Advantech Wireless

Linearity of GaN Based Solid State Power Amplifiers

By Cristi Damian,
M.E.E. Advantech Wireless

White Paper

Introduction

Since the initial launch of GaN based Solid State Power Amplifiers by Advantech Wireless in early 2010, a lot of uncertainties and unknown issues have been clarified. We know today that GaN is the foundation of all new Power Amplifier development and design, and that it offers unmatched performance, reliability, and efficiency.

The purpose of this white paper is to characterize, in particular, the linearity of Advantech Based GaN SSPAS, when operated either in single carrier mode, or in multi carrier mode.

A comparison with TWTs is long overdue, and here included. It is our belief that today,GaN exceeds power levels that were never achieved with any technology, and opens a new range of applications and opportunities for the Satellite Communication market.

Linearity performance

There are now several suppliers who have taken the challenge of designing SSPAs using GaN technology. This is by no means a trivial endeavor. This paper describes the performance of Advantech Wireless GaN based SSPAs, and it is limited to our known measurements and observations on Advantech made units. Results from other suppliers might differ, as linearizing GaN SSPAs proves to be challenging, but at the same time rewarding if successful.

Single carrier mode

Traditionally, SSPAs have been characterized by two power levels:

1. Psat or Saturated Power, it is the maximum power the SSPA will generate. No SSPA should be run at Psat, as the link will only degrade in performance

2. P1dB is the 1dB compression point. This is really the "Output Power Warning Level", a level that should not be exceeded. Gain is starting to compress, we only have 0.8-1 dB before saturation, and the link performance will degrade sharply. Higher order modulations will not run at P1dB power levels, as both amplitude and phase of the signal will be affected.

In a nutshell, both Psat and P1dB will not tell us how many carriers we can transmit, or which modulation type. We need different measurements to characterize that.
TWTs do not specify P1dB, so the confusion is even higher, if we try to compare them with SSPAs.

What is important in single carrier mode is spectrum regrowth. We need to keep the carrier spillover effect, into some other's allocated bandwidth, to a minimum.

This is specified as -25 dBc at 1 Symbol offset for commercial applications, and -30 dBc for Military applications.

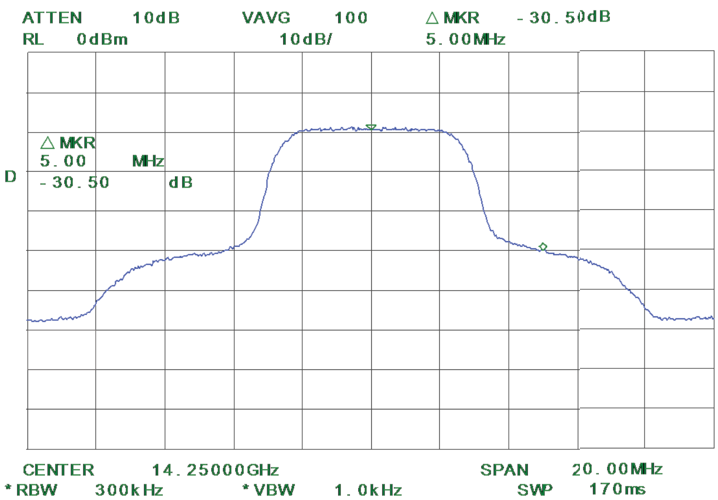

Fig.1 Spectrum Regrowth, GaN based SSPA, 1 dB back off from Psat.

GaN based SSPAs, on the other hand, are much better performing. They will meet same specifications at only 1 dB below Psat.

This brings up an important issue:

1. An older generation SSPA designed using GaAs FETs, will operate in 8PSK or 16 APSK mode for example, at 3 dB below P1dB.

2. A new generation SSPA, using GaN will operated in 8PSK or 16 APSK modes, at only 1 dB below Psat, or previously defined P1dB.

The conclusion is somehow intriguing.

If we have a 250W saturated power SSPA, using older generation GaAs FETs, we can operate it in single carrier mode, higher order modulation, at only 100W. Higher than that, we will generate errors that depending on link margins, might not be permitted.

