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Rejection of Multiple Interfering Bands Using Stepped Impedance Resonators along the Feed Line

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Abstract: Rejection of interfering bands in ultrawide band antenna has become a latest topic of research. For this purpose, etching of slots, EBG structures, folded strip configuration was used but from that only one or two notch bands are obtained. In this paper, multiple narrow bands are being notched on a circular monopole ultrawide band (UWB) antenna by using stepped impedance resonators (SIRs) along both sides of the feed line. The principle of wave cancellation is used and discussed by taking two cases with one stepped impedance resonator(SIR) on each side separately and then by combining their effects. By using two Stepped Impedance Resonators (SIRs), four bands can be rejected simultaneously.

Keywords: Stepped Impedance Resonator(SIR), Ultrawide band (UWB), Wave Cancellation theory, Spurious frequencies, Interfering bands.

I. INTRODUCTION

An increased attention has been paid on ultrawide band (UWB) communication system now a days due to its plenty of advantages such as high speed data rates, low power consumption, large channel capacity etc.

Other standards such as WLAN, WiMAX etc. have frequency band within the ultrawide band (UWB) range. These bands interferes in the working of the ultrawide band (UWB) systems. So reduction of interfering bands in ultrawide band (UWB) systems is a recent topic of interest.

There are a number of methods which can be used to remove interfering bands. The widely used method is etching slots on the ultrawide band (UWB) antenna radiator to achieve notched band performance. A variety of shapes can be chosen for slot such as L-shaped, U-shaped, E-shaped, fork shaped etc. [1-4]. A co-planer waveguide fed antenna is presented in [5] achieved two resonant modes and bandwidth enhancement by using square slot. Bandwidth is enhanced by using narrow slit is shown in [6] and frequency notching is obtained by using U-slot type structure. Dual band notching is obtained in [7] by using two nested C shaped slots leading to destructive interference which causes antenna to be non-responsive at those frequencies. In these type of structures, current flowing through the slot and the patch are in the opposite direction and hence led to cancellation of current and rejection of a particular frequency band. Electromagnetic bandgap (EBG) structures can also be used for the same purpose. They can be varied in shape (mushroom type, cylindrical, triangular etc.). Mushroom-type EBG structure is used in [8] in which multiple identical elements are placed symmetrically to obtain single notch band. Similarly with folded strip configuration, the antenna can achieve a good band-rejection performance as shown in [9] by varying the length and gap width of the coupled lines formed by folded strips according to the frequency at which notch is required. Capacitively loaded loops (CLLs) are used in [10] which act artificial magnetic conductor to obtain notch bands. However, most of the proposed antenna described above have either one or two notch bands and hence not suitable for multiple interference cancellation caused by existing multiple standards. Some of the antennas have multiple notch bands but their bandwidth is quite low. By introducing stepped impedance resonators (SIRs), better multiband rejection can be obtained [11]. A dual band bandstop filter is designed in [12] using tri-section stepped- impedance resonators (TSSIR) in which size reduction is also achieved. A parallel- coupled microstrip bandpass filter is obtained in [13] using stepped impedance coupled resonator (SICR) which suppresses the spurious harmonics depending upon the even and odd

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propagation modes of the coupled microstrip lines. Asymmetric stepped- impedance resonators is shown in [14] which presents a dual-band bandpass filter with independent switchability of each pass band.

In this paper, we aim at designing UWB antennas with multiple notched bands. The notched bands concerned here are centered at 2.4, 3.5, 5.8, 8.7 GHz respectively in a ultrawide band (UWB) antenna operating 2.2 GHz- 10 GHz.

The notched bands are created by stepped impedance resonators (SIRs) loaded on both the sides of the feed line of circular monopole antenna. It forms a band- notched filter, which can generate multiple notched bands.

II. STEPPED IMPEDANCE RESONATOR

A technique of waves cancellation theory [15, 16] is used to introduce single, double or multiple notch-bands in the pass bands of ultrawide band antenna. In this technique, different electrical lengths are introduced by using stepped impedance resonators (SIRs) on both sides of the feed line by providing different paths. The number of bands required to be notched can be obtained by selecting the fundamental frequency and spurious frequencies to be resonated by Stepped Impedance Resonator (SIR) . If single notch band is required then the Stepped Impedance Resonator (SIR) is not required to resonate at spurious frequencies. At fundamental frequency, stepped impedance resonators (SIRs) will resonate and current will not reach to the antenna and a stop band is obtained. If multiple notch bands are required, stepped impedance resonators (SIRs) will resonate at those spurious frequencies. Antenna will reject those frequencies and multiple notch bands are obtained.

