Magnetically Switchable Shorted Patch Antenna

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Key Terms: Ferrites, Switchable antenna, shorting post, Microstrip Patch

ABSTRACT:

Switchable magnetic media and shorting posts are popular in controlling the radiation characteristics and the size of microstrip antennas or array. In this paper, a ferrite based shorted patch antenna is designed to demonstrate magnetically switchable frequency response. Simulated resonance and radiation responses of the probe feed antenna revealed improved impedance bandwidth, antenna size reduction, tunable and non-tunable switched resonance and low biasing requirement for switching the antenna.

INTRODUCTION:

Over the past decade, many techniques have been adopted to reduce the size of a microstrip patch antenna and make it more compliant with small communication devices. This includes using high dielectric constant material and loading the antenna with shorting posts [1] and diodes [2]. Shorting posts are typically placed at the edge of the radiating patch, close to the coaxial feed, to introduce inductive loading and consequently reducing the resonance response of the quarter wave length antennas. Although this reactive loading has little influence on the radiation characteristics, it affects the efficiency and impedance bandwidth of the antenna. So optimizing the size, number and position of the shorting posts are required to achieve acceptable antenna response [3].

A novel way to further optimize the reactive loading is to introduce magnetic ferrite substrate with permeability tensors, which can be externally controlled by the direction and strength of magnetizing field. Externally magnetized ferrite substrates with high dielectric constant are widely used in reconfigurable microstrip antennas with tunable resonant frequency [4] and radiation characteristics [5], switchable polarization [6] and changeable radar cross section [7]. Magnetically swichable ferrite radome allowed the implementation of microstrip antenna or array that can be switched to an "off" of less visible state from interrogating radar [8]. But, this structure required ferrite supersaturates to be magnetized in the resonance region, which often needs large external biasing field.

This paper investigates the operation of a probe feed circular patch antenna based on axially magnetized ferrite substrate and loaded with a shorting post. Full wave analysis is used to accurately predict the resonance, impedance bandwidth and radiation characteristics of the designed antenna. Although the switching properties of magnetized ferrite media are not a new one [8], but its application in the context of electric small microstrip antenna has apparently been unrealized.

METHOD OF ANALYSIS AND RESULTS:

The tensor permeability of an axially magnetized circular ferrite resonator can be expressed in terms of the external magnetizing field, H_{ex}, and microwave (MW) signal frequency, f, as;

$$[\mu_r] = \begin{bmatrix} 1+\dfrac{\gamma^2.(H_{ex}-MN_z).(MN_z)}{\gamma^2(H_{ex}-MN_z)^2-f^2} & \dfrac{\gamma.(MN_z).f}{\gamma^2(H_{ex}-MN_z)^2-f^2} & 1 \\ \dfrac{\gamma.(MN_z).f}{\gamma^2(H_{ex}-MN_z)^2-f^2} & 1+\dfrac{\gamma^2.(H_{ex}-MN_z).(MN_z)}{\gamma^2(H_{ex}-MN_z)^2-f^2} & 1 \\ 1 & 1 & \mu_z \end{bmatrix}$$

where, γ, M and N_Z are the gyromagnetic ratio, magnetization and demagnetization factor of the ferrite slab, respectively. For orthogonally applied biasing field (H_{ex}) relative to magnetic field component of the MW signal, the propagation constant related to the extraordinary wave can be determined from the effective permeability (μ_{eff}) of ferrite;

$$\mu_{eff} = \left(1 + \frac{\gamma^2.(H_{ex} - MN_z).(MN_z)}{\gamma^2(H_{ex} - MN_z)^2 - f^2}\right)\left[1 - \left(\frac{\gamma.(MN_z).f}{\gamma^2.(H_{ex} - MN_z).(MN_z)}\right)^2\right]$$

Figure 1 shows the μ_{eff} values of YIG-G810 ferrite material with respect to H_{ex} and f. The central part of the curve with high μ_{eff} values represent lossy resonance region. In this application, the magnetic bias close to resonance region is used due the requirement of smaller biasing magnets.

