Second Harmonic Reduction of Traveling Wave Tube Amplifier Using Ferrite Material

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***Abstract*- Traveling Wave Tubes (TWTs) consist of different elements. The most important element of TWT is the RF circuit. RF circuits in helix TWTs need a dielectric support to hold the helix; this support also has an effect on electromagnetic properties of RF circuits. A novel dielectric support is proposed to reduce the second harmonic of helix TWTs. The dielectric support in this structure consists of two sections. The first section consists of dielectric material as used in all TWT(s) supports, and the second one is a ferrite rod replacing a portion of the dielectric support. This configuration can act as a tunable band stop filter. The center frequency of the filter can be adjusted based on the second harmonic of the input frequency to reduce the second harmonic of TWT without any loss on fundamental amplified signal.**

Index Terms- Traveling wave tubes, bandstop filter, tunable filter, ferrite, second harmonic.

I. INTRODUCTION

Wide band modules have an important role in satellite communications, measurement equipment, security systems and electronic warfare [1, 2]. Second harmonic level is one of the key parameters that should be considered in evaluating wide band modules. One of the major sources of second harmonic in high frequency systems is a high power amplifier that results from non-linearity property of such amplifiers [3].

Traveling Wave Tube Amplifiers (TWTAs) are one of the most important high power and wideband amplifiers [4], so they have an important role in wideband communication systems, thus their harmonic levels should be controlled. As the core part of TWTs, the slow-wave structure (SWS) basically determines the performances of TWT [5]. Nowadays, coupled cavity [6] and helix [7] are popular SWSs employed in actual TWTs.

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Coupled cavity TWTs bandwidth reach around 30% and they have second harmonic levels better than -30 dBc. In the opposite side, bandwidth of helix TWTs can reach up to two octaves. In some extremely broadband ECM applications, TWTs are used that operate with bandwidths greater than an octave. There have been cases where the second harmonic power output was equal to or greater than the fundamental power when one of these TWTs was driven to saturation at the low end of the frequency band [8].

One of the reasons for this high harmonic output is that, at the low end of the band, the harmonic frequency is within the amplifying band of the TWT [8]. Determining the original signal from a second harmonic is very hard in such a high harmonic level.

Many efforts have been made for second harmonic reduction in helix TWTs. harmonic injection [9], negative dispersion [10], positive phase velocity tapering [11] and using a helix filter [12] are some recent methods proposed for the mentioned purpose. These methods reduce harmonic based on defecting bunching process in vicinity of the second harmonic frequency or filtering it.

This paper proposed a new dielectric support configuration and its electromagnetic characteristics and hot test behavior observed through numerical simulations.

It should be mentioned there is a precedence of employing ferromagnetic material in TWTs, as reported in[13, 14] but they have been employed in a configuration different from the proposed structure. Also this is the first effort for harmonic reduction of helix TWT by the help of ferrite material.

II. DESCRIPTION OF NEW STRUCTURE

Ferrite materials have magnetic anisotropy so magnetic flux density and magnetic field intensity relate by permeability tensor.

$$\vec{B} = [\mu]\vec{\mathrm{H}} \tag{1}$$

Where the tensor permeability $[\mu]$ is given by:

$$[\mu] = \begin{bmatrix} \mu & j\kappa & 0 \\ -j\kappa & \mu & 0 \\ 0 & 0 & \mu_0 \end{bmatrix} \tag{2}$$

Ferrite materials have a narrow band behavior and outside resonance region the elements of the permeability tensor change in such a way ($\mu \rightarrow \mu_0$ & $\kappa \rightarrow 0$) that ferrites act as a dielectric.

