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A NOVEL MICROSTRIP PATCH ANTENNA WITH LARGE IMPEDANCE BANDWIDTH IN VHF/UHF RANGE

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Abstract—In this paper a novel antenna is presented. This antenna, employing microstrip circular disc as radiator is seen to perform over a large impedance bandwidth (130 MHz to 876 MHz). The disk resonator is loaded with *L*-*C*-*R* circuit across a selective location in the disk via a thin shorting pin. The theoretical modeling predicts TM_{01} mode of operation. Therefore the beam pattern shows a null in the broadside direction. The said antenna is proposed to be developed for end use in coal mine where the antenna can be flush mounted on coal strata. Thus it will be able to measure the angle of arrival of any reflective component due to presence of waterbed at a distance. The measured as well as simulated results regarding impedance bandwidth and beam pattern agrees well. The simulated efficiency using IE3D is 48% whereas measured efficiency is nearly 45%.

1 Introduction
2 Theory
3 Results
4 Conclusion
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1. INTRODUCTION

Microstrip antennas have a number of useful properties, but one of the serious limitations of these antennas has been their narrow bandwidth characteristic. The impedance bandwidth of a typical microstrip patch antenna is less than 1% to several percent for thin substrates. Researchers have been engaged in removing this limitation and many new techniques have surfaced using which the bandwidth can be increased to 90%. A considerable amount of literature has appeared on the broadbanding aspect of microstrip antenna. An excellent review of these methods is given by Garg et al. [1].

Presently some research work is continuing on the aspects of design of ultrawideband (UWB) antennas with omnidirectional coverage for increasing military and commercial applications. In a recent publication [2], Suh et al. have demonstrated a new printed monopole antenna (Planar Inverted Cone Antenna) which is compact and thin geometry providing impedance bandwidth of 10:1 and supporting monopole type omnidirectional pattern over 4:1 bandwidth. In another recent communication [3], Chakravarty et al. have demonstrated that use of a load consisting of metallic pin, inductor and capacitor can result in generation of ultra low resonance in circular disc resonator. The unloaded disk resonator used for analysis has the lowest resonant frequency corresponding to TM_{11} mode of operation at 1.76 GHz. It is then shown that by suitable loading the structure using a combination of shorting post, inductance and capacitance the lowest resonant mode of operation can be reduced to VHF range of 70–120 MHz. In the same communication it was demonstrated that the mode of operation for the lowest resonance in the loaded disk is TM_{01}. Therefore the beam pattern is expected to display a null in the broadside direction with azimuth symmetry. However the antenna efficiency has been low because of the thin structure.

Continuing with the above work it is conclusively demonstrated in this paper that the above-mentioned methodology can used for design of a useful antenna, which is broadband in nature in VHF-UHF range (130 MHz–876 MHz). Though it is well known that, using reactive and resistive loading impedance bandwidth can be increased, the novelty in the present work lies in the fact that a simultaneously compact and broadband antenna (8:1) is presented with reasonable efficiency.

The said antenna structure is simulated using IE3D, a commercial MoM solver and an efficiency of better than 48% has been found. The antenna is developed and measured. The measured patterns show an excellent agreement with the simulated pattern. An efficiency of nearly 45% is measured. The said antenna is proposed to be developed for end use in coal mine where the antenna can be flush mounted on coal strata. Thus it will be able to measure the angle of arrival of any reflective component due to presence of waterbed at a distance.

2. THEORY

The geometry of the loaded microstrip disk resonator is shown in Fig. 1. The probe fed disk of radius r_1 is loaded at a certain radial location r_2. The load is connected to the patch through a thin metallic pin of radius Δ. The load configuration is given in Fig. 2. The load consists of inductance L_s in series with a capacitor C_s. A resistor of 50Ω is placed in parallel to the series L-C circuit. The L-C circuit along with patch dimensions determines the resonance frequency. For a given

