satcom division

TechNotes

Overview of Amplifier Technology Choices for Ground Based Ka-band Amplifiers

Given at the 5th Ka Band Utilization Conference, Taormina, Sicily Island, Italy

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Ground based satellite communications amplifiers are either based on solid state devices or vacuum electron devices (VED). Conventional thinking relegates solid state, klystron and TWTs to certain roles based on output power, instantaneous bandwidth, packaging, and other attributes. Recent design improvements and the availability of a broader array of devices challenge that thinking. This paper explores the Ka-band amplifier choices that are now available.

Introduction

High power RF signal amplification was invented many years ago. It has had a long history in playing a key technology role in a variety of applications ranging from military and radar systems to commercial communication systems. In the 1960s, the dream of satellite communications was made a reality. Since then, advances in modulation, amplification and antenna techniques as well as frequency availability have made satellite communications a huge success.

Due to the long history, there are certain assumptions that everyone makes concerning the abilities of certain technologies and what they cannot do. Most people have been predicting the demise of the "tube" due to encroachment by solid state. This is definitely true in the case of lower power and lower frequency. However, there are still plenty of applications where a tube-based approach is the only solution.

The tube industry hasn't been standing still as solid state devices have advanced. Developments in helix TWTs include size reduction, conduction cooling for ground applications and efficiency gains by using multi-stage collectors. Klystrons have been gaining ground also, with recent release of multistage collector klystrons for the C, Ku and DBS frequencies, expanded instantaneous bandwidths (bw), higher powers and the use of air cooling where liquid cooling historically was the only way.

Along with the advances in tube and solid state devices, the amplifier manufacturers have made great strides in improving the complete High Power Amplifier (HPA) package and subsystems. HPA sizes have shrunk considerably, power handling is better, costs have come down, microprocessor control is now standard, other features have increased and reliability is better than ever.

A basic tube-based HPA block diagram (this one for a TWTA) is shown in Figure 1. The basic blocks are the same whether it is a TWTA or KPA. There are minor functional differences between tube and solid state based HPA block diagrams.

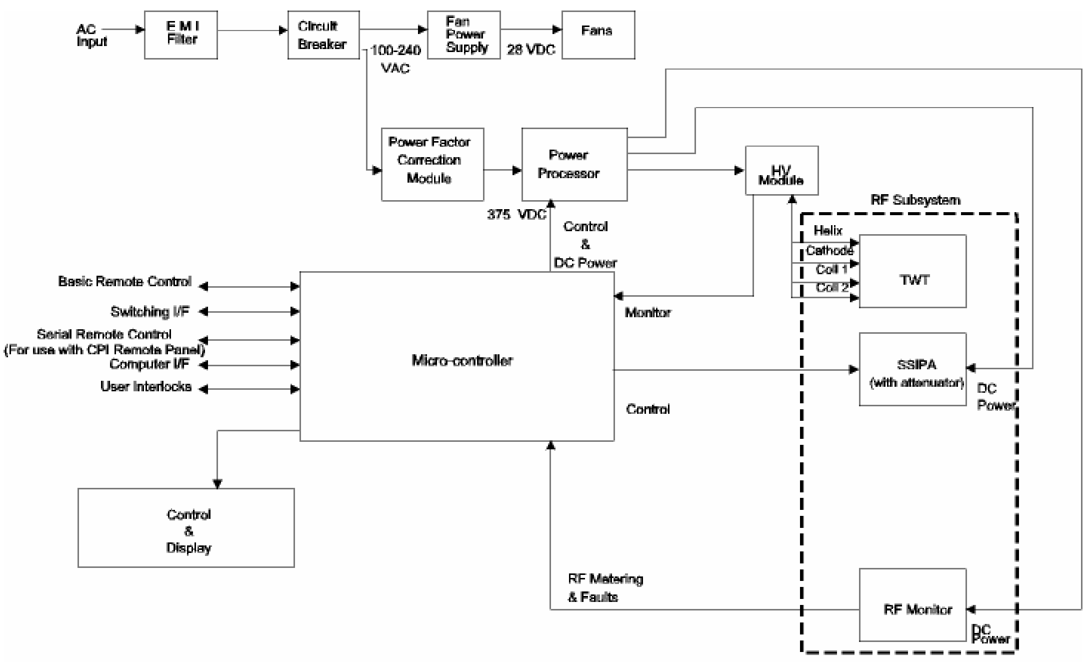

Figure 1

Solid State Power Amplifiers (SSPAs)

