Coupled-Oscillator Scanning Technique for Receiver Applications

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Abstract-- **Scanning oscillator techniques previously developed for transmitter applications have been successfully applied to the receive mode. Scanning is achieved through frequency detuning in a coupled set of local oscillators. The design of a five element receiving array is presented here, demonstrating a 25° scan range. An injection-locking technique is described for low-phase noise applications.**

1. Introduction

Phase-shifterless beam scanning technique in quasi-optical oscillator arrays has been investigated recently by many groups [1] [2] [3] [4] [5]. In our work, the beam scanning is accomplished in a set of coupled oscillators by electronic control of the peripheral elements' natural frequencies [3]. Most of the work on the phase-shifterless beam scanning technique has concentrated on the transmitting mode, using active patch antenna arrays. However, the phase-shifterless beam scanning technique is also of great significance for receiver arrays, because in addition to the fabrication difficulties encountered with MMIC phase-shifters and the requirement of phase control signals at each array element, phase shifters are usually lossy components that can degrade the receiver sensitivity. In this paper we discuss how the scanning oscillator technique can be utilized in a receiving mode, by using the scanning array as the local oscillators for an array of mixers. In our prototype 5 element receiving array with $\lambda/2$ spacing, approximately 25° of beam scanning range has been obtained by detuning the end elements of the local oscillator array. It is possible to increase the scanning range by decreasing the antenna separation in the array, or possibly with frequency doubling techniques.

It is well known that the phase noise of the local oscillator in a receiver forms the limitation to the receiving sensitivity. In our receiving array, we used injection-locking technique to improve the phase noise performance of the local oscillator array. Our previous work [6] shows that a low phase noise signal of identical frequency injection does not interfere with the beam scanning mechanism of a coupled oscillator array.

2. Beam Scanning Technique in a Receiving Array

A far field signal coming in an incident angle α causes a phase difference $\Delta\theta$ between the neighbor elements of the antenna array, which is described by

$$\Delta\theta = \frac{2\pi d}{\lambda} Sin\alpha \qquad (1)$$

If we take the first element as a phase reference (zero phase shift), the received signal at the *i*th element of the antenna array can be written as

$$\upsilon_{si}(t) = V_s Cos[\omega_s t + (i-1)\Delta\theta] \quad (i=1,2,....N) \qquad (2)$$

where ω_s is the signal frequency. Similarly, the output of local oscillator array at the *i*th mixer has the form of

$$\upsilon_{li}(t) = V_l Cos(\omega_l t + \varphi_i) \qquad (i=1,2,...N) \qquad (3)$$

where we assume that the local oscillators have a common frequency, ω_l, but possibly different phase, φ_i. From the mixer theory, the intermediate frequency output after the *i*th IF filter will be

$$\upsilon_{Ii}(t) = g_i V_s Cos[\omega_I t + (i-1)\Delta\theta - \varphi_i] \qquad (4)$$

where $\omega_I = \omega_s - \omega_l$, and g_i is a V_l dependent frequency conversion coefficient. Suppose all the mixers have approximately the same parameters and all local oscillators have the same output power level, then, $g_1 = g_2 = ... = g_N = g$, and the output of IF summing circuit will be

$$\upsilon_{I\Sigma}(t) = gV_s \sum_{i=1}^{N} Cos[\omega_I t + (i-1)\Delta\theta - \varphi_i] \qquad (5)$$

If we can find a way to make $\varphi_i = (i-1)\Delta\theta$ (progressive phase shift in the local oscillator array) then Equation (5) becomes,

$$\upsilon_{I\Sigma}(t) = NgV_s Cos\omega_I t \qquad (6)$$

which is the maximum possible received signal for an array of N-elements. This shows that the receive array is effectively "steered" in the direction of the incoming beam by providing a constant phase difference $\Delta\theta$ between the local oscillators in the array. Refs [2] [3] show that in a coupled oscillator array a constant phase progression can be achieved by using the free-running frequency distribution

$$\omega_i = \begin{cases} \omega_l + \Delta\omega_m Sin(\Phi + \Delta\theta) & if\ i = 1 \\ \omega_l + 2\Delta\omega_m Sin\Phi Cos\Delta\theta & if\ 1 < i < N \\ \omega_l + \Delta\omega_m Sin(\Phi - \Delta\theta) & if\ i = N \end{cases} \qquad (7)$$

where Φ is the phase delay in the coupling network. By properly designing the coupling network, we can let $\Phi = 0$. In this case, Equation (7) indicates that all of the central oscillators be configured for a free-running frequency of ω_l, while the outermost oscillator are detuned according to

$$\begin{cases} \omega_1 = \omega + \Delta\omega_m Sin\Delta\varphi \\ \omega_N = \omega - \Delta\omega_m Sin\Delta\varphi \end{cases} \qquad (8)$$

Equation (8) indicates that a constant phase difference can be realized by slightly raising and lowering the end elements' free running frequencies of the local oscillator array.

