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Analysis and Design approach of 140W space TWT

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***Abstract*—A Ku-band 140 W space TWT of gain (>54 dB), electronic efficiency (>23%), collector efficiency (>74%), overall efficiency (>54%), I/M components (<-10dBc) for frequency 10.7-11.9 GHz has been created and fabricated for satellite communication arrangement. This paper proposes critical design issues and techniques associated with different assemblies like electron gun, PPM focusing, helix SWS, input & output couplers, and 3-stage depressed collector in order to meet the exacting prerequisite of space TWTs.**

***Keywords*— Dispersion, Interaction impedance; Helix slow-wave structure (SWS); Traveling wave tube (TWT)**

I. INTRODUCTION

Traveling Wave Tube Amplifiers (TWTAs) are one of the critical technology equipment used in most of the spacecrafts. This vacuum tube based equipment is a blend of numerous Sciences and Engineering Technologies. Due to overcrowding of C-Band frequencies the satellite communication systems migrated to Ku, Ka band frequencies. Constraints of semiconductor physics towards high frequencies and power made TWTA the right choice for Satellite Amplifiers. Radiation robustness of TWTA make it the best candidate for deep space mission too. The potential of high frequency, high power TWTAs increases manifold in recent time. This paper elaborate the critical requirements of Space TWTAs and developmental efforts of realizing an 140W Ku-TWTA for typical space applications. When a TWTA working at higher frequency it may be suffer with nonlinear behavior characteristics which effect the overall performance of tube and required result are not obtain so there need to be optimized the power characteristics of TWTA. This paper discusses the methods and strategies with which to approach the problems. An overview of the systems requirements will first be given. This will be followed by a description of the performance limitations i.e. linearity can be achieved for a C/I3-10dBc. The procedures for the design of broadband and high linearity will be discussed in addition to a tapered helix pitch design (required for practical tubes). A detailed description on the proposed tools for modeling and analysis of helix TWTs will also be provided.

II. DESIGNLIMITS

It is impossible to design a helix TWT amplifier such that the total efficiency is 100%. This is because there are always limitations in the transfer of energy from the beam to the helix and from the spent-beam to the collector electrodes. The processes in a helix TWT can be optimized however, so that the tube will operate more efficiently. These processes include the electron beam bunching, transfer of RF power from the beam to the circuit, collection of the spent-beam and the generation of a non-linear output RF signal. The practical limitations will always exist regardless of how good the design is. The following discussion will quantify these practical limitations in terms of the efficiency.

For maximum conversion efficiency, it is required to optimize the transfer of RF energy from the beam to the helix. For this to take place, the circuit field must capture all of the electrons, causing the electron velocities u0 to become synchronous with that of the wave vp. Then the electrons must be further decelerated, and become reflected by the circuit field (i.e. An oscillation within the electric field's potential well), reducing their velocities to vp-(u0-vp). The maximum basic tube efficiency can be expressed by figure. This is the upper limit because all electrons are not normally captured. After the electrons are captured, they have different velocities, because their captured velocities vary with initial phase.

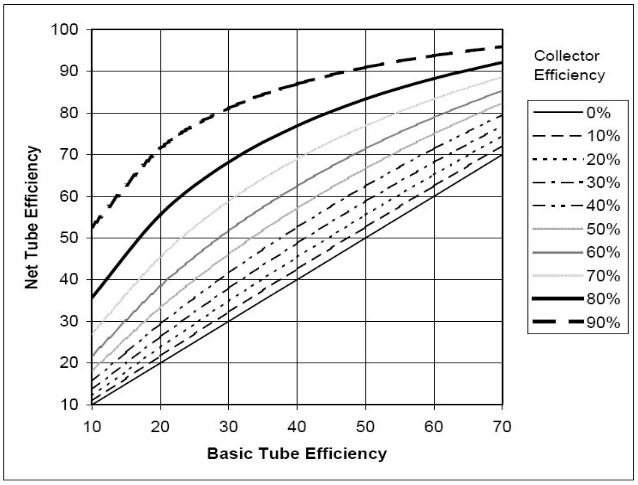

Fig.1.1 Basic tube efficiency v/s Net Tube Efficiency

Designs for Broadband Applications

Helix TWTs have a major advantage over many other microwave devices in that the helix circuit properties are less dispersive. The properties which display low dispersion include the beam-wave coupling impedance and the circuit phase velocity. The selection of dielectric material in the support rods as well as anisotropic loading, i.e. vanes, can reduce the frequency dependence on the electrical properties.

