Beam Scanning with Coupled VCOs

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Abstract — An eight element beam scanning array using strongly coupled voltage controlled oscillators (VCOs) is described. A constant, progressive phase shift between elements can be synthesized by adjusting the natural frequencies of the end elements [6]. The VCOs in the array are used to implement this frequency detuning. Measured radiation patterns indicate continuous scanning from $-15°$ to $+30°$ off broadside with an effective radiated power (ERP) of 8.5 W at 8.4 GHz.

I. Introduction

Quasi-optical oscillator arrays have the potential to generate greater power at higher frequencies than previously available from single solid state devices [1-5]. These arrays achieve power combination through the coherent addition of radiated power from many nearly identical sources. In many practical arrays, mutual synchronization of these sources is achieved through the injection locking of each source to its nearest neighbors.

Recently, several groups have investigated beam-scanning with quasi-optical oscillator arrays [5-7]. It has been shown [6] that it is possible to synthesize a constant phase progression along the elements of a coupled oscillator array by slightly detuning the free-running frequencies of the end elements in a linear array. This phase progression then determines the scan angle of the radiated pattern. Controlling the free-running frequencies of the end elements creates continuous beam scanning throughout a range determined by the element separation and the coupled oscillator dynamics. The prototype array constructed in [6] was sensitive to small variations in the free-running frequencies of the oscillators because weak, radiative coupling was used. One approach to decreasing this sensitivity was proposed in [10], where oscillators were strongly coupled through resistively loaded transmission lines. This increased coupling strength, however, requires greater frequency detuning to achieve the full range beam scanning. This paper discusses an eight element beam scanning array which used coupled VCOs to achieve such frequency detuning.

II. Coupled Oscillator Dynamics

It was shown [6] that a constant phase progression along a linear array of N instantaneously coupled oscillators could be synthesized if the free-running frequency distribution of the oscillators in the array was described by:

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$$\omega_i = \begin{cases} \omega_f[1 - \varepsilon' \sin(\Delta\theta)]^{-1} & \text{if } i = 1 \\ \omega_f & \text{if } 1 < i < N \\ \omega_f[1 + \varepsilon' \sin(\Delta\theta)]^{-1} & \text{if } i = N \end{cases}$$

where ω_i is the free-running frequency of the ith oscillator, ω_f is the synchronized frequency of the array, $\Delta\theta$ is the progressive phase shift between elements, and ε' is a factor proportional to the coupling strength. It can be seen that the free-running frequencies of the innermost elements in the array are identically set to the synchronized frequency, ω_f. Various phase shifts, $\Delta\theta$, can be synthesized by detuning the free-running frequencies of the end elements in the array. A stability analysis performed in [6] showed that stable values of progressive phase shift for instantanously coupled oscillators lie within the range $-90° \leq \Delta\theta \leq +90°$.

III. Array Design

A photograph of the array is shown in Figure 1. The array was designed to operate at 8.4 GHz, and featured an element separation of one half wavelength. The maximum beam-scan range for this array was ±30° off broadside. The array was comprised of eight VCOs, each of which used an NEC 900276 GaAs MESFET. Each VCO in the array consisted of a feedback amplifier with a tunable microstrip patch antenna. This varactor tuned patch served as a resonant load for the amplifier. RF energy was fed back to the input of the amplifier by coupling energy from the non-radiating edge of the patch. Following the approach described by Johnson in [9], about 25% of the output power was fed back to obtain maximum oscillator power. VCO operation was achieved by placing a shunt varactor diode near the center of each patch antenna. By adjusting the varactor bias, the free-running frequency of each oscillator was varied over a range of 150 MHz.

Strong nearest neighbor coupling between elements in the array was accomplished through a resistively loaded transmission line. In [10], it was found that the phase of the coupling signal was determined by the length of these lines, while the coupling strength, ε', was inversely proportional to the coupling resistors used.

IV. Measurements

The effective radiated power (ERP) of the array was measured to be 8.5 W at 8.43 GHz. Figure 2 illustrates a typical broadside pattern which was obtained when the free running frequencies of the oscillators in the array were set to 8.45 GHz. The asymmetry of the side lobe levels of indicate a non-uniformity in the amplitude levels of the elements in the array. Figure 3 illustrates that it was possible to scan the array from −15° to +30° off broadside. This beam scan range indicates that progressive phase shifts between elements varying within the range of $-47° \leq \Delta\theta \leq +90°$ were synthesized. A maximum phase difference of 630° was established between the first and last elements in the array.

V. Conclusions

A beam scanning array using coupled VCOs was constructed. The scan range obtained from this array is substantially greater than previously published results [6] due to both a smaller element separation and the presence of VCOs. Nonuniformities in the hybrid construction of the array produced the higher side lobe levels observed and the asymmetry of the radiation pattern. A monolithic implementation of beam scanning arrays should result in more identical elements, as well as higher frequency operation.

VI. Acknowledgments

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VII. References

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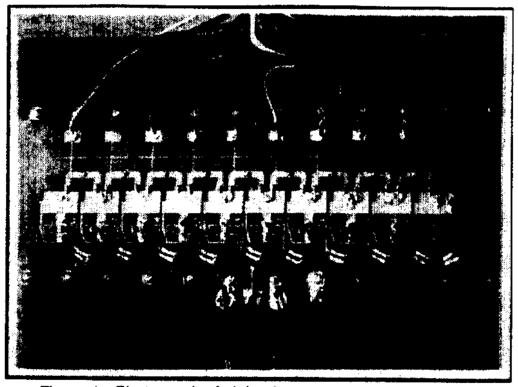

Figure 1 - Photograph of eight element beam scanning array.

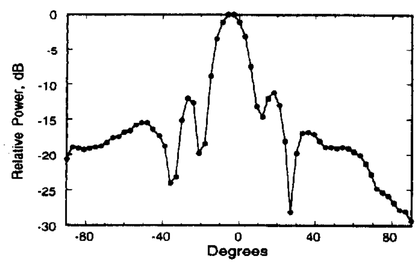

Figure 2 - Measured radiation pattern obtained with all eight elements operating at nearly the same frequency.

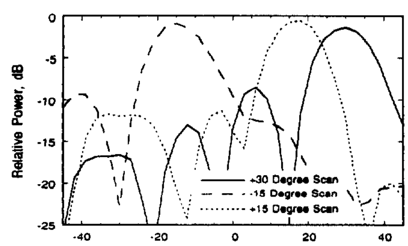

Figure 3 - Three scanned pattern measurements which indicate continuous scanning from -15° to +30° off broadside.