INTERNATIONAL JOURNAL OF RESEARCH CULTURE SOCIETY ISSN: 2456-6683 Volume - 1, Issue - 09, Nov – 2017
UGC Approved Monthly, Peer-Reviewed, Refereed, Indexed Journal Publication Date: 30/11/2017

Review of Micro strip patch antenna for Bandwidth Enhancement by using Metamaterial

HOMA AFROZ HUSAIN[1] **, PURAN GOUR**[2]
[1, 2] NIIST, Bhopal, India
Email - [1] homaafroz22@gmail.com, [2] erpurangour@gmail.com Email -

Abstract: *We have Review different research paper. Accordingly it is used to achieve significant bandwidth enhancement and analyze the matching and radiation properties of sub wavelength resonant patch antenna filled with double-negative, double positive and single negative meta material block ,quasi static equivalent circuit model for analysis and design of different types of artificial magnetic resonator and the possibility of using an active internal matching element in several type of metamaterial inspired electrically small antenna to overcome their inherent narrow bandwidth is demonstrated*

Key Words: *Metamaterials, patch antenna, active antenna, bandwidth, electrically small antenna, Q factor, artificial magnetic inclusion, labyrinth resonators, miniaturization multiple split ring resonator, split ring resonator.*

1. INTRODUCTION:

A **metamaterial** (from the Greek word μετα *Meta*, meaning "beyond") is a material engineered to have a property that is not found nature. They are made from assemblies of multiple elements fashioned from composite materials such as metals or plastics. The materials are usually patterns, at scales that are smaller than the wavelengths of the phenomena they influence. Metamaterials derive their properties not from the properties of the base materials, but from their newly designed structures. Their precise shape, geometry, size, orientation and arrangement gives them their smart properties capable of manipulating electromagnetic waves by blocking, absorbing, enhancing, or bending waves, to achieve benefits that go beyond what is possible with convention Potential applications of metamaterials are diverse and include optical filters, medical devices, remote aerospace application, sensor detection and infrastructure, monitoring, smart solar power management, crowd control radomes, high-frequency battlefield communication and lenses for high-gain antennas, improving ultrasonic sensors, and even shielding structures from earthquakes. Metamaterials offer the potential to create super lenses Such a lens could allow imaging below the diffraction limit that is the minimum resolution that can be achieved by conventional glass lenses A form of 'invisibility' was demonstrated using gradient index materials Acoustic and seismic metamaterial DUAL MODE MINITIARIZED ELLIPTICAL PATCH ANTENNA WITH μ NEGATIVE METAMATERIAL PAI YEN CHEN et al [1] It is used to achieve significant bandwidth enchancement, in principle overcoming the Chu limit on bandwidth for single mode electrically small antenna. The antenna may also be tailored to operate as a dual-band electrically small antenna and intriguing polasrization properties may be envisioned by coupling the two orthogonal mode. The antenna consists of a metallic patch loaded by a grounded Inhomogeneous substrate with thickness consisting of a rectangular DPS dielectric shell with permittivity and permeability and a magnetic material core. Metamaterial based antenna do not explicitly depend on frequency, passivity and kramers- kronig relation imply that required negative permeability varies with frequency. This in turn implies that these sub wavelength device have limited bandwidth consistent with general limit.

2. DUAL-BAND OPERATION:

PAI YEN CHEN et al[1] The possibility offered by the elliptical geometry to operate as a dual-band antenna with resonance at design frequency fo=0.4 GHZ and fe=0.6GHZ,fo and fe represent resonance frequencies of odd mode and even mode. Natural dispersion of the MNG material which may satisfy for same geometry. The MNG core has been chosen with wmp (magnetic plasma frequency)=0.9GHZ.The overall electric field distribution for the antenna at two different frequencies f=0.46GHZ,odd resonant mode with main radiation coming from major axis of antenna and at f=0.63GHZ.It is seen that the discrepancy between the the design frequencies and actual resonant frequencies is very minor, ensuring accuracy of metamaterial based antenna in this long wavelength limit. At both frequencies the two opposite sides of patch radiate in phase ensuring proper radiation despite antenna sub wavelength size .A wider ground plane may be expected to further enhance the gain at both frequencies, with an expectable improvement of upto 3db.For even(f=2.8GHZ)and odd mode (f=3.43GHZ)arising in frequency range. This is consistent with fundamental limit on quality factor Q of an antenna represented by chu-Harrington limit. The Q is inversely related to antenna electrical size and for a sub wavelength antenna its minimum value is

$Qext=(ka)^{-3}+(ka)^{-1}$

K is wavenumber in vaccum, a is major axis of elliptical patch. When the antenna operator in a single resonant mode, its fractional bandwidth is directly related to antenna quality factor.