The same 250W saturated SSPA, using GaN technology, can be now operated at 200W, with no degradations in link performance.

This is the same as operating a GaAs based SSPA of double power, 500 W.

In this context, GaN based model is clearly a winner, it doubles the amount of useable RF power, for the same Psat.

This why we believe that GaN technology truly enables DVB-S2 advanced modulation and error correcting codes.

To meet the same performance, TWTs will need at least 6 dB back off, and Klystrons 9-10 dB back off.

The following table presents our finding when testing a GaN SSPA carrying 16APSK modulation traffic, from 6 dB back off to saturation.

Total back off	Signal to Noise Ratio (SNR)	Eb/No (dB)
6 dB	15.37	10.75
3 dB	17.26	12.05
2 dB	16.58	12.1
0 dB	15.09	10.68

Table 1.GaN based SSPA, single carrier mode, 16 APSK. SNR and Eb/No versus back off.

16 APSKGAN SSPA Performance, Single carrier

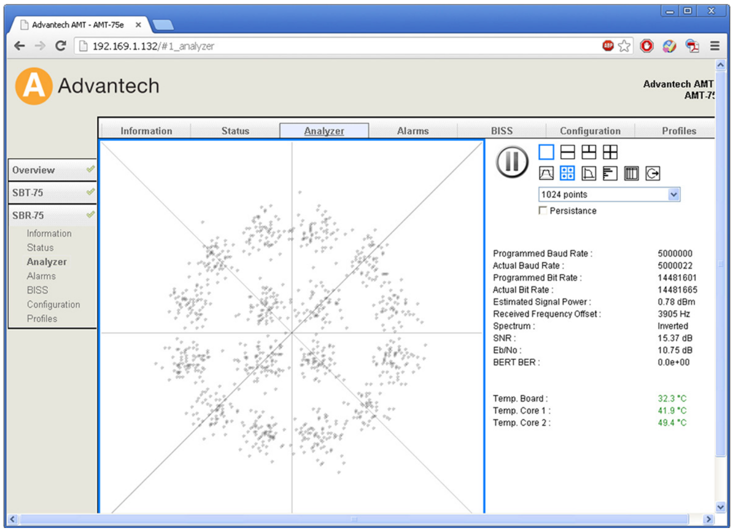

Figure 2 16 APSK constellation at 6 db back off

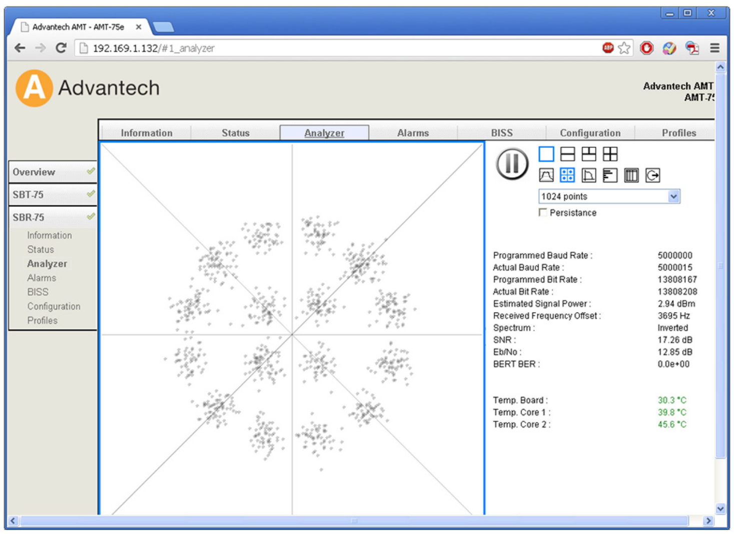

Fig. 3 16 APSK, 3 dB back off.

