High Power TWTA Systems

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Introduction

This paper describes the advantages of using traveling wave tube amplifiers (TWTAs) for high power applications. The applications can vary but often have a common theme of transitioning from klystron power amplifier (KPA) solutions to traveling wave tube amplifier (TWTA) solutions. The reasons for this migration to TWTA solutions vary from customer to customer. Some examples are provided. The same reasons also prompt customers to focus on TWTA solutions for new high-power installations.

The two main applications where the KPA versus TWTA decision is involved are Direct to Home (DTH) applications and high-power applications. In these applications, KPAs have been the traditional choice for many years. However, with the push to higher frequencies where a klystron solution is not available, customers have transitioned to TWTA solutions. In doing so, the traditional approach of using KPAs at lower frequencies is now questioned. The availability of higher power TWTAs, the application of combining techniques to TWTAs, and higher power satellites has enabled TWTA solutions to be considered as desired alternatives to KPA solutions.

There are many benefits to using broadband TWTAs for these demanding applications. The main one is the ability to mount the outdoor capable TWTAs close to the antenna. Considerable power can be saved by generating the RF power close to the antenna feed while also eliminating the problems and costs of cooling indoor equipment.

Direct-to-Home Applications

DTH systems transmit multiple carriers for wide-area distribution "direct to the home". Typically these transmission systems employ klystron-based solutions with switching redundancy, then frequency multiplexing, and finally a long run of waveguide from the indoor facility to the antenna. This complex and expensive approach is required due to the limited bandwidth of a klystron power amplifier (KPA) and the large indoor rack mounted nature of the KPA. A typical 1:4 KPA system is shown in figure 1.

1:4 KPA System		
KPA power	dBm	63.0
Switching losses	dB	-0.25
Frequency multiplexing Losses	dB	-1.0
Waveguide losses to antenna	dB	-10.0
Power at the antenna flange	dBm	51.8
Back off required (TOPBO)	dB	0.0
Per carrier output power (dBm)	dB	51.8
Per carrier output power (Watts)	W	149.6

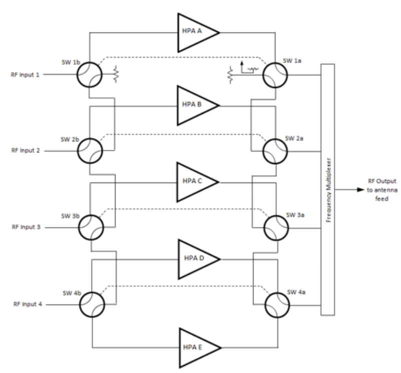

***Figure 1.** One-for-Four KPA System for DTH Application – one polarization shown*

In a one-for-four (1:4) system, four KPAs – one for each carrier – are primaries, and one KPA is available to back-up one of the four primary KPAs should one fail. The four primary KPAs operate at different frequencies and the back-up KPA must have a fast tune capability so it can be automatically tuned to any one of the primary KPA frequencies. The back-up KPA is engaged using coax and waveguide switches. A controller is used to perform the switching function. The switched outputs are then frequency combined to a common waveguide output which is fed to the antenna feed port. This system architecture would be repeated for each polarization.

The high-power multiplexing waveguide system poses significant issues. Firstly, the frequency assignments must be known when ordering and cannot be changed. Secondly, the multiplexing system cannot combine adjacent channels; a guard band is necessary. If complete transponder coverage is required, this can mean that two antennas are required; one to handle odd transponders on a pol, the other the even transponders on the same pol. Often the power handling capability of the multiplexer is limited due to the potential for waveguide arcs. This limits the power available from the system and may mean the KPA cannot be run at full power output. Adding an extra channel will involve introducing another KPA along with changing the cooling system, redundancy system and multiplexer system.

TWTAs, with their higher instantaneous bandwidth, can provide much more power directly to the antenna and can also simultaneously transmit multiple carriers. Furthermore, a TWTA amplifier can be designed to withstand the environment and can be mounted outdoors or inside an antenna hub. These capabilities eliminate the loss and the system complexity associated with switching and frequency combining of klystron amplifiers.