The purpose of anisotropic loading is to reduce the inductive coupling effects from circumferential currents flowing around the metallic shield.

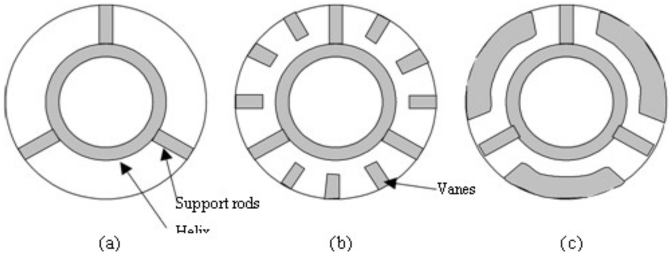

Fig. 1.2 cross-section view of the tube

Fig 1.2(a) shows the cross-section view of the tube without any loading elements attached to the shield, fig 1.2(b) shows the case with vanes attached and a solid configuration is in fig 1.2(c). The effect of these two types of loading on the phase velocity dispersion of the circuit in comparison with case (a) was performed with identical tubes.

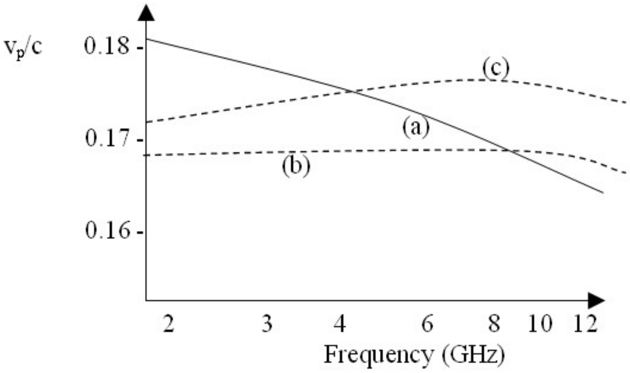

Fig.1.3: Frequency v/s VP/C

The results in fig 1.3 show how vanes, in particular, control the frequency variation of the phase velocity of the structure. Anisotropic loading elements are therefore commonly employed for multi-octave tubes, but are capable of being used in communication applications, where efficient broadband operation is required (V.Srivastava et.al,1991). Alternative design methods for broad banding the slow-wavestructure (e.g. by tapering) and the electron beam have rarely beendocumented in past literature. A design strategy for a broadband TWT becomes more difficult when considering the other criteria that are required in which a trade-off maybe necessary. For example, adjusting the TWT parameters to increase its bandwidth may compromise its output power (V.Srivastava et.al, 2007).

Computer Modeling of Helix TWTs

The tools for the analysis and design of a helix TWT which are available for this research are now described.

1. The Large Signal Model (LSM-1D and 2.5D) is a specialized program which uses physical equations to simulate the processes within a helix TWT. This software is the most useful tool in this project to model the non-linear performance of a helix TWT.
2. The Helix SWS Model (CST-MWS Software) uses the accurate and reliable tape model to determine the forward-wave propagation and impedance characteristics of a helix TWT.
3. Inter-modulation, Harmonics and others non linear parameters are optimize using commercial available software CST-MWS and LSM codes.