3. COMBING THE TWO RESONANCES: BROADER BANDWIDTH OF OPERATION:

PAI YEN CHEN et al[1] In order to improve bandwidth of operation of elliptical patch beyond the results obtained in previous sections.We may combine two orthogonal modes within a closer frequency window. This may be realized by decreasing the eccentricity of elliptical patch to make resonant frequencies of two modes close enough still keeping them nondegenate.Two different sets of design parameter for eccentricity and plasma frequency e=0.27 with Wmp=0.728GHZ(f=0.4GHZ and fe(frequency at even mode)=0.43GHZ e=0.35 and Wmp(magnetic plasma frequency)=0.747 GHZ fo(frequency at odd mode) =0.4 GHZ and fe(frequency at even mode)=0.45GHZ).The Qbw/Qext ratio for the antenna with e=0.27 and e=0.35 are 1.08 and 0.64 resp, providing results unobtainable with such low-profile antenna within a single operation mode. Q and FBW is valid only for an isolated single-mode resonance and when two or more closely spaced resonances are coupled, then the QBW extract from antenna bandwidth does not necessarily reflect resonance Q factor of two modes. By combing two natural resonance of antenna, it is possible to enhance its matching bandwidth beyond Chu limit at the price of a less clean radiation pattern, combination of two orthogonal modes simultaneously excited. Due to finite choice of Wt=50 MHz associated with the necessary loss in the MNG metamaterial which may lower Qbw. Negative shell was employed to compensate inherent reactance of a small electrical antenna and possibly overcome Chu limit by tailoring its frequency dispersion ,here the antenna bandwidth is maximized by using an MNG substrate with naturally available dispersion properties to compensate the inductive reactance of a small magnetic loop, efficitively constituted by the patch aperture.

The 3D radiation pattern at f=455MHz for case of e=0.27 is reported showing a 45 rotation in xy plane due to linear superposition of two orthogonal modes. The pattern is consenhanced aperature efficiency while maintaining antenna electrically small features. When eccentricity is reduced to the optimized value of e=0.22 and Wmp=0.717GHz the corresponding resonance frequencies fo=0.4GHz and fe=0.42GHz.

The two modes may overlap here over a significant range of frequencies providing a Qbw/Qext ratio of 1.48.The radiation pattern at f=0.44GHz is now almost completely uniform as compared to more directive patterns achieved.

4. SUBWAVELENGTH, RESONANT, COMPACT, RESONANT PATCH ANTENNA LOADED WITH METAMATERIALS:

ANDREA ALU et al(2) The matching and radiation properties of sub wavelength resonant patch antennas filled with double negative, double-positive and/or single-negative metamaterials blocks. These configurations may exhibit in principle an arbitrarily low resonant frequency for a fixed dimension, but they may not necessarily radiate efficiently when their size is electrically small. Realistic numerical simulation considering material dispersion, loses and presence of antenna feed are presented. The demand for compact radiators with sufficiently high gain is rapidly increasing in many application areas. Even through such antenna are very thin compared to operating wavelength in their cross section, however still their transverse dimension cannot be made arbitrarily short, since a regular patch antenna resonates at a given frequency when its linear transverse dimension is order of half wavelength.

The use of artificial materials and surfaces properly engineered to improve some prescribed antenna feature may represent novel way of overcoming the limitation, technique to improve performance of miniaturized antenna. The use of magnetic photonic crystal(MPC)that seems to be a avenue for achieving patch antenna miniaturization. The phase compensation properties of DNG metamaterials allow synthesizing sub wavelength cavity resonators, waveguides, scatters with resonant properties essentially independent on their effective physical size. In quasi-static limit when the retardation effects are neglible to the small dimension of such components and only one of two constitutive parameters interact with field depending on its polarization. The use of ENG or DNG covers to enhance the radiation and matching properties of short electric dipoles proposed by Ziolkowski.A patch antenna resonance is closely associated with cavity resonance of the volume between patch and ground plane closed at its sides by magnetic walls.