As the wideband TWTA allow different approaches to the DTH application, multiple solutions with different systems and amplifiers are possible. The solutions can vary depending on the frequency band and power requirement. A 4-way combined TWTA solution at DBS band is shown below but the solution is equally applicable to other bands.

In a 4-way Continuous Power System, each polarization has four amplifiers operating with their outputs phase-combined. If one amplifier shuts down, the combined output power of the system will drop 2.5dB. Control of the system can recognize the loss of the amplifier and adjust the other amplifier outputs up to compensate for the loss. In this system solution, the output RF signal never drops to zero. This architecture is shown in figure 2. In this scheme, each antenna would require two of these systems – one system for each polarization.

The output power for each polarization is 62.9 dBm at the input flange to the antenna. Assuming the system operates at 4.0 dB of back-off, the total useable output power at the antenna flange is 776 Watts (58.9 dBm). If one amplifier should shut down, then the available output power will drop to 436 Watts (56.4 dBm). Each amplifier contains a linearizer. Input and output networks are phase-matched to ensure balance between all the amplifiers within the system.

4 Way Continuous Power System

TWTA power (XTD-750DBS)	dBm	58.1
Isolator losses	dB	-0.2
Combining gain	dB	6.0
Hybrid losses	dB	-0.7
Waveguide losses to antenna	dB	-0.3
Power at the antenna flange	dBm	62.9
Back off required (TOPBO)	dB	-4.0
System output power (dBm)	dB	58.9
System outpower (watts)	W	776.2
Power per carrier for 4 carriers	W	194.1

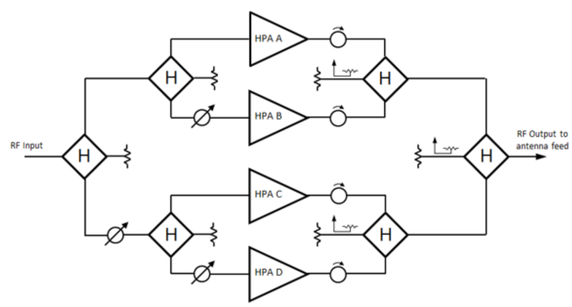

Figure 2. *Four WayTWTA Continuous Power System – one polarization shown*

More power is possible by using more powerful TWTAs such as the XTD-1250DBSHE, or by combining more amplifiers in an 8-way combined system. One advantage of the 8-way approach is the loss of an amplifier in the system has a reduced impact; the output power capability drops by 1.16dB compared to 2.5dB in the 4-way combined system. At the operating power level, the loss of output can be compensated for by adjusting the output of the remaining amplifiers up. This auto-recovery takes the place of the traditional redundancy switching. The result is a system that has no breaks in transmission due to redundancy switching; hence, the name “Continuous Power System”.

The per-carrier EIRP, and the number of carriers for a given application will vary. Higher or lower power can be accommodated by TWTA and system configuration choices. Irrespective of the system, it is important to realize that with a TWT amplifier system, carriers may be added without the need to install more amplifiers if the system operates within the power and linearity requirements of the amplifier.

Isolators at the input to the combining structure can be included. These allow a failed amplifier to be safely replaced while the rest of the system continues to transmit

The efficiency of the system is high as all TWTAs contribute to the output power of the system. No amplifier is operating as a back-up waiting for its output power to be utilized when a fault occurs.

High-Power Applications

Some of the advantages as described for the DTH applications are of value in high-power applications. In these high-power applications, the high power is desired to ensure the transmission is maintained under adverse conditions. The soft-fail nature of the Continuous Power System is ideally suited for this application.

High power KPAs are often used to overcome the significant power loss between an indoor installation and the antenna feed. By mounting an outdoor TWTA close to the antenna, the RF output power required can be reduced. This has an added benefit of eliminating the cooling issues associated with indoor KPA systems. Chiller systems are often less reliable than the KPAs and present significant maintenance issues for operators. With the reduction in output power and the elimination of the indoor cooling systems, overall electricity consumption can be drastically reduced, providing an ongoing savings in electricity year after year compared to the KPA solutions.

The systems involved in these applications vary considerably and will depend on the actual power required.

