Unique tunable RLC ring resonators to improve the patch antenna bandwidth

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Abstract

A unique method is introduced to enhance patch antenna bandwidth. Different arrays of multiple layers of different size of ring resonators, each with tunable RLC network, are placed closely to the patch antenna radiation slots or along non radiating edges. The RLC network Q and resonating frequency can be adjusted by changing RLC components. By adjusting the distance between the patch and rings, the distance between rings, the Qs and resonating frequencies of rings, the proper level of coupling and resonate frequency points can be arranged, the patch antenna bandwidth can be significantly increased. The Software Sonnet Suite is used to simulate and optimize a 1.8 GHz rectangular patch antenna with 4 different size ring resonators. 3.5 times bandwidth of 120 MHz bandwidth (7%) is achieved.

1. INTRODUCTION

Microstrip antennas have low profile and found lots of application, but the limitation of the patch antennas is the bandwidth. Normal patch antenna bandwidth is around 1 to 3%. There are many methods that have been used to enhance the patch bandwidth such as stacked patch microstrip antenna [1], resistive loading [2] and multifrequency operation [3]. Here unique ring array networks with a tunable RLC network in each ring are introduced to enhance the patch antenna bandwidth. These ring resonators are operating at different frequencies (controlled by LC and size of the ring) with different Q factors (controlled by resistance R). Properly tune the network and arrange the separation of the rings and patch, then a wider patch bandwidth can be achieved. The advantage of using the ring over a regular patch is that it takes less space and resonating frequency can be easily tuned and energy coupling can be more flexibility controlled by adjusting series R as well as spacing.

2. ANALYSIS

To understand the method, a block diagram with a patch antenna and different ring resonators is drawn in figure 1. The patch antenna can be all sorts of forms. There are m groups of rings. In each group, there are n different rings. In each ring, there is RLC network as shown in fig. 2 there are electromagnetic energy coupled between the patch and rings. The level of coupling is dependent on the distance between the ring and patch, the distance between the patch resonating frequency and the ring resonating frequency and the Q of the rings. The structure can be described in (m, n) matrix format. The m group can be represented by m rows. The n rings in each group can be represented by n columns. The current in nth ring of mth group is Imn(fmn,Qmn). It induces the voltage Umn (fmn, Qmn) on the patch antenna. The coupling factor between nth ring in mth group and the patch is a_{m0n}. Where,"0" represent patch.

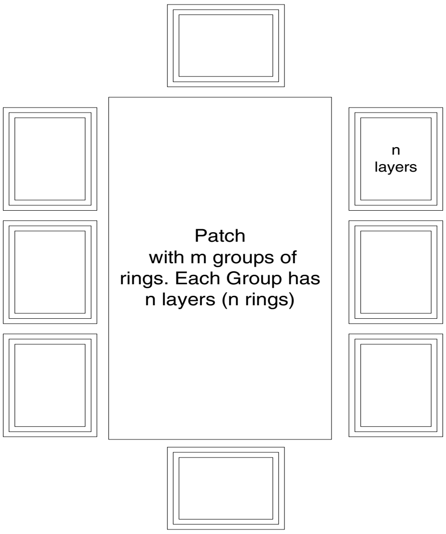

Figure 1. Patch structure with different arrays of rings

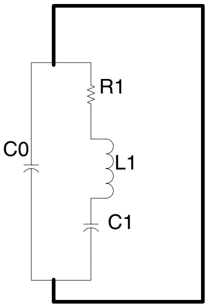

Figure 2. RLC network

The n rings in Mth group induced u_m voltage on the patch

$$[U_m(f_{m1},...f_{mn,},Q_{m1},...Q_{mn}] = [A_m]\cdot[I_m(f_{m1},\ldots f_{mn,},Q_{m1},\ldots Q_{mn})] \qquad [1]$$

Where

$$[I_m(f_{m1},\ldots f_{mn,},Q_{m1},\ldots Q_{mn})] = \begin{bmatrix} I_{m,1}(f_{m1},Q_{m1}) \\ I_{m,2}(f_{m2},Q_{m2}) \\ . \\ . \\ . \\ I_{m,n-1}(f_{m(n-1)},Q_{m(n-1)}) \\ I_{m,n}(f_{mn},Q_{mn}) \end{bmatrix} \qquad [2]$$

$I_{m,n}(f_{mn},Q_{mn})$ is the current or other source element in mth group.

$$A_m = \begin{bmatrix} a_{m,0,1} & a_{m,0,2}\cdots & & a_{m,0,n} \\ 0 & a_{m,0,1}\cdot a_{m,1,2}\cdots & & a_{m,0,(n-1)}\cdot a_{m,(n-1),n} \\ 0 & \cdots & & a_{m,0,(n-2)}\cdot a_{m,(n-2),(n-1)}\cdot a_{m,(n-1),n} \\ 0 & \cdots\cdots & \cdots & \\ 0 & \cdots & \cdots & \\ 0 & \cdots & a_{m,0,1}\cdot a_{m,1,2}\cdots\cdots a_{m,(n-2),(n-1)}\cdot a_{m,(n-1),n} & \end{bmatrix} \qquad [3]$$

A is associated with the position of the rings, structure of the ring and distance between the patch and rings.