RECTANGULAR PATCH-ANDREA ALU et al[2]Consider the rectangular patch antenna consists of a metallic patch with transverse direction L*W placed over a ground plane. The underneath substrate in inhomogenous, filled with two isotropic and homogenous materials with permittivity and permeability The quantity η represent filling ratio of volume underneath the patch. The resonant frequencies of radiator may be evaluated with good approximation by applying a standard cavity model.The resonant frequencies of equivalent cavity for the TMomo modes may be easily obtained by applying all boundary condition and they correspond to solution $K1\tan(k1\eta W)/w\mu 1=-w\varepsilon 2\tan(k2(1-\eta)W)/k2$

The inequality implies that two permittivites are oppositely signed in two materials. The fact that an ENG, MNG or DNG material is necessarily dispersive with frequency ensures indirect dependence of previous dispersion relation on frequency. Due to the polarization of mode under analysis and due to magnetic boundary condition at side walls of cavity in quasi-static limit in which applies permittivities play a dominant role in possibility of achieving such quasi-static resonance. The possibility of this resonant behavior in sub wave length rectangular patch antenna has been predicted applying different approx. technique.

When the filling material is homogenous ieε1=ε_2=2ε_0 the patch has its resonance at f=w/2π=2.12GHz. However loading patch with an ENG material can reduce the resonance frequency in principle without limits. When permittivity ε2=-2ε0,the rasonsnce frequency may be made arbitrarily low.The value of plasma frequency may be directly related to geometric properties of such inclusion designed to synthesize the ENG material.A higher permittivity usually accompanies higher losses and presence of surface waves reducing resonance frequency to very low value would require use of extremely high permittivities. The resonance is not obtained by adjusting wavelength in filling material ,but instead by inducing a plasmonic resonance at interface underneath the patch which allow a phase cancellation similar to effect .For three cases when(solid line)ε2=2ε0 ie when substrate is homogenous and patch resonates at f=2.12GHz for a second material. The standard resonance of the patch would happen at f=2.12GHz as solid lines shows .At this frequency the patch width is λ/2 with λ being the wavelength inside homogenous material loading the patch .Filling the region with a material with ε2(f=0.5GHz)=-2.2ε0 allows getting a resonance at f=0.5GHz.The magnetic field flips the sign of its derivative due to boundary condition at interface between two oppositely signed material and this allow to shrink electrical dimension of equivalent cavity .The electric field variation in this case is almost constant and its phase does not flip passing from one side to other of patch.The resonance frequency is made low by decreasing the wavelength in material which is responsible for all sinusoidal variation of magnetic field. Due to electrically small dimension of patch, the two magnetic current cancel each other for all visible angles, radiation efficiency of such an antenna would be poor. Such a wavelength rectangular patch act more as a resonator rather than as an antenna and ratio of stored versus radiated energy is expected to expected to extremely high for electrically small patches. It plasmonic resonance at y=0, main factor responsible for sub wavelength resonance these surface plasmons when excited would eventually trap some energy from source reducing radiation efficiency of antenna.

4.1 CIRCULAR PATCH (1) :

ANDREA ALU et al[2[Only fundamental mode can be excited in such a wavelength rectangular cavity, providing out of phase radiation from radiating edge of patch. A sub wavelength resonance tuned at desired frequency while gain of radiator is expected to be very poor. The parallel plate cavity showed analogus limitation there are no degree of freedom in selecting the desired operating mode in sub wavelength regime of operation. A circular patch antenna loaded by a grounded inhomogeneous substrate with thickness h ,consisting of a planar layer with permittivity and permeability ε1(w).μ1(w)with a core ring with permittivity and permeability ε2(w).μ2(w).The quantity η represent the filling ratio of volume underneath the patch.

