Ultra Wide Band Filter from Defected Ground Structures as Complementary Split Ring Resonator by with Simultaneously Double Negative Permittivity ε and permeability μ

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Abstract— In this paper, a metamerial of a single resonator operating between 3.1 GHz and 10.6 GHz frequency range is designed for developing ultra-wide band (UWB) filter. During UWB filter designing in CST microwave simulation, defected ground structure (DGS) in the form of complimentary split ring resonator (CSRR) is printed on the metallic plate and strip of wire mounted up on dielectric substrate so that simultaneously double negative permittivity (ε<0) and permeability (μ<0) are extracted. From the simulation result, the transmission UWB bandpass filter having transmission and fractional bandwidth of the transmission is about 2.48 GHz and 27.46% respectively satisfying the minimum requirement of FCC proposal at -10 dB transmission bandwidth

Keywords— Defected Ground Structure & Complementary Split Ring Resonator (DGS-CSRR), Drude-Lorentz Model of Harmonic Oscillator, Negative Refractive Index ,Metamaterial Resonator, Negative permittivity, negativepermeability

1. Introduction

Metamaterials are a special category of artificially engineered structures with sub- wavelength unit cells. In recent years, research on metamaterials, especially on left-handed materials (LHMs, i.e. metamterials with simultaneously negative electrical permittivity (ε<0) and magnetic permeability (μ<0) has aroused much interest due to the many involved intriguing physical properties such as negative refraction [1, 2, 3].

Doubtlessly, the development of research on metamaterials is tightly connected with structure design. As is well known, the difficulty in finding natural materials showing negative permeability is the reason that Veselago's hypothesis on left handed materials (LHMs)[1] had been given a cold shoulder for more than 30 years until the first realistic left-handed (LH) structure in a microwave regime[2] came out; the unit cell of this structure was actually a combination of thin metallic wires leading to (ε < 0[4] and split-ring resonators (SRRs) leading to (μ < 0)[5], both proposed theoretically by Sir J. Pendry. Afterwards, many novel metamaterial designs, especially designs showing negative permeability, were proposed aiming at more simplified fabrication and testing processes, lower intrinsic losses, and operation at higher frequencies, even the visible regime [6] to [7]. Under microwave frequency regime we design a metamaterial as ultra-wide band pass filter from defected ground structure of conducting plane with complimentary split ring resonator (DGS-CSRR)[11, 13] operating within frequency range of 3.1 GHz and10.6 GHz[8, 9, 10, 12]. In recent years, the ultra-wide band (UWB) technology has received much attention in academic and industrial fields [9, 10]. In order to construct a UWB communication system, many UWB components including antennas and microwave filters should be designed and developed. Compared to other parts in a UWB system, the design of wide bandwidth BPF with compact size, low insertion loss and wide band rejection is still a challenging task [9]. A UWB system is defined as any radio system that has a 10-dB bandwidth larger than 25% of its center frequency, or has a 10-dB bandwidth equal to or larger than 1.5 GHz if the central (resonance) frequency (resonance) is greater than 6 GHz[9]. The trends that drive recent R&D activities carried out for UWB transmission for commercial communication applications include:

1**. High data rate**: UWB technology is likely to provide high data rates in short- and medium-range (such as 20m, 50m) wireless communications.

2. **Less path loss and better immunity to multipath propagation**: As UWB spans over a very wide frequencyrange (from very low to very high), it has relatively low material penetration losses. On the other hand, UWBchannels exhibit extremely frequency-selective fading, and each received signal contains a large number ofresolvable multipath components.

3. **Availability of low-cost transceivers**:Recent advances in silicon process and switching speeds makecommercial low-cost UWB systems possible.

4**. Low transmit power and low interference**: For a short-range operation, the average transmits power of pulses of duration on the order of one nanosecond with a low duty cycle is very low. With an ultra-wideband spectrum bandwidth, the power spectral density of UWB signals is extremely low. This gives rise to the potential that UWB systems can coexist with narrow-band radio systems operating in the same spectrum without causing undue interference.

Complementary split ring resonator (CSRR) is a dual split ring resonator (SRR), has been very popular resonator and widely used to synthesize metamaterial. Pendary et al[14]. have demonstrated that an array of SRRs exhibits negative permeability near its resonant frequency. Gay-Balmaz et al.[15] study experimentally and numerically the resonances in individual and coupled split ring resonators. Bonache et al[16] have found the application of complementary circular split-ring resonators to the design of compact narrow bandpass structures in microstrip technology. Consequently this opens the door to a wide range of applications. In this paper a concentric compliantly split ring resonators (CSRRs) are produced from defected ground structure (DGS) on PEC structure to disturb the shield current distribution depending on the shape and dimension of of the defect. This disturbance at shield current distribution will influence the input impedance and the current flow of the antenna. It can also control the excitation and electromagnetic waves propagating through the substrate layer. DGS is any defected etched in the ground plane of the microstrip can give increasing the effective capacitance and inductance. DGS has the characteristics of stop band slow wave effect and high impedance. DGS are basically used in microstrip antenna design for different applications such as antenna size reduction, cross polarization reduction, mutual coupling reduction in antenna arrays, harmonic suppression etc. DGS as CSRR is widely in microwave device to make the system compact and effective. Jigar M. patel et al[17]. Designedmicrstrip patch antenna with defected ground structure DGS for bluetooth to determine the effect on its application. Microstripbandpass filters are particularly popular structures because they can be fabricated using printed circuit technology, compact size and low-cost integration. An effective way to obtain tight coupling within fabrication limit is to use defected ground structure (DGS) or aperture compensation technique, which can realize strong coupling compared with the coupled line structure. This process modifies the characteristics of the transmission line such as the line capacitance and inductance. Therefore, the DGS is usually used to improve the passband and stopband characteristics. Several methods have been developed using different forms of DGSs. Moreover, reducing size is also the main challenge of the filter design for microstrip filters. Several types of resonators have been designed to overcome these problems, such as stepped-impedance resonator, meander resonator, and slow-wave open loop resonator. Nevertheless, miniaturized resonators lead to a reduced size of filter, but not always improve the spurious response. In recent years, several filter applications at microwave frequency have been developed by means of metamterials (MTMs) based on sub-wavelength resonators such as the split-ring resonators (SRRs) and different resonators. Because of the small electrical size of the unit cells, the metamaterial based resonator (MBR) offers a great solution to the design of miniaturized microwave resonator. However MBRs have usually been used for notch band and narrow bandpass filters and, furthermore, there is still a vast need for research on miniaturization of wide-band transceiver components using MBRs[18]. A special sub-class of metamterials with both effective parameters negative in a certain frequency, are so called double-negative (DNG) or left-handed (LH) metamaterials. The first theoretical speculation on the existenceof DNG media and prediction of their fundamental properties was done by Russian physicist Victor Veselago in 1967,[19]. Veselago anticipated unique electromagnetic properties of DNG media and showed their support propagating modes of the electromagnetic waves, but exhibit negative propagation constant. The energy would still travel forward from the source but the wave fronts would travel toward the source. Consequently, vector of the electric field, vector of magnetic field and wave vector of an electromagnetic wave in a double negative material will form a left-handed triad. Therefore, LH materials are characterized by antiparallel phase and group velocities and exhibit negative refractive index (NRI). Therefore the constitutive parameters are the effective permittivity ε_{eff} and μ_{eff} which are related to the refractive index by:

$$n = \pm\sqrt{\varepsilon_{eff}\,\mu_{eff}} \quad \text{---(1)}$$

2. Designing Ultra Wideband Filter from Metamaterial Resonator

Designing of metamaterial resonator basic structure is not separated from designing of microstrip patched antennaon dielectric substrate mounted on ground plane so as to filter or detect the right signals falling up on it over some frequency range. As it has been indicated on different literature [20, 21], electromagnetic metamaterials are composite arrays of resonator of sub-wavelength size designed to have specific microwave or optical properties. The properties of metamaterial resonators depend on the geometry of individual unit cell. Many unique effects such as negative refractive index, sub-wavelength imaging, cloaking, perfect absorption etc., are difficult to achieve with natural materials. But with careful designing of noble metals as metamaterial with sub-wavelength dimensions have been obtained at specified frequencies.

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$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{12d}{W}\right]^{-0.5} \text{---(-2)}$$

where ε_r is relative dielectric, W denotes the width of the strips, d is the thickness of the substrate on which thestrips mounted, other parameters like characteristic impendence Z_0 that can be related by the following conditions in the following two equations. For a given W/d ≤ 1, Z_0 1, Z_0 becomes

$$Z_0 = \frac{60}{\sqrt{\varepsilon_e}} \ln\left(\frac{8d}{W} + \frac{W}{4d}\right) \text{---(3)}$$

For a given $W/d \geq 1, Z_0$ becomes

$$Z_0 = \sqrt{\varepsilon_e}\left[W/d + 1.393 + 0.667\ln\left(W/d + 1.444\right)\right] \text{---(4)}$$

For a given characterize impendence Z_0anddielectricconstant ε_r , W/d is calculated by the following equations. For W/d ≤ 2 assumed:

$$\frac{W}{d} = \frac{8e^A}{e^{2A} - 2} \text{--(5)}$$

For $W/d \geq 2$ assumed

$$W/d = \frac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B - 1) + 0.39 - \frac{0.6}{\varepsilon_r}\right\}\right] \text{--(6)}$$

$$\text{Where } A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \text{ and } B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

3. Drude-Lorentz Model of Harmonic Oscillator

This model is a system of non-homogenous Maxwell differential waveequations helping to visualize the scatteringand dispersion of electron gases when they are exposed to incident electric field $\vec{E}$ and magnetic field $\vec{H}$. The electromagnetic wave equations are summarized for the purpose for this paper as:

$$\left.\begin{aligned} &\vec{\nabla} X\vec{E} = -\frac{\partial \vec{B}}{\partial t} \\ &\vec{\nabla} X\vec{H} = \frac{\partial \vec{D}}{\partial t} \\ &\vec{B} = \mu_0\vec{H} + \vec{M} = \mu\vec{H} \\ &\vec{D} = \varepsilon_0\vec{E} + \vec{P} = \varepsilon_0\varepsilon_r\vec{E} \\ &\vec{P} = n\vec{p} = ne\vec{r} \end{aligned}\right\} \text{--(7)}$$

where $\vec{D}$ and $\vec{B}$ corresponding to electric and magnetic flux densities are emerged in response to the correspondingelectric $\vec{E}$ and magnetic $\vec{H}$ propagating either conducting or non-conducting media. ε_0 is permittivity of free space, ε_r is the relative permittivity of the medium and μ_0 is permeability of free space. Where $\vec{P}$ is polarization, n isthe number of electric dipole moment $\vec{p}$ per unit volume, $\vec{r}$ is position vector of the electron, $\vec{M}$ is magnetization. Motion of electron whose effective mass m_{eff} and charge amount e either free or bounded medium in the externalelectromagnetic field is governed by classical Newton's second law of motion explained byW. CaiV.Shaleaev[26],R. Fowles[27], W. Millonni& H. Eberly[28,29].

$$m_{eff}\frac{\partial^2 r}{\partial t^2} + m_{eff}\Gamma_e\frac{\partial \vec{r}}{\partial t} = -e\vec{E} \text{--(8)}$$

Where Γ_e is the electric damping or collision frequency in Drude-Lorentz model.

The applied electric field is varied harmonically with time according to the usual factor $e^{-i\omega t}$ assuming that the motion of the electron has the same harmonic time dependence, combining eq(8) with the last sub-equation eq(7), the following of Drude-Lorentz are extracted as

$$\frac{\partial^2\vec{P}}{\partial t^2} + \Gamma_e\frac{\partial\vec{P}}{\partial t} = \varepsilon_0\omega_p^2\vec{E} \text{---(9)}$$

.

$$\varepsilon_{eff}(\omega) = \left(1 - \frac{\omega_p^2}{\omega(\omega + i\Gamma_e)}\right) \text{---(10)}$$