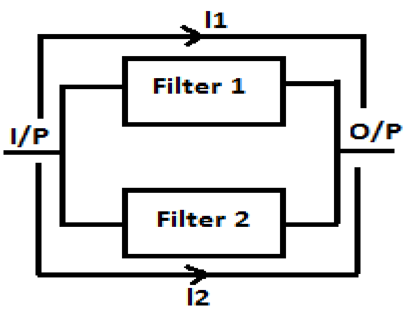

Fig.. 1. Filters are connected in parallel

The wave's cancellation theory is used to notch multiple frequency bands in Stepped Impedance Resonator (SIR). In this theory, we consider two band stop filters with different centre frequencies connected in parallel to each other which will create different path for the same input given to them and hence resulting in different frequencies to be passed at different times. At the output, the response provided by both the filters are added either constructively or destructively, depending upon the path length. It provides either rejection or passage of band depending upon the construction or destruction at the output terminal.

According to waves cancellation theory, when two signals from both the filters have 180^0 phase shift and equal amplitude, they cancel out each other i.e. they are added destructively and hence a notch band is introduced at that particular frequency.

The two paths provided by filters should have a phase difference of 180^0 and they should satisfy the condition-

$$|\beta_1 l_1 - \beta_2 l_2| \cong (2n+1)\pi \qquad ....(1)$$

where, n=0,1,2…..

β_1, β_2 are the phase constants

l_1, l_2 are the physical lengths of the two filters respectively as shown in Fig. 1 and Fig. 2.

The simple stepped impedance resonator (SIR) is described as in Fig. 2. In this case, we have two different impedances having different lengths.

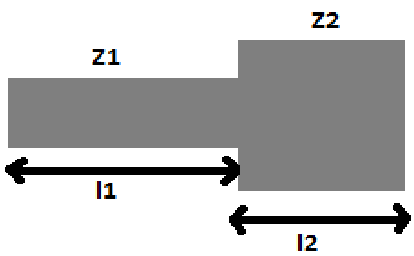

Fig. 2. Basic Stepped Impedance Resonator

Here the resonant condition can be given by [9] :-

$$\frac{Z_2}{Z_1} = tan\beta_1 l_1 tan\beta_2 l_2 = K \qquad ....(2)$$

$$K = \frac{tan\,\theta_1(\tan\,\theta_T - \tan\,\theta_1)}{1+tan\,\theta_T tan\,\theta_1} \qquad ....(3)$$

where,

θ_1, θ_2 are electrical lengths of two filters respectively.

$$\theta_T = \theta_1 + \theta_2 \qquad ....(4)$$

and if $\theta_1 = \theta_2 = \theta$, we have-

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$$\theta = \tan^{-1}\sqrt{K} \qquad \text{…….(5)}$$

If f_0 is fundamental frequency and if f_1, f_2, f_3 are spurious frequencies. Spurious frequency can be calculated by:-

$$\frac{f_1}{f_2} = \frac{\pi}{\tan^{-1}\sqrt{R_z}} - 1 \qquad \text{…….(6)}$$

$$\frac{f_2}{f_0} = \frac{\pi}{\tan^{-1}\sqrt{R_z}} + 1 \qquad \text{…….(7)}$$

$$\frac{f_3}{f_0} = \frac{2\pi}{\tan^{-1}\sqrt{R_z}} - 1 \qquad \text{…….(8)}$$

$$\text{where, } R_z = \frac{Z_2}{Z_1} \qquad \text{…….(9)}$$

III. ULTRAWIDE BAND (UWB) ANTENNA DESIGN

The geometries of the UWB circular monopole antenna is shown in Fig.. 3 and the same antenna is loaded with stepped impedance resonator (SIR) along the feed line is shown in Fig.. 4. The dimensions are also listed The reference antenna [11] is modified in this paper.