μ2 Jn(K2ηa)/Jn’(K2ηa)=μ1 Jn(K1ηa)Yn’(K1a)-Yn(k1ηa)Jn’(k1a)/Jn’(k1ηa)Yn’(k1a)-Yn’(k1ηa)Jn’(K1a)Jn(.) and Yn(.)represent the Bessel and Neumann cylindrical Bessel function is angular order of mode variation being azimuthal angle in cylindrical coordinates. Under the same quasi static assumption applied to rectangular case which is a<<min[2π/k1,2π]

$H^2/1-\eta^2=-\varepsilon1/\varepsilon2 n=0$

$$1-\eta^{2n}/1+\eta^{2n}=-\mu1/\mu2 \quad n>0$$

The permeability of inner core material for an example of circular patch with a=20mm,η=0.6,ε1=3ε0,μ1=μ0. Due to different boundary condition in cavity the permeability plays a dominant role for this mode in quasi static limit. In order to excite a different mode, for instance the mode n=1 may be excited at desired f=0.5GHz by choosing μ2=-2.36μ0.

The field distribution clearly shows that in the limit of sub wavelength size of patch the two equivalent magnetic current loops at outer and inner side of ring would radiate out of phase with each other. Other patch shapes ie elliptical or more complex geometries may be treated similarly to analysis and proper resonant modes may be chosen to have more efficient radiation combined with a small size.

4.2 NUMERICAL SIMULATION:

ANDREA ALU et al[2] RECTANGULAR PATCH:-The behaviour of rectangular patch antenna with w=50mm,L=40mm,h=1.5mm,η=0.5,ε1=2ε0,μ1=μ2=μ0 loaded with a drude dispersive and lossy ENG material with ε2(w)=ε0(1-w^2ep/[w(w-jwr)].The plasma frequency has been set at wep=5.6GHz to get ε2(f=0.5GHz)=-2.2ε0.Losses in metamaterial have added to reflect the possible ohmic losses in conducting inclusion and thus damping frequency in drude model has been set at wr=50MHz.The antenna is fed by a coaxial probe placed at position xp=0,yp=-w/4 with inner radius of rin=o.3mm and characteristic impedance Zp=125Ω.Finite substrate and ground pane have been considered both with total size of 100*100mm.The return loss and input impedance showing two distinct resonance at f=0.48GHz and f=2.44GHz with good agreement with cavity model. The power taken from the feed is expected to be lost in ohmic losses or trapped into plasmonic waves travelling into the plasmonic waves travelling into plasmonic waves travelling along interface y=0.This clearly shows how the fringing fields are oppositely directed in sub wavelength case, different from usual resonance at f=2.44GHz.

4.3 CIRCULAR PATCH (2):

ANDREA ALU et al[2]The outer dielectric slab and ground plane were supposed to be finite with circular symmetry and outer radius a=30mm.For a realistic implementation of inner code with an MNG material,again a drude model has been assumed with μ2(w)=μ0(1-wmp^2/[w(w-jwt)]and thickness of substrate has been increased to h=5mm with respect to previous design in order to allow more spacing for future hosting the split ring resonators to construct an MNG material.The magnetic plasma frequency has been fixed at wmp=4.31 GHz.The damping frequency has been set at w=50MHz again to take into account some possible ohmic losses in conducting inclusion that will be needed for construction of MNG material. The coaxial cable has been designed to have a Zp=50Ω characteristic impedance with rin=0.2mm .The electric field distribution on plane y=0 at frequency f=0.47GHz showing how despite the small dimension of the patch can be indeed radiate in phase. Although the patch is sub wavelength the excitation of n=1 mode allows electric field to flip its sign passing from one side to other side of patch.The electric current induced on the metallic patch at f=0.47GHz shows how n=1 mode is at resonance and it is indeed interesting to notice how the current can be closed in electrically small resonant loops despite the small dimension of patch.The front to back ratio is lower than one of a patch of regular dimension since reduced size of ground plane does not allow a significant reflection.Due to overall subwavelength size of patch the inclusion dimension should be markedly lower than wavelength of operation this implies that it should be of order of λ/100 or less.For example the possible use of lumped capacitance in SRR design may be a viable way to reduce their size even though this solution may not represent the most practical/optimal way for mass production of these materials in our proposed setup.