The axially magnetized ferrite based circular patch antenna with a shorting post is shown in figure 2. The ferrite substrate is made of YIG-G810 material with saturation magnetization M_S =60 KA/m, line width ΔH=10 Oe, dielectric constant ε_r=14 and thickness t=1.2mm. The radius (R) of the patch and the feed location (x_f , y_f) is initially calculated to produce a 10-GHz response for an un-biased antenna. Then the shorting post of radius r_s is introduced near the antenna edge at x_s,y_s point. Consequently, the resonance frequency of the antenna shifted upwards to 12.6 GHz, due to its capacitive loading. The radius (r_s), position (x_s, y_s) and number of the shorting posts could have been easily optimized to introduce inductive loading, and consequently lowering the resonant response [3]. Instead external biasing field is applied to the ferrite based antenna in an axial (z) direction.

Since the input impedance of the antenna is very sensitive on the relative positions of the shorting post and the coaxial feed, a rigorous full-wave analysis is required to accurately predict the antenna characteristics. The simulated dual frequency responses of an unbiased and axially biased shorted patch are shown in figure 3. Note that the biasing or latching field of 70 KA/m introduces a lower resonant behavior at 2.4 GHz, without changing the properties of upper resonant at 12.6 GHz. It is noted that externally tunability is limited only to the upper resonance, as lower response is not influenced by the biasing conditions. The radiation responses of the antenna are also shown in the inset of figure 3. The radiation efficiency of the switched resonance is observed to be lower compared to the upper resonance and can be improved using high impedance ground plane [9] or the methods described in the following section.

To improve the inherent narrow band response of microstrip antennas, the reactive loading of the shorting post is modified by changing its length. The impedance bandwidths for four different lengths of reactive post are shown in figure 4. Note that the best total bandwidth of the antenna is achieved with a 0.75mm reactive post compared to 1.2mm shorting posts. Finally, the position of the shorting post is optimized to introduce external tunability for both the resonant responses of the antenna at the cost of increased electrical size. Figure 5 shows the reflection response of the antenna, with shorting post located at x=1.9mm (see fig 2), for variable biasing condition. It is clear from this figure that the lower resonance of this antenna exhibits superior tuning behavior compared to the upper resonance. The radiation characteristics of these resonant responses are plotted in figure 6. It is evident from this figure that increasing biasing field improves the radiation efficiency of the lower resonant mode. The substrate dielectric constant and radius of the shorting post are observed to influence the resonant frequency in the same manner with that of dielectric based shorted patch antenna [10]. Due to the unavailability of experimental setup and as the simulated response of this software has repeatedly been verified by experimentation [9], the measured data are not included here.

CONCLUSION:

The switching properties of latched ferrites are integrated with small size patch antennas to design an electrically small (80% smaller) ferrite based switchable microstrip antenna. The methods of introducing the external tunable property, improving the antenna efficiency and overall impedance bandwidth of the switched resonance are presented and optimized.

ACKNOWLEDGEMENT: The authors are thankful for the support of King Fand University of Petroleum & Minerals (KFUPM), Dhahran, Saudi Arabia.

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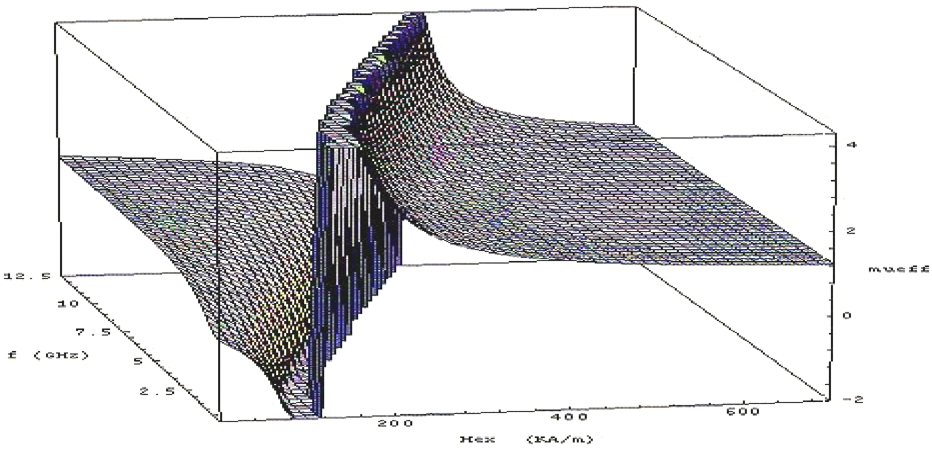