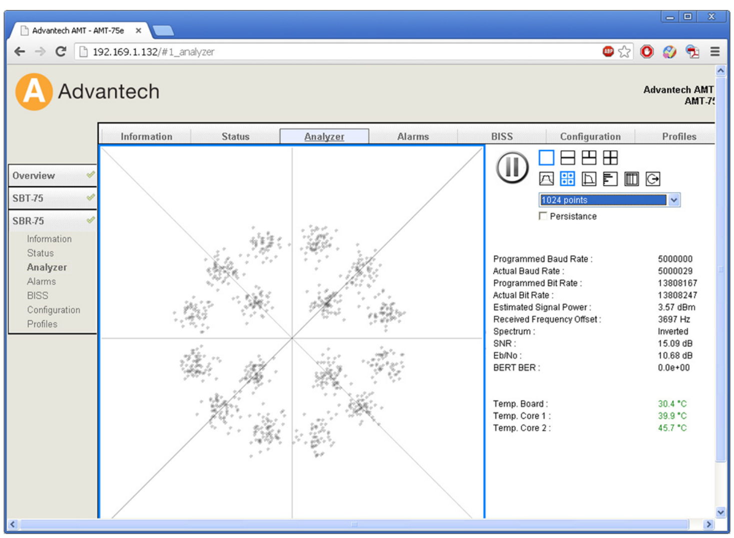

Fig. 4 16 APSK, 1 dB back off.

Multiple carriers operation

In multiple carrier mode, the traditional system specification measure is Third Order Intermodulation, or IM3.

It is generally required that two carriers, 5 MHz apart each, should not generate more than -25 dBc intermodulation.

This was obviously enough when all satellite modems where 70 MHz IF, and transmission was limited to one transponder.

Today's modems can cover full satellite bandwidth, and we can saturate all transponders on a specific satellite, with multiple carriers.

But no specific information exists on how SSPAs behave over multiple carriers.

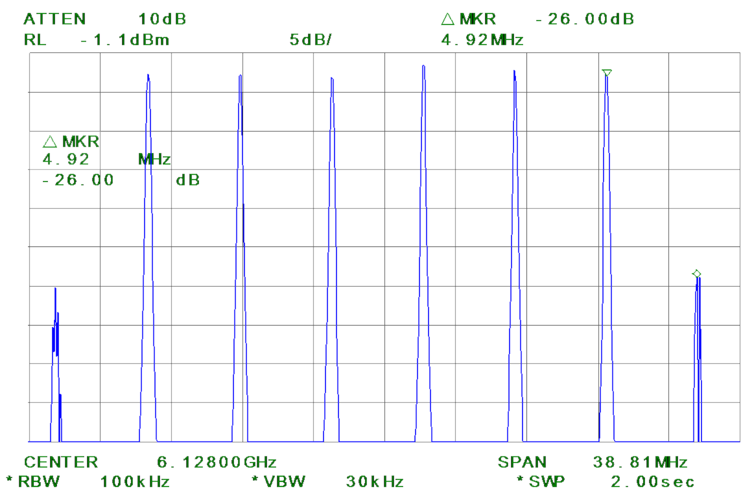

Fig 5. Typical multicarrier versus IM3 characterization.

That will be the subject of the following section.

For the purpose of this analysis, a 1.2 KW GaN based Ku-band SSPA was tested starting with 2 carriers and going up to 16 carriers, and IM3 levels were measured.

In order to simulate with maximum accuracy, the real life applications, all carriers were modulated, not CW.

The results were compared with similar published tests results for TWTs.

The conclusions are remarkably clear. GaN technology exceeds the performance of TWTs, and Klystrons and offers large linear power levels, which are simply not achievable with any other technology.

The table below presents the total back off required for a 1.2 KW GaN based Advantech SSPA, when operated with 1 to 24 Carriers, in order to meet -25 dBc third order intermodulation, IM3.

What is really interesting, is that once we reach 6 dB back off, the total number of carriers does not affect IM3 values. Actually, from 8 carriers and up to 24 carriers, all we need is just 6 dB back of in total from Psat.