Where're ω_p is named as plasma frequency at which density of the electron gas oscillates, $\varepsilon_{eff}(\omega)$ is effective permittivityin frequency domain. Taking a conducting wires of radius r and separated by a (the dimension of unit cell isalso called lattice constant) is immersed in external electric field to drift free charges with velocity v_d. Estimatingthe plasma frequency of medium wire would depend on the estimation of effectivemass and effective electrondensity in the metal. The electron density in the wire of radius r of arrays in the dielectric medium separated from each other by a distance is given by

$$N_{eff} = N \frac{\pi r^2}{a^2} \text{--(11)}$$

where N is the actual electron density in pure metal. The effective mass is resulted from the self-inductance is relatedto the the magnitude of magnetic vector potential $\vec{A}$ and drift velocityv_d is given by

$$m_{eff} = \frac{eA}{v_d} \text{--(12)}$$

According to Ampere's law, the current flow gives rise to an azimuthal magnetic field $\overleftarrow{H}$ around the wire at radius Rgiven by

$$\left.\begin{aligned} H(r) &= \frac{\pi r^2 eNv_d}{2\pi r} \\ H(r) &= \vec{\nabla} \times \frac{\vec{A}(r)}{\mu_0} \end{aligned}\right\} \text{--(13)}$$

Where the magnitude of the vector potential choosing according to H.Hayat[30] and W.Shalaev [31] as

$$A(r) = \frac{\mu_0 r^2 eNv_d}{2} \ln(a/r) \text{--(14)}$$

Combining eq(12) and eq(14), we obtain the "effective mass" of the electrons in the medium as

$$m_{eff} = \frac{\mu_0 r^2 eN}{2} \ln(a/r) \text{--(15)}$$

Now with both N_{eff} and me m_{eff} availablility, the plasma frequency of the medium is presented as

$$\left.\begin{aligned} \omega_p^2 &= \frac{N_{eff} e^2}{\varepsilon_0 m_{eff}} \\ \omega_p^2 &= \frac{2\pi c}{a^2 \ln(a/r)} \end{aligned}\right\} \text{--(16)}$$

Where c is the speed of light in free space given by $c = 1 / \sqrt{\mu_0 \varepsilon_0}$ and assumption of $r << a$

The bound current circulating about a differential area $d\vec{S}$ establishing a dipole moment is defined as

$$\vec{m} = I_b d\vec{S} \text{---(17)}$$

Magnetization $\vec{M}$ as the magnetic dipole moment per unit volume established because of bound charges (orbitalelectrons, electron spin, and nuclear spin) is defined as,

$$\vec{M} = \lim_{\Delta v \to 0} \frac{1}{\Delta v} \sum_{i=1}^{n\Delta v} \vec{m}_i \text{ ---(18)}$$

Now a metallic square split ring resonator (SRR) of length ℓ, ring width w, thickness t and split gap g isimmersed in time varying harmonic external magnetic field $\vec{H}$ perpendicular to the plane of SRR as shown in figure1(a), and its simplified equivalent circuit with capacitance C, resistance R, inductance L is also shown on figure1(b). According to Faraday's Law, there is induced electromotive force ξ_m since there is harmonically changingmagnetic field perpendicular to the plane of rectangular ring. Latter it is adapted to figure 2 for simulation work.Applying Kirchhoff's circuit and Faraday's rules to figure 1, the following differential equation is obtained.

$$L\frac{d^2 I_b}{dt^2} + R\frac{dI_b}{dt} + \frac{1}{C} I_b = -\frac{d^2 \phi_B}{dt^2} \text{ -------------------------------------(19)}$$

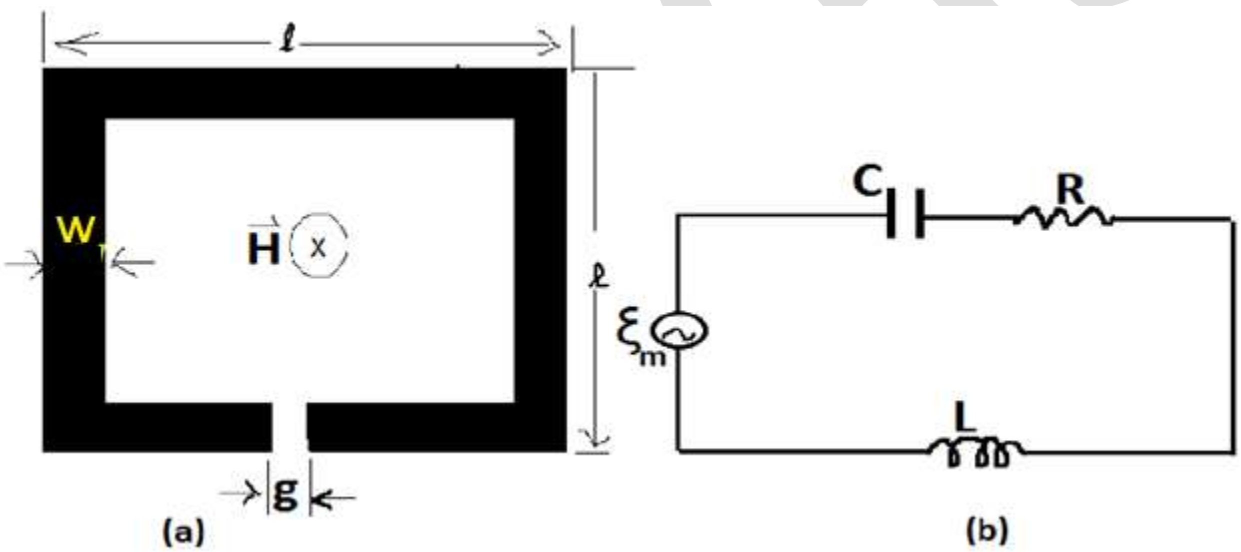


Figure 1: (a) a single square-Split Ring Resonator (SRR) as magnetic field $\vec{H}$ oscillated perpendicularSRR plane (b) The equivalent circuit of the single squared SRR

Where I_b is the bound current or Amperian current, ϕ_b is the magnetic flux density passing through area element $d\vec{S}$, therefore ϕ_b is mathematically written as

$$\phi_b = \int_s \vec{B} \bullet d\vec{S} = \mu_0 \int \vec{H} \bullet d\vec{S} \text{ --(20)}$$

The associated harmonic variation of magnetic bound current I_b, magnetization M, magnetic susceptibility χ_m, filling factor F, magnetic plasma frequency ω_m, magnetic damping frequency Γ_m, relative permeability μ_r, volumeV occupied by an N number of unit cells, magnetic field intensity H and other parameters listed below are usedto drive frequency dependent effective magnetic permeability $\mu_{eff}(\omega)$ of eq.(22) using equations from eq(17) to Eq.(20).

