‘THE DESIGN AND ANALYSIS OF FERRITE COMPONENTS FOR BEAM FORMING NETWORKS’

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ABSTRACT

In the rapidly evolving global telecommunications industry, switching and routing of signals through communications satellites that may have in orbit lifetimes of fifteen years, must offer the flexibility for a communication payload to reconfigure its antenna beam patterns after the spacecraft has been placed in orbit. This flexibility is achieved within the stringent requirements of size, mass, cost, power handling, power consumption, reliability and technical risks that are carried for all satellite payloads.

Latched ferrite waveguide components such as switches and phase shifters are still the most popular technologies in the applications of switched and variable BFNs (Beam Forming Networks) employed in space communications. These are considered to be favourable over competitive technologies as they offer low loss, high reliability, hot switching, low power consumption and superior non-linear performance at high power. The choice of the most suitable ferrite material is dictated by the operational frequency, insertion loss, switching time, phase accuracy (for phase shifters), power consumption and power handling. The paper presents the brief guideline for the design and analysis of latched ferrite switches and phase shifters for the space applications. The paper focuses on a ka band design and is illustrated with a number of animated plots from 3D EM and magnetostatic analysis. Finally, the theoretical and practical results are compared.

INTRODUCTION

Switching and routing of signals through communications satellites must offer the flexibility for a communication payload to reconfigure its antenna beam patterns after the spacecraft has been placed in orbit. This flexibility is required to keep up with the pace in the fast evolving worldwide telecommunication industry that is achieved through beam switched networks (BSNs) and beam forming networks (BFNs). The applications of ferrite components in both beam switched networks and beam forming networks are well known in the space communication systems in microwave and millimetre wave frequencies [1].

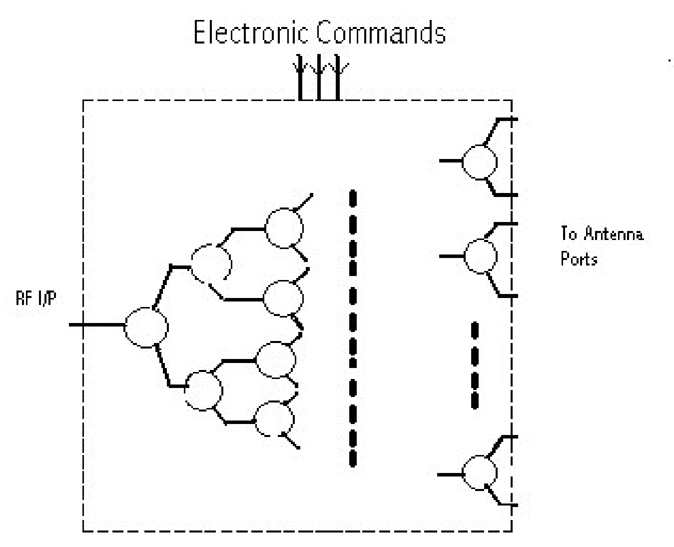


Figure 1 The switched beam forming network.

The switched BFN consists of network of SPDT switches and the variable BFNs network have phase shifters [1] employed for beam switching and beam forming, respectively. In this paper, ferrite switches acting, as SPDTs switches will be discussed. Ferrite technology is preferred over other types of switches as they offer low insertion loss, high reliability, low power consumption and superior non-linear performance. This paper focuses on the design and analysis aspects of ferrite switches. The analysis is done using the commercial FE solvers. In the end, ka band internally latched ferrite switches are discussed and hence, compared with the practical obtained data.

DESIGN AND ANALYSIS

The H-plane waveguide junction comprises a side coupled triangular ferrite with extensions on each side forming a wye shaped resonator as shown in Fig.2. A low loss dielectric material on both sides holds the resonator across the E-plane of the waveguide. For internal latching a current carrying wire that forms a loop is inserted around a ferrite resonator.