Fig 1. Operating and resonance regions of an axially magnetized YIG G-810 ferrite (γ *=35173.24 KA/m*, M_S = 60 KA/m, ε_r = 14 and ΔH = 10 Oe.)

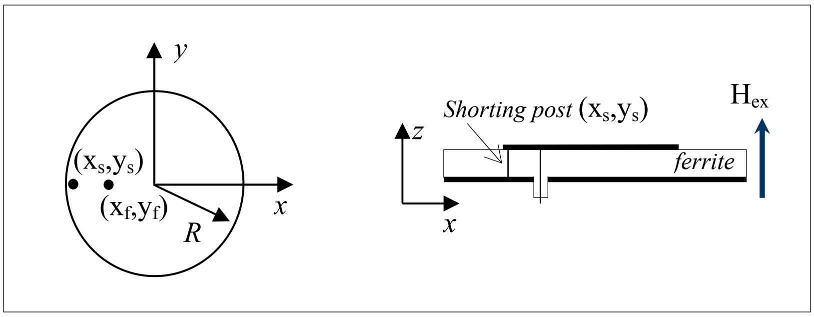

Fig 2. Schematic diagram of coax-feed circular patch antenna with single shorting post *(R=2mm , t=1.2mm ,* r_f *=0.2mm ,* x_f *=-1.1mm ,* y_f*=0 ,* r_s*=0.1mm ,* x_s*=-1.9mm ,* y_s*=0)*

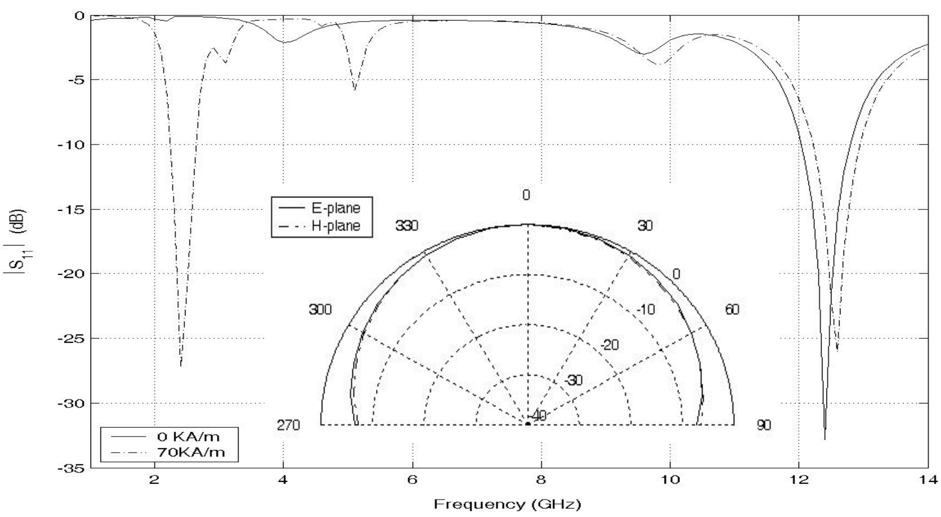

Fig 3. Reflection response and radiation characteristics of the ferrite based shorted antenna for no biasing (H_{ex}=0) and H_{ex}=70 KA/m biasing.

