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Investigation and Representation Approach of 140W Space TWT

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Abstract—*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 elaborates 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.*

Introduction

Traveling wave tubes (TWTs) designed for telecommunications applications in multichannel power amplifiers (MCPAs) are required to have high linearity, low intermodulation distortion, high efficiency and high power outputs. They are widely used as high power RF amplifiers in the transponders of communication satellites. Normal-size communication satellites have more than 60 TWTs of different frequency bands, e.g., C-band (3.6-4.3GHz), Ku-band (10.9-11.75GHz) and Ka-band (20.6-21.3GHz). TWTs are the most critical and expensive components of a satellite. Life and performance of a communication satellite are primarily decided by TWTs. Broad bandwidth, high gain, high efficiency and high linearity of a space TWT are highly desirable parameters for handling a large number of downlink signals in communication satellite. The design and development of space TWT need special considerations in order to achieve high flexibility, high efficiency, high linearity and long life. High efficiency more than 60% and high linearity with phase shift less than 30 degrees of a space TWT for communication are highly desirable requirements. Major parameters by which non-linearity of a space TWT are specified by carrier-to-intermodulation level (C/3IM), noise-power ratio (NPR), 1 dB compression Point, and multi-signal intercept points. Helix-TWT is a broadband moderate power amplifier used in ground, air borne and space application. TWTs for space communications essentially require long life, high efficiency, high reliability along with the lowest possible size and weight. The SWS plays significant role in determining the above stringent requirement of space TWTs. SWS of helical type due to its low dispersion characteristic is usually used in satellite communication application. Short-length TWT is used in a microwave power module (a combination of solid-state amplifier and TWT) to provide gain at high power level. The driver of the short-length TWT is a solid-state power amplifier to provide gain at low power level. Helical SWS for Ku-band 140W short length TWT has been designed in single section.

Here the short length TWT is designed to provide gain around 25dB at 140W output with electronic efficiency more than 26% over the operating frequency band of 10.9GHz to 11.7GHz. This paper presents the design approach for the SWS of high efficiency short-length space TWT. A systemic study has been made by using design approach. Short-length TWT is driven by the solid-state power amplifier to provide high power at low gain.

DESIGN AND APPROACH:-

The major components of a space TWT are: electron gun, helix slow-wave structure (SWS) and integral-pole-piece (IPP) barrel assembly with samarium-cobalt periodic permanent magnets (PPM), input and output RF couplers, beam refocusing section (BRS) and multi-stage depressed collector (MDC) along with the base plate and isotropic fin-type radiator. In-house developed software packages were used for design of different components of the helix TWT [3-4] for meeting the major requirements of the space TWT, e.g., high efficiency, high linearity, high reliability, long life, low mass and small size. The initially the tube in one section with no sever for achieving the maximum saturated efficiency for the given drive power and the beam voltage and beam current at desired frequency band.The helix radius (a) is decided for maximum beam wave interaction. Other dimension like barrel diameter and APBN support are decided suitably. CST-MWS code [1] has been used for computing propagation constant (β) and interaction impedance on axis (K) of helix SWS from its physical dimension for the desired frequency band of 10.9 to 11.7GHz. Using the above RF parameters of helix SWS, complete SWS with centre loss and velocity taper has been designed for Ku-band 140W short-length TWT, operating at different beam parameter. As shown in Fig.2, the SWS have been designed in a single section with centre loss for short length for low and high Perveance. In-house developed 1-dimensional large signal model (SUNRAY-1D) [3,4] and 2.5-D large signal model (SUNRAY-2.5D) [5] have been used for both design. Both codes are suitable for large signal multi signal analysis for simulating higher order harmonics and inter-modulation components, along with simulating different output parameters of TWT like output power gain, efficiency, phase shift, AM/PM factor. The SWS length with helix pitch and loss profiles is finalized for the desired RF output performance like output power 140W, saturated gain 25dB, phase shift less than 50 degrees and electronic efficiency around 30%, with minimum possible length of the SWS.