KPA versus TWTA Comparison

The preceding sections have focused on the TWTA system advantages compared to KPA systems. When looking at the individual amplifiers, several other advantages can be identified beyond the main benefit of suitability for outdoor environments:

- Individual TWTAs can be treated as Line Replaceable Units (LRUs).
- TWTAs are smaller and lighter
- TWTAs can be easily transported (klystrons have strong magnetic fields and special arrangements are required to transport)
- TWTAs are easier to operate and maintain (KPAs require more experienced technicians).
- Multiple TWT vendors are generally available to provide ongoing TWTA support.

Application Examples

A few examples are presented where customers have chosen TWTA solutions. In some cases, these TWTAs systems are replacing existing transmission solutions based on KPAs.

Example 1 – 1:1 KPA replaced by 4-Way Continuous Power Systems

In this example, a US Defense Contractor has replaced antenna mounted 1:1 KPA systems with antenna mounted 4-way XTD-750DBS Continuous Power Systems. 3 systems to date have been updated with the CP systems. Locations are unknown.

Advantages were soft-fail characteristic; no break in transmission with a TWTA off-line. Power automatically adjusts back to the original power output following a TWTA going off-line. The system was designed with waveguide quick-disconnects and TWTA slide mounting to enable fast TWTA replacement if necessary.

The customer had also raised concerns over KPA availability and the ability of the KPA to operate with the amplifier tiled due to antenna elevation.

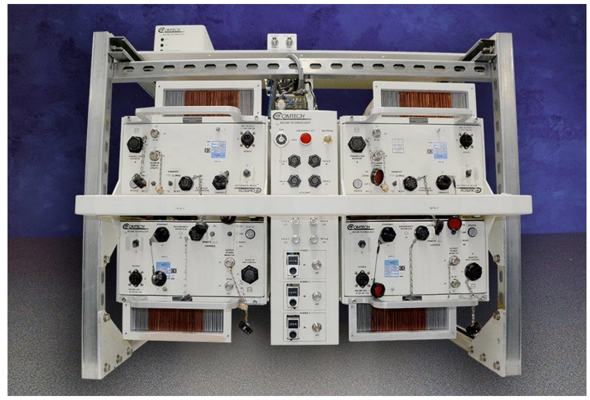

Figure 3. *Four WayTWTA Continuous Power System*

Example 2 – Multiple 1:1 KPA Systems replaced by 2:1 XTD-750C Systems

In this example, a major Cable TV distributor in the USA (facility in Long Island, NY), is replacing multiple indoor 1:1 KPA systems with antenna mounted 2:1 XTD-750C systems.

Advantages were significant electricity savings and reclaim of building floor space for future expansion of streaming services. The calculated electricity saving once all 32 KPAs had been transitioned to TWTA systems was $85,000 per year. This calculation did not include the savings associated with eliminating the large chiller system to cool the KPAs. Currently, 6 x 2:1 XTD-750C systems (18 TWTAs) are installed with a 7th system planned for 2021. This is an ongoing, long term project to replace all KPAs over an extended time frame.

The 2:1 system was desired to ensure the critical services would maintain a redundancy ready configuration even after a TWTA fault. This allowed corrective action to only be necessary during normal working hours. This system also included output load and polarity select switches.

Customer had raised concerns over KPA availability and reliability of indoor chiller systems.

Remote controller touchscreen display for the 2:1 TWTA system is shown in figure 4.

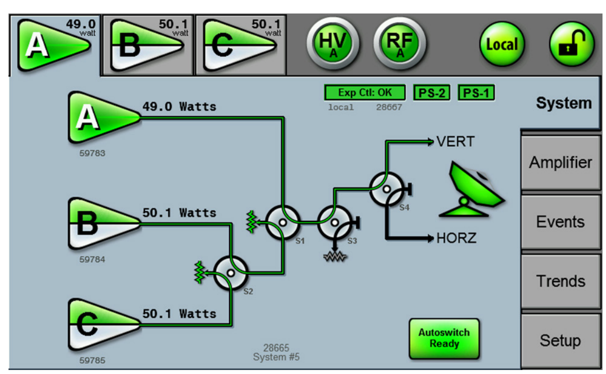

Figure 4. *2:1 TWTA System Remote Controller Screen*

Example 3 – New 1:2 XTD-1250KHE with Hybrid Combining

In this example, a major DTH Broadcaster in Latin America (Brazil) has installed 3 new antennas with 1:2 XTD-1250KHE TWTAs systems with hybrid combining on both pols. 3 existing antennas have KPA systems supporting the uplinks. These will eventually be upgraded to match the new TWTA systems.

