWT-based HPAs being used in wide-band multi-carrier applications.

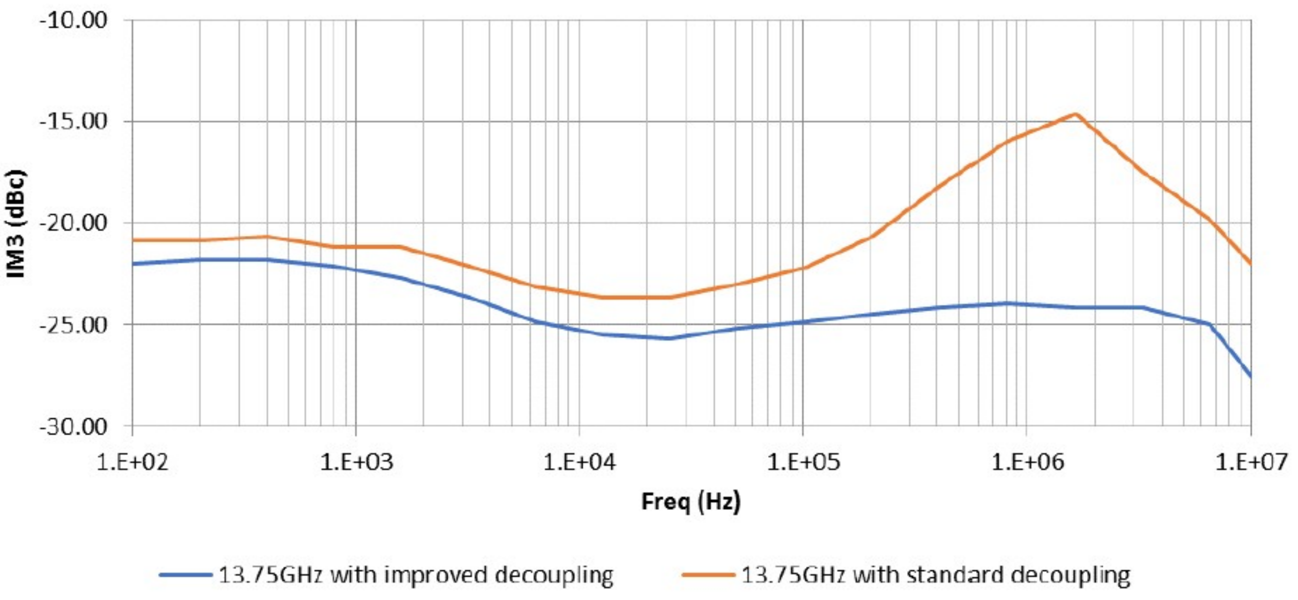
CPI has conducted further tests with SSPAs and found that increasing the number of carriers makes memory effect worse. The tests shown in this paper are with just two carriers. However, for CPI SSPAs, those effects have been mitigated and the amplifiers perform as they should, even in multicarrier applications. System designers should be aware of the threat that unmitigated memory effect is to linear EIRP, and should take the necessary steps to ensure that any HPA they are considering is properly designed for wide-band multi-carrier applications.

CPI SOLUTION

CPI has invested significant resources to study the problem in an effort to produce a product that can reliably operate no matter the transmission type, mitigating the impact of the memory effect. CPI has carefully designed bias networks to match the specific devices used in both our GaAs and GaN amplifiers to minimize memory effect. Not all GaAs and GaN amplifier devices behave the same way. Some are less impacted than others. Therefore selecting the best GaN devices is also key to the overall HPA performance.

The graph on the next page shows the results for a FET used in the CPI 80 W Ku band SSPA.

50 W Ku-Band Amplifier – Improvement in IMD Via Better Decoupling of Bias Lines



CPI has decades of experience producing amplifiers that are used in broadband, multi-carrier environments. CPI has been able to apply that knowledge in the development of its GaN based products, to actually fulfil the promise of exciting GaN technology. There are many products available on the market that provide a simple specification to make it appear that they will function well in an uplink system. However, satcom technical requirements are more complex and nuanced. Complex transmission schemes require state of the art technologies with advanced engineering.

For more information on memory effect, GaN amplifiers, and amplifier technology in general, please do not hesitate to contact your local CPI sales office. Visit us at www.cpii.com/satcomsales to find the CPI office closest to you.