Comparative analysis of HPA technologies for DTH Broadcast Earth Stations

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Abstract
Modern Television and Broadcast technologies are Satellite based and therefore there exist Earth Stations for the various teleport networks involved in signal transmission, whether it is primary C band TV broadcast or DTH Ku band broadcast, Earth Stations with RF setup are mandatory for signal transmission, Antennas play key role in beaming the signal towards Satellite at transmitter side and receive antennas at receive side. HPA(High Power Amplifiers) feed Antennas with power which is finally beamed as EIRP towards satellite, so it's the HPA that adds life to a baseband modulated and up-converted low power signal by amplifying it many times , HPA technology primarily have three popular variants i.e. TWT(Travelling wave Tube) based, Semiconductor based SSPA's (Solid State Power Amplifier) and Klystron based KPA's (Klystron power amplifier), generally these three technologies has dominated the HPA market in Broadcast Engineering's RF installations, In this paper suitability of HPA based on its application power requirement is discussed and comparative analysis in terms of performance metrics MER, BER and characteristics i.e. Broadband, Narrowband, Inter-modulation is done. In the end, the paper concludes that TWT is the winner when it comes to power plus economic budget, KPA is winner when cost factor are relaxed and back-off power availability is main concern, SSPA remains a luxury item among three, but the advantage lies in clean output wave form with less distortions and high linearity curve. All the three technologies are discussed and analyzed in DTH Ku band environment under the purview of standard industry results available for them and the situation test conducted for the three technologies.

Keywords: Broadcast Earth Stations, HPA, TWT, KPA, SSPA, Back-off, Intermodulation.

Broadcast Earth Stations

In order to transmit the signal from Earth to Satellite, Earth stations with suitable RF link installations and Outdoor Units Antennas are must, The signal is encoded ,multiplexed ,modulated and finally is up-converted into suitable RF band ,but at this stage signal is not capable enough to travel roughly 35000kms i.e. the distance of geostationary satellites from earth, the signal need to be amplified, and here comes the HPA role, High power amplifier is the device that acts on the input signal and amplify it many times than its given input hence the signal become that much powerful that it can travel a such a long distance from earth to the geostationary orbit.

HPA Technology

HPA technology mainly has its three variants that are being used by most of the broadcast stations around the world they are; Linear beam tube based technology that is travelling wave tube and Klystron technology and another is semiconductor based technology that is Solid state Power amplifier. All the three have their unique characteristic curves for operating modes saturation modes, Like wise based on their broadband character and narrow band characteristics they have their Inter-modulation effects or No Inter-modulation effects, these all lead to their usage criteria for their suitability in particular broadcasting application.

Linear Tube Based technologies:

The conventional vacuum tubes, such as triodes, tetrodes and pentodes are still used as single sources of low output power at low microwave frequencies. The most important microwave tubes at present are the Linear Beam Tubes (O type).The Paramount O type tube is the two cavity klystron and is followed by reflex klystron. The Helix travelling wave tube is also O type tubes but they have non- resonant periodic structures for electron interactions.[1].The advent of Linear beam tubes began with the Heil Oscillators [2]in 1935 and the varian brothers klystron amplifier[2] in 1939.The work was advanced by the space charge wave propagation theory of Han and Ramo[2] in 1939 and continued with the invention of the helix type travelling wave Tube (TWT) by R Kompfner in 1944 [3].

TWT based HPA's

Travelling wave Tube are broadband amplifiers. The can take a wide band input and amplify it as an output, They work on the principle of velocity modulation and Slow wave structure Helix, they are broadband devices can give high power output, TWT are suitable for Multi Carrier applications, In the case of TWT, the microwave circuit is non resonant and the wave propagates with the same speed as the electrons in the beam. The initial effect on the beam is small amount of velocity modulation. A Helix TWT consists of an electron beam and a slow wave structure .The electron beam is focused by a constant magnetic field along the electron beam and the slow wave structure .This is termed as O type TWT. The Slow wave structure is either the helical type or folded back line .The applied signal propagates around the turns of Helix and produces an electric field at the centre of the helix, directed along the helix axis .The axial electric field progresses with a velocity that is very close to the velocity of the light multiplied by the ratio of helix pitch to helix circumference. As the electrons travel further along the helix they bunch at the collector end. The bunching shift the phase by π/2. Each electron in the bunch encounters a strong retarding field. Then the microwave energy of the electrons is delivered by the electron bunch to the wave on the helix and amplification of signal wave in TWT is accomplished[1].