Number of carriers	Actual Intermodulation (dBc)	Total Output Power, 1250W Ku-band GaN SSPA (dBm)	Total back off relative to Psat (dB)
1 carrier	Meets - 25 dBc spectrum regrowth specifications	58.5	1
2 carriers	-27.3	57	2
3 carriers	-25.5	55.5	3.5
4 carriers	-25.17	54.8	4.2
5 carriers	-25.50	54.5	4.5
6 carriers	-26.67	54.3	4.7
7 carriers	-25.50	54.2	4.8
8 carriers	-25.16	54.0	4.9
9 carriers	-25.3	53.8	5.1
10 carriers	-25.3	53.8	5.1
11 carriers	-26.66	53.6	5.3
12 carriers	-25.5	53.5	5.5
13 carriers	-25.67	53.4	5.6
14 carriers	-25.17	53.2	5.8
15 carriers	-25.5	53.0	6.0
16 carriers	-25.0	53.0	6.0
24 carriers	-25 dBc	53.0	6.0

Table 2. Total Output Power versus number of carriers for 1.250 KW GaN based SSPA, while meeting min -25 dBc IM3.

The following similar table was built using published information about linearity of 1.2 KW TWT, in the same scenario

Number of carriers	Actual Intermodulation (dBc)	Total Output Power, 1250W Ku-band linearized TWT (dBm)	Total back off relative to Psat (dB)
1 carrier	N/A	57.3	3.6
2 carriers	< - 25 dBc	57 .3	3.6
3 carriers	< - 25 dBc	55.5	4.75
4 carriers	< - 25 dBc	54.3	6.0
5 carriers	< - 25 dBc	53.4	6.84
6 carriers	< - 25 dBc	52.75	7.54
7 carriers	< - 25 dBc	52.1	8.20
8 carriers	< - 25 dBc	51.6	8.65
9 carriers	< - 25 dBc	51.3	8.95
10 carriers	< - 25 dBc	51.1	9.25
11 carriers	< - 25 dBc	50.9	9.38
12 carriers	< - 25 dBc	50.8	9.50
13 carriers	< - 25 dBc	50.7	9.60
14 carriers	< - 25 dBc	50.6	9.70
15 carriers	< - 25 dBc	50.5	9.80
16 carriers	< - 25 dBc	50.43	9.87
24 carriers	< - 25 dBc	50.4	10.20

Table 3.Total Output Power versus number of carriers for 1.250 KW Linearized TWT, while meeting min -25 dBc IM3.

The two tables provide some key information regarding multicarrier operations, in GaN based SSPAs/ TWT

1. First of all, the GaN based SSPAs levels off at 6 dB back off, which means more carriers can be added without additional back off. The TWT on another hand, requires more back off as more carriers are added.

2. Up to 4 carriers, both units behave similar, but after that, the difference is significant.

3. We can see now that for example a 1.2 KW TWT when operated with 10 or more carriers will only deliver half of the power level which can be done with the 1.2 KW Ku-band GaN SSPA.

In other words, a 1.2 KW TWT is not the equivalent of a 1.2 KW GaN SSPA anymore, but the equivalent of a 500W Ku-band GaN SSPA. This has a major impact on the entire system design, cost wise. Both CAPEX and OPEX will be significantly lower by using just a 500W Ku-band GaN SSPA.

The following charts, will summarize the findings, and will display the differences between the two technologies.

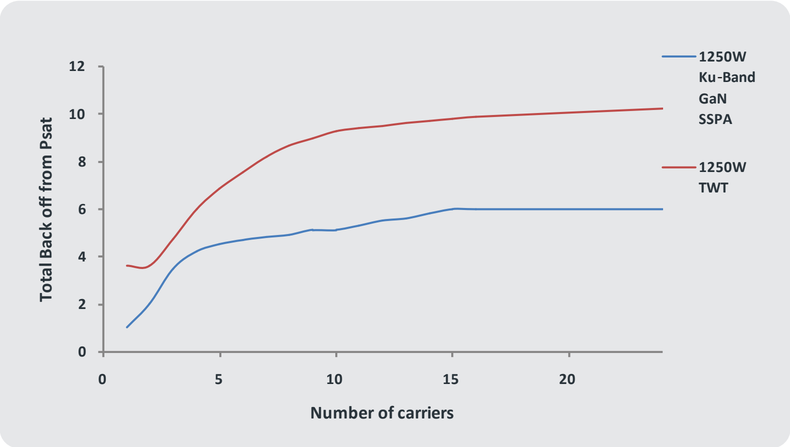

Fig 6. Total Back off from Psat versus numbers of carriers.