A 1:2 XTD-1250KHE system with phase combining is shown in figure 5.

***Figure 5.** 1:2 XTD-1250KHE TWTA System with Hybrid Combining*

Example 4 – New 4-Way Continuous Power Systems

In this example, a US Defense Contractor has ordered two antenna-mounted 4-way XTD-750DBS Continuous Power Systems. These are currently being built ready for new installations.

As per example 1, the advantage was the soft-fail characteristic; no break in transmission with a TWTA off-line. Power automatically adjusts back to the original power output following a TWTA going off-line. The system was designed with waveguide quick-disconnects and TWTA slide mounting to enable fast TWTA replacement if necessary.

The remote controller touchscreen display for the 4-way Continuous Power System is shown in figure 6.

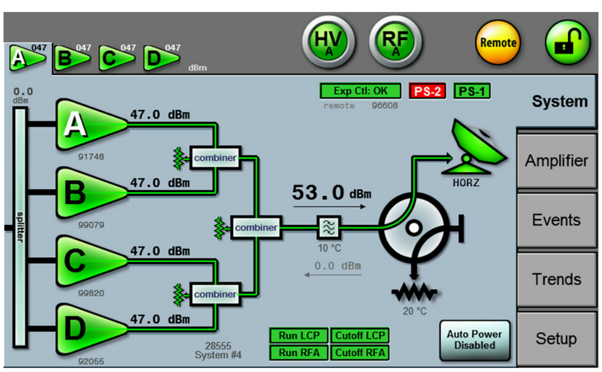

***Figure 6.** Four Way Continuous Power System Remote Control Screen*

Example 5 – Hypothetical 4-way TWTA CPS vs 1:4 KPA/Mux System

In this hypothetical example, Xicom evaluated the purchasing decision between a 4-way XTD-750DBS Continuous Power System and a 1:4 DBS-band KPA system with a 4-channel multiplexer on the output. Including the equipment room floor space, UPS requirements and HVAC requirements, significant savings can be obtained with the Continuous Power System approach.

Analysis shows that the Continuous Power System, compared to a 1:4 KPA solution with multiplexer, has:

- ❖ Capital equipment costs down **57%**.
- ❖ Annual electricity power consumption/costs down **89%**
- ❖ Facilities and ancillary equipment (chillers and UPS) costs down **81%**
- ❖ Overall equipment and operating expense savings over a period of 7 years (includes 5% cost of financing) down **70%**

These savings are in addition to the benefits of easier maintenance and operations, and the ability to easily expand the number of carriers.

Conclusions and Recommendations

The use of high power TWTAs capable of outdoor operation enable cost effective and efficient high power transmission systems. Wherever possible, it is recommended to use an antenna mounted TWTA system to prevent wasting power in a transmission line from an indoor location to the antenna. The outdoor TWTAs eliminates the need for major indoor cooling systems. This, along with the improved efficiency of TWTAs compared to KPAs, and the efficient Continuous Power System approach reduces the UPS requirements. Earth station efficiency is significantly improved reducing the "carbon footprint" of the earth station and reducing operating costs.

For Direct-to-Home applications, additional benefits can be obtained by eliminating the need for expensive and rigid multiplexer systems. The broadband nature of a TWTA based system can significantly reduce the number of amplifiers required and allow new channel requirements to be met easily when the system is appropriately sized for the expansion. Potential problems with waveguide multiplexing such as power limitations and adjacent transponder operation are eliminated.

For high power applications, the outdoor TWTA system approach reduces operating costs compared to KPA solutions. This is achieved with a much lower capital investment compared to KPA solutions.

Xicom has designed and supplied many high power TWTAs systems. The most appropriate solution will be dependent on several factors including the size and number of carriers required, the output power margin desired, the degree of redundancy required, and the desired initial capital and operating costs. Xicom has the experience to work with customers to achieve the most appropriate solution for all applications.