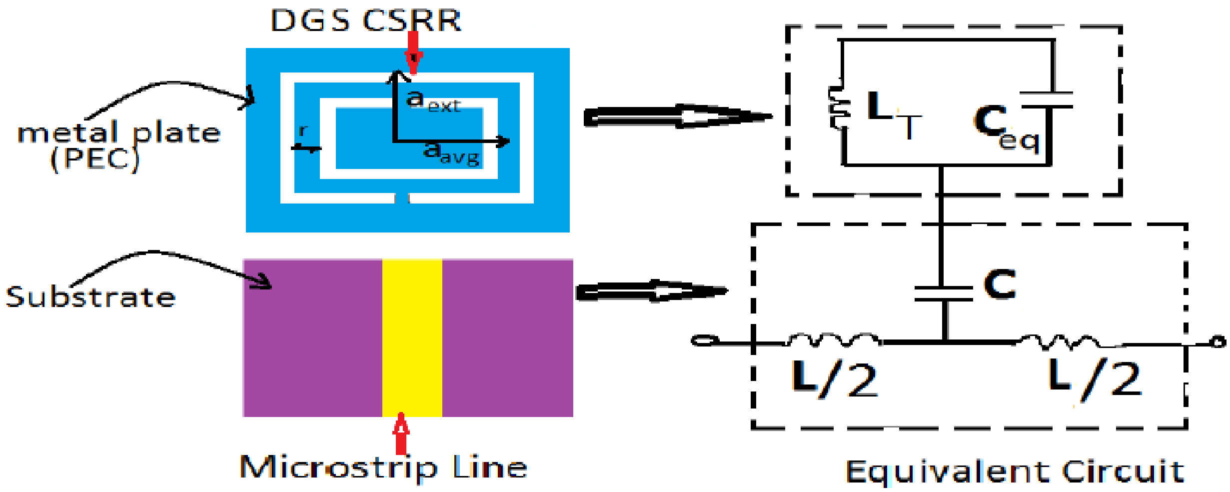
$$\left.\begin{aligned} I_b &= I_0 e^{-i\omega t} \\ M &= M_0 e^{-i\omega t} \\ H &= H_0 e^{-i\omega t} \\ M_0 &= \chi_m H_0 \\ M_0 &= \frac{N\ell^2}{V} I_0 \\ F &= \frac{\ell^2 t}{V} \\ \omega_m &= \frac{1}{\sqrt{LC}} \\ \Gamma_m &= \frac{R}{2L} \\ \mu_r &= 1+\chi_m \\ \mu_{eff} &= \mu_0 \mu_r \end{aligned}\right\} \text{---} \quad (21)$$

$$\mu_{eff} = 1 - \frac{F\omega^2}{\omega^2 + \Gamma_m \omega - \omega_m^2} \text{---} (22)$$

the filling factor F ($0 < F \le 1$) measuring the portion of the volume occupied by the split rings. The larger F, thestronger the magnetic resonance of the system[32, 33].

4. Developing UWB Bandpass Filter

An 8X8 mm^2 PEC plate of thickness 1 mm is prepared. The plate is etched in the form of two squares 6X6 mm^2 and 4.88X4.88 mm^2 complimentary split ring resonator (CSRR) so that negative permeability (µ < 0) is obtained in the medium. The depth and the width of the etched surfaces are 0.28 mm, A 2.5 mm thick Arlon AR 450 (ε_r =4.5) substrate is loaded on the non-etched surface as shown in figure 2. A 2 mm width of microstrip line is mounted upon the substrate to obtain a negative permittivity (ε_r < 0) in the medium. The composite structure of DGS-CSRR and the microstrip line from a new class of metamaterial forms a resonator. This metamaterial could simultaneously have negative permittivity and permeability near the resonance frequency when the sum of the impedance zero condition in the circuit is satisfied. From the equivalent circuit model of figure 2, etching split-ring defective pattern in the ground plane will add a parallel resonant circuit to the equivalent circuit, but L2 has little contribution overall effect of system[34, 35], the sum of the impedance zero is written us.



$$Z_1 + Z_2 = 0 \text{--}(23)$$

Where Z_1 is

$$Z_1 = \frac{1}{j\omega C_{eq} + \frac{1}{j\omega L_T}} = j\frac{\omega L_T}{1-\omega^2 L_T C_{eq}} \text{--------------------------}(24)$$

And Z_2 $Z_2 = \frac{1}{j\omega C} = -j\frac{1}{\omega C}$ --(25)

The resonance frequency of the circuit is

$$f_r = \frac{1}{2\pi\sqrt{L_T(C_{eq}+C)}} \text{--}(26)$$

5. Theoretical Analysis of UWB Resonator

When an electromagnetic wave is launched in the coplanar waveguide (CPW) guide, propagating along y direction,the magnetic field directing along z axis interact with the DGS-CSRR placed on the back of the CPW. Thisarrangement produces induced electromotive force inside the ground plane. Since the ground plane is defected, theflow of induced current is disturbed inside the plane. The disturbance can change the characteristic of transmissionline such as equivalent capacitance and inductance to obtain the slow wave effect and band-stop property. If thecapacitance C contributed from the strip of wire is ignored or suppressed, the resonance frequency f_r in eq(26) canbe rewritten as

$$f_r = \frac{1}{2\pi}\sqrt{\frac{1}{L_T C_{eq}}} \text{ --(27)}$$

Where L_T the total inductance of CSRR is structure and C_{eq} is the total equivalent capacitance of the structure. This total equivalence capacitance, C_{eq} can be evaluated as

$$C_{eq} = \frac{(C_1 + C_{g_1})(C_2 + C_{g_2})}{(C_1 + C_{g_1}) + (C_2 + C_{g_2})} \text{ --(28)}$$

