New Group Antenna Concept with High Efficiency Traveling Wave Tubes

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Abstract: *The paper show a new antenna concept or idea for satellites using high efficiency high power traveling wave tube (TWT) amplifiers, dedicated especially for geostationary satellite systems. A new TWT, named TL 2500, a high efficiency S-band TWT feasible for 500W continuous wave output power will be used inside this idea. Usually today a single deployable antenna is used for geostationary S-Band systems and 32-96 TWTs feasible each for 250W are power combined to reach an output power between 7 kW up to around 20 kW[1]. Due to the fact that the output power of today SSPA (solid state power amplifier) are far below 250W a power combining would be very complex and would end in high implementation losses. Therefore often group antenna concepts are the preferred solution for SSPAs. For redundancy reasons and due to the need for high overall output power today all amplifiers runs at same output power and usually the antenna beams with the lowest elevation angle will suffer with the lowest EIRP (equivalent isotropically radiated power) on earth. With the new TL 2500 TWT two output power versions with 500W and 400W will be available with nearly same efficiency. Together with the today available 200W - 275W TWT [2] a high output power range can be generated for a new group antenna idea with TWTs.*

Keywords: Traveling Wave Tube; TWT; Antenna; S-band.

Introduction

The communication of the modern world is growing continuously and it demands high signal qualities and high channel capacities. For satellite applications this will be realized for all frequency bands with very high EIRP systems, which means very high output power and a huge antenna size. Especially in S-Band mainly for direct broadcast and direct radio with geostationary or highly inclined elliptical orbits the overall output power is typically between 7kW and 20kW to guarantee the high signal quality. Due to the low frequency of S-band and the corresponded long wavelength huge deployable antennas must be used, typically with an diameter of 9m to 12m, but also 24m antennas are considered, especially for SSPA satellite systems. For dedicated broadcast signals linguistic beams can be used either with TWT systems (Figure 1) or with SSPA systems (Figure 2), but especially for SSPAs also multibeam concepts with 60 beams and more are planned to build up a flexible communication downlink path. The goal would be dedicated communication cells strongly isolated like it is the case in terrestrial networks where a frequency reuse of 3 can be achieved.

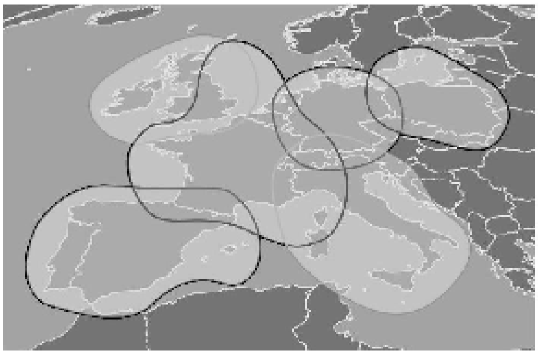

Figure 1. Linguistic Beams from W2A Satellite

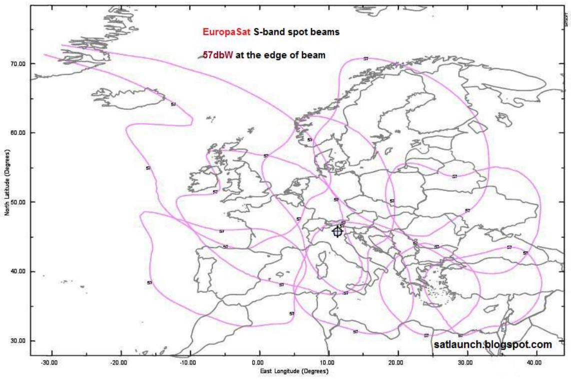

Figure 2. Linguistic Beams from EuropaSat [3]

For geostationary satellites this system is more complicated due to a relatively low elevation angle for most industrial areas. Europe for example has elevation angles between 20° and 45° [4]. With an elevation angle of only 20° a single beam will be no more circular but strongly elliptical. The correspondent cell area will increase significantly and the received power will be reduced. Furthermore the longer distance from the satellite to areas with low elevation angles reduces additional received power. Third aspect are increased shading effects with reduced elevation angles (Figure 3) which can be converted in an additional lower average EIRP for this regions. Due to the fact that ideal satellite positions in the geostationary orbit are rare, the system will normally degrade further by none ideal azimuth angle of the satellite. All together this will lead to a strong imbalance of the different cells.