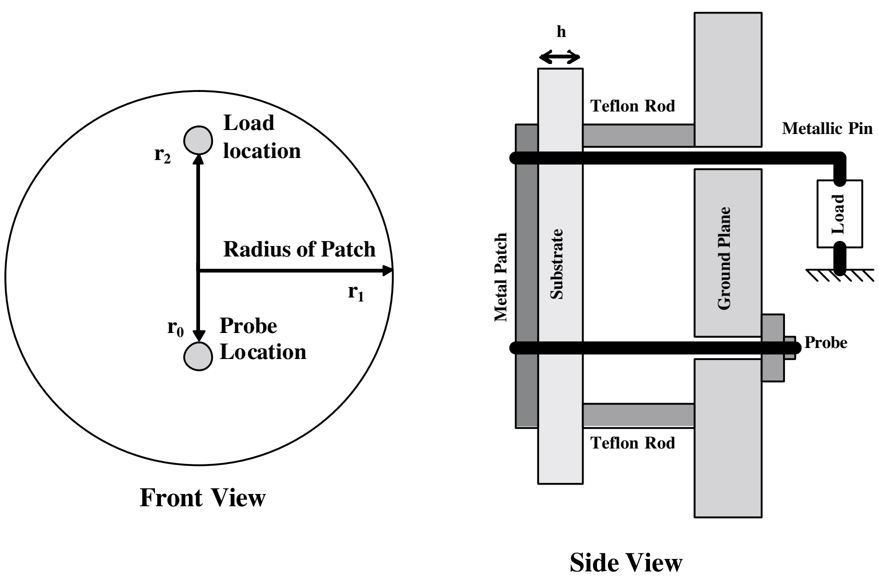

Figure 1. Geometry of the antenna.

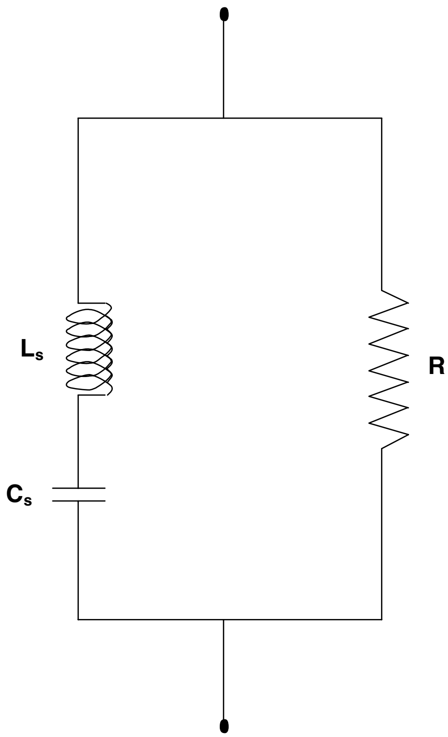

Figure 2. The load circuit.

antenna structure, it is important first to choose suitable values of L & C so that resonance occurs in VHF /UHF range. Then the resistor is placed to improve the impedance matching over a wide bandwidth. Using cavity model analysis one can obtain a transcendental relation that predicts the resonance to excellent accuracy [3]. The method of analysis is outlined as below.

The analysis is based on cavity model [4] where it is assumed that the substrate is electrically thin ($h \ll \lambda_0$). We assume that the load divides the patch into two concentric circles namely region I ($0 < r < r_2$) and region II ($r_2 < r < r_1$). For region I ($r_2 > r > 0$), the expressions for electric and magnetic fields are obtained as

$$E_z^{(1)} = -j\omega_{np}\mu\{C_1 J_n(k_{np}r)\}\cos n\phi \tag{1}$$

$$H_r^{(1)} = -(n/r)\{C_1 J_n(k_{np}r)\}\sin n\phi \tag{2}$$

and

$$H_\phi^{(1)} = -k_{np}\{C_1 J_n'(k_{np}r)\}\cos n\phi \tag{3}$$

where $J_n(X)$ is bessel function of first kind of order n, ω_{np} & k_{np} are the angular frequency and propagation constant for TM_{np} mode and C_1 is a constant. Prime denotes a derivative with respect to its argument. The integer 'n' corresponds to the order of the Bessel function and 'p' denotes the pth zero of $J'_n(k_{np}r)$.

Similarly for region II ($r_1 > r > r_2$), the expressions for electric and magnetic fields are obtained as

$$E_z^{(2)} = -j\omega_{np}\mu\{C_2 J_n(k_{np}r) + C_3 N_n(k_{np}r)\}\cos n\phi \tag{4}$$

$$H_r^{(2)} = -(n/r)\{C_2 J_n(k_{np}r) + C_3 N_n(k_{np}r)\}\sin n\phi \tag{5}$$

and

$$H_\phi^{(2)} = -k_{np}\{C_2 J'_n(k_{np}r) + C_3 N'_n(k_{np}r)\}\cos n\phi \tag{6}$$

where $N_n(X)$ is bessel function of second kind.