For simplicity, there are basically two coupling paths between $ring_{m,n}$ and the patch: direct energy coupling and indirect coupling through layers of rings towards patch.

$a_{m,0,n}$ represents the direct coupling and $a_{m,(n-1),n}$ represents coupling factor between nth ring and (n-1)th ring. $a_{m,0,1}\cdot a_{m,1,2}$ represents the $ring_{m,2}$ coupling energy to $ring_{m,1}$ and then coupling to patch "0". $a_{m,0,(n-2)}\cdot a_{m,(n-2),(n-1)}\cdot a_{m,(n-1),n}$ represents the "nth" ring coupling energy to "n-1"th ring, then coupling to "n-2" th ring, then coupling to patch. (0).

The total mth group coupling affect can be expressed in the matrix form as:

$$[U_{mn}] = \begin{pmatrix} A_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & A_m \end{pmatrix} \cdot \begin{bmatrix} I_1 \\ \vdots \\ I_n \end{bmatrix} \qquad [4]$$

Add all the induced voltages on patch and include patch itself (I_0, u_0, A_0), the source voltages at different frequencies and different levels can be simplified as

$$[U] = [1,1\ldots1]\cdot \begin{pmatrix} A_0 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & A_m \end{pmatrix} \cdot \begin{bmatrix} I_0 \\ I_1 \\ \vdots \\ I_m \end{bmatrix} \qquad [5]$$

Where u is the function of patch resonating frequency and Q, the function of and each rings resonating frequency and Q and the function of distance among the rings and distance associated patch edge.

$$u = u(f_0, f_{11},\cdots f_{1n},\cdots f_{m1}\cdots f_{mn}, Q_0, Q_{1,1}\cdots Q_{m,n}, D_{m,n}) \qquad [6]$$

The bandwidth of patch input impedance can be expressed as function of the resonating frequencies, Q and ring positions.

$$Fband = F(u(f_0, f_{11},\cdots f_{1n},\cdots f_{m1}\cdots f_{mn}, Q_0, Q_{1,1}\cdots Q_{m,n}, D_{m,n})) \qquad [7]$$

To maximize the bandwidth of this patch antenna system, we can adjust the ring's resonating frequency, Q and position. Once ring positions are fixed, it is not easy to change. However, RLC network provide good flexibility.

3. SIMULATION

Sonnet suite simulation tool is used. A 1.8GHz GSM band rectangular patch antenna with 2 groups of 4 total rings is constructed. This is matrix 2 by 2. The patch dimensions and rings dimension are shown in figure.3, 4 and 5. The dielectric layer is Rogers RTT5880 with $\varepsilon_r = 2.2$ and tangential loss of 9.e-4. The height of the dielectric layer is 1.6mm. The distance from the first layer of the rings to the patch is 1.47mm. The distance between the rings in the same group is 0.49 mm. The ring width is 0.49mm. To reduce the size of the ring, an E shape of ring structure is used instead of the rectangular ring. To assure good coupling between the rings and patch, the long sides of the E shapes are placed close to the patch radiating slot. There are total 5 ports in the simulation. The port 1 is the main source to excite the patch. It is coax feeding at the centre left edge of the patch. It has a source impedance of 50 ohm. There is one port in each ring. Each port has a source RLC network. The RLC source network in each ring will be adjusted until the max bandwidth is achieved. Only R and L are used in each network. The Table 1 lists all R and L components in the networks.

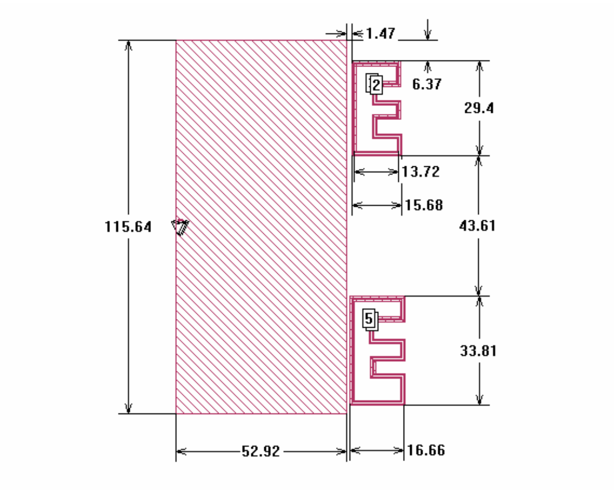

Figure 3. A rectangular patch with 4 rings (unit: mm)