5. BROADBAND, EFFICIENT, ELECTRICALL SMALL METAMATERIAL INSPIRED ANTENNAS FACILATED BY ACTIVE NEAR FIELD RESONANT PARASITIC ELEMENTS:

PEN JIN et al(3) metamaterial inspired electrically small antennas(ESAs)to overcome their inherent types The possibility of using an active internal matching element in several of narrow bandwidth is demonstrated. An analytical relation between the resonant frequency and inductor value is determined via curve fitting of the associated HFSS simulation results. With this inductance frequency relation during inductor values a broad bandwidth electrically small canopy antenna with ka=0.0467 that has over a 10%bandwidth is finally demonstrated. The potential implementation of required frequency dependent inductor is explored with a well defined active negative impedance converter circuit that reproduce the requisite inductance frequency relation. Electrically small antennas(ESAs)have been studied extensively in past and have many potential application in all wireless communication and sensor systems because of their compact dimension. The performance characteristic of an ESA are limited by its physical dimension .If FBW3 db is its half power VSWR fractional bandwidth its Q value is given by Q=2/FBW3 db.If its radiation efficiency is ηrad then the Chu based lower lower bound is Qchu=ηrad(1/ka^{3}+1/ka)where k is free space wavenumber and a is minimum radius of a sphere that completely encloses antenna.

Qratio=Q/Qchu

A resonant ESA usually has an associated lower radiation resistance and usually requires an external matching network to achieve a high accepted level. Such a matching network will add additional size to ESA and usually it will further limit the overall system bandwidth. To surpass the chu limit non-foster matching networks has been proposed. Metamaterial inspired efficient ESAs have constructed as a driven element and a resonant parasitic element in very near field of driven element. These properties are achived through parasitic element which replaces need for an external matching network and works with driven element to enhance radiation process. We realized that if one could develop self tuned lumped elements fulfilling the response requirements at all frequencies in a certain frequency band of interest ie forf1<f<f2the Z antenna would have an instantaneous bandwidth of f1<f<f2.The impedance of the lumped element required to achieve a broad bandwidth is then revealed numerically. The relation between the lumped element and resonant frequency of antenna is obtained. It is used to decline a circuit model could be used to implement desired self tuning lumped element ie the internal matching network (IMN).

5.1 ANSOFT HFSS AND DESIGNER SIMULATIONS OF THE Z ANTENNA:

PEN JIN et al[3]The Z antenna loaded with a lumped element 1000mH inductor. Its HFSS (High Frequency Structural Simulator)predicted value for a 50Ωsource. The minimum enclosing sphere for this Z antenna has a radius a=11.18mm so that ka=0.0461 where k=2πe/fr,c being the speed of light in vacuum and fr=195.3292MHz being its resonant frequency. The overall efficiency as expected was approx ηrad=100%.The 3db fractional bandwidth was FBW db=0.0027% and the 10db fractional bandwidth was FBW=8.84*10^{-4}%.Thus one finds Qratio=7.3 this value is rather far from Chu based lower bound because the z antenna physically occupies only a small portion of its minimum enclosing space. The Z antenna components were treated in this design as lossless. Alossy Z antenna design would have exhibited a lower overall efficiency and a broader bandwidth. Its Q value have been approx same when its lower radiation efficiency ηrad was properly taken into account. Losses are inherent with any real electrically small design and can significantly impact its performances. Both the losses in lumped element inductors and copper losses were included in Z antenna design. These antenna were fabricated and measured. Themeasured results were in good agreement with their predicted reasonably high values

5.2 INDUCTOR VERSUS RESONANT FREQUENCY:

PEN JIN et al[3]The Z antenna was used to establish a relation between its inductor value and its resonant frequency fr.Leff and Ceff its effective inductance and capacitance. According to relation if Ceff remains same, effective inductance Leff=a/ $fr^2=4\pi^2$Ceff is a constant. Thus the antenna will be resonant at fr if its effective inductance Leff satisfies. The effective inductance is composed of inductance of lumped element L and of all of the radiating element Lo.Ceff do not change its value. The lumped element inductance L is much larger than Lo which means Leff=L.The resonance frequency of Z antenna can be controlled simply by changing values of lumped element inductor. Satisfaction of Leff-fr was readily demonstrated with set of discrete HFSS simulation. The frequency was swept from 60MHz to 1.0 GHz.