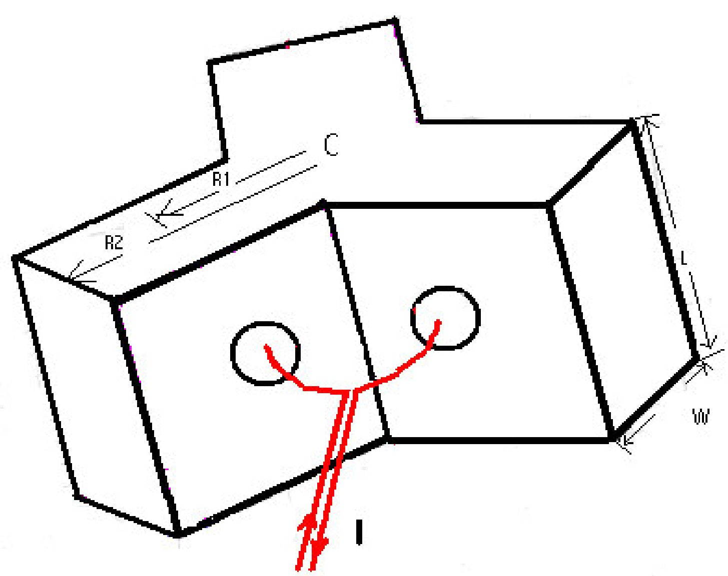


Figure 2 A WYE Latched Resonator

Ferrite Material

The resonator is manufactured from a low loss ferrite material chosen with regard to electrical performance in terms of insertion loss, bandwidth, and RF power handling of a ferrite switch.

A WYE Resonator

The electrical field within the uncoupled resonator in the absence of magnetisation is shown in Fig.3 showing the maximum field strength in the centre. As shown the E-field is in the same orientation as the E-field of feed waveguide that allows the coupling to take place between the feed and the resonator. The resonator is initially modelled using the eigenmode solution for predicting the dimensions of the selected TM mode.

In the presence of magnetisation, permeability 'μ' is replaced by 'μ_{eff}' in the calculation of wave number, K=$\frac{2\pi f}{c}\sqrt{\varepsilon_r \mu}$. RF magnetic field is perpendicular to internal static field 'H' and direction of plane wave propagation, therefore, $\mu_{eff} = \frac{\mu^2 - \kappa^2}{\mu}$. Where, μ and κ are the components of tensor permeability that can be obtained at operating frequency 'f' of a ferrite with remanence, '$4\pi M_r$' biased at H=0 A/m. The wave number, K=$\frac{2\pi f}{c}\sqrt{\varepsilon_r \mu_{eff}}$' can therefore be obtained of a ferrite resonator having dielectric constant 'ε_r'. Where, c is the speed of light.

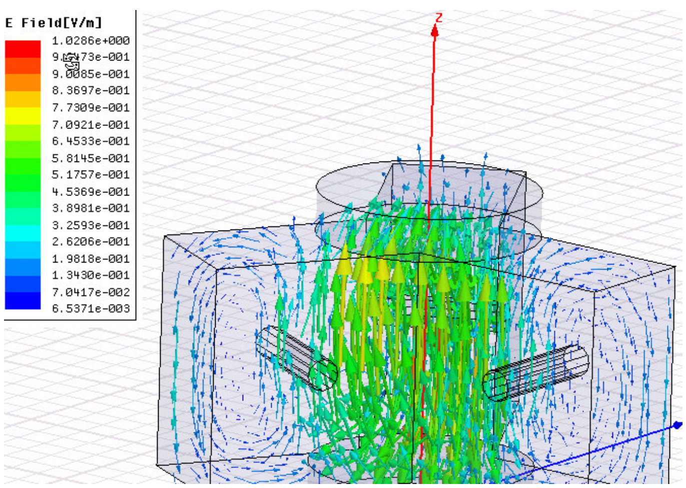


Figure 3 Electrical field pattern in uncouplrd Wye resonators.