Blue: 1250 W Ku-band GaN SSPA
Red: 1250W Ku-band linearized TWT

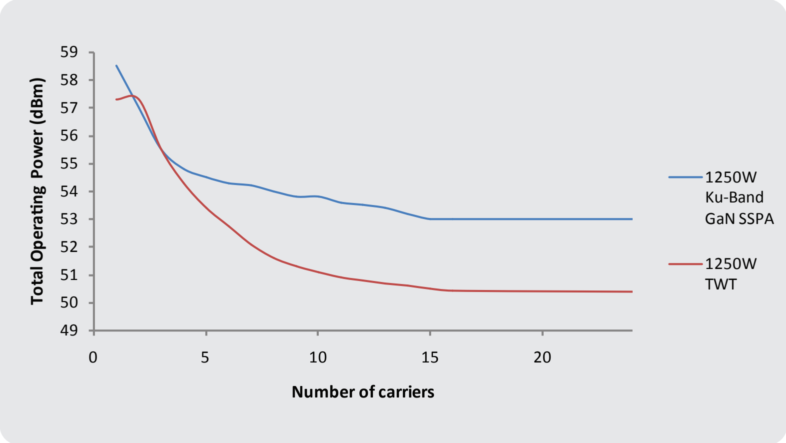

Fig.7 Total Transmit power versus numbers of carriers.

Blue: 1250 W Ku-band GaN SSPA
Red: 1250W Ku-band linearized TWT

As seen from Figures 6 and 7, GaN SSPAs require 3 to 5 dB less back off than linearized TWTs, in multicarrier operation mode, as soon as the traffic exceeds more than 6 carriers.

A Quick selection guide

It is now clear in our opinion, that just by specifying units as per usual Psat designation, is no longer good enough. That makes the job of system designer confusing. The intent of this exercise is to provide a simple guide line to selecting a high power amplifier, and to simplify it.

Considering that going forward, we will see more and more use of high order modulation schemes, and higher traffic, we believe that the following suggestions will be useful in real life applications.

The following correspondence table intends to be a quick selection tool.

The main assumptions considered here are:

1. It is required that we tolerate maximum 1 deg/dB of AM/PM degradation. This is line with transmitting high order modulation schemes as in DVB-S2.

2. It is assumed that we require minimum -25 dBc spectrum regrowth, in order to eliminate interference between adjacent channels.

3. It is assumed that we intend to transmit multiple carriers, high data rate, high modulation schemes, and wide bandwidth, as in any typical broadcast applications.

However, it should be noted that each case is particular, and proper link budget analysis should always be done. Selection of power amplifiers requires knowledge of specific satellite performance, rain fade, geographical coverage, antenna sizes , and link availability specifications.

Case 1. Single carrier mode equivalence selection guide.

No.	GaN SSPA	Previous generation GaAs SSPA	TWT technology
C-band			
1	200W	300W	400W Linearized TWT
2	350W	500W	750W Linearized TWT
X-band			
3	300W	400W	500W Sup erlinear TWT
4	400W	500W	750W Linearized TWT
Ku-band			
5	80W	100W	200W Linearized TWT
6	100W	150 W	250W Superlinear TWT
7	200W	300W	400W Linearized TWT
8	250W	350 W	400W Superlinear TWT
9	400W	500W	750W Linearized TWT
10	600W	700W	1250W Superlinear TWT

Case 2. Multiple carrier mode equivalence selection guide. (5 to 9 carriers)