5.3 BANDWIDTH ENHANCEMENT FOR METAMATERIAL-INSPIRED ESAs:

PEN JIN et al[3]The Z antenna can be predictably tuned by varying its lumped element value and the monopole height its achievable bandwidth by only varying the inductor value. When all of these resonant near field parasitic antenna are designed with passive inductors their bandwidth is restricted by the Chu-lower bound. When active inductor is included significant enhancement of their bandwidth can be realized. Active artificial molecules were considered for several scattering application. Active unit cells were to achieve wide bandwidth negative permittivity and permeability metamaterial. It is to recover large bandwidth associated with idealized.

5.4 ANTENNA:

PEN JIN et al[3]The value of the lumped element inductor was varied. Because the Z antenna has a very small ka value and a high Q ratio its bandwidth was found to be very limited. A larger Ka value Z antenna was designed. This Z antenna has ka=0.266,fr=877.715MHz,Qratio=11.2 and BW10db=0.1% for an 100nH inductor. The variation of these resonant frequency values as a function of the inductance was curve fit with a minimum mean square error.
L=a1/f2+ao
A1=8.113*10^7 and a0=-5.2999
The units of inductance L and frequency are nH and MHz
L=a1*10^3/f2+ao*10^{-9}
Where Lo=-ao*10^{-9}
Leff=L+Lo
The frequency dependent impedance Zl corresponding to inductance L can be written in form
$ZL=jwL=j(2\pi f)L=j2\pi fa1*10^3/f^2+j2\pi fao*10^{-9}$
$=1/J2\pi f(-1/4\pi^2a1*10^3)+j2\pi fa0*10^{-9}$
=1/jwCeq+jwLequ
According to equation the component value reproduce curve fit are
$Cequ=-1/4*\pi^2a1*10^3=-0.31222pf$
Lequ=a0*10^{-9}=-5.299Nh
Relation between input impedance and desired load
Zin=-Kzl
K=positive constant

5.5 STUB ANTENNA:

PEN JIN et al[3]In the Z antenna the meander line that is the Z portion of parasitic element, was designed originally to provide additional inductance to the system as well as to enhance the radiation mechanism. It was recognized that a structure which have more complex design will generally lead to non-trival fabrication sensitivities. The length of inductor and conductor of parasitic are 3.35mm and 14mm.This stab antenna has ka=0.1092 the radius a measured from centre of the parasitic element was increased from 1.205 mm to 3mm and inductor value was decreased to L=282n.This thicker parasitic element one stab antenna has ka=0.1094 and resonates at 300.3901 MHz.Q ratio=8.2.A similar set of HFSS simulations was run based on 3nH increments of L=282nH inductors value. Thus Qratio=6.48 for four stub antenna. Another similar set of HFSS simulations were run based on 1% increments of L=780nH inductors value.

5.6 CONOPY ANTENNA:

PEN JIN et al[3] To achieve yet a smaller ka antenna that achieves more than a 10% fractional bandwidth the one, two and four-leg canopy antenna. All these antennas have same, even lower Q ratio Qratio=1.75. For both cases, each leg was treated as an ideal inductor, canopy was treated as copper whose thickness coincided with diameter of inductor. For outer radius a=7.417575345mm,an inductor L=408nH,a 0.2mm shell thickness,a 4.4mm inductor height,a 0.5mm monopole radius and a 1.98mm monopole height,the one leg canopy antenna has a resonance frequency, frcentre=297.4MHz has ka=0.0467.With a passive inductor its fractional bandwidth is 0.0133%.One observes that curve fitting resonance frequency error are even more separated from their limiting FBW10db values than they were for stab antenna cases thus ensuring active one leg ka=0.0467 canopy antenna would be resonantly well matched to source over more than a 10% fractional bandwidth. With inductor value now L=1600nH and height of the monopole now 1.88mm the HFSS predicted value for the centre frequency was fr.center=300.0567MHz the ka value was ka=0.0466.The derived constant for the curve fit are a1=1.4454*10^8 and a0=-5.3682.The curve fitting errors in resonance frequencies along with corresponding HFSS predicted FBW10db limiting values.