A Latched WYE Junction

In internal latched configuration the circulation occurs primarily within a unidirectional magnetised inner portion of the ferrite element, and closure of the dc magnetic circuit is completed around the current carrying hole as shown in Fig. 4. The figure illustrates the non-linear variation of magnetic flux distribution (in the latched state). The direction of circulation is switched by reversing the polarity of the current pulse.

Fig.5 shows the circulation phenomenon by the aid of H-field plot in the 3-port waveguide switched circulator. The figure also shows the RF H-field orientation perpendicular to the static magnetic field (Fig.3). This ensures that there is no interference to the RF performance of the switched circulator.

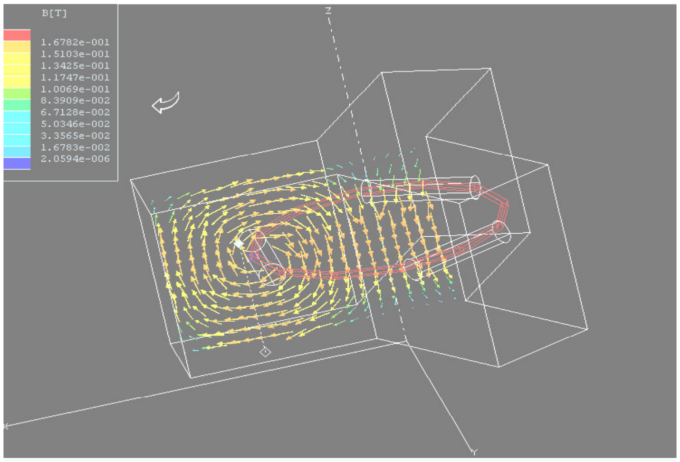


Figure 4 Static magnetic flux pattern in the latched ferrite.

When the resonator is magnetised the normal TM mode splits up into TM^+ and TM^- modes that allows the circulation to take place. The bandwidth of the junction is proportional to the splitting between the two resonant modes and is smaller than of the

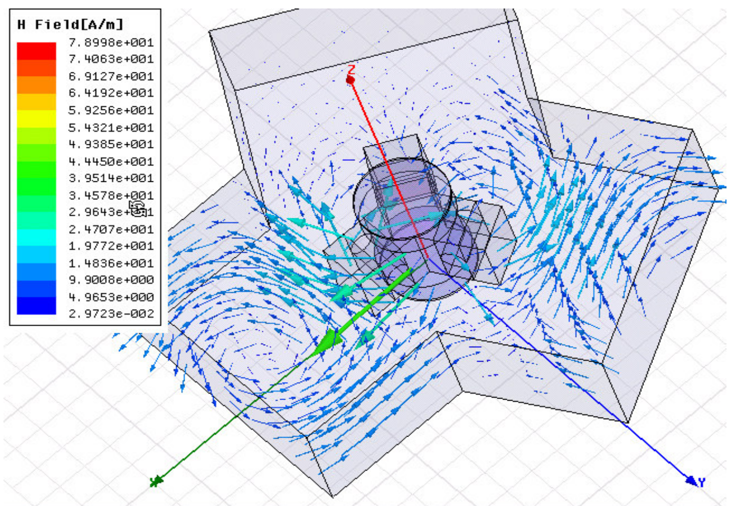


Figure 5 H-field plot of a waveguide ferrite switch junction.

uni-directionally magnetised ferrite junction. This is due to the effect of outer arms that has magnetic flux directed in opposite direction to the inner arm.

The predicted wideband response of the latched circulator is shown in Fig.6. The ferrite was biased using the non-linear flux density data 'B' obtained from magneto-static analysis of the selected ferrite as explained in Fig.4. The ferrite is latched at static magnetic field, H=0 A/m. The junction is matched to TE_{10} mode waveguide with the simple matching network.