Where C_1 and C_2 are the capacitance of the upper and lower half portion between the CSRR about an imaginaryline passing through the centers of the split gaps g_1 and g_2. The split gaps are incorporated in the model as gapcapacitances C_{g_1} and C_{g_2} .From figure 2, all gaps are identical ($C_{g_1} = C_{g_2} = C_g$) where g_1 is the gap of thesmaller split ring, where g_2 is the gap of the t larger split ring. These gaps also affect the total inductance L_T ofthestructure of the model in figure 2. Since the split gaps have identical dimensions $g_1 = g_2 = g$, hence the gapcapacitance is denoted as $C_{g_1} = C_{g_2} = C_g$ and the series capacitance is denoted as $C_1 = C_2 = C_0$ and thereforeeq(28) is modified as

$$C_{eq} = \frac{C_0 + C_g}{2} \text{ ---(29)}$$

Considering a metal thickness, t of the strip conductors, the gap capacitance C_{g_1} and C_{g_2} represented as

$$C_{g_1} = C_{g_2} = C_g = \frac{\varepsilon_0 wt}{g} \text{ ---(30)}$$

Where w is the width of the ring, t is the depth of the etched surface forming rings; $\varepsilon_0 = 8.85 \times 10^{-12} F/M$. The distributed capacitance C_1 and C_2 are also a function of the split dimensions $g_1 = g_2 = g$ average ring dimension a_{avg} is given by

$$C_1 = C_2 = (4a_{avg} - g)C_{pul} \text{ -----------------------------(31)}$$

Where

$$a_{avg} = a_{ext} - w - \frac{r}{2} \text{ --------------------------------------(32)}$$

r is the gap between the two rings, a_{ext} is the distance from the center to the outer ring, C_{pul} is defined asthecapacitance per unit length and calculated as

$$C_{pul} = \frac{\sqrt{\varepsilon_r}}{cZ_0} \text{ ---(33)}$$

Therefore, the equivalent capacitance by substituting the value of C_0 and C_g in eq(29), we obtain

$$C_{eq} = \left(2a_{avg} - \frac{g}{2}\right)C_{pul} + \frac{\varepsilon_0 wd}{2g_1} \text{---------------------------------(34)}$$

Hence, the resonance frequency of the squared split ring resonator is derived as

$$f_r = \frac{1}{2\pi\sqrt{L_T C_{eq}}} = \frac{1}{2\pi\sqrt{L_T\left[\left(2a_{avg} - \frac{g}{2}\right)C_{pul} + \frac{\varepsilon_0 wt}{2g_1}\right]}} \text{----------------------------(35)}$$

A simplified formulation for the evaluation for the total equivalent inductance L_T for a wire of rectangular cross- section having finite length ℓ and thickness t is proposed as .

$$L_T = 0.0002\ell\left(2.303\log_{10}\frac{4\ell}{t} - \gamma\right)\mu H \text{---------------------------------(36)}$$

Where the constant γ =2.853 for a wire loop of square geometry. The length ℓ and thickness t are in mm. Theevaluation of the wire length ℓ is straight forward and is given as $\ell = 8a_{ext} - g$ for square geometry[37].Theparameters and the numerical calculation of the DGS-CSRR unit cell based on the figure 2 and 3 are displayed ontable 1.

Table 1: This table displays both settled and extracted value of the parameters which are used on the next subsequent simulations

Name of the Parameers	notation	settled value	extracted value
the length of the outer string(mm)	a_1	6	-
the length of the inner ring(mm)	a_2	4.88	-
width of the rings(mm)	w	0.28	-
thickness or the depth of the ring(mm)	t	0.28	-
gap between rings(mm)	r	0.28	-
gap between ring's split(mm)	g	0.28	-
thickness of the PEC plate(mm)	M_t	1	-
thickness of the dielectric substrate(mm)	d	2.5	-
thickness of the Metallic strip(mm)	t	0.28	-
width of the metallic stripe(mm)	W	2	-
average ring dimension(mm)	a_{avg}	-	2.58
effective permittivity	ε_e	-	3.2
characteristic impedance (Ω)	Z_0	-	77.8
capacitance per unit length (F/m)	C_{pul}	-	9.08×10^{-11}
equivalent capacitance(pF)	C_{eq}	-	46.1
equivalent inductance (nH)	L_T	-	0.56
resonance frequency (GHz)	f_r	-	9.9

Compact UWB bandpass filters with low insertion loss, compact size, high selectivity, wider bandwidth and good stop band rejection are required for the next generation mobile and satellite communication systems. This paper reports on the development of UWB bandpass filters operating in the frequency range of 3.1 GHz and 10.6 GHz by designing a defected ground structure complimentary split ring resonator (DGS-CSRR) on PEC ground plane to obtain stop band characteristic as in figure 2 and 3. The parameter used in the simulation task are listed down in table 1. The limiting size of the two waveguide ports are also adjusted as in figure 3 for a bettor performance. The single DGS-CSRR with metallic strip on the Arlon 450 substrate are activated by the two ports in the UWB frequency range as shown in the figure 4. To verify the filtering property of the DGS-CSRR from the result of figure 5, the cut off frequencies region of the transmission curve (S21) at -10 dB are lied between 7.62 and 10.01 GHz. Therefore the transmission bandwidth lieswithin the frequency region is 2.48 GHz about central frequency 9.04 GHz with transmission curve less than -1 dB . Again there are two weak signals of -41.75 dB at 8.69 GHz and -50.52 at 9.53 GHz embedded in the transmission bandwidth are rejected back by UWB bandpass filter not to affect the performance. The central frequency of the bandwidth that we obtain from simulation and the resonance frequency we calculate numerically in table 1 are deviated from each other by 0.5%. The transmission UWB bandpass filter having fractional bandwidth of the transmission is about 27.46 % as shown in figure 5.

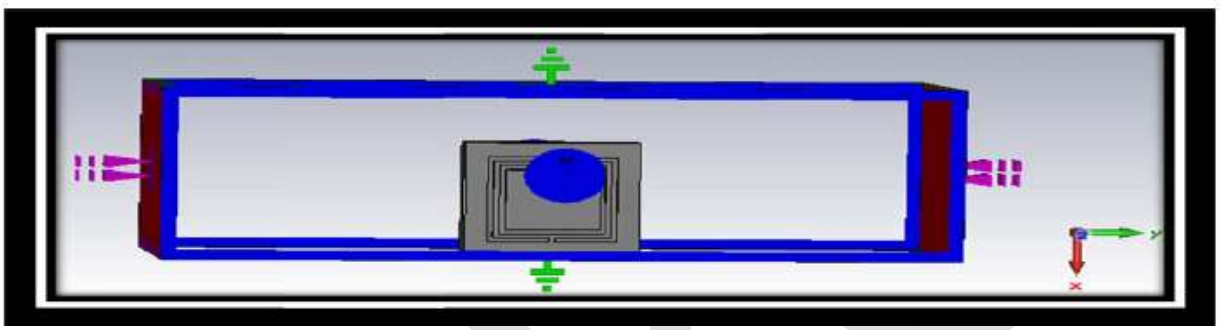


Figure 4: Adesigningand modelling of single DGS-CSRS with metallic strip during CST microwave simulation within UWB frequency range. From boundary condition set up, the electric field is directed along the vertical, while the magnetic field is directed perpendicular to the page.