The load is connected to the patch via a thin metallic post. It is assumed that the diameter of the circular post is small. Such a thin post can be assumed to be replaced by a conductor in the form of a circular arc strip having arc length equal to diameter of the post coincidence with a circle of radius r_2. For arc strip of small arc length the axial current may be assumed to be uniform along its width. This current is given as E_z/Z_0 where Z_0 is the impedance per unit length for the post. The impedance of such a post is given as [5]

$$Z_0 = \frac{\eta k}{4}\left[1 - J_0^2(kr_2) + j\left\{\frac{2}{\pi}\ln\left(\frac{2}{\gamma k\Delta}\right) + J_0(kr_2)N_0(kr_2)\right] CF\right\} \tag{7}$$

where

$$CF = \frac{\sin\left(\frac{\pi}{2\varepsilon_n}\right)\left\{J_0\left(\frac{P}{4\varepsilon_n}\right)\right\}^{2P}}{J_0^{1.3}(\alpha_n td)J_0^{1.8}(td)}$$

The disk radiator structure is seen to be loaded with two reactances namely the post inductance L_p and the load reactance Z_d. These two reactive components are placed in series to each other and can be considered to be loading the disk resonator in shunt. The total impedance can be written as

$$Z_T = j\omega\left\{\frac{\mu}{2\pi}\left[\ln\left(\frac{2}{\gamma k\Delta}\right) + \frac{\pi}{2}J_0(kr_2)N_0(kr_2)\right] CF + L_s - \frac{1}{\omega^2 C_s}\right\} \tag{8}$$

Application of boundary conditions elaborated in [6] leads to

$$\frac{F_n^{(2)'}(tx)}{F_n^{(2)}(tx)} - \frac{F_n^{(1)'}(tx)}{F_n^{(1)}(tx)} - \frac{\varepsilon_n(1+\cos(2n\phi_i))}{2txX_T} = 0 \tag{9}$$

where

$$X_T = \left\{ \ln\left(\frac{2t_2}{\gamma x}\right) + \frac{\pi}{2} J_0(tx) N_0(tx) \right\} CF + \left(L_s - \frac{1}{\omega^2 C_s} \right) \frac{2\pi}{\mu_0} \quad (10)$$

where

$$t = r_2/r_1; \quad x = k_{np} r_1 \text{ and } \varepsilon_n = 1 \text{ for } n = 0, \quad \varepsilon_n = 2 \text{ for } n \neq 0,$$

The resonance frequency for a given mode 'np' is obtained by solving eq. (9) where integer 'n' denotes the order of Bessel's function and 'p' corresponds to the pth zero of eq. (9).

In the above expressions

$$\begin{aligned} F_n^{(2)}(k_{np} r) &= [J_n(k_{np} r) N_n'(k_{np} r_1) - J_n'(k_{np} r_1) N_n(k_{np} r)] \\ F_n^{(1)}(k_{np} r) &= J_n(k_{np} r) \end{aligned}$$

When the microstrip patch is loaded by an inductor and capacitor in series with a metallic post, TM_{01} mode (static mode in unloaded patch) is generated below the resonant frequency for TM_{11} mode, which remains the fundamental resonance for unloaded patch. For the present case, the dimensions are as follows: $r_1 = 33.1$ mm, $r_2 = 28$ mm, h (height of the substrate) = 10.79 mm (10 mm is air dielectric), r_0 (feed probe location) = 16mm, $\Delta = 0.95$ mm.

The load comprises of $L_s = 220$ nH, $C_s = 10$ pf, $R = 50\Omega$. Here $\phi_I = 180°$ the angle between the feed probe and the load. Using equations (9) and (10) and for these values L_s and C_s the fundamental resonance is seen to occur at 150 MHz. Thus using these values of L_s and C_s one can generate VHF range of resonance from the normally L-band microstrip antenna. However, it is seen that the resonance is very narrow. To improve the impedance bandwidth a 50Ω resistor is placed in parallel to the load consisting of an inductor and the capacitor as shown in Fig. 2.