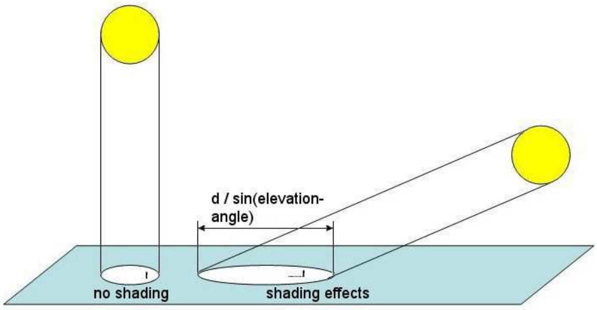

Figure 3. Effects of elevation angle

Comparison between TWTA and SSPA

A traveling wave tube amplifier (TWTA) is a device with a linear electron beam on which the RF is coupled at the input and coupled out of the electron beam with about 50 dB gain at the RF output. In case of the TL 2500 (Figure 4) the RF output is already a WR340 quarter height waveguide output, which is a common interface for S-band satellite high power applications. A TWT has three big advantages compared to a SSPA: 1.) The device is extremely robust to the harsh environment on a satellite like extreme temperatures, x-ray and other radiations , all proven in an unrivaled heritage for nearly all frequency bands. 2.) The overall efficiency of an TWT is much better than the efficiency of an SSPA. In this example (Figure 5) the overall efficiency of the TL 2500 is about 70% which gives a correspondent power added efficiency (PAE) of the TWTA of about 65% (including the power supply). Common GaAs SSPAs in S-band are in the range of 40% to 45% and even new GaN-SSPAs in the Lab are below 55% [5]. 3.) The most important advantage are the heat flux density of the devices. In a TWT the heat will be generated by decelerated electrons in a so called collector. This can be done with an excellent efficiency in a huge area. Also the heat generation of RF losses is placed at a different location. For the TL 2500 a worst case dissipated power in the collector of about 220W will be distributed into an area of ~110 cm² (2W/cm²) with a peak value of only 3.6W/cm². Nevertheless this value is near the technical limit of today satellite cooling systems. A SSPA generates the main heat in its output buffer stage were additional RF losses will generate heat. This area is in [5] roughly 6 cm² or less. Even if a third of the heat can be distributed to the neighborhood, a peak heat flux density of about 10W/cm² will be generated with only 150W output power. Parallel layouts has problems of distributing the power equally and due to the thermal and RF coupling the devices are too risky for failure and no real option for 15 year operation in orbit. Therefore main issue in future development of GaN-SSPAs will be an adequate cooling system for their devices in satellite applications.

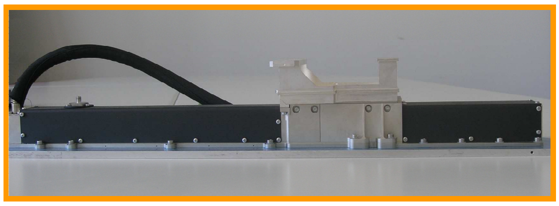

Figure 4. New High Efficiency High Power TWT TL 2500

	Broadband	Nearband		Broadband
	TL 2500			
Parameter	2.16 GHz	2.21 GHz	2.26 GHz	2.31
Pout (W)	493.6	504.5	502.5	497.9
Pout (dBm)	56.93	57.03	57.01	56.97
P_{Harm2} (dBm)	41.57	39.36	39.71	40.65
Pin (dBm)	15.43	15.48	15.7	15.94
Gain sat. (dB)	41.5	41.55	41.31	41.03
Gain ss (dB)	46.19	46.49	46.64	46.79
Ih (mA)	1.43	1.51	1.55	1.43
Qdc(W)	723.23	724.12	725.73	727.41
Overall Eff. (%)	68.2	69.7	69.2	68.4
Basic Eff. (%)	38.9	39.8	39.6	39.3