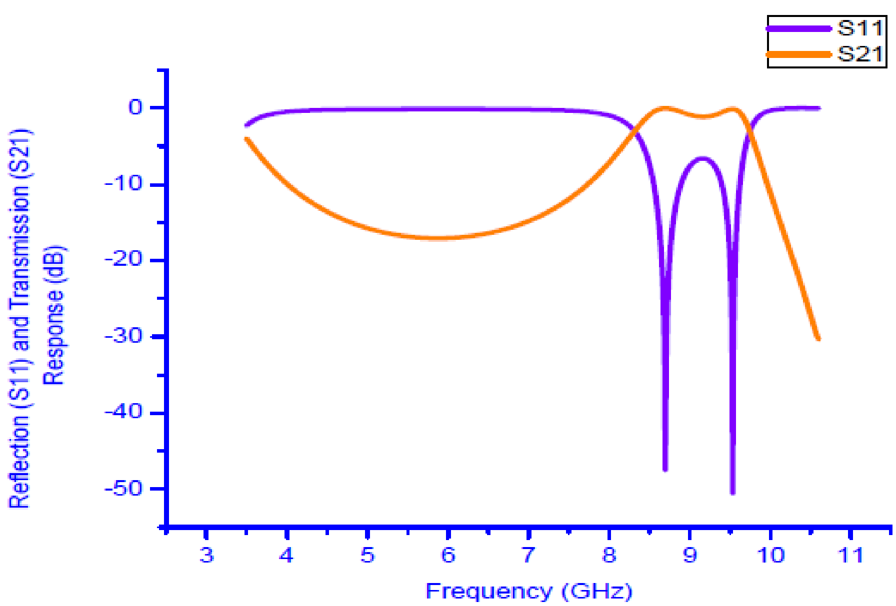


Figure 5: Frequency response of a single DGS-CSRR with metallic strip mounting up on the arlon 450 (ε_r = 4:5) substrate.

6. Extraction of Negative Permittivity from DGS-CSRR

From section 3, the discussion on derivation of the frequency dependent permittivity of metamterial consisting of arrays of wires is given by the following equation

$$\varepsilon_{eff}(\omega) = \left(1 - \frac{\omega^{p}}{\omega(\omega + i\Gamma_e)}\right) \text{--(37)}$$

where ω_p is the characteristic 'plasma' frequency, Γ_e is the collusion frequency in the Drude-Lorentz model. The plasma frequency of the wire depends up on the number of electrons per unit volume is called effective electron density N_{eff} and the effective 'mass' m_{eff} of the electron due to the self-inductance. The empirical formula for solving the plasma frequency is given as

$$\left.\begin{aligned} \omega_p^2 &= \frac{N_{eff}e^2}{\varepsilon_0 m_{eff}} \\ \omega_p^2 &= \frac{2\pi c^2}{a^2 \ln(a/r)} \end{aligned}\right\} \text{---(38)}$$

A modified expression for the reduced plasma frequency may then be written as[36, 38]:

$$\omega_p^2 = \frac{2\pi c}{a \ln\left(a^2/4r(a-r)\right)N_{eff}} = \frac{2\pi c}{a^2 \ln\left(a^2/4r(a-r)\right)\varepsilon_r} \text{--------------------------(39)}$$

where a is the the dimension of DGS-CSRR unit cell, r is the radius of the wire. Here we approximate half of the width W of the metallic strip as the radius for extracting plasma frequency. From the modified equation of (37), the electric plasma frequency f_p of the metallic strip is computed as 9.08 GHz. The electric damping frequency Γ_e as we can extract from Drude-Lorentz model discussing before

$$\Gamma_e = \frac{\varepsilon_r \varepsilon_0 a^2 \omega_p^2}{\pi r^2 \sigma} \text{---(40)}$$

As silver is used in the metallic strip, the conductivity σ is given by $6.3\text{x}10^7$ S/m. Hence the electric damping frequency Γ_e using the linear plasma frequency f_p is obtained from eq(38) as

$$\Gamma_e = 2\frac{\varepsilon_r \varepsilon_0 a^2 f_p^2}{r^2 \sigma} \text{---(41)}$$

Therefore, the electric damping frequency is computed as 104.2 MHz. From figure 6, we note that negative permittivity ($\varepsilon_{eff} < 0$) occurs lower than the resonance frequency. Above the plasma frequency, the effective permittivity is positive and the medium acts as a transparent dielectric. This onset of propagation has been identified with an effective plasma frequency dependent on the wire radius and spacing, with the effective dielectric function following the form of eq(37). A reduction in ω_p can be achieved by restricting the current density to the thin wires, which also increases the self-inductance per unit length L[39]. When the conductivity of the wires is large, the plasma frequency has been shown to have the general form

$$\omega_p^2 = \frac{1}{\varepsilon_0 a^2 L} \text{ --(41)}$$

Combining the DGS-CSRR medium having a frequency band gap due to a negative permeability with a thin wire medium produces a resultant left-handed material in the region where both ε_{eff} and μ_{eff} have negative values. Figure 6 demonstrates that the the metallic strip, which gives negative permittivity below plasma frequency and exhibits high pass characteristics, in combination with DGS-CSRR, which gives negative permeability and exhibits resonant characteristics can be used together to design plasmonicmetamaterial[40].