The Fig. 1 shows a waveguide isolator and its attenuation constants versus frequency. Terms α_+ and α_- indicate forward and backward attenuation respectively and H_0 stand for DC bias field. The center frequency of isolator can be adjusted to any desired frequency by adjusting DC bias magnetic field

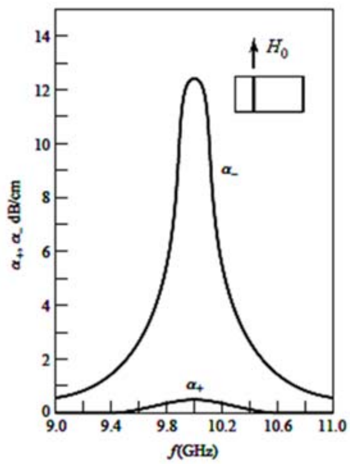


Fig. 1. Frequency response of rectangular waveguide isolator.

Table I-TWT Specifications

Parameter	Value
Max Gain	27 dB
Beam current	0.65 A
Beam Velocity	4.05x10^7 (0.135 c_0)
Confining Magnetic Field	> 0.044 T
Helix Length	137 mm
Helix inner Diameter	4.9 mm
Barrel inner Diameter	9.6 mm
Bandwidth	2-5 GHz
P1dB	270 W
Psat	430W

[15]. Waveguide isolator can be called tunable band stop filter. With the help of tunable feature, center frequency can be aligned at second harmonic frequency.

First of all a reference TWT should be considered which is shown in Fig. 2 & it's specifications presented in Table I.

This TWT consists of a helix and three dielectric rods and is designed to operate in frequency range of 2 to 5 GHz. Fig. 3 shows the scattering parameters of slow wave structure & it's hot test simulation result of the reference TWT [16]. It is obvious that the slow wave structure is reciprocal.

The goal is to implement a tunable band stop filter. To achieve this goal, a portion of dielectric rod removed and replaced by a ferrite rod as shown in Fig. 4 (shown in violet). Table II represents the ferrite properties which are used in the new structure.

The scattering parameters of new SWS should be compared with the reference SWS. Fig. 5 shows the scattering parameters of ferrite loaded SWS with 39.8 kA/m (500 Oe) bias magnetic field. The ferrite rods add a stop-band to the reference SWS. The behavior of ferrite rod in SWS is the same as ferrite slab in a waveguide isolator.

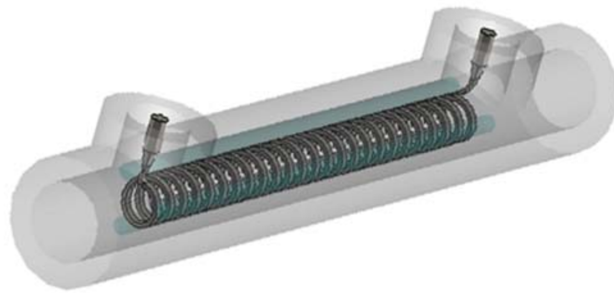
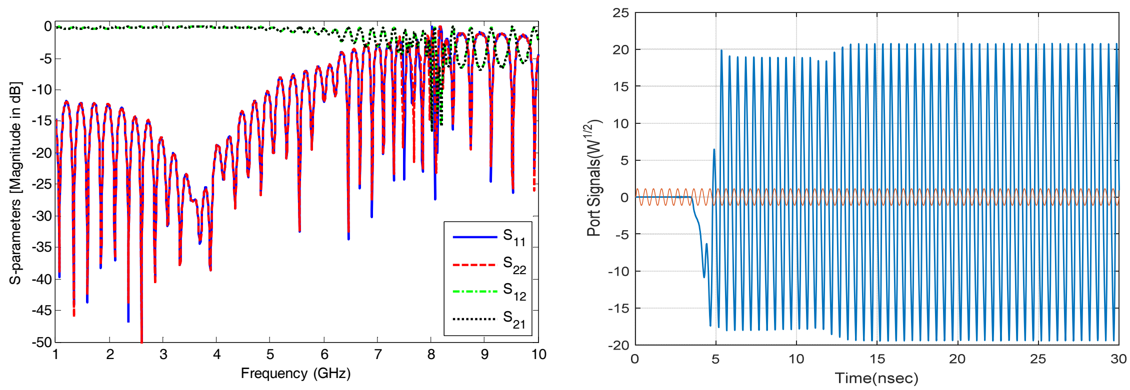


Fig. 2. Reference TWT operate in 2-5 GHz.