SSPAs are expected to completely dominate tube-based HPAs in the future. The question is just a matter of when: 5 years or 20 years. Devices have been made that operate over the required Ka uplink frequencies, even though the technology is inherently a narrow band one, with generally 500MHz of instantaneous bandwidth. High volume production is available today for low power devices (1W and less) for point-to-point microwave radios.

Looking to the future, both terrestrial and satellite systems should provide additional production volume requirements. People are planning for huge volumes of low power 28GHz amplifiers to support the expected global LMDS/LMCS network growth. End-user terminals for the upcoming satellite systems are being proposed and built in small quantities to use 0.5W to 2W SSPAs. Power levels of 100mW to 1W have been demonstrated in production-type volumes. The higher power SSPAs are still only produced at low volume, engineering-build type levels.

Solid state modules are designed by matching and combining individual devices along with a gain stage. The lower power requirements are integrated along with the upconverters to reduce cost and improve manufacturability. Modules are power combined in order to reach SSPA P1dB output power levels of 5W or greater. 20W is currently considered the cutting edge while still reproducible. The additional steps of power combining provides an additional benefit of built in soft-fail capabilities, however it also means more complexity, more difficulties in cooling, larger physical size, and increased cost.

SSPA Advantages

- High volume production capability
- Built in soft-fail capabilities in case of single device or module failure
- No expected RF section sparing requirements
- Inherently good linear performance for multicarrier, digital transmission

SSPA Disadvantages

- Practically limited in the near term to low output powers
- Highly inefficient
- Increased size and weight at the higher power levels due to the added cooling requirements (air flow, heat sinks etc)

Traveling Wave Tube Amplifiers (TWTAs)

TWTAs are prevalent in non-mmWave satellite communication applications requiring instantaneous, broadband coverage with low to high power output. In the case of Ka band, TWTAs again have wide, instantaneous bandwidths (2.5 GHz but tuned for the optimal operation over the required 500 or 750 MHz) at low to medium power levels (10-200W at the flange of the tube). TWTAs have been the historical preferred Ka band communication HPA for any power requirements over 10W.

Current amplifiers are working full-time and proving to be extremely reliable and worry free, with field data MTBF figures of greater than 30k hours. Recent TWTA developments in Ka band include:

1. The ability to use multistage, depressed collectors to increase efficiency (therefore reducing packaging size, cooling and input power requirements)
2. The development of a 10W linear TWT that can be packaged as a microwave power module (MPM), a complete HPA or as a complete IF to Ka radio/transceiver
3. The development of a "personality interface" option on certain HPAs that provides the ability to use various brands of TWTs without the need for power supply tweaking between types.

TWTA Advantages

- Low to medium output power requirements (10W-200W)
- Proven fielded robust performance
- Efficient operation
- Instantaneous, broadband capability
- Long Life
- Improved linearity (~6dB) with an optional linearizer

TWTA Disadvantages

- TWT production limited to 1000's not millions per month
- Physical deterioration requires eventual replacement of TWT
- No soft-fail capability in case of failure (unless the HPA is part of a 1:n or power combined subsystem)

Klystron Power Amplifiers (KPAs)

Klystron power amplifiers have historically been used for high power, narrow band applications such as video uplinking. Klystrons, due to their narrower bandwidths, perform very well in terms of 3rd order intermodulation (IM3) performance. High power also allows more headroom for backoff for optimal linear performance. Klystrons and klystron power amplifiers have developed a reputation as extremely reliable technologies. CPI's C & Ku band klystrons have shown average life spans of 7.5 to 8 years.