Analysis of space TWT

The effect of the basic parameters of a uniform Ku-band helix TWT amplifier on its nonlinear performance was investigated before. For this purpose, the transfer curves and the carrier-to-IM ratio for a 2-carrier signal were generated; this is a useful and convenient way of identifying the substitution between linearity and alteration efficiency. For a non-uniform slow-wave structure, an initial approach was to synchronies the phase velocities of the beam and the forward circuit wave. This ensured active coupling thus high gain, which gives maximum tube efficiency in the linear power region; this strategy also gave a non-dispersive output RF power.A design spreadsheet was developed in Excel basedon the Sheath Helix Model to compute the slow space-charge and forward-wave propagation constants (β-andβ0 respectively).The solver obtains a solution for the TWT parameters subject to the condition where β- = β0. This design strategy is particularly useful when the TWTA is operated at well backed-off drive levels as this would also correspond to the maximum efficiency condition. It was found that the basic parameters resulting in maximum tube efficiency at an output back off (where C/I3 = - 15dBc)In practice, the two most effective design parameters for controlling βo and β- are the helix pitch and beam voltage respectively. The results in Chapter 3 revealed how these parameters affect the nonlinear performance and the bunch intensity of a helix TWT. By plotting the nonlinear characteristics as a function of pitch with all other parameters fixed, the development of amplitude and phase nonlinearity has been revealed in a unique way as the amplifier is driven towards saturation. The results revealed how the pitches corresponding to maximum output power (or conversion efficiency) and phase lag varied as power saturation is approached. As the tube becomes more non-linear, the peak RF beam current was shown to limit; this effectively increases the helix pitch corresponding to maximum electron bunch intensity. On the other hand, the nonlinearity in the TWT reduces the pitch corresponding to maximum phase shift and conversion efficiency. It has also been discovered from the results that for a given pitch, a condition occurs where the phase shift reverses sign and is therefore zero at this transition point.

This condition is also independent to drive level up to power saturation. The pitches corresponding to the conditions for optimum AM/AM linearity and optimum phase linearity differed slightly: by about 20µm. In-between these two conditions therefore exists the condition for optimum overall linearity condition or minimum generation of IM products. The pitch for zero phase shift was found to overlap that of maximum bunch intensity or maximum RF beam current. The above simulations were repeated for different beam voltages (or beam perveances). A number of trade-offs were concluded from the results. At the optimum AM/AM linearity condition, a higher beam perveance increases the conversion efficiency, but at the expense of greater phase conversion. At the zero phase condition however, the output power remains constant as the beam perveance is increased, but at the expense of AM/AM linearity. Uniform un-severed helices are not used in practice, because the saturated output gain is too high for stable operation. But the results did provide a basis on which to fully optimize the design of a helix by identifying the parameters which correspond to the desirable conditions, such as high linearity and high efficiency, that are required in modern communications systems. The work has also contributed to our understanding on the development of nonlinearity in helix TWTs across a range of helix and beam designs.

III. CONCLUSION

We can use the relationship as shown (in SUNRAY 1D-LSM). The loss is specified in the LSM as dB of power loss per axial meter length of the helix. If this value is made too small (below say 5dB/m), the excessive gain will generate backward-wave oscillations (due to the beating effects with the input signal). As a result, the simulation will fail to converge properly. A loss greater than say 5dB/m should achieve convergence after about 3 iterations for a 1-metre tube. A longer tube will have a higher gain i.e. increased likelihood of backward-wave oscillations. A cold loss of 5dB/m is appropriate for a uniform 1-metre length helix. For a tapered pitch profile with severs, an attenuation profile that is typical in practical TWTs will be employed.

Scope for Further Work

Their search in this thesis has covered a broad range of issues. Hence, there are many ideas for future work to be carried out as a continuation of this research. Suggestions will be given in this section covering the fundamental understanding of the physics of a TWT, design method and linearization techniques of a TWT amplifying system. By relating this model to one in which the generation of inter modulation products occurs would give a more thorough understanding on the nonlinear mechanisms that cause harmonics and inter modulation products to arise and their relationship. The improved understanding on the interaction processes in a TWT provided by this work gives a better idea of a design methodology for a simultaneously linear and efficient performance. An aim would now be to design a slow-wave structure where, if possible, the bunch intensity maintains consistency to minimize the phase lag whilst, at the same time, the bunch decelerates. Such a design would give low phase conversion and high efficiency, howeverachieving these two conditions simultaneously have, so far, been difficult.

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