THE ELECTRICALLY SMALL DIPOLE-LOOP

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ABSTRACT. Loops, with orthogonal dipoles, have been claimed to provide exceptional bandwidth. These are examined via Moment Method calculations, and the bandwidth of a matched loop-dipole is determined.

Key Words: electrically small antennas, antenna Q, fundamental limitations, dipole, loop

1 INTRODUCTION

A square loop, with feed at the center of one side, can be combined with a dipole, where the dipole is parallel with the loop axis, and shares the feed point; see Fig. 1. With the dipole length twice the loop side, there will be a frequency where the dipole reactance and loop reactance are equal and opposite. It has been suggested [1, 2] that this loop-dipole together with a second loop-dipole fed 90 deg. out of phase provides broadband performances, in fact a Q equal to zero. The plane of the second loop-dipole is normal to the plane of the first loop-dipole. Because stored energy is an inevitable feature of electrically small antennas, the loop-dipole is examined to determine bandwidth capabilities.

2 MODELLING

The Tilston-Balmain Moment Method code was used [3]; this is a bridge current modification of the Richmond Galerkin piecewise sinusoidal code, and it removes the impedance matrix asymmetry due to radius offset. The dipole-loop consists of a short dipole normal to the plane of a small square loop; the dipole is connected in series or in parallel with the loop at the center of one side; the dipole length is twice the loop side [2]. See Fig. 1. Previous experience with PWS Moment codes indicated that satisfactory results are obtained using 6 segments (5 unknowns) for the dipole, and 4 segments per loop side (4 unknowns). An additional unknown connects the dipole and loop, making 22 unknowns. The code is double precision complex, and is run on an HP 64 bit UNIX workstation. The dipole and loop are orthogonal; from field symmetry considerations the mutual coupling should be zero. From the computer results, the coupling was roughly -170 dB, an excellent result.

3 RESULTS

Input resistance was obtained separately for the dipole and the loop of Fig. 1. Since the concept of reference [2] is to radiate equal powers in TE and TM modes, the frequency should be adjusted to make the radiation resistances equal. However, in this case the reactances are not equal. Thus the frequency was adjusted to make the reactances equal and opposite. In principle the wire radius might be adjusted along with frequency to equate resistances and reactance magnitudes, however both reactance magnitudes decrease as wire radius/λ increases, although at slightly different rates. Fat wires might allow matching, but more elaborate modelling is required for fat wire antennas, and this was not deemed worth pursuing. The resistances (radiated powers) were nearly equal, and thus the results should be general. When the dipole and loop are in parallel, as in [2], the input impedance at resonance is approximately $R/2 + X^2/2R$, assuming equal resistances. Since for these small antennas $X >> R$, the parallel resonant impedance is very large. Taking the example of [2], where loop width is .12 m, the reactance magnitudes match at a frequency of 198.153 MHz; the dipole length/radius is 100 and the same radius is used for loop and dipole. Dipole impedance is 4.515 -j 624.5 while loop impedance is 4.901 +j 624.5. These values compare well with those calculated from simple formulas. Parallel impedance is 41380 ohms, while a series arrangement gives 9.416 ohms. For both cases VSWR = 2 bandwidth is .596%, corresponding to an unloaded Q = 168. This narrow bandwidth is due to the large reactances; a small change in frequency produces a reactance change comparable to the small resistance. Also use of both a loop and a dipole exacerbates the bandwidth limitation, as the reactance spread increases twice as fast as it would for a single element. This doubling of reactance spread also occurs of course for a single loop or dipole tuned by a conjugate reactance; however, with the loop-dipole both resistances are also changing with frequency. Dipole length is $.15852\lambda$, while loop side is $.07926\lambda$. As the radius of the enclosing sphere is $\sqrt{3}W$, the kr for the sphere is 1.306 so that the Q of 168 is very much higher than that of the fundamental limit [4]. This is partly due to the thin wires, and partly because a square loop inscribed in a circle has a smaller area than the circle, and loop radiation resistances increases as the fourth power of diameter. A circular loop would yield a larger bandwidth. Even with fat wires the dipole-loop does not appear attractive as a component of a low Q antenna.

When the second loop-dipole is added, the coupling situation changes; see Fig. 2. The loops are orthogonal and do not couple. However the dipoles are off-center, and the dipoles are coupled. Further each dipole couples to the other loop. Calculations show that some of the four radiation resistances are negative, resulting in power transfer from one port to another. Now there are four reactances changing with frequency, resulting in an even smaller bandwidth. The loop dipole pairs, fed in quadrature, produce circular polarization, but the stored energies add, as always. There is no physics that suggests that two orthogonal elements fed in quadrature will have improved bandwidth. One must not integrate field components separately to get stored energy. There are no correct arguments, nor any validated experiments, that show that reactive energies do not add. There are no physics reasons to expect Q lower than the fundamental limitations prescribe.

