A Review of Recent Developments in the Application of Coupled Oscillators to Phased Array Antennas

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Some years ago it was proposed that an array of electronic oscillators coupled to nearest neighbors can be made to mutually injection lock and oscillate as an ensemble thus implementing spatial power combining.[1] Later, it was noted that such a locked array can provide suitable excitation for the elements of a phased array antenna and that beam steering may be effected by tuning only the perimeter oscillators.[2][3] JPL has over the past several years extended this work in an effort to develop a low cost phased array antenna for use in planetary exploration. The incentive is that the higher data rates associated with high gain antennas are only usable if the beams are steerable and beam agility achieved through conventional means is expected to be prohibitively costly. Our early work was primarily analytical and resulted in the development of the so-called continuum model. [5] This and related work were reviewed at the 1999 URSI General Assembly. [6]

During the three years since the 1999 General Assembly, JPL has expanded the effort to fabrication and experimental evaluation of several arrays. These include a seven element onc-dimensional S-band array, a nine element (3 by 3) two-dimensional array at S-band, and a twenty-five element (5 by 5) array at S-band. These are shown in Figure 1 below.

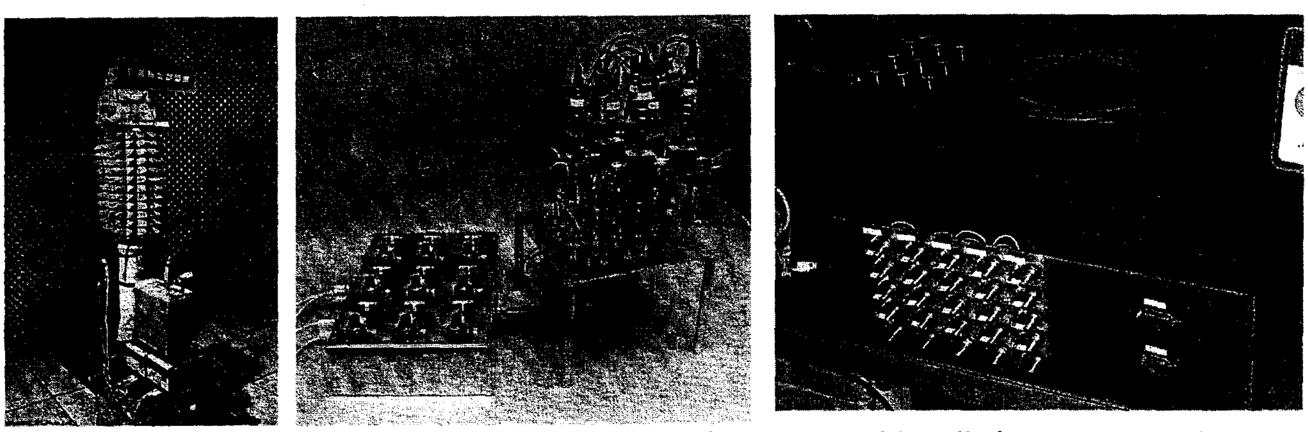

Figure 1. S-band arrays, left to right: seven element linear array with radiating aperture, 3 by3 square oscillator array, 5 by 5 square oscillator array.

An interesting phase measurement system was also developed for use in assessing the behavior of these arrays. The system comprises a set of mixers and quadrature hybrids arranged to indicate the phase differences between adjacent oscillators. The resulting data is processed in a virtual instrument implemented in Labview™ and displayed as a line graph or a two-dimensional surface depicting the aperture phase distribution of the array. The system for the 25 element array is shown in Figures 2.