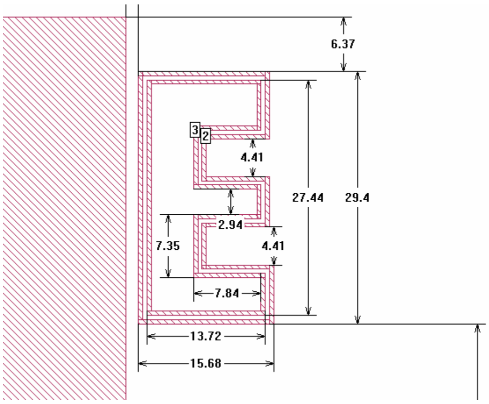

Figure 4. Upper rings (unit: mm)

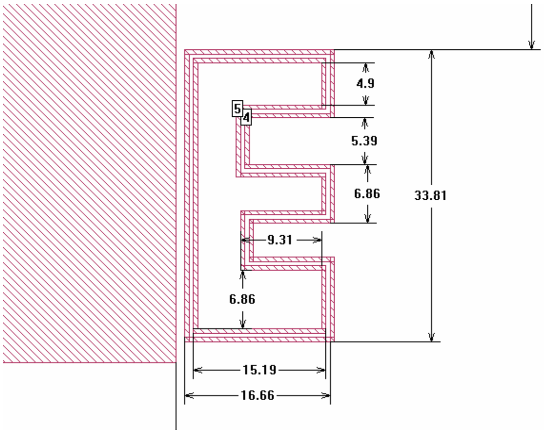

Figure 5. Bottom rings (unit: mm)

Table 1 RLC Network

Network	Source 2 (ring 1)	Source 3 (ring 2)	Source 4 (ring 3)	Source 5 (ring 4)
R (ohm)	6	0.1	7.5	0.1
L (nH)	9	8.9	0	0.35

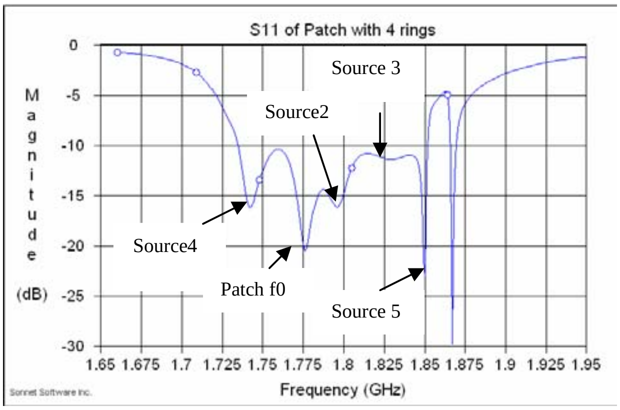

Figure 6. The return loss

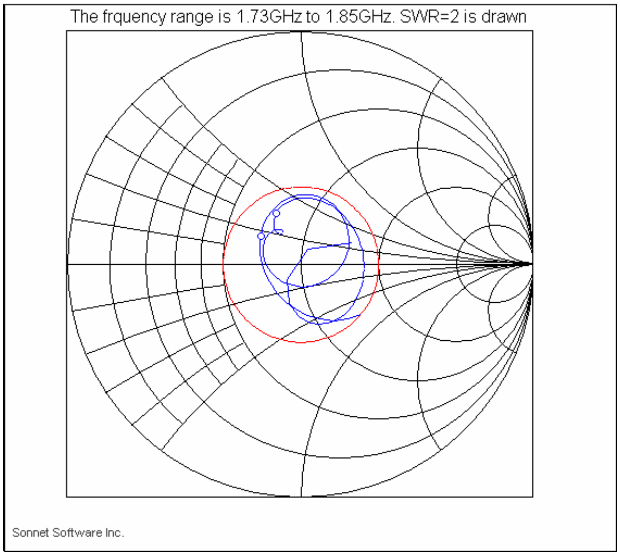

Figure 7. Impedance on Smith Chart

The return loss is plotted in fig. 6. 1. The impedance at frequency from 1.73GHz to 1.85GHz is plotted in fig. 7. The SWR=2 circle line is also plotted in fig.7 for comparison purpose. 5 resonating points are shown in fig.6. These resonating points are contributed by the patch antenna and 4 ring resonators. There is a large dip at 1.87GHz. This is caused by the ring edge close to the patch antenna. Patch S11, ring 1(source 2) S22 and the coupling factor S21 are plotted in figure 8. It showed the coupling factor between the ring 1 and patch. S21 is $a_{1,0,1}$ in eq. [3]

The current distribution at 1.804GHz is shown in figure 9.