The practical problem of feeding the loops and dipoles must be considered. To provide a single feed point, the two loop-dipoles must be connected. Whether coax or twin wire is used, the feed conductors will provide further coupling among the four elements. Thus performance is expected to degrade further; the feed coupling increases reactive energy but does not correspondingly increase radiation resistances.

4 CONCLUSIONS

The loop-dipole pair, at the self match frequency, has about the same bandwidth as a single reactance matched loop or dipole. Adding another loop-dipole fed in quadrature may reduce the bandwidth. Due to the physical asymmetry it is not feasible to match both loop-dipoles unless dimensions are radically changed. Thus the pair of loop-dipoles presents a significant mismatch, and at worst power transfer among the elements.

5 REFERENCES

[1] D. M. Grimes and C. A. Grimes, "Radiation Q of Dipole Generated Fields", ***Radio Science,*** Vol. 34, 1999, pp. 281-296

[2] C. A. Grimes et al, "Characterization of a Wideband, Low-Q, Electrically Small Antenna", ***Microwave and Optical Technology Letters,*** Vol 27, Oct. 5, 2000, pp. 53-58

[3] M. A. Tilston and K. G. Balmain, "On the Suppression of Asymmetric Artifacts Arising in an Implementation of the Thin-Wire Method of Moments", ***Trans. IEEE,*** Vol. AP-38, 1990, pp. 281-285

[4] R. C. Hansen, "Fundamental Limitations in Antennas", ***Proc. IEEE,*** Vol. 69, Feb. 1981, pp. 170-182