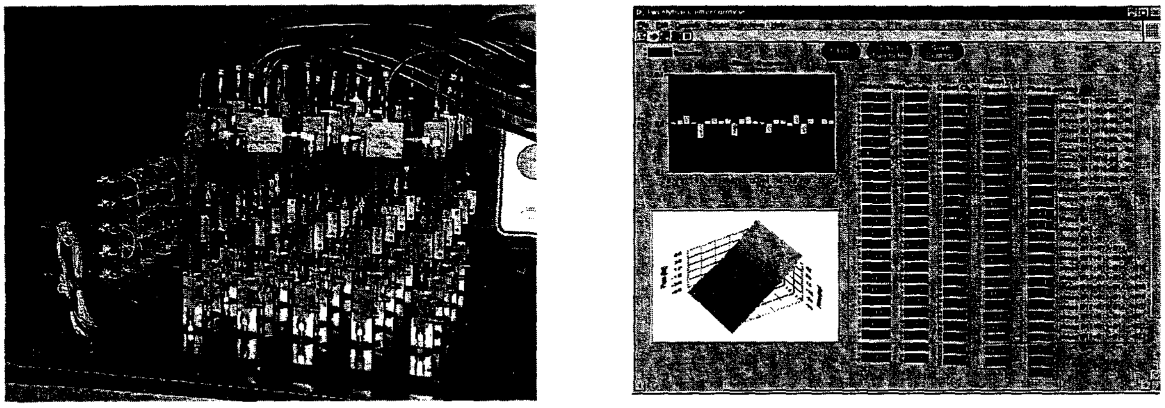

Figure 2. Left: Diagnostic system installed on the 25 element array. Right: Computer display of aperture phase.

The frequency doubling approach to scan range enhancement suggested by York and Itoh [7] has been recently demonstrated by Shen and Pearson.[8] Thus, the usual theoretical limit of 90 degrees between oscillators, corresponding to 30 degrees of scan from normal for half wavelcngth element spacing, translates into a 180 degree phase difference between adjacent radiating elements. In practice, however, the theoretical limit of 90 degrees is never achieved so in fact one cannot expect to obtain 180 degrees between elements. The JPL nine element array has recently been enhanced with frequency triplers to provide wider scan range. This resulted in an X-band output. When the oscillator output frequency is multiplied by three, so is the phase and 60 degrees between oscillators becomes 180 degrees between elements which, for half wavelength spacing this is sufficient to yield scan to endfire. The enhanced 9 element array is shown in Figure 3 together with its diagnostic system display.

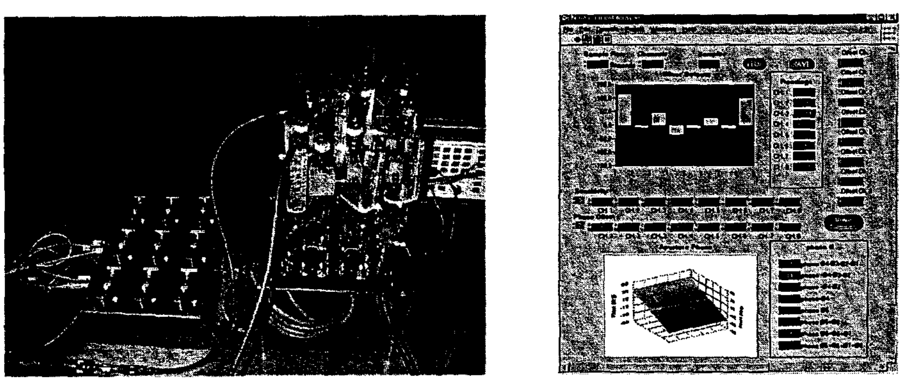

Figure 3. Left: Diagnostic system installed on the 9 element array. Right: Computer display of aperture phase.

In addition, further theoretical work using the continuum model has resulted in an analysis of the dynamics of an array coupled on a triangular grid as shown in Figure 4 as opposed to the usual rectangular arrangement. This yields a slightly more robust system with respect to locking but one which is somewhat slower to respond to steering voltages applied to the perimeter varactors. Figure 5 shows a time sequence of aperture phase distributions over a triangular array during the beamsteering transient.