Recent KPA developments include:

1. The development of multistage depressed collectors (MSDC) for C & Ku band, which can be leveraged onto the Ka band versions. This increases efficiencies (therefore reducing size, cooling requirements and input power requirements)
2. Development of digital ultrafast tuner for C, Ku and DBS bands providing channel changing times of less than 1 second (virtual instantaneous bandwidth)
3. The availability of an Extended Interaction Klystron (EIK) with an expected 700 W power output and 1 GHz instantaneous bw. Proven power and bandwidths at Ka band include:
    i. 600W & 400 MHz bw
    ii. 300W & 900 MHZ bw
    iii. 400W with dual mode bw
4. Proven air cooling capability of standard klystrons (vs. historical water cooled requirements)
5. Standard klystrons are now available with up to 125 MHz instantaneous bandwídth and up to 1.2kW power level at Ka band frequencies
6. Studies to move to high efficiency and conduction cooling for the EIKs
7. Installed and operating high power communications klystron power amplifiers at Ka band

KPA Advantages

- High power capability to improve availability
- Inherently good linear performance for multicarrier, digital transmission
- Provide a cost effective, lower power solution for applications like tracking, telemetry & control (TT&C)
- Efficient through utilization of MSDC technology
- Broad instantaneous bandwidth through EIK technology

KPA Disadvantages

- Narrower instantaneous bandwidths
- Today's production capability limited to 10s to 100s per month

Overall HPA configuration and packaging trade-offs

Amplifiers are available in a variety of packages depending on the system designer's preferences. Since RF losses at Ka band are so high, it is optimal to mount the RF section as close to the antenna feed as possible. Suppliers provide HPAs in one of three different packages: hubmount (or weatherized), rackmount or splitmount.

Hubmount units are single box HPAs that can be mounted and operated outside of a shelter, whether they are on the arm of the antenna, the back of the antenna, on the roof near the antenna or some other outdoor location. They are usually specified to operate over a temperature range of -30° or -40°C to +50°C, using standard adiabatic derating for altitude. Environmental specs are usually similar to the US military's "mil-spec" product requirements.

Rackmount or indoor packages products are not usually the first choice for Ka band system designers due to the losses from waveguide runs from the HPA to the antenna. That said, rackmount Ka band HPAs are preferred by some customers in the EMI/EMC testing equipment market.

Single outdoor box: Advantages

- Single box to install
- No interconnect cables
- Enables longer connections from main station to HPA/antenna (no limited by high voltage cables)
- Weatherized for locating outside as close as possible to the antenna feed for reduced RF losses

Single outdoor box: Disadvantages

- Maintenance is more difficult due to required removal of complete amplifier
- The outdoor environment is more stressful (even for properly rated components) than the indoor, "controlled" environment possibly affecting long term reliability

Splitmount: Advantages

- Smaller, lighter package for mounting on/near antenna
- There is less environmental stress on power supply/M&C section
- Maintenance on indoor section can be done with out exiting shelter and disconnecting waveguide etc
- Part sparing can be done at a complete RF level for easy replacement of the RF section allowing minimal downtime and a less expensive "spare" than a complete HPA

Splitmount: Disadvantages

- Requires external cables
- Limited to max 100m between shelter and RF section

Rackmount: Advantages

- Easy to install and connect with other earth station equipment
- Easy access to the unit for routine maintenance
- Reduced environmental stress on the amplifier, improving expected long term reliability

Rackmount: Disadvantages

- Potentially more expensive system design requirements due to longer waveguide runs
- Higher power required due to increased signal losses because of added waveguide runs from the amplifier to the feed

Conclusion

In conclusion, one can see that there a variety of choices are available to the system designer when considering the HPA and the key role it plays in a system's link budget. Advances in tube technology enable designers to look at high power technologies without giving up full bandwidth coverage. Field data is disproving some people's perception of poor tube reliability. SSPA designs are improving in both power output and efficiency. Because the opportunity is so great, HPA suppliers will continue to work hard and push the technology to better support the technical and economic requirements for the new Ka band systems.