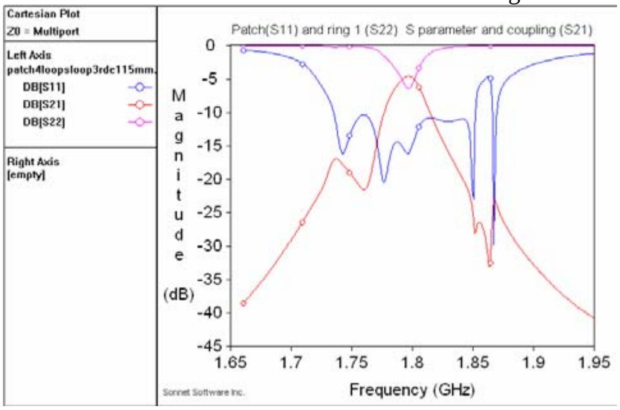

Figure 8. Patch and ring 1 coupling

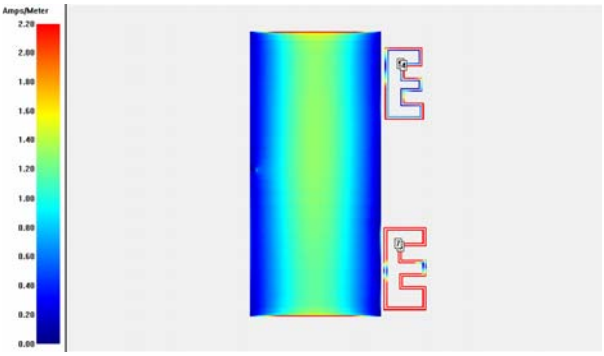

Figure 9. The current distribution

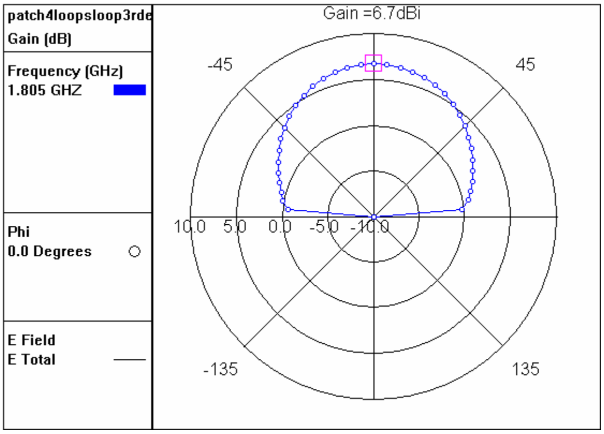

Figure 10. The antenna gain is 6.7dBi

The gain is plotted in figure 10. It shows the gain of 6.7dBi.

-10dB return loss bandwidth is 1850-1730=120 MHz. An Empirical formula [4] by Jackson and Alexoplus for the bandwidth (VSWR<2) of a rectangular patch is

$$Band = 3.77 \cdot ((\varepsilon_r - 1)/\varepsilon_r^{\,2}) \cdot (W/L) \cdot (h/\lambda 0) \qquad [8]$$

According to this equation, this patch without rings has the bandwidth of 1.9% or 34MHz for 1.8 GHz. Figure 6 and 7 shows that the -10dB (SWR=2) bandwidth of patch with 4 rings is 6.7% or 120MHZ. It improves the bandwidth 3.5 times.

4. CONCLUSION

The paper presents an array of ring structure to widen the patch antenna bandwidth. It provides tunable R, L, C elements in the rings to change the Q and resonating frequency to optimize the patch antenna bandwidth. It provides the flexibility and means to optimize the antenna bandwidth. A simulation with 4 tunable ring resonators has shown that the 3.5 times more bandwidth has been achieved. It has shown that with proper management of Q(R), resonating frequency (LC) and distance between the rings and patch and the distance among the rings, patch antenna bandwidth can be significantly improved without adding large resonating structures.

REFERENCES

[1] Long, S.A and M.D.Walton,"A Dual-Frequency, Stacked Circular Disc Antenna," *IEEE Antenna and Propagation Symp. Digest,* 1978, pp.260-263.

[2] Wong, K, L and Y.F.Lin, "Small Broadband Rectangular Microstrip Antenna With Chip-Resistor Loading," Electron, Lett., Vol.33, 1977, pp. 1593-1594.

[3] Croq, F., and D.M. Pozar, " Multifrequency Operation pf Microstrip Antenna using Aperture-Coupled Parallel Resonators," *IEEE Antenna and Propagation* Author, Vol. AP-40, 1992. pp.1367-1374. *Book Name*, E^{d} Ed, vol V, Publisher, Place, Year, pp. YYY.

[4] D. R. Jackson and N. G. Alexopoulos, "Simple Approximate Formulas for Input Resistance, Bandwidth, and Efficiency of a Resonant Rectangular Patch" *IEEE Trans. Antennas and Propagation*, Vol. AP-39, pp. 407-410, March 1991Authors.