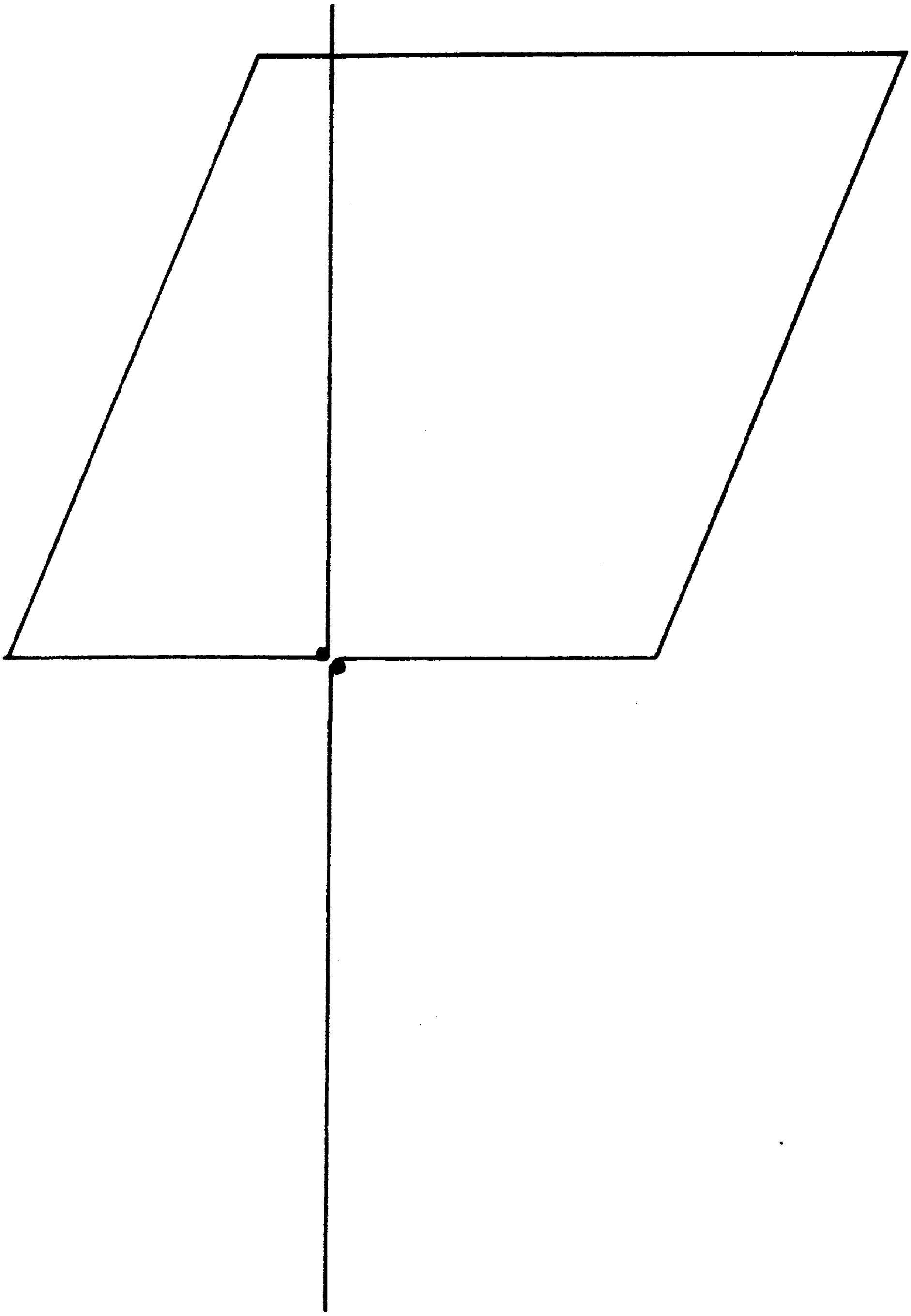

Fig. 1

Dipole and Loop in Parallel

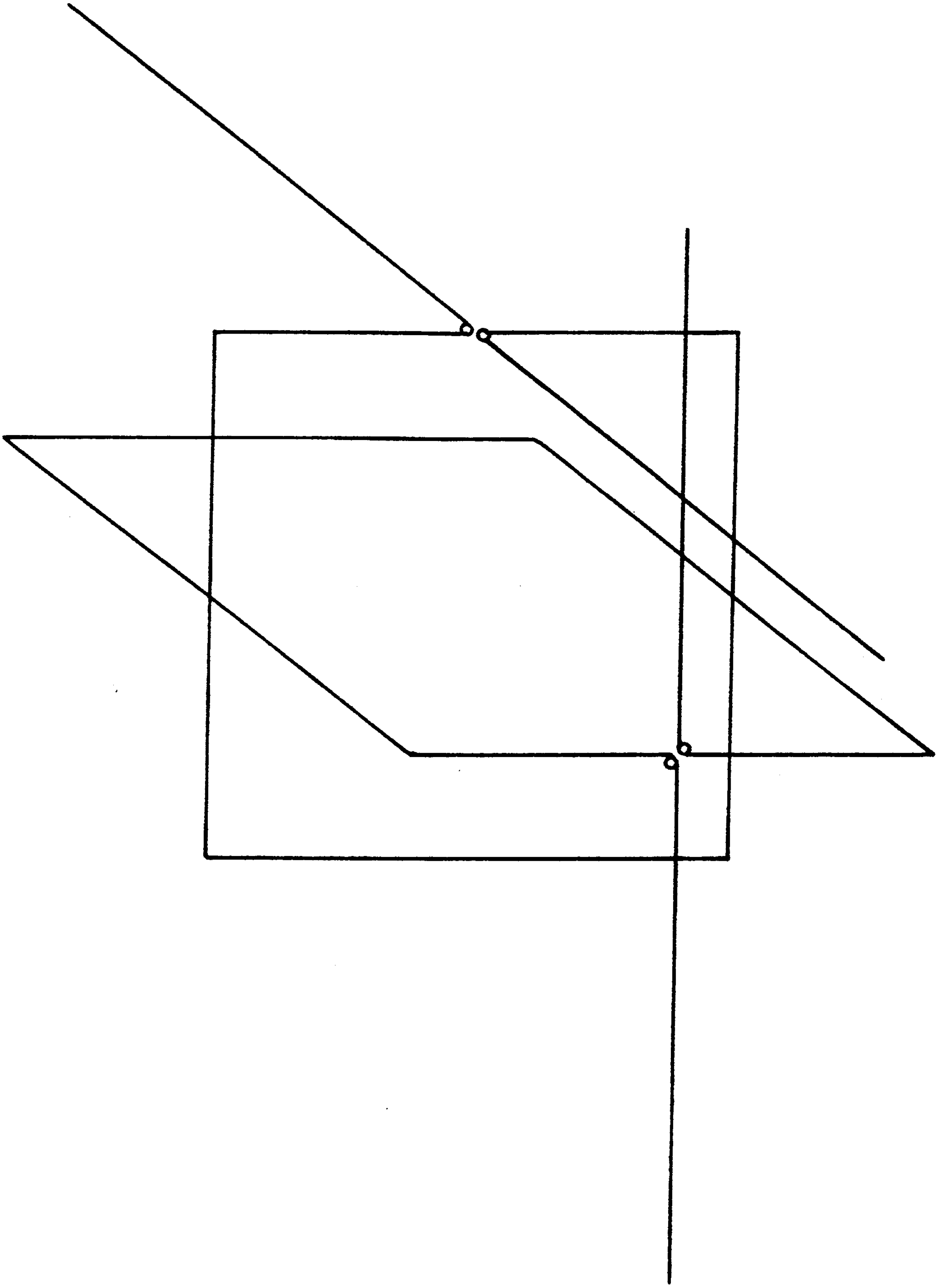

Fig. 2

Dipole-Loop Pair