3. RESULTS

The given antenna has been fabricated and return loss measured using HP8757D Scalar Network Analyzer. Fig. 3 shows the return loss measurement plot. It is seen from the plot that 2:1 VSWR bandwidth for this antenna ranges from 130 MHz up to 876 MHz. It is important to optimize the feed probe location. This is done through simulation using IE3D, a commercial MoM solver for obtaining the maximum 2:1 VSWR bandwidth. It is also important to evaluate whether there is any significant changes in pattern over the entire band. The same

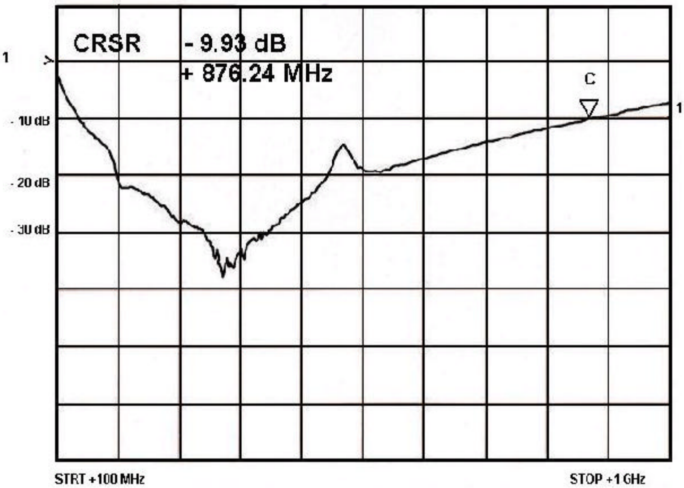

Figure 3. Measured return loss of the antenna ($h = 10.79\,\text{mm}$; $r_1 = 33.1\,\text{mm}$; $r_2 = 28\,\text{mm}$; $L_s = 220\,\text{nH}$; $C_s = 10\,\text{pf}$; $R = 50\Omega$).

antenna pattern has been measured over the band using different combinations of standard VHF/UHF antennas. A representative plot of the pattern measured at 400 MHz and 800 MHz is presented in Figure 4. A comparison is also made with simulated pattern at 400 MHz. The measured results agree well with simulation results. It is clearly seen that for all the cases there is a dip evident in broadside direction. This confirms the theoretical postulate of generation of TM_{01} mode. An interesting point is worth mentioning regarding Fig. 4. It represents the total power measurement comprising both co-polar and cross-polar component $(\sqrt{E_\Theta^2 + E_\phi^2})$. It should be noted that conventional pattern cuts are not presented. For dual polarized applications, the actual measurement is seen to give the total power measurement only. From the representative plot of Fig. 4 it is seen that the null depth at broadside direction varies with frequency. Therefore at lower frequencies, this antenna displaying a greater null depth is more suitable in indoor communication systems as postulated by Guo [7].

It has been suggested in the previous section that such antenna will find use in determination of angle of arrival of reflective component when RF is launched in coal strata with the antenna embedded in it. For such application broadband VHF/UHF transmission is normally used. It is difficult to predict the polarization of the reflected

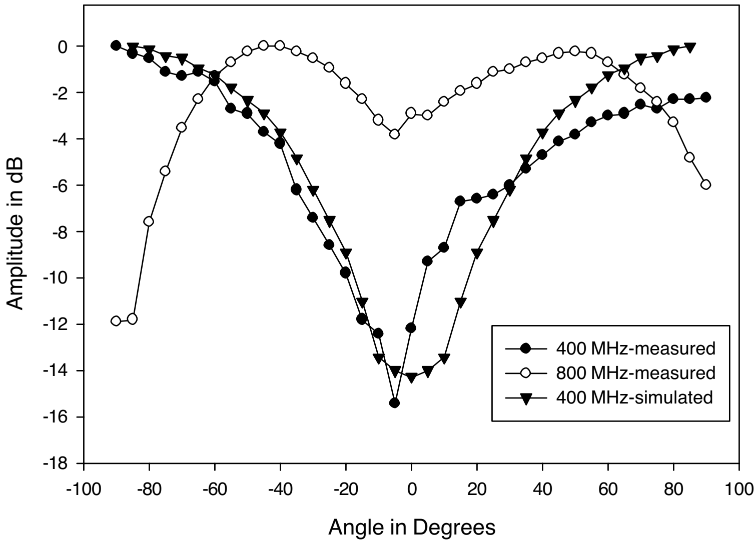

Figure 4. Measured and simulated elevation pattern for the antenna.

