microstrip line, with their axes parallel to the vector of the electric field.

II. SRR Band Stop Filter Design

The resonance frequency obtained from this inclusion (SRR) is typically much smaller than that corresponding to the classical ring or square open loop resonators of similar dimensions. This feature is related to the large distributed capacitance between the two rings. The small electrical size of the SRRs suggests the possibility of applying this peculiar configuration (or some suitable modified version) to the design of compact filters. There are many different parameters that affect the resonance frequency of a SRR, most dominant being the permittivity of the substrate and the length of the resonator. In the microstrip technology, split-ring resonators can only be etched in the upper substrate side, next to the host microstrip transmission line. To enhance the coupling, the distance between the line and the rings should be as small as possible. A microstrip line loaded with split-ring resonators is a single negative medium, and therefore exhibits a stop-band characteristic.

In order to apply the time varying **H**-field perpendicularly to the square SRRs surface, a microstrip line which can generate the quasi-TEM wave was used. Microstrip lines are widely used in microwave planar circuit design and microwave integrated circuit (MIC) technology. As it is an open conduit for EM wave transmission, not all of the electric or magnetic fields will be confined in the structure. This fact, along with the existence of a small axial **E**-field, leads not to a purely TEM wave propagation, but to a quasi-TEM wave of propagation [14]. A microstrip transmission line generates magnetic field lines that close upon themselves around the line. If two arrays of SRRs are placed closely at both sides of the central line, a significant portion of the magnetic field lines induced by the line is expected to cross the SRRs with the desired polarization giving rise to a negative-μ effect over a narrow band around the resonant frequency of the individual SRRs. Hence, inhibition of signal propagation over this band can be achieved as in Fig.2.

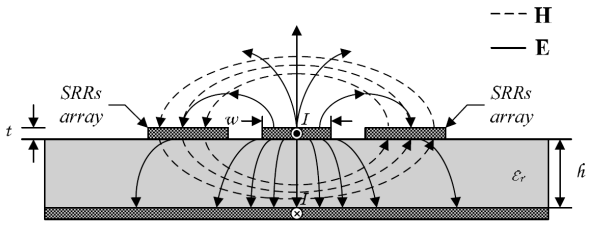

Fig. 2 Microstrip line **E** and **H** field distribution where h is dielectric thickness, t is the copper thickness and w is the microstrip line width

Based on this idea, SRR based band stop microstrip filter has been designed as shown in Fig. 3, where 5 SRRs have been added on each side. The number of SRRs can be varied. The microstrip line with square SRRs (rather than originally proposed circular ones to enhance the SRRs coupling to the central line) printed on a conventional high frequency laminate which is commercially available from Rogers Corporation [15] with 17 μm thick copper patterns on both sides and dielectric substrate thickness 25 mm. The substrate has a dielectric constant of 3.38 and a dissipation factor of 0.0036 at 10 GHz. In addition, the microstrip line was designed with a 1.46 mm width and a 36 mm length.

Formulas given in [3] which described the SRR structure behaviour were first used to obtain an estimate where the resonances of SRR would occur before the dimensions optimization. These estimates dealt with the radius of the rings, the distance between the rings and the periodicity of the elements. The dimensions of the microstrip line with 50 Ω impedance were calculated using AWR−TXLINE microstrip line calculator [16]. The geometry of the split ring resonators (SRR) coupled with microstrip line is shown in Fig. 4 with its relevant dimensions.

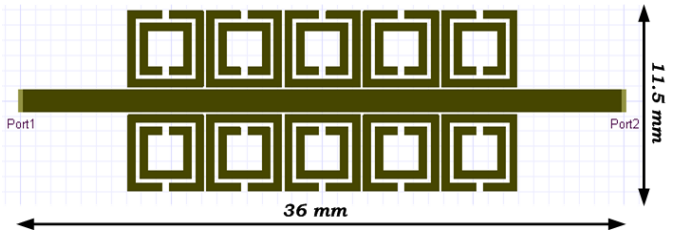

Fig. 3 Microstrip line loaded with 5 SRRs on each side.

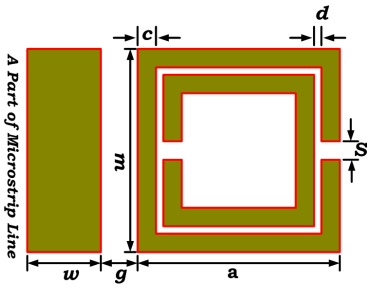

Fig. 4 Dimensions of the square SRR unit cell: a=m=5 mm, c=0.5 mm, and d=0.2 mm, *S*=0.5 mm, the gap between square SRR and microstrip line is *g*=0.2mm and *w*=1.46 mm.

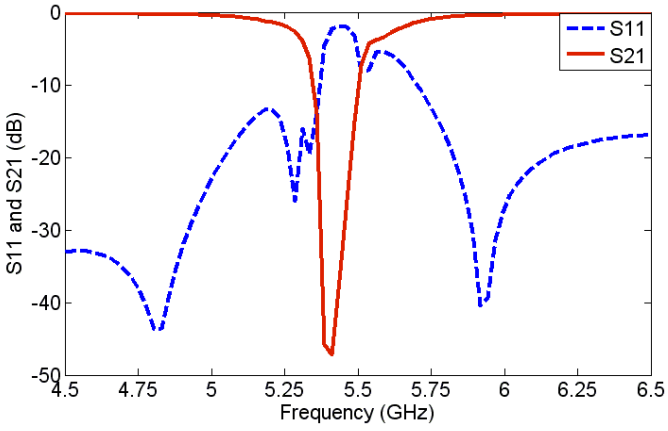

Fig. 5 S_{11} and S_{21} of microstrip line loaded with 7 SRRs on each side.

Numerical calculations of the scattering parameters are performed using the Method of Moments (MoM)-based