6. EQUIVALENT CIRCUIT MODELS FOR THE DESIGN OF METAMATERIAL BASED ON ARTIFICAL MAGNETIC INCLUSION

FILIBERTO BILOTTI et al[4] Quasi static equivalent circuit model for the analysis and design of different types of artificial magnetic resonator ie the multiple split ring resonator, spiral resonator and labyrinth resonator which represent popular inclusion to synthesize artificial material and metamaterial with anomalous values of the permeability in microwave and millimeter waves frequency ranges. The extended model take into account the presence of a dielectric substrate hosting the metallic inclusion and the losses due to finite conductivity of conductor and finite resistivity of dielectrics. Explotting these circuits model it is possible to accurately predict not only resonant frequency of individual inclusion but also their quality factor and relative permeability of metmaterial samples. The three models have been tested against full-wave simulation and measurements showing a good accuracy

The models presented are able to accurately predict only resonant frequency of the individual inclusion without giving any information about their quality factor, which may give a good indication of bandwidth of operation of metamaterial constituted by those inclusion. New concept have to be employed in design of inclusion and a possible solution consists in employment of so called labyrinth resonators. The model is limited to a labyrinth resonator immersed in air and made by an ideal conductor. We extend formulation presented and propose a complete model which take into account the presence of dielectric substrate and losses in conductor and dielectric. We present the extended analytical modes of the multiple split ring, spiral, labyrinth resonators in terms of suitable RLC equivalent circuits, validated through comparision with proper full wave numerical simulation and experimental measurements.

6.1 MULTIPLE SPLIT-RING RESONATORS:

FILIBERTO BILOTTI The electromagnetic behavior in the quasi-static regime of the lossless multiple split ring resonator immersed in air is described by equivalent LC series.

$L=\mu0/2*Lavg/4*4.86[\ln(0.98/p)+1.84p]$

μ0=vaccum permeability

l=side length of external ring

w=width of strips

s=separation between two adjacent strips

Lavg=4[l-(N-1)(w+s)]is avg strip length

P=(N-1)(w+s)/[l-(N-1)(w+s)]is called filing ratio

The expression of capacitance

$C=N-1/2*[2l-(2N-1)(w+s)]C0$

$Er\hat{}sub(\varepsilon r,h,w,s)=1+2/\pi arctg[h/2\pi(w+s)](\varepsilon r-1)$

The equivalent resistance Rc in series with inductance L can be cast in form

$L=L0lavg(p)$

Where L0=μ0 is per unit length inductance

lavg(p)=lavgf(p) is avg length of loop with f(p)being a correction function depending on filling ratio.

$Rc=Rolavg(p)$

Ro=(p/wt)is per unit length resistance

Pc is electrical resistivity of metal

T is thickness of metallic strip

$Rc=Pc/wt*L/\mu o$

The shunt resistance Rd is in parallel with the total capacitance Cd.The total conductance of most external pair of ring is given by

$G'=Gol'/4$

Where l'=4l-4(2w+s)is total length of gap between two rings.

The shunt resistance $R=R'g(N)$ with $g(N)$ being a decreasing function of N
$g(N)=(lavg/4l)$

For a different type of resonator the isolated multiple split ring resonator has been placed between two electrically small monopole antennas connected to HP-8510C network analyzer to measure the transmission coefficient. The antenna and resonator are arranged in such a way that magnetic field produced in near zone by the antenna excite the multiple split ring resonator. We considered a plane wave impinging on isolated inclusion depicted in spiral resonator with impinging magnetic field aligned along axis of magnetic inclusion. A few rings are enough to obtain a good reduction of resonant frequency giving a typical miniaturization rate of order of $\lambda/40$-$\lambda/50$ in linear dimension of inclusion.

6.2 SPIRAL RESONATORS:-

FILIBERTO BILOTTI et al[4] For multiple split ring resonator an accurate LC equivalent model for the lossless isolated spiral resonator immersed in air.The presence of a dielectric substrate effects only disturbed capacitance between turns of spiral.
$L=\mu o/2\pi*lavg[\ln(lavg/2w)+1/2]$
$C=l/4(w+s)*N^2/N^2-H*[l(N-1)-\text{N\^{}2}-1/2(w+s)]Co$
Assuming the presence of losses in metallic conductor and in dielectric the equivalent circuit model of spiral resonator is one depicted.The series resistance taking into account the losses in conductor has been determined analogously to multiple split ring resonator.
$Rc=Pc/wt*L/\mu o$