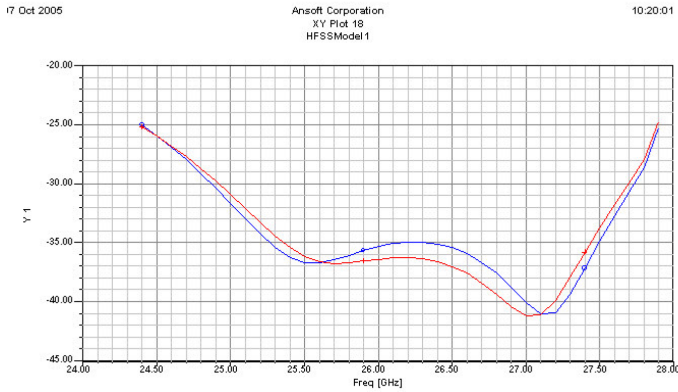
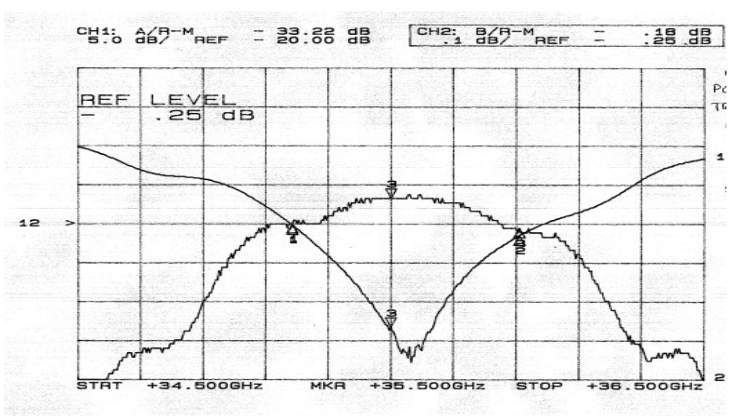


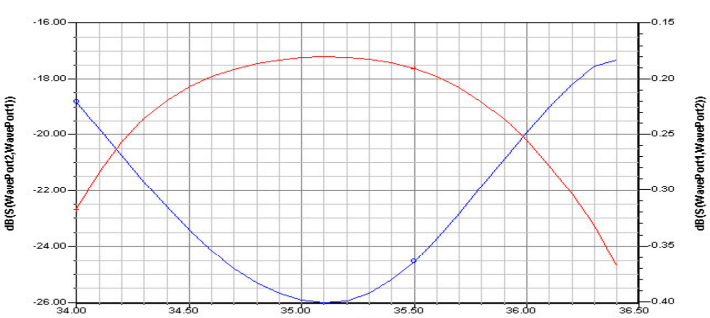
Figure 6 Isolation/Return Loss plots of the wideband junction.

RESULTS

Fig. 7 compares the practical results with the theoretically analysed results for the Ka band switch. As seen there is a good correlation. The junction has relatively narrower bandwidth because it was tuned for high isolation (>30dB). In a typical BFN a single switch has a low insertion loss (in the order of 0.2 dB), –20 dB isolation and faster switching time ($\approx 1\mu s$). Insertion loss of 0.2dB and isolation of –20dB is achieved over 700MHz bandwidth. The theoretical results suggest that the bandwidth in access of 1.7GHz is achievable for –20dB isolation.



(a) Experimental



(b) Theoretical

Figure 7 Isolation/insertion loss plots of Ka band switch.

Conclusion:

The design and analysis of ferrite switches junction is presented with a number of 3D animated plots describing the electromagnetic behaviour of ferrites in the application of ferrite switches. The theoretical results were compared with the practical ones and as seen good correlation is achieved. The examples shown are ka band but the design technique is applicable to other microwave frequency bands. ComDev has successfully produced latched circulators at C, X, Ku and Ka bands for space, defence and commercial applications.

References:

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3. P.C. Goodman, ‘A Latching Ferrite Junction Circulator For Phase Array Switching Applications’, IEEE G-MTT Symposium, 1965