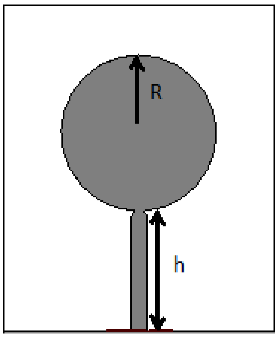

Fig. 3. Circular monopole antenna (h=17.5, R=12)

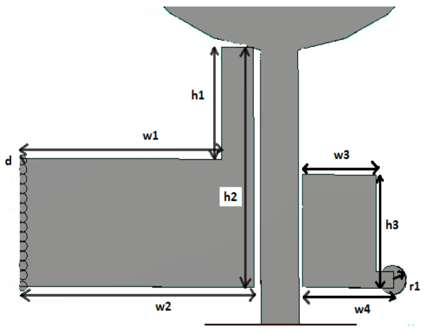

Fig. 4. Antenna with stepped impedance resonator loaded along the feed line (h1=7, h2=15, h3=7, w1=14.75, w2=16, w3=5, w4=6.19)

This antenna has 1.5 mm thickness with a dielectric constant ϵ_r of 4.7. Stepped impedance resonators (SIRs) are used on both sides of the feed of the planar circular monopole antenna to create multiple notched bands at the desired frequencies [11]. A tapered feed line is used for impedance matching. A comparison between S-parameters of planar circular monopole antenna and the same antenna with stepped impedance resonators (SIRs) on it are shown in this paper.

IV. SIMULATIONS AND RESULTS

The return loss of the proposed antenna in fig 3 is shown in Fig. 5.

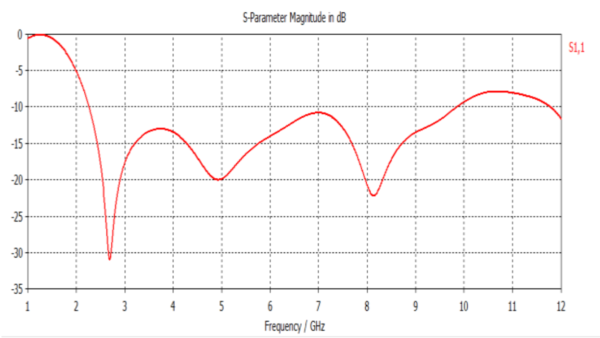

Fig. 5. S11 parameter of basic antenna

From Fig. 6, it is found that the bandwidth of antenna lies in the range 2.2 GHz- 10 GHz thereby creating a wide band. In order to study the effect of stepped impedance resonators (SIRs) on ultrawide band antenna, two stepped impedance resonators (SIRs) are placed one by one along the feed line. The effect of placing both the stepped impedance resonators (SIRs) simultaneously along the feed line is also studied.

We want to obtain notches at 2.4, 3.5, 5.8, 8.7 GHz . In the first case, we want to have notch at 3.5 GHz(f_0) which will be treated as fundamental frequency. Since only one notch band is required, we want to have spurious frequency at 12 GHz. Therefore, $\frac{f_1}{f_0} = 3.43$ and hence R_z is calculated using (6) to be 0.736. The values of Z_1 and Z_2 are obtained using (9). Ultrawide band antenna with single stepped impedance resonator (SIR) placed along the right side of the feed is shown in Fig. 6 and its return loss is shown in Fig. 7.The stepped impedance resonator (SIR) can be placed on either side of the feed line.

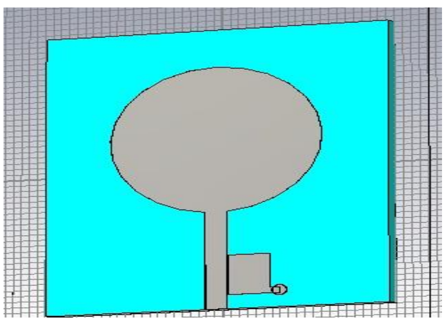

Fig. 6. Antenna structure with SIR on right side of feed line

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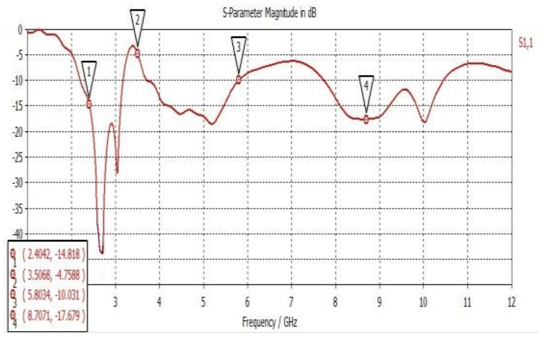

Fig. 7. S11 parameter of antenna structure with SIR on right side of feed line.