(a) **(b)**

Fig. 3. (a) Scattering parameters of reference TWT (b) Input & output signals.

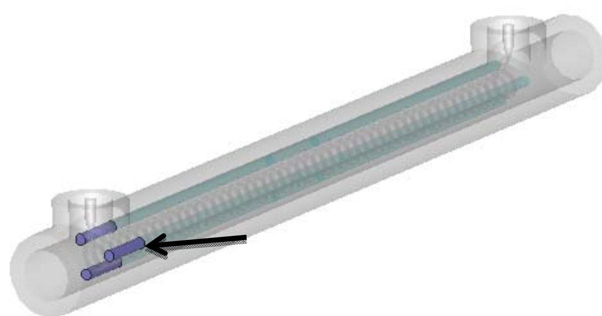


Fig. 4. New SWS created by removing a portion of dielectric rod and replacing by ferrite rods.

Table II. Ferrite Properties

Specification	Value
ϵ_r	9
Saturation Magnetization	1137 Gauss
Resonance Line width	103 Oe
Bias field	100 ~ 900 Oe
Length	15 mm

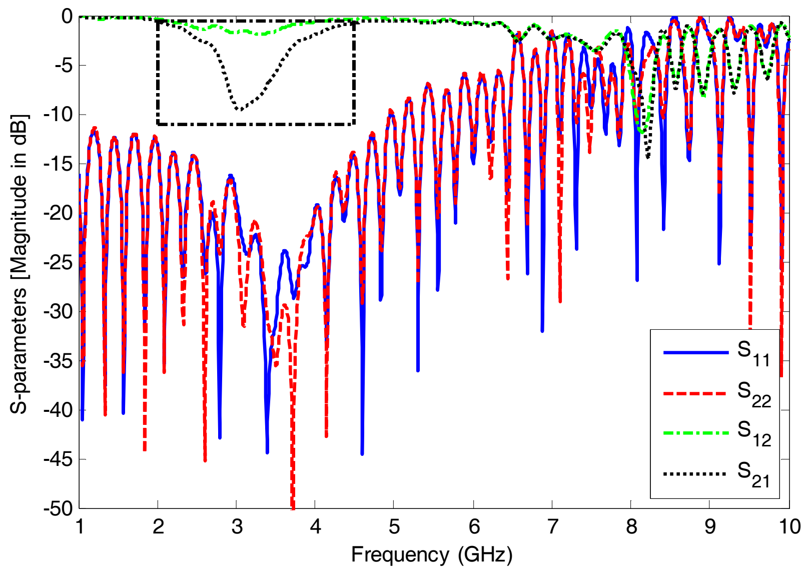


Fig. 5. Non-Reciprocal Scattering Parameters of Ferrite Loaded SWS

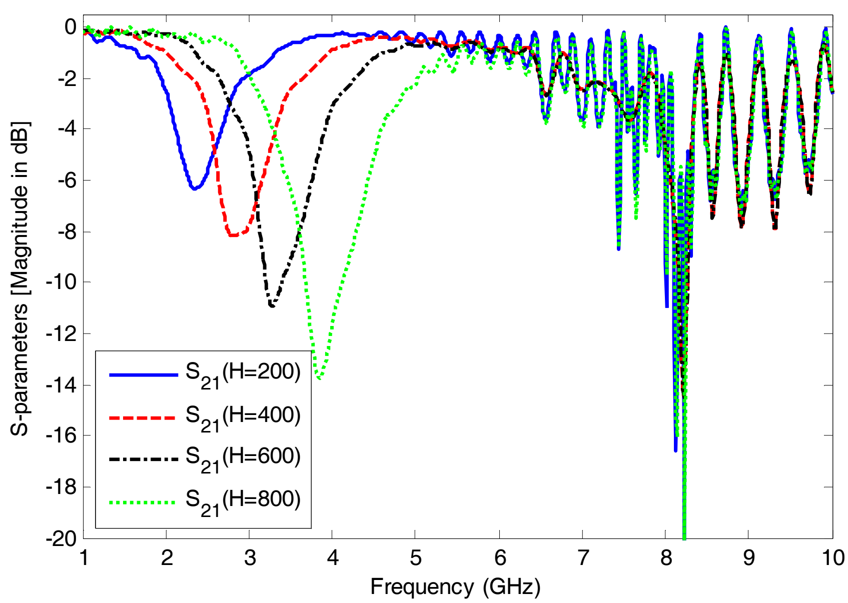


Fig. 6. Center Frequency of Band Stop Filter Based on Different Bias Field

Like the waveguide isolator, strength of bias magnetic field can adjust the central frequency of ferrite loaded SWS, which can be called one-way tunable bandstop filter. In Fig. 6 the change in central frequency of filter based on different strengths of magnetic field plotted.

The resonance frequency can be calculated by Kittel's equation

$$\omega_r = \mu_0 \gamma \sqrt{[H_a + (N_x - N_z)M_s][H_a + (N_x - N_z)M_s]} \tag{3}$$

Where ω_r is the resonance frequency, γ is gyromagnetic ratio, H_a is applied field strength, [N_x N_y N_z] are demagnetization factors and M_s is saturation magnetization of ferrite. Resonance frequency for

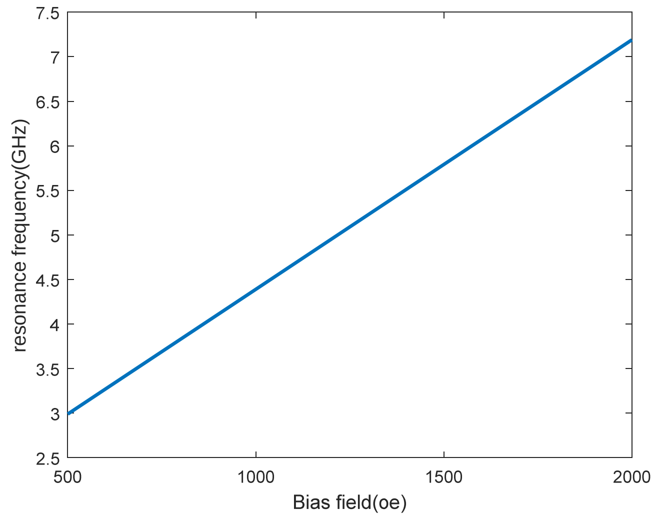


Fig. 7. Resonance Frequency of ferrite rods.

a thin rod will reduce to [15]:

$$\omega_r = \mu_0 \gamma [H_a + M_s/2\,] \tag{4}$$

III. NEW STRUCTURE INFLUENCE ON SECOND HARMONIC

This tunable band stop filter can be applied for reducing second harmonic content of the output signal. Second harmonic reduction can be achieved by adjusting the center frequency of filter on 2nd harmonic frequency. Harmonics appear near saturation; so, the ferrites placed near the output port of TWT.

As the TWTs are wideband, the input frequency will change from one case to another. So, the center frequency of the filter must vary according to the input frequency during the operation of TWT. Therefore center frequency of filter & ferrite bias must be changed with any change in the input frequency.

The applied signal frequency is 2GHz so the second harmonic of signal and band stop frequency of the filter should be aligned at 4 GHz. Appropriate bias fields should be found and set for ferrite rods.

The Proper magnetic field for aligning the notch filter frequency can be calculated via (2) and plotted in Fig. 7 for desired frequency the bias field must be 71.6 kA/m (900 Oe) the equivalent magnetic flux density in free space is 0.09 T.

An important & necessary comparison between this field and confining field must be performed. The brillouin flux is a goof measure of required confining field [4]. Brillouin flux of the subject TWT is 0.044 T. So the confining field can be 0.09T which means the same field applied for biasing ferrites and beam confining.

