Analysis of cavity backed printed dipoles

S. Dey, C.K. Aanandan, P. Mohanan and K.G. Nair

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The closed form expression for the radiated power of a half-wave microstrip patch is modified to calculate the impedance bandwidth of a printed dipole. Analyses of cavity backed flared and end-loaded printed dipoles are presented.

Introduction: Dipoles printed on thin dielectric substrate and backed by a metallic ground plane, with foam like spacer, whose dielectric constant is close to unity, have been developed by several researchers [1,2]. This approach conserves the basic advantages of microstrip antennas such as light weight, convenience for mass production etc., with the added advantage of large bandwidth in comparison with single layer microstrip structures. The resultant bandwidths of such antennas are 15 – 20%. Recently, techniques to improve the impedance bandwidth of such antennas by flaring the dipole arms and by end-loading the dipole arms with triangular shaped loads have been presented by the authors [3,4].

In this Letter, a theoretical analysis to estimate the impedance bandwidth of a cavity backed dipole due to flaring and end-loading of the dipole arms is presented. The quality factor Q of the structures is derived to calculate the bandwidth of the antenna. For this, the approach suggested by Levine *et al.* [5], for a rectangular printed dipole, is suitably modified to incorporate the flaring given to the dipole arms. The effect of end loading is incorporated by calculating the Q of the triangular load separately and adding it to the Q of the remaining antenna.

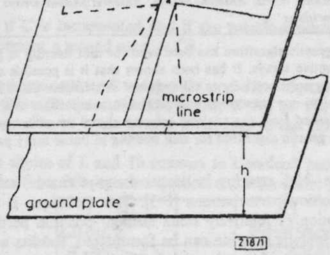

Fig. 1 *Schematic diagram of cavity backed flared printed dipole*

Analysis of flared dipole: Fig. 1 shows a sketch of the cavity backed flared printed dipole, fed by a 50Ω microstrip line and backed by a large ground plane. The dotted line shows the arm etched on the other side of the substrate. For small flaring, the dipole can be approximated as a rectangular dipole with an average width w_{av}, given as

$$w_{av} = w + \frac{l}{2}\tan\theta \tag{1}$$

where l is the length of dipole, w is the arm width at feed point and θ is the flaring angle.

Now, the dipole can be approximated as a lossless transmission line, excited by voltage V_0 and surface current

$$J(x) = \frac{V_0}{Z_c}\sin(\beta x) \qquad \begin{array}{c} 0 < x < l \\ -\frac{w_{av}}{2} < y < \frac{w_{av}}{2} \end{array} \tag{2}$$

Z_c is the characteristic impedance of the microstrip line whose width is w_{av} and the substrate thickness is h. The transverse current component is assumed to be constant.

The real part of the radiated power P_r is derived from the current, using the appropriate Green function. For this, the closed form expression for a half wavelength microstrip patch on relatively thick substrate [6], is modified to calculate the radiated power for any dipole length and is given below:

$$P_r = \frac{V_0^2}{Z_c^2}\frac{60}{\pi}\epsilon_{eff}$$
$$\times \int_0^{2\pi}\int_0^{\pi/2} \frac{\cos^2(\pi l \sin\theta\cos\phi/\lambda_0)}{(\sin^2\theta\cos^2\phi-\epsilon_{eff})^2}\,\mathrm{sinc}^2(wk_0\sin\theta\sin\phi/2)$$
$$\times\left[\frac{\cos^2\theta\sin^2\phi}{(\epsilon_r-\sin^2\theta)\cot^2(hk_0\sqrt{\epsilon_r-\sin^2\theta})+\cos^2\theta}\right.$$
$$\left.+\frac{\cos^2\theta\cos^2\phi(\epsilon_r-\sin^2\theta)}{(\epsilon_r-\sin^2\theta)+\epsilon_r^2\cos^2\theta\cot^2(hk_0\sqrt{\epsilon_r-\sin^2\theta})}\right]\sin\theta\, d\theta\, d\phi \qquad (3)$$

where λ_0 is the wavelength corresponding to the central frequency of the band of interest and $\mathrm{sinc}(x) = \sin(x)/x$.