Klystron based HPA's

Klystron devices are narrow band amplifiers. The two cavity klystron is the simplest and widely used microwave amplifier operated by the principles of velocity and current modulation. All electrons injected from the cathode arrive at the first cavity with uniform velocity .Those electrons passing the first cavity gap at zeros of the gap voltage pass through with unchanged velocity; those passing through positive half cycles of the gap voltage undergo an increase in velocity; those passing through the negative swings of the gap voltage undergo a decrease in velocity. As a result of these actions the electrons gradually bunch together as they travel down the drift space. The variation of electron velocity in the drift space is known as velocity modulation. The density of the electrons in the second cavity varies cyclically with time. The electron beam contains an ac component and is said to be current modulated .The maximum bunching should occur approximately midway between the second cavity grids during its retarding phase; thus the kinetic energy is transferred from the electrons to the field of second cavity. The electrons then emerge from the second cavity with reduced velocity and finally terminate at the collector. In a two cavity Klystron amplifier the cavity close to cathode is known as buncher cavity or input cavity which velocity modulates the electron beam. The other cavity is called as catcher cavity or output cavity it catches energy form the bunched electron beam .The beam then passes through the catcher cavity and is terminated at the collector. This is the working principle for the simple two cavity klystron amplifier[1].

They are high power output devices but are narrow band in nature hence they are not suitable for Multi carrier environment or a wide band, so they can be utilized for bands that are narrow and close to each other as KPA need to be tuned to a particular frequency bandwidth that is very less as compare to what TWT supports, An example to this is that where a TWT based HPA supports 750 MHz Bandwidth KPA there supports 80 MHz bandwidth channel. But KPA are clean and free from intermodulation as most of the times they have to support single carrier.

Semiconductor based Technology

In the past two decades, Microwave solid state devices such as Tunnel diode, Gunn diodes, transferred electron devices (TED's),and avalanche transit time devices have been developed to perform the microwave generation and amplification functions. The conception and subsequent development of TED's and avalanche transit time devices were among the outstanding technical achievements. B.K Ridley and T.B Watkins in 1961 and C. Hilsum in 1962 independently predicted that the transferred electron effect would occur in GaAs (Gallium Arsenide).In 1963 J.B. Gunn reported his "Gunn effect". The common characteristic of all microwave solid state devices is the negative resistance that can be used for microwave oscillation and amplification. The progress of TED's and avalanche transit time devices has been so swift that today they are firmly established as one of the most important classes of microwave solid state devices.[1]

Solid State Power Amplifiers

Most of the SSPA that are in use today are based on GaAs type FETs .Compared to both TWT and Klystron they are low power and relatively expensive one hence their use is less popular in Broadcast industry for high power applications ,Their advantage is that output Power contains very clean wave with less noise, less distortion, up to certain limit they can support multi carriers but their power output in actual is much less than TWT ,where TWT can work well in saturation modes also ,SSPA saturates very easily and fails to work after that and failure chances occurs if overloaded that means very sensitive devices .SSPA are defined by their 1 dB compression point wrt rated power while TWT and KPA by their saturated powers and rated powers.

DTH Broadcasting

Direct to Home, popularly called DTH is a popular Ku band television standard in many countries around the world ,where under single system one can watch several hundred channels, and with the technologies like DVB-S2 and HD the trends are changing day by day, DTH with improved image processing technologies now have more to offer. The common thing between DTH and CATV systems is that both are satellite based system, where DTH have advantage of having small 30-60 cm's rooftop antenna with complete customer control. DTH Systems have their centralized Earth Stations NOC's which uses RF Installations based on various HPA technologies available in the market. In coming Paragraph a situation test for DTH Environment conditions has been conducted for the three available HPA technologies.

