Adjustable sub-wavelength waveguide by uniaxially designed artificial magnetic media

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In this study, we investigate sub-wavelength transmission through waveguides which includes artificially designed magnetic materials (SSRRs). The changeable transmission properties of waveguides have been observed by loading varicaps to internal/external gap regions and splits between rings on waveguides and then applying different DC bias to provide variable capacity values. Best variation ranges have been obtained for external gap regions down to 1.5 GHz.

1. Introduction

Electric permittivity (ε) and magnetic permeability (μ) describes the electromagnetic properties of any bulk media. These parameters macroscopically define the effects of applied electric and magnetic fields in such media. Recently, artificial electromagnetic (EM) structure design for specific macroscopic properties has received considerably interest within scientific community [1]. Artificial dielectrics composed of discrete obstacles or scatters, extensively studied in 1950's [2]. In this composed media, the wavelength of EM fields are much longer than one unit cell, in other words it could be thought as effective media and the electromagnetic properties of that media could be described in terms of effective permittivity and permeability, different than Bragg diffraction phenomena. Although Bragg diffraction could be realized using scatterers, their electrical lengths are on the order of wavelength, such as frequency selective surfaces (FSSs), so it couldn't be possible to describe them as a homogenous media.

Meta-materials have very important properties such as left handedness (LH), backward wave (BW), perfect focusing and negative refraction that couldn't be possible to achieve with another way[3-7]. These materials generally consist of two types of inclusions to realize electrical and magnetic response. The dimensions of these inclusions are much less than the wavelength to mention about effective media characteristics, negative permittivity and permeability. It could be possible to compensate lagging in a forward wave slab since this type of media exhibits phase advance.

Nowadays, meta-material application areas have been enlarged with many different disciplines to realize novelty properties such as waveguide miniaturization, sub-wavelength imaging, cloaking objects, antenna gain improvement, etc. [8-12]. One of these application areas is waveguide technology. Although planar type structures have been preferred than waveguides, there are still inevitable antenna applications such as antenna arrays.

In a rectangular waveguide, the transversal dimensions have been equal or greater than one half of wavelength. Below this frequency, boundary conditions couldn't be satisfied and EM waves couldn't propagate in waveguides. Although the reduction of dimensions is possible by filling with dielectric, high loss characteristics is one of the major problem.

The most common inclusions to achieve negative permeability have been split ring resonators (SRRs). These types of inclusions have been used in a waveguide to realize wave propagation below the cut-off frequency in rectangular waveguide [9]. It has been observed that SRR loaded waveguides exhibit transmission below cut-off frequency for dominant TE mode and it has been possible to reduction of waveguides transversal dimension below one half of a wavelength. Since magnetic response have been achieved with resonance phenomenon, it has been possible to propagate EM waves in a small frequency band.

In this study magnetic effects will be realized using varicap loaded SRRs (split ring resonator) type inclusions. Using numerical techniques S parameters will be obtained for those inclusions. This artificial uniaxial media will be placed in a rectangular waveguide and transversal dimension reduction will be investigated.

2. Numerical computations

It is well known that SRR type inclusions have been used as meta-material to minimize waveguide miniaturization in J band waveguides. In this approach, unwanted bi-anisotropic effects due to asymmetric shape of SRR's have been ignored, but that is a real unavoidable problem for this type of inclusions.

Since the longitudinal propagation factor [9];

$$k_l^2 = \varepsilon_r \mu_t (k_0^2 - \frac{k_t^2}{\varepsilon_r \mu_l}) \qquad (5)$$

To achieve propagation below cut-off frequency both permittivity and longitudinal part of permeability must be greater, and real part of permeability must be less than zero. So if it could be possible to achieve negative permeability, propagation in any frequency range below cut-off frequency has been realized in waveguide and if it could have been varied to magnetic resonance in waveguide, one waveguide could have been used to different frequency for different stuff. We have tried to realize variable resonances by placing varicaps to different splits and gaps of SSRRs.

SSRRs consist of two split rings. Outside (inside) ring length is 100 mils (70 mils) and thickness in all part is 10mils. The split between rings is 5 mils. These rings have been introduced on dielectric ($\varepsilon_r = 2,3$) for low loss for microwave band and assumed as 2D and PEC to evaluate results easily. To achieve periodicity for structure the waveguide walls have been assigned as 2D-PEC (PMC) perpendicular to electric field (magnetic field). SSRRs central axis have been placed parallel to the PMC walls to realize magnetic response, since this inclusions shows uniaxial behaviour due to asymmetric shape.

EM waves have been applied as TEM from waveports and reflected (S11) and transmitted (S21) scattering parameters have been evaluated. To minimize near field effect the distance between waveports and closed SSRRs have been adjusted to quarter of wavelength for minimum frequency in range. The magnetic component of EM wave has been directed towards central axis of SSRRs to realize magnetic response.

To observe the variations in the uniaxial permeability and transitivity of waveguide, varicaps have been located in gap regions on outside ring/ inside rings and splits between rings. By applying DC bias to varicaps, capacitances between metal parts have been adjusted to any value so resonance frequencies have been increased or decreased. When metal parts show inductive behaviour gaps/splits are the capacitive elements. By placing lumped element it could be possible to shift this resonance frequency ever much lower frequency. So the equivalent circuit representation of SSRRs with LC lumped element give true results.

In this study, the magnetic resonance behaviour have been realized with non-planar type of periodic SSRRs and the resonance frequency for pure SSRRs have been obtained at 10 GHz (Table 1).

Table 1. Resonance frequency of periodically arranged SSRRs at 10 GHz.