At 2.4, 3.5, 5.8 and 8.7 GHz the values of return loss are -14.818 dB, -4.7588 dB, -10.031 dB and -17.679 dB respectively.

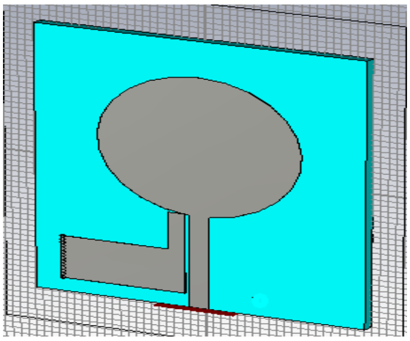

Fig. 8. Antenna structure with SIR on left side of feed line

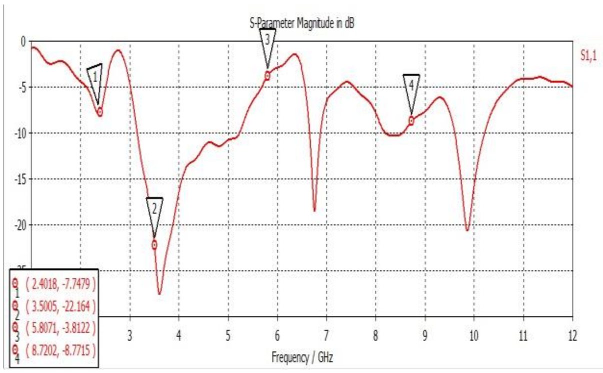

Fig. 9. S11 parameter of antenna structure with SIR on left side of feed line

In the second case, notches are created at 2.4, 5.8, 8.7 GHz in the ultrawide band (UWB) antenna. In this case, 2.4 GHz (f_0) is treated as fundamental frequency and 5.8(f_1), 8.7(f_2) GHz as spurious frequencies. So, $\frac{f_1}{f_0} = 2.417$ and $\frac{f_2}{f_1} = 3.625$. The values of R_z is found to be 1.72 in both cases using (6,7). The values of Z_1 and Z_2 are obtained using (9). The proposed stepped impedance resonators (SIRs) along the left side of the feed as shown in the fig 8. The return loss curve is shown in Fig. 9.

At 2.4, 3.5, 5.8 and 8.7 GHz the values of return loss are -7.7479 dB, -22.164 dB, -3.8122 dB and -8.7715 dB respectively. It is observed that a passband is obtained at 3.5GHz whereas 2.4 , 5.8 , 8.7 GHz frequencies are rejected.

An ultrawide band (UWB) combined with stepped impedance resonators (SIRs) along both the sides is shown in Fig. 10. The return loss of the same antenna is shown in Fig. 11.