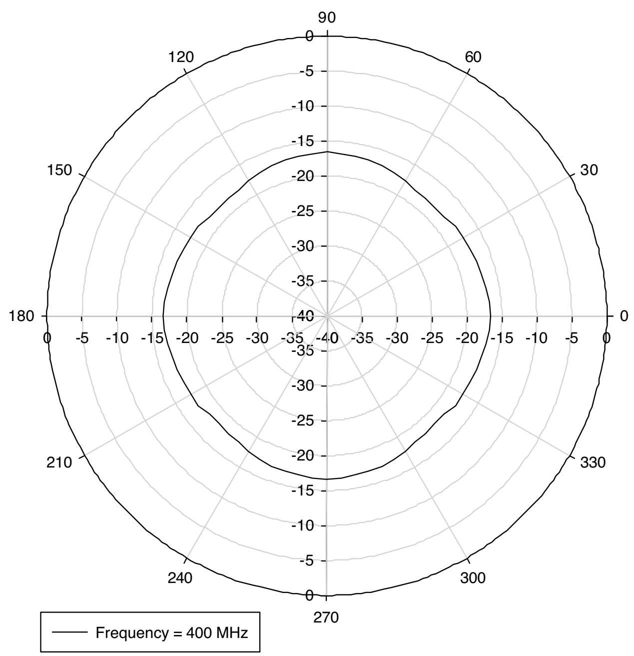

Figure 5. Simulated azimuth pattern of the antenna (at 400 MHz).

component for such applications. Therefore this type of antennas will be more useful in such applications. The azimuth symmetry is demonstrated in Fig. 5. Table 1 gives the actual gain as measured using replacement technique with respect to a standard dipole. From the ratio of directive gain (given by pattern) and the actual measured gain the efficiency is deduced.

Table 1. Measured gains at 800 MHz for the antenna under study. ($h = 10.79$ mm; $r_1 = 33.1$ mm; $r_2 = 28$ mm; $L_s = 220$ nH; $C_s = 10$ pf; $R = 50$ W).

Directive gain (dB)	**Measured gain (dB)**	**Efficiency**
6.22	2.8	45%

It is worth mentioning the effects of different capacitance values. Normally the capacitance values used for such applications in VHF/UHF range varies from 2.2 pf to 47 pf. Using repeated simulations with different values of capacitor, it is seen that the largest bandwidth is obtained for C_s close to 10 pf. For all other values the impedance bandwidth obtained is marginally less. The resistor value as well as the height of the substrate obtained through simulation is optimum. It is also worth mentioning that the effect of load location has minimal effect on bandwidth performance.

4. CONCLUSION

In this paper, a wide bandwidth VHF/UHF antenna has been presented. The measured pattern agrees excellently with the simulated results. Therefore it is safe to assume that a result of 48% efficiency as simulated (IE3D) is correct. The directivity of this patch at 400 MHz is 6.2 dB. To the best of author's knowledge such high impedance bandwidth range, particularly below 1 GHz and using a microstrip structure has never been reported For ultrawideband applications, there is a need for omnidirectional pattern along with compact structure. The classic solution for achieving an omnidirectional pattern is to use a thin wire dipole or monopole. In this communication the same application is covered using a printed circular disk antenna. For the present case, a normally L-band antenna structure has been chosen. However it is theoretically possible that a reduced lateral dimension (normally higher frequencies) can also be used for such applications. For such L-C values are to be chosen in such a way that resonance is obtained in VHF or UHF range and impedance matching is obtained using a 50Ω resistor. Further studies on this aspect is continuing.

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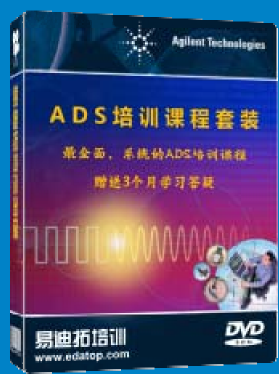

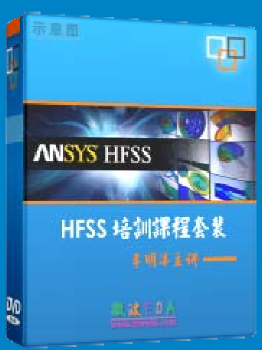

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