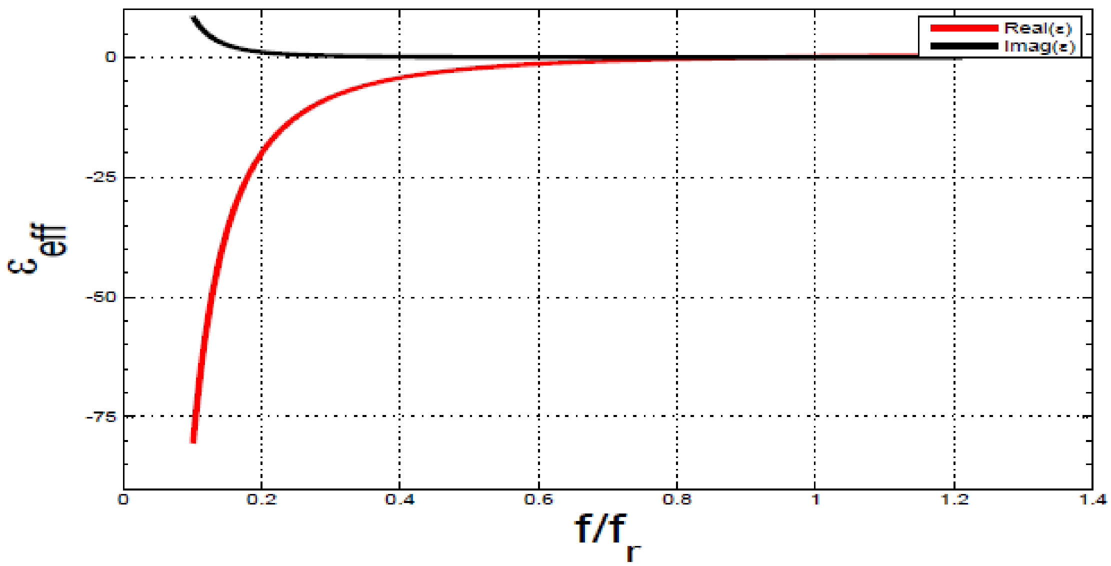


Figure 6: The frequency response of both the real and imaginary of the effective permittivity within UWB frequency range of DGS-CSRS with metallic strip loaded up on arlon 450 substrate.

7. Extraction of Negative Permeability from DGS-CSRR

By combining the split ring resonators into a periodic medium such that there is strong (magnetic) couplingbetween the resonators, unique properties emerge from the composite. In particular, because these resonatorsrespond to the incident magnetic field, the medium can be viewed as having an effective permeability, μ_{eff} . Fromsection 3, bycombining Kirchhoff's circuit rule and Faraday's law for harmonic time varying magnetic fieldperpendicular to the plane of split ring resonator SRR indicated in figure 1, the frequency dependent of magneticpermeability μ_{eff} of meta-material is derived as

$$\mu_{eff} = 1 - \frac{F\omega^2}{\omega^2 + \Gamma_m - \omega_m^2} \text{ --(42)}$$

where F(0 < F 1) is the filling factor of the fractional factor of of the the volume of DGS-CSRR in the unit cell.

It is advisable to keep F small to avoid strong magnetic interaction or coupling among adjacent unit cells. If we

ignore the material loss, □m can be set to zero, and Eq.(41) can be rewritten as:

$$\mu_{eff} = 1 - \frac{F\omega^2}{\omega^2 - \omega_m^2} \text{ --(43)}$$

The filling factor F can be approximated as

$$F = \frac{Ah}{V_{cell}} \text{ --(44)}$$

Where A is the area occupied by the DGS-CSRR, h is the thickness of the ring, V_{cell} is the volume of the unit cell.So the filling factor F of DGS-CSRR is approximated as 0.2. When the plate of DGS-CSRR are made of good conductors (i.e., σ is small), the imaginary part of effective permeability given in figure 7)is almost zero or ignored.Behavior of its real part versus linear frequency is plotted in figure 7. There are two critical frequencies seen at this graph. f_r , the frequency where the effective permeability diverges, is called the resonant frequency. The frequencywhere the effective permeability crosses the $\mu_{eff} = 0$ axis is called the magnetic plasma frequency f_{mn} of the DGS-CSRRs.As it is clearly seen from this figure, the effective permeability μ_{eff} exhibits an asymptotic behavior in itsfrequency response by taking extreme values around the resonant frequency. It is highly positive near the lowerfrequency side of f_r , whereas, most interestingly and strikingly, it is highly negative near the higher-frequency side of f_r . Throughout a narrow frequency band which extends from f_r to f_{mn} , the effective permeability possessesnegative values It becomes less negative as the frequency increases towards f_{mn} and outside this negative μ region,the effective permeability (relative to that of vacuum) becomes positive and quickly converges to unity.

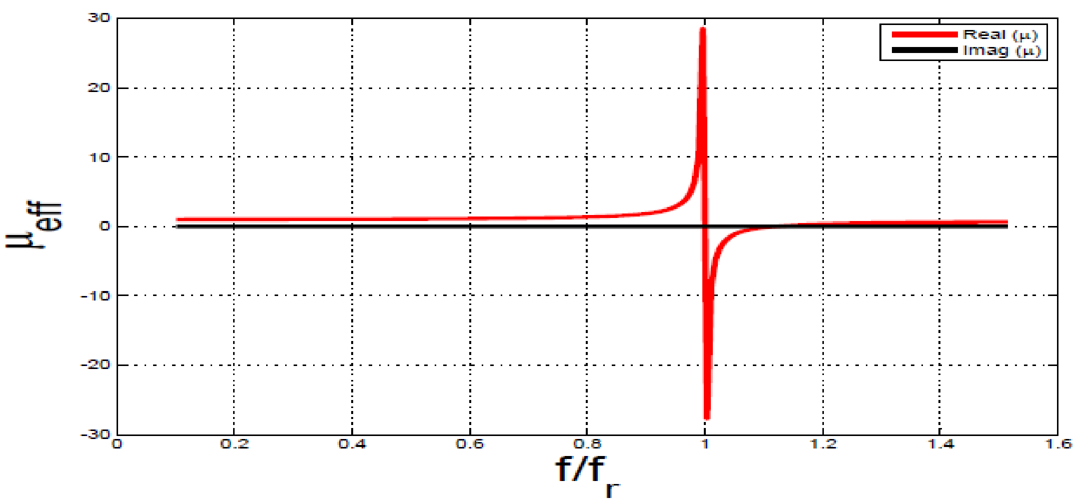


Figure 7: The frequency response of both the real and imaginary of the effective permeability within UWB frequency range of DGS-CSRS with metallic strip loaded up on Arlon 450 substrate.