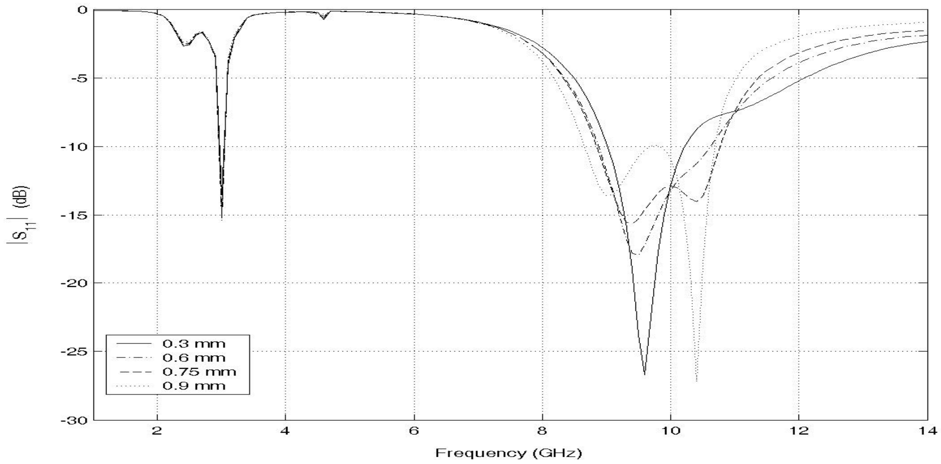

Fig 4. The reflection response for variable length of reactive-posts. The length of the shorting post is 1.2 mm.

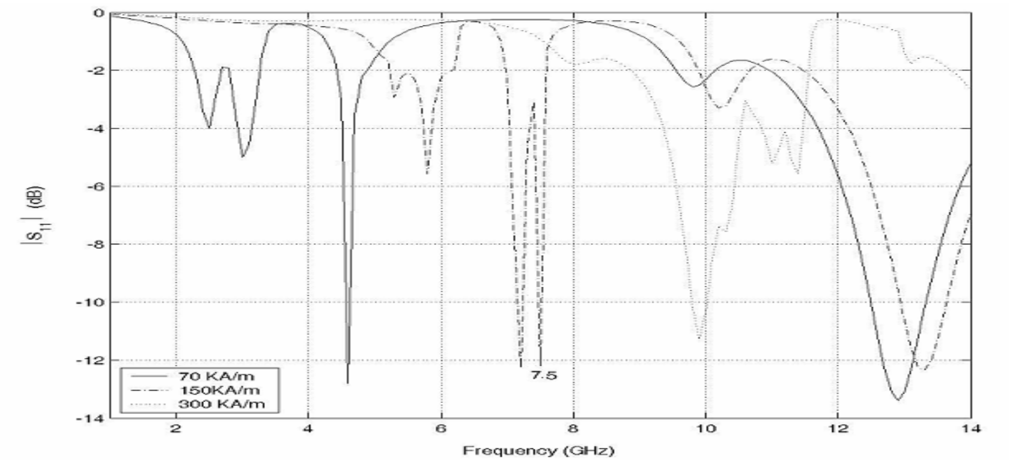

Fig 5. The reflection response of the antenna with shorting post located at (1.9mm,0), for variable biasing condition of H_{ex}=70, 150 and 300 KA/m

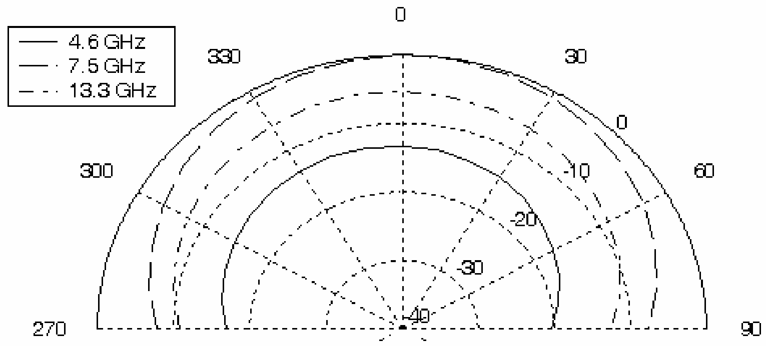

Fig 6. Radiation patterns for selected upper and lower resonance responses of fig 6.