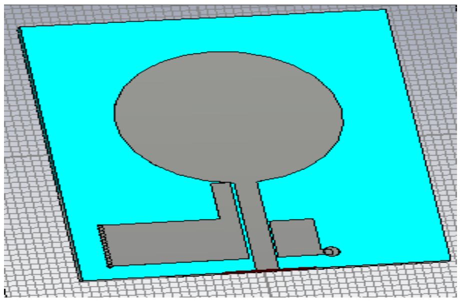

Fig. 10. Antenna structure with SIR on both sides of feed line

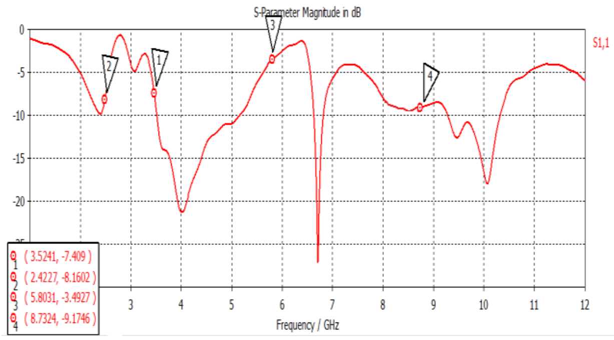

Fig. 11. S11 parameter of antenna structure with SIR on both sides of feed line

As shown in Fig. 11, the stop bands are obtained at 2.4, 3.5, 5.8 and 8.7 GHz ,when two Stepped Impedance Resonators (SIRs) are placed along the feed line.The final comparison of single Stepped Impedance Resonators (SIRs) and combined Stepped Impedance Resonators (SIRs) is shown in Table 1.

The current distribution is shown at different frequencies. When there is simple antenna, the current distribution at 3.5 GHz is shown in Fig.12 and the current distribution of the same antenna with stepped Imedance Resonators is shown in Fig. 13.
Here the current reaches at the antenna at 3.5 GHz and a pass band is obtained at this frequency but when we have the stepped impedance resonators (SIRs) along the feed line, the current distribution is obtained as shown in Fig. 13.

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Table 1. Comparison of return loss at various frequencies with different conditions of SIR.

Notch Frequencies (in GHz)	**With no SIR (in dB)**	**SIR on the left side of the feed (in dB)**	**SIR on the right side of the feed (in dB)**	**SIR on both sides of the feed (in dB)**
2.4	-12.35	-7.7479	-14.818	-8.160
3.5	-13.68	-22.164	-4.7588	-7.409
5.8	-16.14	-3.8122	-10.031	-3.492
8.7	-17.34	-8.7715	-17.679	-9.174

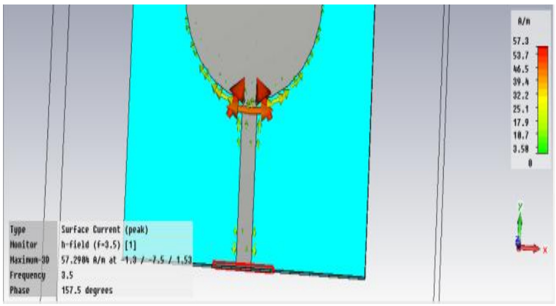

Fig. 12. Current distribution of basic antenna at 3.5 GHz

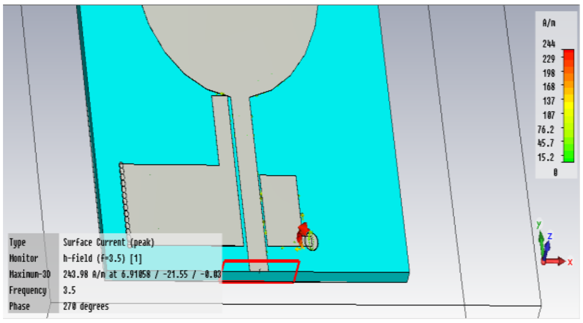

Fig. 13. Current distribution of antenna with SIRs along the feed line at 3.5 GHz

In this case, the current is directed towards the stepped impedance resonator (SIR) resonating at 3.5 GHz and placed on the right side of the feed line. This stepped impedance resonator (SIR) does not allow any current to reach the antenna thereby blocking the signal reaching the antenna.

Similarly, the current distributions of circular monopole antenna and the same antenna with the stepped impedance resonators (SIRs) are shown in the following figures.