8. Negative Refractive Index Materials NRM

One of the main objectives at the very beginning of metamaterial research was to construct and verify negative refractive index materials (NRM). Though there has not yet been reported for occurrence of NRM naturally, there is no theoretical obstacle which would prevent the existence of such material. In the paper published in 1968[41], Veselago predicted that electromagnetic plane waves in a medium having simultaneously negative permittivity and permeability would propagate in a direction opposite to that of the flow of energy. This result follows not from the wave equation, which remains unchanged in the absence of sources, but rather from the individual Maxwellcurl equations. The curl equation for the electric field provides an unambiguous "right-hand" (RH) rule between the directions of the electric field $\vec{E}$, the magnetic induction $\vec{B}$, and the direction of the propagation vector k. The direction of energy flow, however, given by $\vec{E} \times \vec{B}$, forms a right-handed system only when the permeability is greater than zero. Where the permeability is negative, the direction of propagation is reversed with respect to the direction of energy flow, the vectors E, H, and k forming a left-handed system; thus, Veselago referred to such materials as "left handed" (LH).

Veselago went on to argue, using steady-state solutions to Maxwell's equations, that a LH medium has a negative refractive index (n). While there are many examples of systems that can exhibit reversal of phase and group velocities with associated unusual wave propagation phenomena, negative group velocity bands in photonic crystals being an example, we show that the designation of negative refractive index is unique to LH systems. An isotropic negative index condition has the important property that it exactly reverses the propagation paths of rays within it; thus, LH materials have the potential to form highly efficient low reflectance surfaces by exactly canceling the scattering properties of other materials.

The absence of naturally occurring materials with negative μ made further discussion of LH media academic until recently, when a composite medium was demonstrated in which, over a finite frequency band, both the effective permittivity $\varepsilon_{eff}(\omega)$ and the effective permeability $\mu_{eff}(\omega)$ are shown to be simultaneously less than zero right to the resonance frequency as shown in figure 8. The composite of DGS-CSRR with metallic strip upon the dielectric exhibits not only extra ordinary property that is not existence naturally, but also is made of small size and spacing much smaller than the wavelengths in the frequency range of interest. Thus, the composite medium can be considered homogeneous at the wavelengths under consideration. With this practical demonstration, it is now relevant to discuss discuss in more detail the phenomena associated with wave propagation in LH materials, as both novel devices and interesting physics may result.

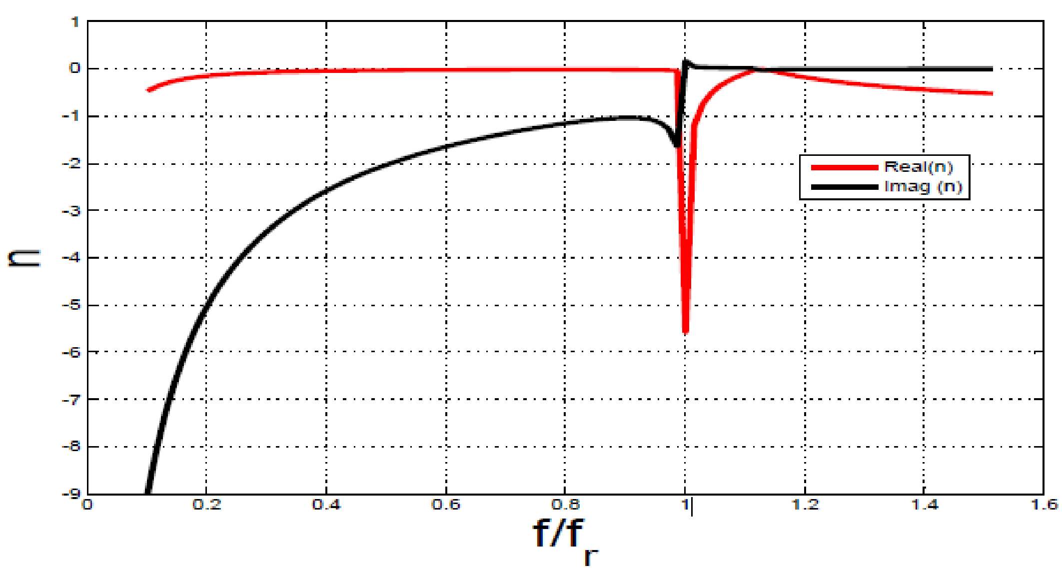


Figure 8: The frequency response negative refractive index within UWB frequency range of DGS-CSRS with metallic strip loaded up on Arlon 450 substrate.

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Conclusions

Ultra-wideband (UWB) communication techniques have attracted a great interest in both academia and industry in the past few years for applications in short-range wireless mobile systems. This is due to the potential advantages of UWB transmissions such as low power, high rate, immunity to multipath propagation, less complex transceiver hardware, and low interference. However, tremendous R&D efforts are required to face various technical challenges in developing UWB wireless systems, including UWB channel characterization, transceiver design, and coexistence and interworking with other narrow-band wireless systems, design of the link and network layers to benefit from UWB transmission characteristics.

Metamaterials and especially left-handed metamaterials present a new paradigm in modern science, which allows design of novel microwave components with advantageous characteristics and small dimensions. Ultra-wide band(UWB) technology owing to its attractive characteristics, such as low complexity, low cost, and extremely high data rates, has been widely used in communication systems. As one of main issues of UWB systems, UWB bandpass filter or antenna has received increased attention because of its wide impedance bandwidth, simple structure, and omnidirectional radiation pattern. UWB communication systems use the frequency band 3.1-10.6 GHz, which was approved by the Federal Communications (FCC). From the simulation result, the transmission UWB bandpass filter having transmission and fractional bandwidth of the transmission is about 2.48 GHz and 27.46% respectively satisfying the minimum requirement of FCC proposal. All these results are achieved through the widely used methods for generating band-notch function by etching the ground plane to be defected ground structure with complimentary split ring resonator (DGS-CSRR). This DGS-CSRR forming metamaterial could simultaneously have negative permittivity and permeability near the resonance frequency when the sum of the impedance zero condition in the circuit satisfied.

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