Frequency(GHz)	reflection(dB)
5,00	-10,10
6,00	-17,33
7,00	-19,77
8,00	-9,84
9,00	-7,17
10,00	-0,12
11,00	-6,65
12,00	-7,26
13,00	-11,25
14,00	-33,78

Initially we placed varicaps into the external ring gaps of SSRRs and by applying DC bias we observed waveguide transmission frequency changes. Although resonance frequency for 0.1 pF value is 4.8 GHz, this resonance has been reduced to 1.5 GHz for 1.3 pF varicap adjustment by applied DC voltage as shown in Fig. 1.
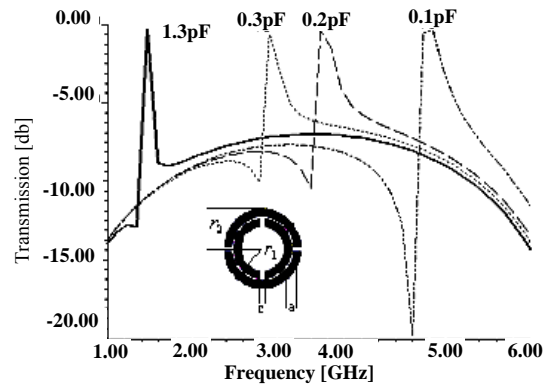

Fig. 1. Transmission variations in waveguide with varicap changes between internal gaps.

This is really very important result since sub wavelength transmission has been realised for $\lambda / 80$ dimensional waveguide and one other thing is variable waveguide properties down to sub wavelength. Since the inclusions used to obtain negative permeability are resonators, the bandwidths for transmission are quite low. If it could have been realised to create non-resonant type of inclusions, transmission for high bandwidth range could be possible.

The other SSRR region where varicaps have been placed is internal ring gaps and for five different DC values, we observed transmission variations in the waveguide between 3GHz-8GHz. Although for 0.1 pF DC value resonance has been realized for 7.4 GHz, as DC value have been increased resonance reduced down to 3.05 GHz and sub wavelength transmission and DC bias dependent waveguide have been achieved with internal ring gap varicaps. So H band waveguide could be used to provide transmission for E-G-F-C band waveguides. But this transmission frequency values are not as low as

external gap varicap values, and transmission losses have been increased down to -15 dB. For all this values meshes have been evaluated for 10GHz so lower meshes have been used. The transmission bands for all frequencies are resonant narrow bands.
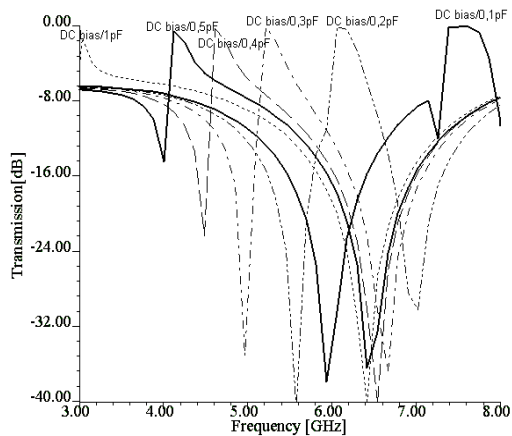

Fig. 2. Transmission variations in waveguide with varicap changes between internal gaps.

Last varicap capacitors have been placed between two rings. The transmission properties have been investigated between 5-15GHz bands. By DC bias varicap values have been varied between 0.1 pF-2.5 pF. When it was 0.1 pF, the transmission frequency is 8.23 GHz and as it was increased resonance frequency has been decreased down to 7 GHz value. Although by placing varicaps between ring splits, it could possible to produce variable waveguide, but the variations are not as effective as the others. One important thing is the bandwidth for this transmission. This is approximately 500 MHz for 0.1 pF and this bandwidth is fairly larger than the others.
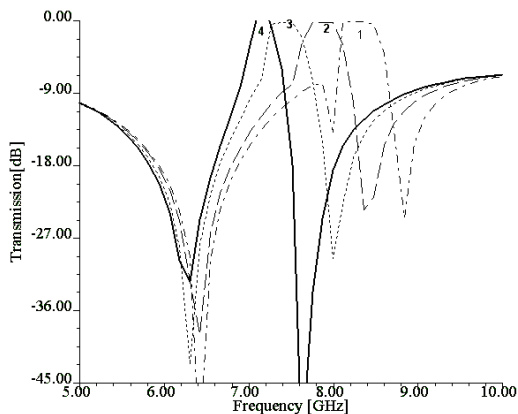

Fig. 3. Transmission variations with varicap changes between rings (1=0.1pF; 2=0.2pF; 3=0.5pF; 4=2.5pF).

Since if we assume that both rings are two separated parts, these are series to each other and the varicaps which have been placed to gaps connected series to metal part so it will be more effective than the split varicaps. Since the

varicaps between rings will be parallel to these half parts, even DC bias increased to enhance the capacity; it will not affect the whole circuit.

3. Conclusions

We have initially tried to realize magnetic response means negative permeability by using uniaxially placed SSRRs and for narrow band we obtained quite good response using numerical techniques. Than by placing varicaps to different regions of SSRRs in the waveguides and changing capacity with DC bias, we observed transmission variations. Although it could be possible to achieve sub wavelength transmission with varicaps which placed any gaps or splits, most efficient place is external ring gap. The varicaps placed to splits between rings doesn't give good response to variations of DC bias. Since the transmission frequency reduced down to $\lambda/80$, so it could be possible to use conventional waveguides for much different type of waveguides.

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