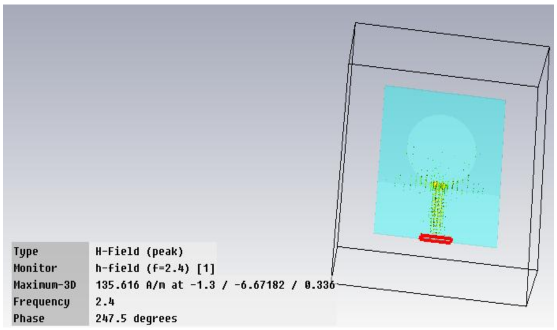

Fig. 14. Current distribution of basic antenna at 2.4 GHz

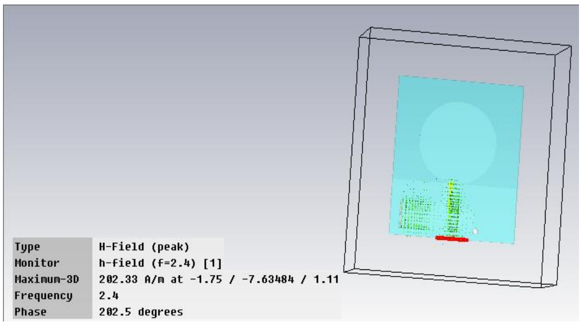

Fig. 15. Current distribution of antenna with SIRs along the feed line at 2.4 GHz

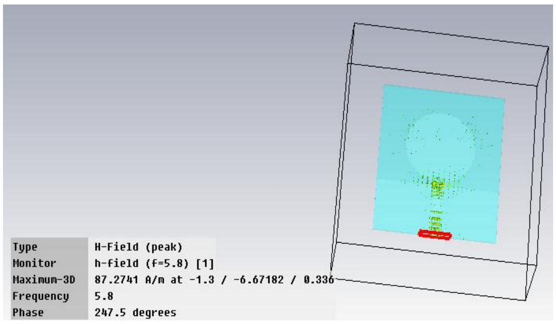

Fig. 16. Current distribution of basic antenna at 5.8 GHz

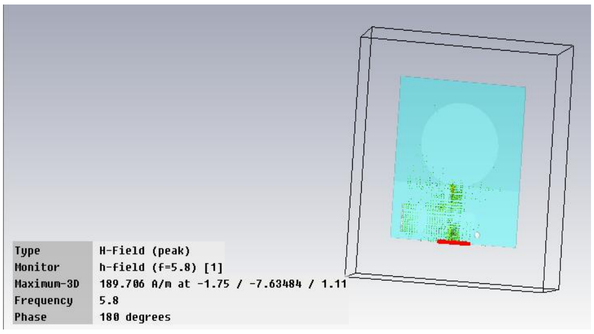

Fig. 17. Current distribution of antenna with SIRs along the feed line at 5.8 GHz

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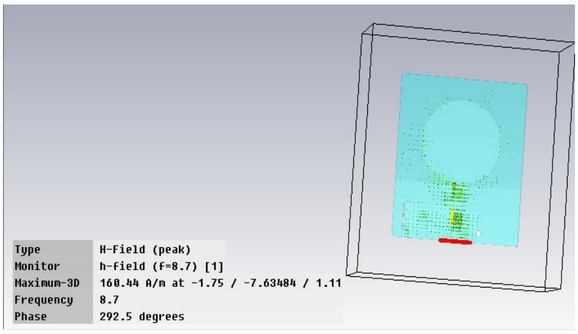

Fig. 18. Current distribution of basic antenna at 8.7 GHz

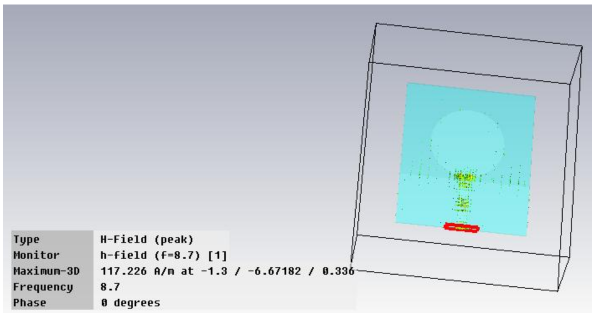

Fig. 19. Current distribution of antenna with SIRs along the feed line at 8.7 GHz

V. CONCLUSION

In this paper, four notch bands are obtained at various interfering frequencies i.e. 2.4, 3.5, 5.8 and 8.7 GHz using stepped impedance resonators along the feed line of the circular monopole antenna using wave's cancellation theory. The difference in the return loss at different interfering frequencies with different conditions of stepped impedance resonators is done. Current distribution is shown which demonstrate that without using stepped impedance resonators, antenna will resonate even at interfering frequencies and after using stepped impedance resonators, stepped impedance resonators will resonate at those frequencies blocking current to pass through antenna.

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