3. Receiving Array Design

Fig. 1 illustrates the technique for a five element receiving array. The array consists of a local oscillator array, mixers, an antenna array and a IF summer. The local oscillator array is composed of five varactor tuned FET VCOs which are designed to work at 8.6 GHz. The VCOs are coupled together by a 1λ length microstrip transmission line and two 75Ω chip resistors at each end of the line. Each oscillator has approximate 1GHz tuning range and delivers its 10dBm output to a SMA connector in a 50Ω environment. A low phase noise signal is injected to the middle element of the array via a 75Ω chip resistor and a section of microwave transmission line. The purpose of low phase noise injection is to reduce the phase noise of the local oscillators [6]. The antenna array consists of five patch antennae spaced by $\lambda_0/2$. A two-section impedance transformer is used in each element to match the patch antenna with the mixer of 50Ω input impedance. Both the oscillator array and the antenna array are constructed on 0.7878mm thick ε_r=2.2 Rogers Duroid 5880 microwave substrate. Since the purpose of the work is to demonstrate the scanning technique and not the receiver sensitivity, we simply use a resister as an IF summer. The mixers used are commercially available product, model M77C by Watkins-Johnson Company.

4. Measurement

The receiving pattern measurement of the array was carried out in microwave anechoic chamber. The array was mounted on a rotating pedestal. A HP8530B Sweep Oscillator provided the incident signal through a standard gain horn in the far-field of the array. A HP8563 spectrum Analyzer was used as an IF receiver to process the signal coming from the IF summer. By tuning all the oscillator in the local oscillator array to the synchronizing frequency, synchronization was achieved and a broadside pattern was measured. Three beam-scanned patterns were measured when the free running frequencies of the end elements of the local oscillator array were detuned from the synchronizing frequency by +/-110MHz, +/-50MHz, and -/+50MHz. The receiving patterns measured are illustrated in Fig. 2. The results show that about 25 degree scan range was obtained, which is the same as the scan range when a much similar oscillator array and the same antenna array were used in transmitting mode [6].

5. Conclusions

A far field signal coming in an off broadside direction produces a phase difference between the elements of the antenna array of a receiver. This phase difference can be canceled in the mixer by the local oscillators output signals if they have the same phase difference so that the IF signals from all mixers are in phase and can be summed positively. A coupled oscillator array can provide this canceling phase to the signal to be received by detuning its end elements. This basic idea for phase-shifterless beam scanning in receiving mode has been proved by the measurement results of our receiving array.

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7. References

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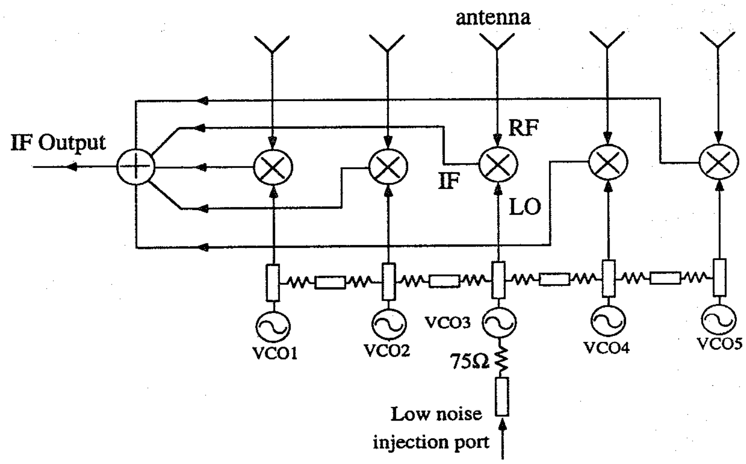

Fig. 1 Diagram of five element receiver array

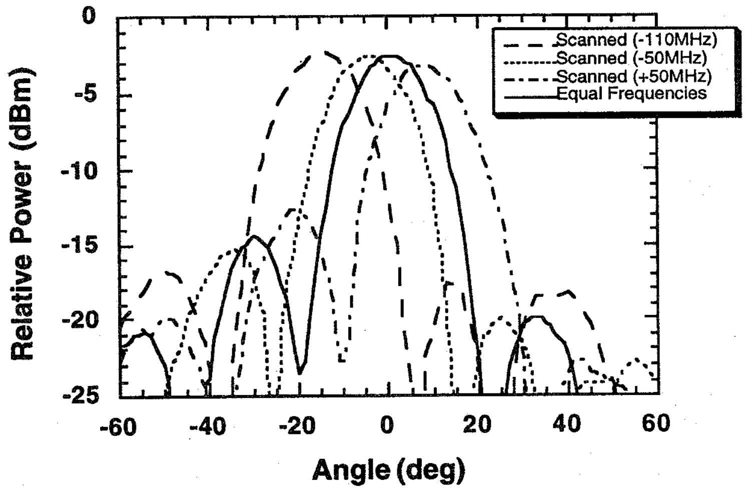

Fig.2 Beam scanning was realized by adjusting the End elements free running frequencies of the local oscillator array