6.3 LABYRINTH RESONATOR-

FILIBERTO BIILOTTI et al[4]When metamaterial with anomalous values of the permeability are to be designed for higher microwave frequencies miniaturization is not always desired. To this end a suitable inclusion called labyrinth resonator has been proposed. It is better to replace total external length of inclusion 4l with average length of ring as
$L=\mu o/2*lavg/4[\ln(lavg/w)-2]$

The total capacitance of the labyrinth resonator is given by two contribution which are the distributed capacitance as for previous inclusion and the capacitance associated to the cuts.The first contribution is given by sum of the distributed capacitance between any pair of adjacent rings as
$C1=Co/16\{(N-1)[4(l-g)-N/2(s+2w)]\}$

Where time Nis no. of concentric rings,l is side length of external ring,w is width of strips is separation between two adjacent rings,g is length of cuts, Co is defined as for multiple split ring and spiral resonator.
The second contribution is given by sum of the capacitance of 2N gap as
$C2=2N\varepsilon o\varepsilon r(\varepsilon r,h,w,s)2w+\sqrt{2g/}\pi arc\ \cosh[2w+g/g]$
The gap capacitance is connected in parallel to the distributed capacitance the total capacitance is given by
$C=C1+C2$
The series resistance of labyrinth resonator is obtained in the same way as for previous inclusion as
$Rc=Pc/wt*L/\mu o$
The shunt resistance is instead given by two following contributions
Average length of rings
$Lavg=4l-2g-(N-1)(s+w)$
Rd1 which is resistance associated to the dielectric losses between the strips has been calculated as for multiple split ring and spiral resonator while Rd2 represent dielectric losses in cuts
The final expression of equivalent shunt resistance
$Rd=Rd1Rd2/Rd1+Rd2$

6.4 QUALITY FACTOR AND PERMEABILITY FUNCTION-

FILIBERTO BIOLOTTI et al[4]Quality factor of isolated inclusion

One of main issues related to real life metamaterials is their inherent narrow bandwidth of operation. The bandwidth of fabricated metamaterial is strongly related to resonance behaviour of inclusion used to implement material.

The inverse of quality factor Q related to the resonance of individual inclusion.In RLC circuit the quality factor Q in presence of losses both in the dielectric substrate and metallic conductor.
$1/Q=1/Qc+1/Qd$
Qc is quality factor related to losses in metallic conductor and is given by
$Qc=woaL/Rc$ with A=MSRR,SR,LR
Qd is quality factor related to the losses in dielectric substrate and given by

Qd=woARcC with A=MSRR,SR,LR
WoA=1/$\sqrt{LC}$ being angular resonant frequency of circuit
The behaviour of quality factor of individual multiple split ring and spiral resonators as a function of number of rings/turns N.The quality factor is normalized to one of split ring resonator with same space occupancy.

REFERENCES:

1. J.G.Joshi, Shyam S.Pattnaik, S.Devi and S.Raghavan,(January 2012.) "Magnetro-inductive Loaded Microstrip Patch Antenna", International Journal of Microwave and Optical Technology,Vol.7,no1,.
2. Pai Yen Chen, student member , IEEE, and Andrea Alu, member,IEEE ,(2010) "Dual-Mode Miniaturized Elliptical patch Antenna with μ-Negative Metamaterials" IEEE Antenna and Wireless Propagation letters, Vol 9,
3. Andrea Alu, Student Member, IEEE , Filiberto Bilotti, Senior Member, IEEE, Nader Engheta, Fellow, IEEE, and Lucio Vegni, Member, IEEE, " Sub wavelength, Compact, Resonant Patch Antennas loaded with Metamaterials.
4. Pen Jin,Student Member, IEEE and Richard W.Ziolkowski , Fellow, IEEE (February 2010) : "Broadb and, Efficient, Electrically Small Metamaterial-Inspired Antennas Facilitated by Active Near-Field Resonant Parasitic Elements" IEEE Transactions on Antennas and Propagation ,Vol 58,No 2,.
5. Filiberto Bilotti ,Senior Member, IEEE, Alessandro Toscano, Member, IEEE, Lucio Vegni, Member, IEEE, Koray Aydin, Student Member IEEE, Kamil Boratay Alici and Ekmel Ozbay (December 2007) "Equivalent-Circuit Models for the design of Metamaterials based on Artifical Magnetic Inclusions" IEEE Transactions on Microwave Theory and Techniques VOL,55,No 12,.