The radiation resistance R_r of the dipole is now given by

$$R_r = \frac{Z_c^2}{2P_n} \qquad (4)$$

where P_n is the radiated power normalised to unit current amplitude ($I_0 = V_0/Z_c$). The quality factor Q in terms of R_r is given by

$$Q = \frac{\pi R_r}{2Z_c} \qquad (5)$$

and the bandwidth for $VSWR = 2$ is

$$BW_{VSWR=2} = \frac{1}{\sqrt{2}Q} \qquad (6)$$

To verify this approach, dipoles of different widths are etched on a substrate of dielectric constant 4.5 and thickness 1.6mm. The length and flaring angle of the dipoles are 9cm and 10°, respectively. Because the substrate thickness is much less than the separation between the dipole and the reflector plate, its effect is neglected and the value of ϵ_r is chosen as unity.

Table 1 shows the experimental results and the computed values of dipoles for various separations h between the dipole and the ground plate. The theoretical values agree well with the experimental data.

Table 1: Experimental and theoretical values of percentage bandwidths of cavity backed flared printed dipole

Separation h	Percentage bandwidth			
	Width w = 0.80cm		Width w = 1.00cm	
	Experiment	Theory	Experiment	Theory
cm				
2.0	5.60	7.02	8.81	8.04
2.5	8.70	9.23	9.25	9.82
3.0	12.49	11.86	12.97	12.45
3.5	14.06	14.49	15.05	15.06
4.0	18.15	17.29	16.20	17.75
4.5	20.88	19.78	18.42	20.37
5.0	24.76	22.27	20.94	22.92
5.5	25.99	24.31	24.94	25.11

Analysis of end-loaded printed dipole: Fig. 2 shows a diagram of a cavity backed triangular end-loaded printed dipole. The dipole can be divided into two sections; the flared arm section (AA′) and the triangular shaped load portion. The Q of both portions are calculated separately and added in parallel to obtain the Q of the complete structure.

The structure of the portion AA′ is the same as the flared printed dipole structure except that the arms are coupled to the loads, whereas for a flared printed dipole, the arms are open. This considerably modifies the Q of the portion AA′ from its value without end loads. This effect is incorporated by multiplying the unloaded Q of portion AA′ with an empirically selected weighting factor and is given as

$$Q_l = Q \times h^{0.15} \qquad (7)$$

The triangular loads can be assumed as a triangular patch and Q can be calculated using the ray optics approach. A closed form expression for a 45°-45°-90° triangular patch is given in [7]. The

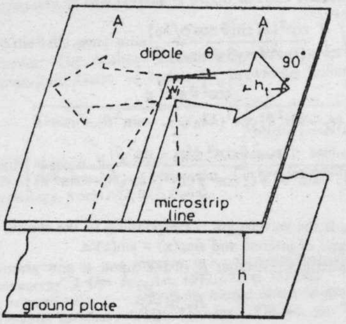

Fig. 2 *Schematic diagram of cavity backed triangular end-loaded printed dipole*

quality factor Q_l due to both the triangles is given by

$$Q_l = \frac{Q_t}{2} \tag{8}$$

where Q_t is the Q of a single triangle.

Now, the Q of the complete dipole (Q_d) can be written as

$$\frac{1}{Q_d} = \frac{1}{Q_f} + \frac{1}{Q_l} \tag{9}$$

Q_f and Q_l can be calculated from eqns. 7 and 8, respectively.

The validity of the assumptions made is confirmed by fabricating dipoles having length l = 9cm, arm width at the feed point w = 0.75cm and flaring angle θ = 10°, for two different heights of triangles h_t. Table 2 shows the comparison between the experimental values and the computed data for various separations. The theoretical results agree well with the experimental data within the tolerable limits.

Table 2: Experimental and theoretical values of percentage bandwidths of cavity backed triangular end-loaded printed dipole

Separation h	Percentage bandwidth			
	Height h_t = 2.0cm		Height h = 2.5cm	
	Experiment	Theory	Experiment	Theory
cm				
2.5	11.41	13.01	9.91	13.93
3.0	16.42	16.12	19.59	17.55
3.5	18.53	19.18	21.30	20.92
4.0	22.82	22.41	28.19	24.43
4.5	24.79	25.61	29.92	27.72
5.0	25.93	19.10	31.93	30.73
5.5	29.46	31.36	36.58	33.87

Conclusions: We have analysed the effect of flaring and end loading of the arms of a cavity backed printed dipole on the impedance bandwidth. The theoretical results agree well with experimental data. This justifies the validity of the theory and the approximations incorporated.

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S. Dey, C. K. Aanandan, P. Mohanan and K. G. Nair (*Department of Electronics, Cochin University of Science & Technology, Kochi 682 022, India*)

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