No.	GaN SSPA	Previous generation GaAs SSPA	TWT technology
C-band			
1	150 W	200W	400W Linearized TWT
2	250W	300W	750W Linearized TWT
X-band			
3	250W	300W	500W Superlinear TWT
4	300W	400W	750W Linearized TWT
Ku-band			
5	80W	100W	200W Linearized TWT
6	80W	100 W	250W Superlinear TWT
7	200W	250W	400W Linearized TWT
8	250W	300 W	400W Superlinear TWT
9	300W	400W	750W Linearized TWT
10	600W	700W	1250W Superlinear TWT

Case 3. Multiple carrier mode equivalence selection guide. (10 carriers or more)

No.	GaN SSPA	Previous generation GaAs SSPA	TWT technology
C-band			
1	100W	125 W	400W Linearized TWT
2	200W	250W	750W Linearized TWT
X-band			
3	150W	200W	500W Superlinear TWT
4	300W	250W	750W Linearized TWT
Ku-band			
5	60W	70W	200W Linearized TWT
6	70W	80 W	250W Superlinear TWT
7	125 W	150W	400W Linearized TWT
8	200W	250 W	400W Superlinear TWT
9	250W	300W	750W Linearized TWT
10	500W	600W	1250W Superlinear TWT

In multiple carrier mode, for example 16 carriers, a 250W Ku-band GaN based SSPA will be the equivalent of 750 W Ku-band linearized TWT.

A 500W Ku-band GaN SSPA can easily replace a 1.2 KW linearized TWT.

A 1.2 KW SapphireBlu™ GaN SSPA will have in the same context no equivalent in TWTs.

We can now see that GaN based SSPAs are ideally positioned at both extremities. They can deliver maximum power in single carrier mode, and require minimum back off in multi carrier mode.

But the difference is even higher, when we introduce the new generation of modular very high power SSPAs.

These Advantech units now deliver 3 KW in Ku-band and 6 KW in C and X-band, by phase combining multiple units.

The main reason is that this approach provides built in redundancy, or soft failure modes. If one unit fails, it will cause the power to drop around 1 dB, which can be easily compensated by uplink power control systems.

Replacing a defective unit is relatively fast, requiring on average 30 minutes.

But the unexpected result, is that somehow, these phase combined system, perform better in terms of intermodulation, than the individual SSPAs used as building blocks.

This seems strange at the beginning, but it has a clear explanation.

When phase combining multiple units, transmitted power adds coherently, i.e. they have same phase and amplitude.

The IM3 products, do not add coherently, and in many cases, they will cancel each other.

This is visible in a real operating system, as below, where multiple carriers generate visible IM3 products on a single SSPA, Figure 8, but are not visible on a system including 8 similar units phase combined, Figure 9, even if the back off is the same.

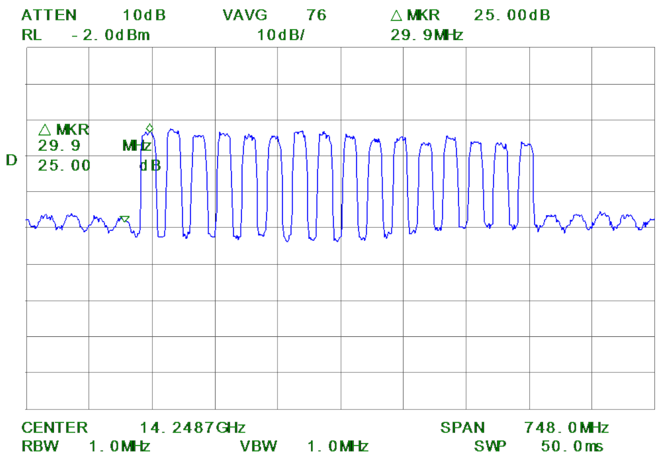

Fig 8. IM3 performance, 16 carriers, 6 dB back off, GaN based SSPA. IM3 levels are visible on sides.

The next figure below, shows the performance of a 2.5 KW system in real time operation. Although still run at 6 dB back off, the IM3 products are now cleared, or much improved, and in the noise floor.

