Enhanced Scanning Range of Coupled Oscillator Arrays Utilizing Frequency Multipliers

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Abstract - Scanning in arrays is conventionally achieved through phase shifters. Recent work has indicated that scanning can be achieved with significantly reduced complexity and cost using coupled-oscillator techniques. However, the scan range has been somewhat limited using this technique. This paper describes a simple method to greatly enhance the scan range using varactor frequency doublers, which has the added advantage of simplifying the fundamental mode oscillator design.

I. Introduction

In an effort to combine power in an efficient way the field of quasi optical power combining was born. [3]-[6] A large number of solid state oscillators can be integrated in such a way that their respective outputs coherently add in free space. The low loss properties of free space, especially at higher frequencies, along with the reliability of solid state devices make this approach particularly attractive.

Extensive work, theoretical [1,7,8] and experimental [1,2] on the coupling dynamics of these discrete oscillators has already been performed. A significant breakthrough of this research was the discovery of a simple way to induce beam scanning in such an array of coupled oscillators[2]. This can be achieved by frequency detuning the end elements of the array. Since conventional beam steering mandates the use of one phase shifter per array element, the simplicity of implementation of this new technique becomes obvious. There is no more need for a cumbersome control network to create a phase shift between successive elements. Nevertheless, the phase shift and therefore the scan angle is now limited by coupled oscillator dynamics. Some concern has been expressed over these limitations. In this paper we are proposing a slight modification on the coupled oscillator beam scanning array that will drastically enhance its scanning characteristics. A small increase in implementation complexity is expected, but is somewhat offset by other advantages. A frequency doubler is inserted between each oscillator and its respective antenna Fig. 1. The phase shift generated between each oscillator is doubled along with the oscillator's frequency. The radiating elements are phase shifted with respect to each other, twice as much as the oscillators feeding them are. Clearly the scan angle is increased. Furthermore, the oscillators need to be designed, at only half of the array operational frequency.

II. Theory

As was shown in [1,7] the theoretical phase shift $\Delta\phi$ that can be generated between successive coupled oscillators lies within $-90^{o} \leq \Delta\phi \leq 90^{o}$. In an array of element

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spacing d=$\lambda/2$ that would correspond to a maximum scan angle of $\theta_{scan}=\pm30^o$. This limit is predicted by antenna array pattern analysis :

$$\left.\begin{aligned} \Delta\phi &= \frac{2\pi d}{\lambda}\sin[\theta_{scan}] \\ d &= \lambda/2 \end{aligned}\right\} \Rightarrow \theta_{scan} = \sin^{-1}\left[\frac{\Delta\phi}{\pi}\right] \qquad (1)$$

The output of the nth oscillator in the array is proportional to $\cos(2\pi f+n\Delta\phi)$. If a frequency doubler is placed between the oscillator and the antenna, then the radiating element will be fed by a signal proportional to $\cos(4\pi f+2n\Delta\phi)$. So, the phase shift between consecutive antennas becomes $2\Delta\phi$. With d=$\lambda/2$ the maximum scan angle becomes $\theta_{scan}=\pm90^o$ as dictated by (1). Thus the full scan coverage can be achieved with this minor modification of the array.

III. Design

The array design frequency was chosen to be 8 GHz. Therefore the fundamental mode oscillators are designed for 4 GHz. The design of these oscillators is similar to that used in [2], and have a typical output power of 9dBm at 4GHz using low power NEC GaAs MESFET. The array is a hybrid, microstrip design, implemented on Duroid (substrate: h=30mils, ε_r=2.2). Rectangular patch antennas serve as the load for the doubler. For a doubler circuit we have explored both varactor frequency multipliers and FET multiplers. Both designs preserve the simplicity and compactness of design. In theory, a variable capacitance multiplier has close to 0dB conversion loss and excellent noise properties, which initially attracted us to the diode topology, however this has proved difficult to obtain, and the circuits have limited bandwidth. Our prototype arrays therefore use the FET multipler shown in figure 2.

The FET doubler uses the same low-noise MESFET (NEC 32184A) as used in the VCO design. An output $\lambda/4$ transformer stack provides a short circuit at the pump frequency and passes the even harmonics. A simple input matching network provides a good match to the 50Ω output impedance of the VCO. This doubler demonstrated 1 dB conversion gain, with a 3dB bandwidth of 1.5 GHz. Currently the combined doubler-oscillator array is begin tested, and the results will be presented at the conference.

IV. Conclusions

Beam scanning in antenna arrays without the use of phase shifters has been theoretically and experimentally [1] [2] verified. The limitations on scan angle imposed by coupled oscillator dynamics can be easily lifted. We are proposing the insertion of frequency doublers between the oscillators and the antennas. As a result the phase shift is doubled, thus giving us the full scan range. For design simplicity and low frequency conversion loss we advocate that a varactor doubler be used.

V. Acknowledgements

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VI. References

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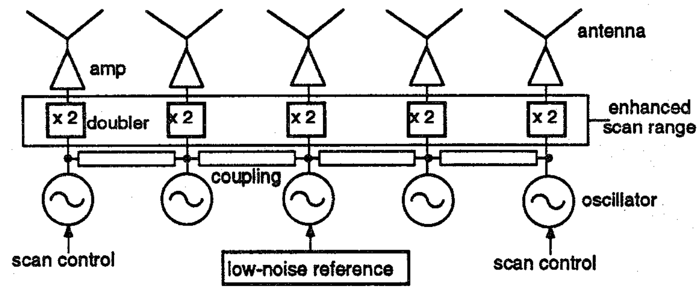

Figure 1 - Illustration of the improved coupled-oscillator scanning system using frequency doublers for larger scan range. The center element can be phase locked to a low-noise reference generator for improved performance.

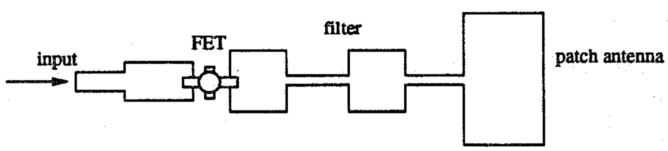

Figure 2 - Microstrip layout for the 4-to-8 GHz frequency doubler. The doubler input is matched to the VCO output, and feeds a patch antenna.