The helix pitch and loss profiles are decided for high interaction efficiency based on the approach discussed in [6]. Three helix pitches (p1, p2 and p3), as shown in Fig.5 are selected, respectively, for maximum small signal gain, effective beam bunching and maximum electronic efficiency. Using this pitch arrangement, the section lengths and the position of centre loss in Fig., have been optimized to give maximum electronic efficiency with high gain and high linearity. We have take three pitches for the low Perveance i.e. (high voltage, low current). So for this approach we have taken beam voltage 5kV and beam current 100mA. In the second design approach we have select two pitch for design of SWS for short length TWT at high Perveance i:e(low voltage ,high current). For simulation, the beam fill factor is chosen 0.5, circuit loss 2dB/inch, return loss at both input and output 10dB, and center loss (Gaussian shape) 60dB over the length of 24mm. In order to avoid instability for any change in beam voltage and beam current, π-point frequency has been kept much above 20 GHz. In addition to above, care is taken to avoid regenerative oscillation by having short length for 10dB (return loss) matching at the input and output RF couplers [2].

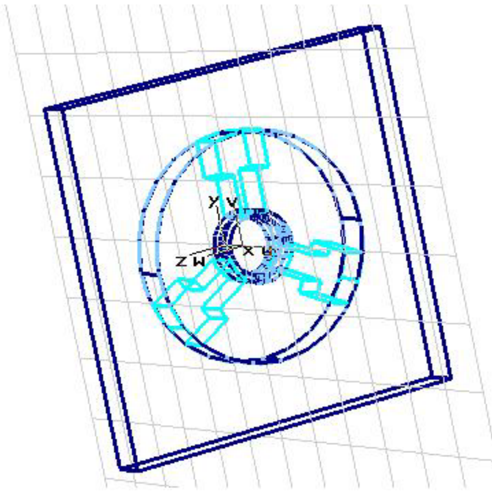

Fig. 1. Helix modeled in CST-MWS

(Helix supported with 3 APBN step-shaped rods in a Barrel assembly)

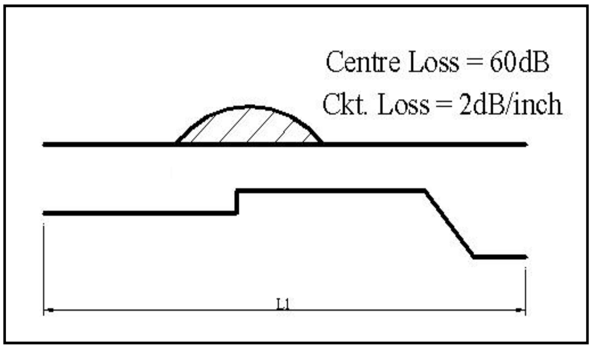

Fig. 2: Pitch profile and loss profile for

Design 1

For this study we have take input parameter which are listed below in table 1.

Parameters	Design 1
Beam Voltage	5.9Kv
Beam Current	100mA
Beam radius	0.32mm
Beam filling factor	0.5
Tunnel radius	1.124mm
Barrel inner radius	3.5mm
Helix inner radius	1.105mm
Tape size	A x B
Support rod	T-shape APBN
Pitch profile(mm)	P1,P2,P3
Length profile(mm)	L
Perveance	0.22μm
Pierce gain	0.0864

All dimensions are in normalized form.

RESULTS AND DISCUSSION

Parameter	Design.1.
Output power(dBm)	52.004
Saturated gain(dB)	25.035
El.efficiency, TWT (%)	26.722
Gain flatness	0.8dB/GHz
Phase shift	< 45deg
AM/PM	<3deg/dB

The simulated RF output power and gain at saturation are shown in Table: 1 for the operating band of 10.9 to 11.7GHz. As shown in the figure, the designed Ku-band short TWT delivers output power (>140W) with gain (>25dB) and electronic efficiency (>26%) for the operating band of 10.9 to 11.7GHz. The AM/PM conversion factor at saturation and at different input drives below saturation are found less than 3 deg./dB, Phase shifts at different frequencies from saturation to 20dB below saturation are found less than 40 degrees.

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