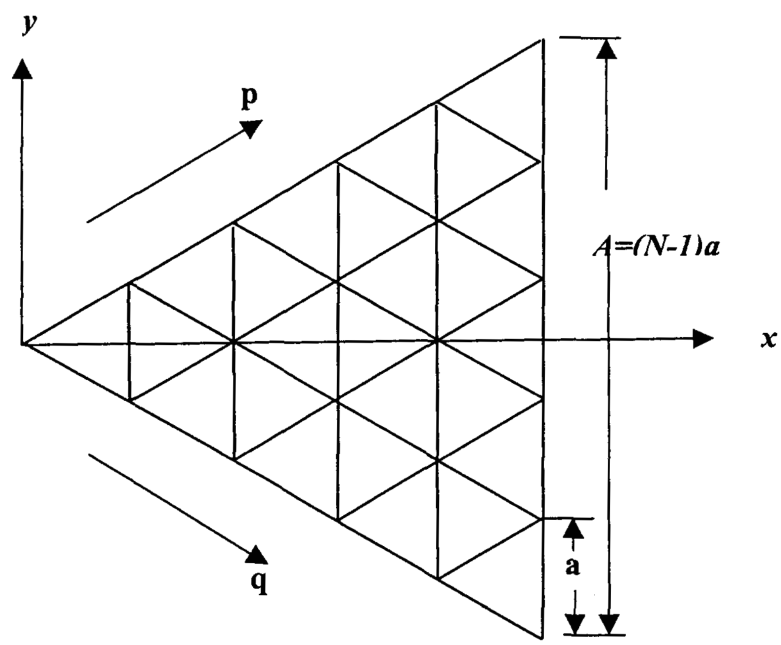

Figure 4. Triangular grid couping topology.

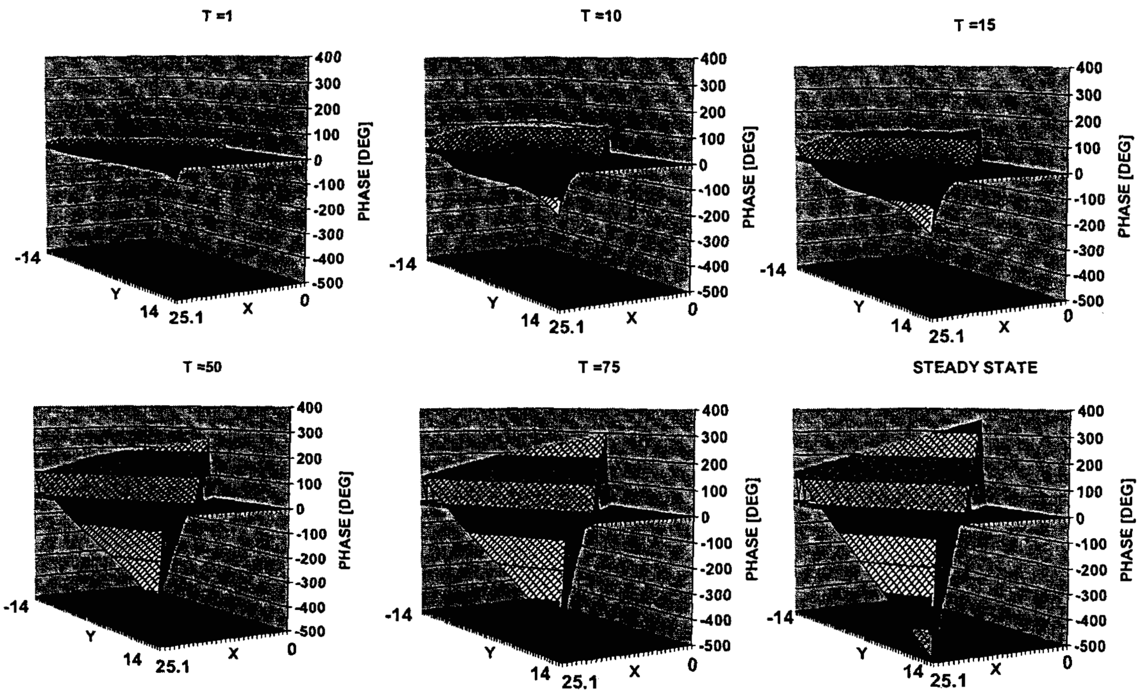

Figure 5. Aperture phase dynamics of a triangular array computed via the continuum model.

Some aspects of frequency or phase modulation of such arrays have also been studied.[9] This paper will review all of this recent work and its relation to that of other researchers in this area.

Acknowledgment

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