Figure 5. Typical Operation Data of TL 2500

Antenna concepts with SSPA and TWTA

If a 20kW S-band payload must be built with today available SSPA with around 60W output power and an power added efficiency of roughly 45% about 350 amplifiers must be used. It is very complex to handle the phase accuracy of 350 amplifiers but how to handle the redundancy of 350 amplifiers? Usually two amplifiers in the same device can be switched but inside the same device the probability is high that both amplifiers can fail during a satellite mission life. Separate devices shall be flexible usable for different amplifiers (redundancy switches of TWTAs are usually 4/5 or 4/6 were four out of five or six devices can be used flexible). This results in an additional phase problem of redundant amplifiers if they are used in a group antenna and will usually disturb the overall performance. A fail of a redundant portion inside a group antenna, usually lead to a disoriented antenna beam and is equivalent to a serious failure of a complete communication cell. With an overall efficiency of 45% for the complete SSPA antenna system a DC power of 44.4kW out of solar panels would be needed and 24.4kW dissipated power must be cooled by the satellite structure. All together would result in a clear mass disadvantage of the overall satellite even if the SSPA would have itself a mass advantage compared to the TWTA. But due to lower power ability even best GaN device with 150W [5] would have a clear mass disadvantage of 3.3 x 1.25kg > ~3kg for the new TWTA.

With our new TL 2500 TWT, capable for 500W output power only 40 amplifiers will be needed for 20kW overall output power. With standard technology a power combining of 32 amplifiers with example 8/11 redundancy switching in total 44 amplifiers will be used for about 16kW output power system.

Now a cell structure shall be realized with a multi beam antenna design and the different EIRP for different elevation angles shall be compensated. Therefore the maximum power of 500W per TWT will be used for areas with the lowest elevation angle. For the highest elevation angle only 275W shall be used, which results in a mean power value of about 400W. 50 amplifiers would then be needed for 20kW output power. For example Europe could be divided in 8 x 6 = 48 cells, realized with 48 feeds and a single deployable antenna. But naturally also two times 24 feeds each with a different polarization can be advantageous. If more feeds are needed also power splitter can be used with two phase stable feeds usable for symmetric group antennas.

In Figure 6 an example with 32 beams is depicted and considers that the cells are elliptical and therefore usually fewer rows than columns are needed. A multiple of eight (or four) feeds are advantageous for using a butler matrix [6] for feeding different feeds in parallel. All inputs of one butler matrix shall have the same input power for proper functionality. These inputs can then be combined in a standard 8/11 redundancy network and gives for the complete antenna an unrivaled reliability proven by heritage.

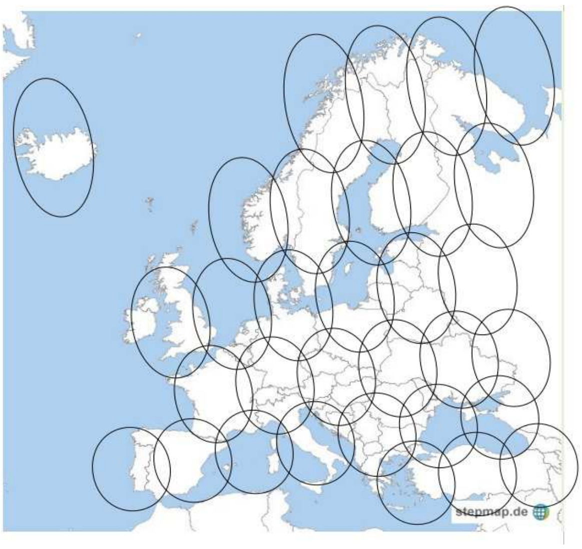

Figure 6. Cell Structure of Europe Including Elevation Angle Effects

Due to the high efficiency value of each amplifier itself an overall efficiency of nearly 65% for the complete group antenna system can be achieved. This results in only 30.8 kW DC power needed for 20 kW RF output power, which is 30% less solar panel area with huge mass and cost savings. Additional only 10.8 kW instead of 24.4 kW thermal load must be cooled by the satellite structure which results in additional mass and cost savings. Especially due to the fact that each kg mass saving will be doubled at the end since less fuel will be needed to get the satellite into a geostationary orbit.

Summary

A new group antenna idea for geostationary satellite down link path is presented which compensates the path losses resulting with low elevation angles. Realized with multi feeds with different output power up to 3 dB variation is feasible due to a new high efficiency S-band TWT with nearly double of today output power. Therefore the antenna feeding can be done with a reasonable number of feeds and the complete antenna can be secured with standard redundancy switching networks. In a next generation mobile satellite communication system the down link path shall be used mainly for broadcast services, streaming services and signaling were the main precondition is an overall availability 24 hours a day, ideal for a geostationary satellite. The subsequent resulting communication mesh size will be also dominated by assisting terrestrial networks and/or by the satellite receiving mesh size which can be naturally much finer than the transmitting one.

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