Total Cost of Ownership
A Comparison of SSPA and TWTA Amplifier Systems

Background

Solid state circuitry has been steadily replacing vacuum-tube technology since its invention in 1948. Beginning with the early transistor radio receiver, and continuing with the television receiver and the computer, solid state systems have become ubiquitous in our society. As solid state systems have evolved there are two inexorable trends in their development, increasing operating frequency and increasing power output. In fact, two vacuum tube dominated applications, high powered HF, VHF, and UHF transmitters for broadcasting, and high powered microwave amplifiers for satellite systems are now migrating to solid state systems in response to those trends.

The following discussion examines some of the factors that are enabling the proliferation of solid state technology in the microwave amplifier field. This is based on the best knowledge currently available and will serve to introduce the operational differences between solid state and tube technology.

Non-Linearities in Amplifiers

Microwave systems use amplifiers that are required to process complex signals faithfully and in many cases there are a number of independent signals being carried through the amplifier. In order to assess the potential of amplifiers on a standardized basis, the two tone intermodulation distortion test is used. In this test two signals of a standard type are passed through the amplifier under test (two tone IMD) and the output of the amplifier analyzed. The amplifier output will include the original signals and a number of new signals generated by interactions within the amplifier. The strongest of those undesired signals are quantified and used to determine how the amplifier must be operated. These are the third order intermodulation products, or IM3 which are generally located close in frequency to the desired signals and therefore cannot easily be filtered out. The results of this test indicate whether the amplifier is suitable for the service required.

In addition to the third order intermodulation products, digital signals (i.e. QPSK) passing through a microwave amplifier generate sidelobes which effectively spread the signal across more of the spectrum than it needs, potentially causing interference to other services.

Linear Operation

In order to reduce the generation of IM3 products to an acceptable level, the amplifier must be operated under the most linear conditions feasible, which is at less than its full rated power. Most satellite standards require that the IM3 products be at least 26 dB less (-26 dBc) than the desired signals being carried. Neither solid state nor tube type amplifiers can satisfy this requirement when operated at full rated power. It is necessary to reduce the output power to reach an acceptable intermodulation value. A unit reduction in output power results in the intermodulation distortions being reduced by several times. Typically, for TWTAs, for every dB that the amplifier's power is reduced, or " backed off " from rated power, the IM3 products are reduced 3 dB. For example, a TWTA must be backed off 7 dB or more in order to keep the generated intermodulation distortion at or below –26dBc level.

Experience shows that an SSPA can achieve an intermodulation performance of -26dBc with an output back-off of only 2.2 dB. This gives the SSPA a performance advantage of 4.8 dB, requiring an SSPA that is approximately one third the power rating of a TWTA for a given application. Conversely, a TWTA about three times the rating of an SSPA is required for the same useable power output.

Amplifier Placement

The size and low voltage characteristics of SSPAs can be exploited in many installations by placing the HPA at the antenna to reduce the length of, and losses through, the transmission line between the HPA and the antenna system. The load placed on the air conditioning system is reduced which yields both capital cost and operating cost savings. This strategy can significantly reduce the power required from the amplifier and result in both capital cost and operating cost reductions compared to conventional indoor technology.

Energy Cost

In many locations the costs for electricity contribute significantly to the overall operating cost of electronic equipment. In the case of microwave amplifiers there are two principal components to this energy cost. The first is the actual input energy to the amplifier, and any reduction in that amount is a direct saving. The second is the cost to maintain the equipment environment at acceptable ambient conditions, for example by providing HVAC (Heating, Ventilation and Air Conditioning). It should be noted that Hub Mount amplifiers designed to operate at the antenna do not impose any HVAC load on the building air conditioning system.

In the case of standby equipment, the SSPA may be left in a muted mode which consumes very little power. When it starts operation as a replacement for an operating amplifier it starts instantly to offer smooth continuous service. The TWTA amplifier must be maintained in a fully operating condition if it is to be available for instant takeover. This involves costs for both the power used and the need to replace the tube at the same intervals as the other operating tubes. Both of these cost components may be reduced by using amplifiers that are the most efficient available. The following table compares the power needs for some equivalent typical solid state and TWT microwave amplifiers. Using Hubmount equipment would reduce the HVAC cost for SSPA. Costs for energy may be higher in certain jurisdictions and the savings would be more than shown.

Energy Cost Comparison – TWTA vs SSPA Equivalent C-Band Systems			
System Type	Power Consumed KWH/year	Cost Of Power Annual Cost	Present Value of Power Cost 10 Years
TWTA 700 Watt System 1:2 Redundant	104,832 typical	$15,723	$118,000
SSPA 400 Watt System 1:2 Redundant	48,921 typical	$7,338	$55,080
Present Value of SSPA vs TWTA Power Savings for 10 Years			**$62,920**

Notes:
1. These figures are for 24 hour-per-day continuous operation
2. Electricity cost estimated to be $0.15 per Kilowatt-hour
3. Figures do not include HVAC

The savings are shown as the present value of annual savings over a ten year study period. In this calculation, interest is 6% annual, and power bills are paid each month.