DTH Environment test of three technologies

In this paper a situation test of HPA technology for DTH Earth station is done. Consider we have 6 transport streams going on six transponders where 4 are 36 MHz each, (2 Horizontal ,2 vertical), remaining 2 are 18 MHz each all vertical transmission ,Now if these 6 streams need to be sent on the air , then how the above mentioned HPA technologies can be utilized for the mission ,the following are the details:

Utilizing TWT technology: Being a broadband device TWT can handle two carriers with linearizer and take 3dB back-off and can send the combined output, by this analogy we just need 3 TWT one for horizontal polarization carriers and two for vertical polarization carriers.

Utilizing KPA technology: Being a narrow band device here we need 4 KPA's for each 36 MHz carrier, now remaining two 18 MHz can be combined in KPA depends that they lie adjacent to these 36 MHz and their centre frequency comes in such a way that they can be accommodate in the 80 MHz band, or if the two 18 MHz carriers are adjacent then a 5^{th} KPA can be used as amplifier here. The number of unit then becomes 5 in this case.

Utilizing SSPA Technology SSPA can support multicarrier but their power levels need to be ensured as they already considered for 1 dB compression point and when working with 2 carriers further 3dB back-off will result in total 5 dB less power than rated ,still under performing in comparison to only 3 dB back-off requirement for TWT's with Linearizer, that means vacuum tube cathode system power outclass semiconductor based power systems in high power requirement.

According to the Paper's DTH environment test for different HPA technologies following table is obtained:

TABLE 1

	TWT technology	KPA Technology	SSPA Technology
Regular Units Requirement	3	5	3
Redundancy units Requirement (Max)	3	5	3
Electricity consumption	Average	High	Low
Back-off Availability in case of Rain	P dB	2P dB	{P -2} dB
Intermodulation Performance	High Intermodulation wrt SSPA. [4]	No Intermodulation	Less Intermodulation [4]
Operating Budget (Overall)	Medium	High	High
Restart Boot time	3 Minutes	3 Minutes	Immediate
MER Performance	Average	Good	High
MTBF	100000 Hrs	100000 Hrs	1000000 Hrs [4]

Conclusions & Results

Based on the results in table no following are the conclusions

(a) KPA's are the workhorses ,they have plenty of back-offs and margins they are capable to overcome Rain fade from transmission side but they come with high cost and are narrowband, With KPA the performance metrics MER and BER are improves very fast as enough power and distortion less wave is transmitted to maintain good SNR.

(b) HPA's are always the choice available as they are Broadband, but rain plays foul when it comes to add more power to overcome as 3 dB back-off need to be maintained, Now if satellite operating margins are fulfilled and 3 dB mandatory requirements also full filled, and still **3 to 4 dB** Power is available then HPA's can be good choice, Though Linearizer provides acceptable intermodulation levels but still in terms of best MER performance HPA's lags KPA.

(c) SSPA comes out to be the Luxury item and not recommended for DTH kind of applications in large numbers especially for high power applications, as they work 2 dB down as compared to a TWT and even they don't work effectively as TWT do at High Power levels, They are very costly also as compared to TWT's available in the market. The advantage of SSPA's lies in Immediate booting and clean output waveform free from distortions.

(d) From a ,b and c it is clear that KPA is the winner in long terms, but it's not like this that TWT's can't, but depends how much good redundancy available for TWT setup and back-off available as chances are either that TWT operating with Multi-carriers are more prone to failure as compared to KPA's working on low load single carrier, With good amount of redundancy TWT also holds good and cost effective at compared to High cost KPA's.

An alternative scheme can be mix of KPA and TWT technology in Broadcast Operations and occasionally shifting carriers to each other, This may help in analyzing the individual results in case of Rain fade or for MER margins etc. This activity can help in long term optimization of Earth station that which HPA technology is better for that Earth Station and the application concerned.

References

[1] Samuel.Y. Liao Microwave devices and circuits pp 353 Third Edition Pearson Education.
[2] WARNECKE, R.R,. et al., Velocity modulated tubes .In advances in electronics. Vol 3. Academic Press, New York,1951.
[3]CHODOROW,M.,&C .SUSSKIND ,Fundamentals of Microwave Electronics .McGraw-Hill BOOK Company, New York,1964.
[4] "Total Cost of Ownership A Comparison of SSPA and TWTA Amplifier Systems"Advantech WirelessRef.:WP-SSPA-TWTA-12190. www.AdvantechWireless.com.

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