

## Using mutual coupling to calculate the radiation pattern for parasitic patch antennas

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**Abstract:** The far field radiation pattern of closely spaced dipoles can be calculated using mutual impedance and network equations. The definition of mutual coupling for patch antennas must be reviewed to determine the radiation pattern for parasitic patch antennas.

### Introduction:

Two side-by-side wire-dipoles forming an antenna array can be modelled using network equations [1]. The currents in each element  $I_1$  and  $I_2$  are calculated using the matrix equation:

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{12} & Z_{11} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \quad (1)$$

where  $V_1$  and  $V_2$  are the driving voltages,  $Z_{11}$  is the self impedance of the dipole and  $Z_{12}$  is the mutual impedance of the dipole elements defined as:

$$Z_{11} = \left. \frac{V_1}{I_1} \right|_{I_2=0} \quad Z_{12} = \left. \frac{V_1}{I_2} \right|_{I_1=0} \quad (2)$$

Array theory can be used to calculate the H field radiation pattern.

$$E(\phi) = F_E (I_1 + I_2 e^{2nd \sin \phi / \lambda}) \quad (3)$$

where  $F_E$  is the element factor and  $d$  is the center-to-center spacing between the elements.

If one element is parasitic (i.e. the central feed position consists of a short circuit), then the applied voltage for this dipole is zero (i.e.  $V_2 = 0$ ), and the array radiation pattern calculated using (1-3).

For all separation distances  $d$  in the side-by-side configuration where the mutual coupling is significant, the parasitic element acts as a

reflector in the array and the principal radiation direction is in the direction of the center-to-center radial line away from the parasitic element.

### Collinear dipoles

The same technique is used to calculate the radiation pattern for a collinear array of two dipoles; one driven element and the other parasitic. In this case the variation is in the  $\theta$  plane as the array is rotationally symmetric.

Figure 1 shows the variation in normalised radiation pattern for two collinear dipoles, one centre driven and the other a short-circuited parasitic element. The radiation pattern is skewed slightly from the  $\theta = 90$  degree plane towards the parasitic element. The separation distance between the closest ends of the two dipoles was  $0.025\lambda$ . The results were calculated using the mutual coupling expression for infinitely thin wires [1] followed by standard array theory and checked using NEC code [3]. A wire radius of  $10^{-6}\lambda$  was used in the NEC calculation. The radiation pattern for an isolated dipole has been plotted for comparison. There is strong agreement between the NEC and network theory results (within 2 dB for all angles).

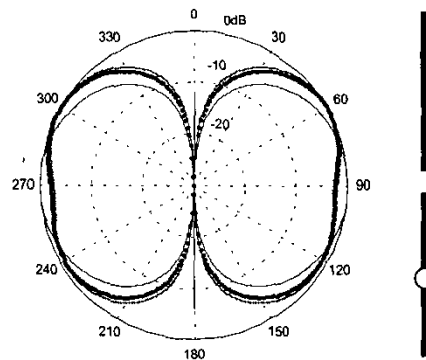


Figure 1: E field radiation pattern for collinear array of two half-wavelength dipoles (one driven element and one parasitic). The nearest point of separation was  $0.025\lambda$ . The radiation pattern for a single half wave dipole has been plotted for comparison (light line).

### Rectangular patches

There are a number of difficulties in using equations (1-3) for a resonant rectangular patch antenna element with an adjacent identical parasitic patch.

- (a) The calculation of the mutual coupling between patch antennas is quite complex as a number of different coupling modes are present in the dielectric substrate [4-6].
- (b) At close distances  $|I_2| > |I_1|$ . It appears as though the driven patch is acting as a feed transmission line to the parasitic patch.
- (c) The usual definition of mutual impedance requires that all ports in the network are open circuit, and have zero current apart from the port under consideration [1, 6]. For a half-wave wire-dipole an open circuit at the center of the parasitic element results in virtually zero current. An open circuit at a probe feed point in a parasitic patch does not result in insignificant current in the patch.
- (d) The current flow is two-dimensional and so the definition of  $I_1$  and  $I_2$  must be resolved.

A single, isolated, rectangular patch was optimised for operation at approximately 5 GHz. The patch had length 1.319cm, width 2.60cm and was located on a dielectric slab of thickness 0.160cm and relative permittivity 4.4. The probe feed was located at 0.100cm from one radiating edge. With the patch defined, a second patch with identical size without a feed probe was located at various nearest-edge separation distances  $t$  as shown in Figure 2.

The currents in the patches were calculated using Ansoft Ensemble [7].  $I_1$  and  $I_2$  were defined as the maximum surface current vectors located in the centre of the patch length and immediately adjacent to the non-radiating edges of the patch. From these currents,  $Z_{11}$  and  $Z_{12}$  were calculated using the inverse of (1) assuming  $V_2 = 0$ . The E-plane radiation pattern was calculated using equation (3).

Figure 3 shows the radiation pattern in the  $\theta$  plane defined in Figure 2, when  $t = 1$ mm. In this case  $|I_1| = |I_2|$  and the phase difference between the  $I_2$  relative to  $I_1$  is -38 degrees. The main lobe of the radiation pattern is deflected from the vertical direction towards the parasitic element.

Alternative approaches to resolving these issues will be presented.

References:

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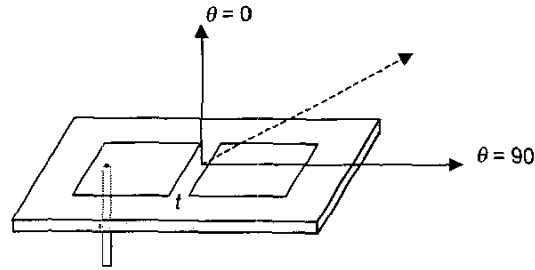


Figure 2: Probe-driven, half-wave resonant patch with adjacent parasitic patch of identical size - E plane configuration.

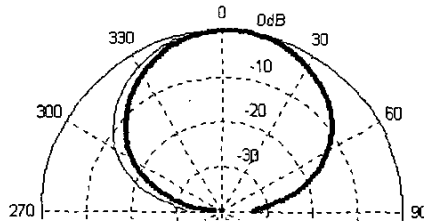


Figure 3: Relative gain of a probe-driven patch with adjacent parasitic patch (bold line). The nearest edge spacing  $t = 0.025\lambda$ . The element pattern has been plotted for comparison (light line).