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Spares Costs

In addition to the direct costs of electricity, the replacement of parts of the amplifier which wear out must be calculated. In the TWTA case it is the TWT which must be replaced when it can no longer meet its specifications due to aging. A typical maintenance schedule would require tube replacement every 3 to 4 years. The cost for replacement TWT's is between one third and one half the cost of a complete TWT amplifier. The SSPA has no electronic parts that require replacement due to aging, however it is recommended that mechanical fans be replaced at regular intervals.

Spares Cost Comparison – TWTA vs SSPA Equivalent C-Band Systems			
System Type	Replacement Parts typical cost	Replacement Interval	Present Value of Replacement Parts 10 Years
TWTA 700 Watt System 1:2 Redundant	$40,000 per tube $120,000 for system	Every 4 years Starting at Year 4	$203,800 estimated
SSPA 400 Watt System 1:2 Redundant	$ 225 typical per fan $ 675 for system	Every 2 years	$ 3,300 estimated
Present Value of SSPA vs TWTA Spares Savings for 10 Years			**$ 200,500 estimated**

Notes: 1. These figures are for 24 hour-per-day continuous operation
2. TWTA system standby transmitter operated in hot-standby mode
3. The savings are shown as the present value of annual savings over a ten year study period. In this calculation, interest is 6% annual.

Personal Safety

Solid state devices operate at low voltage with high currents. Vacuum tube systems depend on much higher voltages at lower currents for their operation. In general, high voltages are by their nature a peril to anyone who is involved with maintenance, adjustment and fault correction. High currents, on the other hand, require far less caution from a personal safety standpoint. The normal operating voltage in solid state amplifiers seldom exceeds 12 volts, the same as is used in a motorcar. Tube amplifier manufacturers must design elaborate safety precautions into their equipment to prevent accidental operator contact with dangerous high voltages, resorting to complex safety interlocks and other schemes.

Reliability

SSPAs are designed with multiple output devices (transistors) in parallel, and the resulting cost to repair or replace a single device is far less than the cost of tube replacement. The other benefit in this design strategy is to limit the signal loss in the event that one output device in an SSPA becomes defective. The typical signal reduction under that circumstance is 0.5 dB or less.

The reliability of the microwave power Gallium Arsenide Field-Effect Transistors (GaAs FETs) used in today's solid state power amplifiers is so good that their mean time between failure (MTBF) is measured in millions of hours.
Generally, other common electronics components are more likely to fail than the output devices. The standby amplifier in redundant systems is ready to switch on at a moment's notice. The SSPA amplifier on standby is

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muted to reduce its power consumption while idle to a low value. The standby amplifier can take over service in less than a second when needed. The standby TWTA may require a significant warm-up period and as a result must be fully powered while it waits to be used. In addition to the direct power costs this is a factor that reduces the useful life of the standby traveling wave tube.

Maintenance Aspects

Solid-state power amplifiers are easier and safer to maintain, have higher reliability, lower maintenance and operating costs and lower spares costs than vacuum tube amplifiers. Typical preventative maintenance on an SSPA consists of keeping the air inlets and outlets free of dirt, and replacing the fan(s) approximately every five years. With TWTAs, the power output continually decreases as the tube ages, requiring readjustment and eventual tube replacement. There is no equivalent aging mechanism in an SSPA.

Amplifier Management and Control

(The following description is typical for SSPA products by Advantech and others) The Monitor and Control system is driven by the monitor and control (MAC) modules located in every amplifier unit of an SSPA . Each MAC module contains a microprocessor that monitors all key operating parameters and status of the amplifier (i.e output power, baseplate temperature, power consumption and switch position). For the gain adjustment (in driver unit) the 12 bit DAC (Digital to Analog Converter) provides a 0.1 dB step increment across the full 20 dB range of the attenuator.

Through a menu driven interface all the key operating parameters and status can be verified locally via the alphanumeric display, or remotely via the RS232 or RS 485 /422 serial interface. Each of the amplifier units has its own serial interface address and may be accessed individually. The serial interface address is assigned during the unit set up and may be changed by the operator using the serial interface software. The built in test facilities (i.e. output RF detector, reflected power detector) when combined with other monitored parameters provides an effective means for troubleshooting. The calibrated input and output sample ports provide a convenient means to locally verify the operation during service.

Conclusions

In summary, it would appear that the use of solid state power amplifiers offers superior IMD performance, higher reliability, lower maintenance cost, lower cost of spares, longer operating life, higher personnel safety, lower power consumption, reduced cost of electricity and, in the end, lower total cost of ownership.

Where extremely high reliability is required the SSPA in redundant configurations offers protection on a number of levels, from the actual amplifier modules to the instant-on hot standby equipment and switching that effectively provides uninterruptable communications services for common carriers and broadcasters alike.

**Figure 1 500W C-Band
1:2 Hub-Mount System**

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