The scattering parameters of SWS that included ferrite rods is shown in Fig. 8 which has a stop

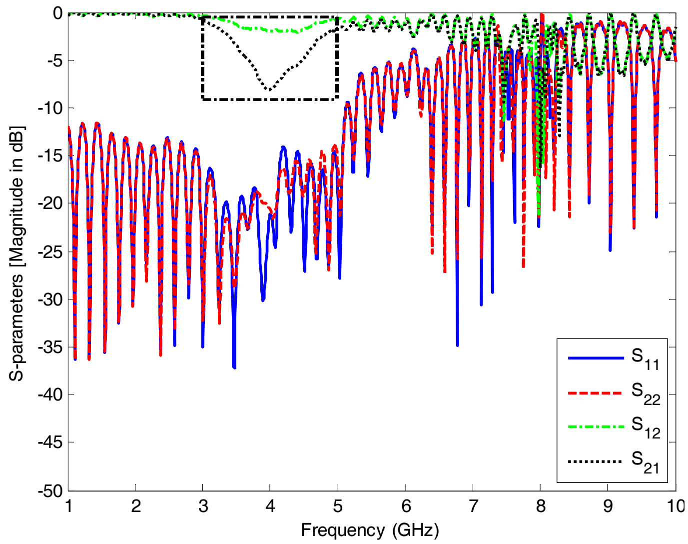


Fig. 8. Scattering Parameters of new structure for reducing 2nd harmonic

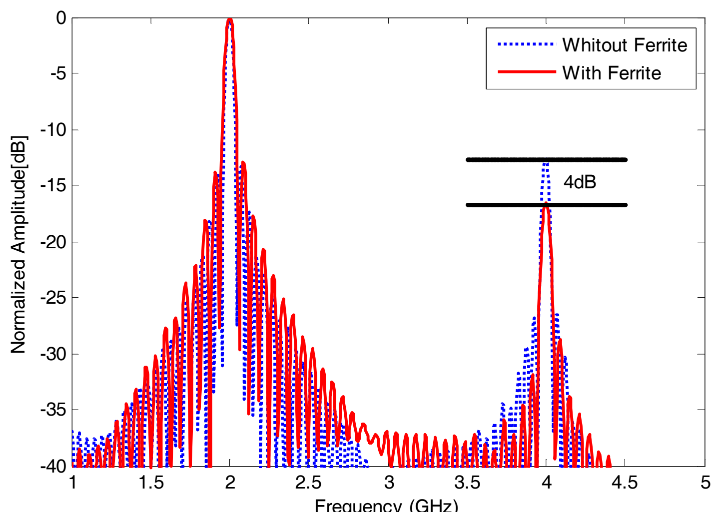


Fig. 9. Output signals spectrum for both structures show that 2nd structure has lower harmonic

band in 2nd harmonic frequency.

Output signal frequency spectrum without and with ferrites plotted in Fig. 9. The figure shows that the second harmonic level is 12 dB lower than fundamental signal without ferrite rods and reduced to 16 dB after adding ferrite rods to dielectric supports. Better harmonic reduction can be achieved by increasing the length of ferrites as shown in **Error! Not a valid bookmark self-reference.**. It should be mentioned that TWT gain remain unchange at 25 dB and the ferrite rods didn't affect the gain of TWT.

Table III. Second Harmonic level at different ferrite rod length

Ferrite Length (mm)	**2nd Harmonic Level (dBc)**
10	-16
15	-18
20	-20
25	-21.5
30	-22.5

IV. CONCLUSION

A novel tunable band stop filter was introduced and simulated on a helix slow wave structure via CST studio. The filter takes advantage of a unique feature of ferrite material. The frequency response of tunable filter observed. According to hot test simulation carried out the second harmonic content of the output signal sucesfully reduced. Unlike other harmonic reduction methods this method modified the dielectric support of TWT, so it can be combined easily with other harmonic reduction methods which reduced the harmonic levels by helix modification.

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