Electronic beam steering in wire and patch antenna systems using switched parasitic elements

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Introduction:

Current methods of electronically controlling the radiation pattern of an antenna system include the use of servo-motors and phase switched active elements. The servo-motor system is slow, power intensive, requires regular maintenance and also is physically large. The phased array systems require that the RF path to each element has a number of power splitters and one electronically controlled phase shifter. These components add to the insertion loss between the RF source and the radiating elements. In addition, the software required to steer the beam can be quite complex. Other electronic control methods described in the literature include switchable phasing stubs in parasitic patch arrays [1], and switchable short circuit terminations in patch antennas [2].

In this paper we will explore the application of two alternative methods of electronically controlling the radiation pattern from an antenna array which has a single feed line. Type (a) involves switching one of the parasitic elements to become active. Type (b) requires switching the parasitic elements located in the vicinity of the active element between short circuit (i.e. continuous conduction in the element) and open circuit at a point where the induced current is maximised. Both techniques offer a reduced radiation loss in the feed network and relatively simple control circuitry and tracking software.

Through the use of high speed, multiple throw, low loss, RF switches and p.i.n. diodes controlled by TTL voltage levels, it is possible to rapidly change the broad direction of radiation. At present, these concepts have been applied to applications in both wire and patch antenna structures where full 360 degree azimuthal coverage is required. These techniques can be applied to a wide

range of frequency bands. Applications include land mobile satellite communications, vehicle location via radio direction finding, and vehicle anti-collision radar.

Two element wire antenna array - Type (a):

Fig. 1 shows two $\lambda/2$ thin wire elements separated by a distance of 0.2λ. In the case of a type (a) structure, the directivity of the antenna is changed by connecting one element to the RF source (v) and the other element is parasitic but with a centrally located switch (s). The polar pattern for this array is given in Fig. 2 for two cases. Firstly when the parasitic element is short circuited, and secondly, when the switch is open circuit at its centre (where the induced current is maximum). When the switch is open circuit, the parasitic element plays almost no part in the radiation pattern and the polar pattern is almost the same as that for a half wave dipole alone. The change in the parasitic element is achieved via a p.i.n. diode which is forward biased for the effective short circuit and unbiased for the open circuit. This can be accomplished using the circuit given in Fig. 3. The resistor limits the current through the diode. The switching voltage required is the standard TTL voltage levels of 0 and +5V.

Given that the p.i.n. diode is not a perfect short circuit when forward biased, the performance of the antenna system was modelled using a number of lumped impedance values at the centre of the passive element. Fig 4. shows the change in the front to back ratio of the polar pattern as the forward resistance of the diode is varied. It is clear that for resistances of less than 10Ω, the parasitic element functions adequately. A typical forward resistance for a p.i.n. diode is 1Ω.

Two element wire antenna array - Type (b):

In this case, a switch is used to reverse the positions of the feed point (v) and the switch (s) as shown in Fig. 1. The resultant polar pattern is given in Fig. 5., and, given the symmetry of the arrangement, the direction of the radiation is reversed. The switching circuitry is a little more complex as it requires both an RF switch and a p.i.n. diode switch.

Cost/efficiency analysis

In a four element phased array, the RF path to each element must pass through two 3dB power splitters and an electronically controlled phase shifter. Ignoring conduction and dielectric loss, the total insertion loss is likely to be approximately 3dB. A similar antenna system based on a type (a) arrangement will effectively have zero loss, and a type (b) arrangement will have the insertion loss of the RF switch alone. For a single pole four throw switch this is typically 1.5dB at L band frequencies.

There are cost savings in the electronics also. These relate to the smaller RF component count, and the fact that standard TTL voltage levels can be used to control the antenna array.

There are, however, disadvantages with this technique. For example there are problems related to how directional one can design the system, and certainly there is more flexibility in the beam shaping when using a phased array. Thus, the switched parasitic arrays are most effective in requirements where the beam width is quite broad. For example, a radial arm, microstrip Yagi patch antenna has been described previously [3], in which a central reflector patch was surrounded by switchable active patch antennas. Once the feed points for the array had been selected, all other possible feed point patches were shorted to ground to enhance the front to back ratio of the array. Other applications include anti-collison radar for moving vehicles and beacon location systems. In this presentation, a number of examples will be given.

References:

[1]   R.J. Dinger, Reactively steered adaptive array using microstrip patch elements at 4GHz. IEEE Antennas & Prop. AP-32, (8), pp 848-856, 1984.
[2]   D.H. Schaubert, F.G. Farrar, S.T. Hayes, and A.R. Sindoris, Frequency agile, polarisation diverse microstrip antennas and frequency scanned arrays., U.S. Patent #4367474., Jan. 1983.
[3]   D. Gray, J.W. Lu, and D.V. Thiel, Electronically steerable Yagi-Uda microstrip patch antenna array. IEEE AP-S Meeting, Newport Beach, p181, 1995.
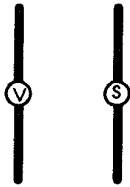
Figure 1: Two element wire antenna element length is 0.5λ and spacing is 0.2λ. v is the applied RF voltage and s is p.i.n. dipode switch.
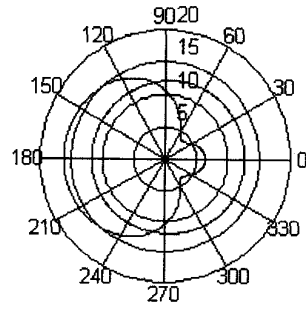

Figure 2: Polar pattern (dB) for a type (a) antenna. The parasitic element is switched between open and short circuit.
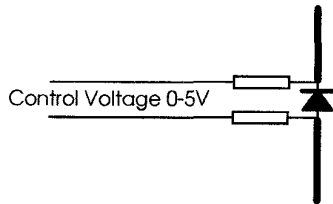

Control Voltage 0-5V

Figure 3: Support circuit required for the parasitic element. The resistors include RF suppression.
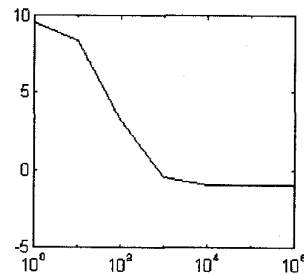

Figure 4: Variation in the front to back ratio (dB) as a function of the resistance of the p.i.n. diode (ohms)
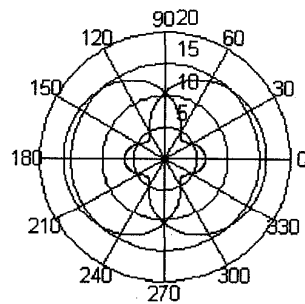

igure 5: Polar pattern (dB) for Type (b) with feed point switched between two ements. Half wave elements with separation 0.2λ.