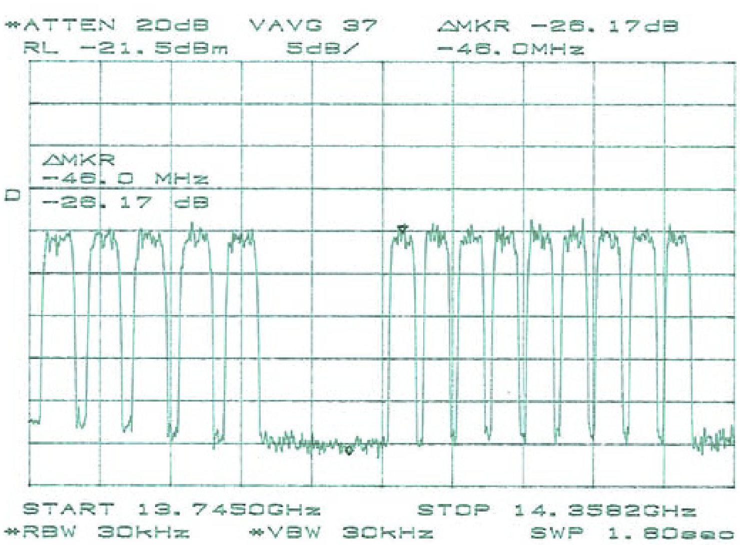

Fig 9. Real life operating 2.4 KW Ku-band GaN SSPA, multicarrier mode, 6 dB back off.

IM3 products are better than those of single SSPA, as seen in Fig 8.

The 3KW Ku-Band GaN system is now breaking any previously set limits.

It can transmit a single carrier at 2 KW, no other TWT or Klystron is able to do that.

Fig 10. 2.5 KW Ku-band SapphireBlu™ GaN SSPA.

It can also transmit 24 carriers at 600W total power, over 750 MHz.

This will be the equivalent of a 6 KW linearized TWT, if available.

A 6KW Klystron will not be adequate because it is bandwidth limited to 80 MHz only.

To our knowledge, these TWTs are not available yet, which brings us to the final conclusion.

It seems that finally now, the 50 years old debate, SSPA versus TWT, is reaching to its end.

Today, GaN based SSPAs exceed by far their TWT/Klystron equivalents.

They reach power levels with wide bandwidth that are not possible with any other technology.

They do that with higher efficiency, and much higher reliability.

This is state of the art, superb technology, the future for our Satcom needs, and the ground of all new exciting developments that are still to come.

Advantech Wireless

NORTH AMERICA

USA
Tel: +1 703 659 9796
info.usa@advantechwireless.com

Canada
Tel: +1 514 420 0045
info.canada@advantechwireless.com

EUROPE, MIDDLE EAST & AFRICA

United Kingdom
Tel: +44 1480 357 600
info.uk@advantechwireless.com

RUSSIA & CIS

Tel: +7 495 971 5918
info.russia@advantechwireless.com

ASIA PACIFIC

Tel: +1 514 420 0045 ext. 3116
info.asia@advantechwireless.com

INDIA

Tel: +91 33 2415 5922
info.india@advantechwireless.com

SOUTH AMERICA

Tel: +1 514 420 0045
info.latam@advantechwireless.com

Brazil
Tel: +55 11 3054 5701 (São Paulo)
Tel: +55 21 3578 5632 (Rio de Janeiro)
info.brazil@advantechwireless.com

Venezuela
Tel: +58 21 2844 3545
info.venezuela@advantechwireless.com

Mexico
Tel: +521 55 5435 4989
info.mexico@advantechwireless.com

Colombia
Tel: +57 315 596 1857
info.colombia@advantechwireless.com

At Advantech Wireless we provide industry-leading innovations in advanced end-to-end satellite communication technologies. Our commitment is to help our customers achieve best performance and maximize ROI by providing complete customized turnkey solutions. We design, manufacture and deploy networking solutions for broadband connectivity, broadcast solutions and backhaul requirements using satellite and terrestrial wireless communications.