AUTOMATIC BEAM STEERED ACTIVE ANTENNA RECEIVER

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ABSTRACT

This paper describes the design and behaviour of a novel compact self-phased integrated mixer active antenna receive array. The array performs automatic beam steering at low IF frequencies by the use of a pilot carrier inserted in-channel with the information signal. The phasing considerations, advantages, properties and practical considerations of this type of array are outlined. An experimental array based on this technique has been constructed to verify the principles involved. Experimental results on self-mixing and self-phasing performance are included in order to illustrate the automatic beam steering capability of this type of array.

INTRODUCTION

Much research effort is directed towards sophisticated phased arrays employing advanced integrated technologies but in some applications there is a need for cheaper designs arising from innovative ideas. The present paper describes an alternative category of the phased array, which is called the self-phased (or self-steered) array. Here beam steering is performed at low IF frequencies automatically by the use of a pilot carrier placed close to the information signal. Since the pilot frequency is at nearly the same frequency as the signal frequency, it can be used as a remote local oscillator in a mixing process to automatically phase compensate for the differing path lengths between the source and each element of the array. This array has particular application in mobile satellite communications systems where a single beam is formed at the ground station which is automatically pointed in the direction of the incident pilot carrier (i.e. at the satellite). Such an array could remove the need for accurate alignment of highly directional antenna systems situated on the spacecraft. Other applications involve point-to-point mobile communication systems and wireless LANs. Such a self-phased array is attractive because it offers many distinct advantages. First, it performs self-phasing at each element of the array without using any control electronics. Second, it operates without the use of phase shifters, adaptive control (feedback loops) and potentially allows for more compact and economical implementation of beam-scanning systems. Also, there is no need for extensive computations to steer the beam.

PHASING CONSIDERATIONS

The self-phased integrated mixer receiving array configuration, shown in Fig.1, uses a form of phase compensation to achieve beam steering. However, unlike conventional phased arrays which use phase shifters, here phase compensation is achieved by an integrated mixer

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using an in-band pilot carrier-as a phase reference. The pilot carrier is used as a remote local oscillator to down-convert the incoming signal [1].

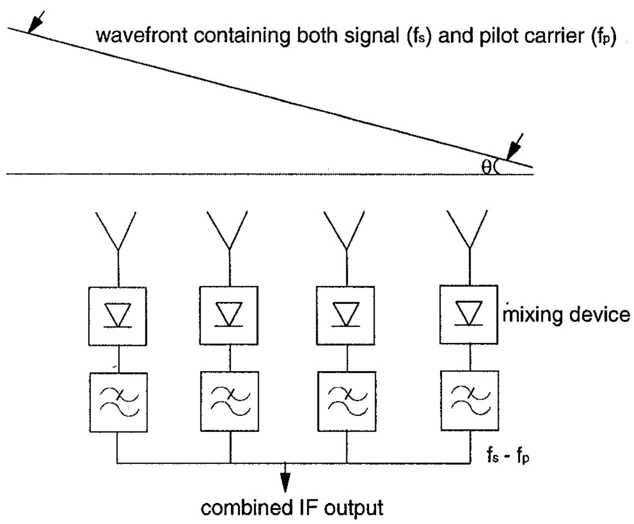

Fig.1 Schematic of the self-phased integrated mixer receiving array configuration

The pilot carrier must be close to the signal frequency for the array to work effectively, consequently the array output is at very much lower IF frequency than the incoming signal. For an array of finite length L, the output signal phases at each array element will differ slightly due to pilot and signal frequencies being non-equal. At extreme ends of the array, the instantaneous phases of the output signals can be expressed as

$$(\omega_s - \omega_p)t \text{ and } (\omega_s - \omega_p)t + \psi_p - \psi_s$$

where ψ_p and ψ_s are the phase shifts of the pilot and signal wavefronts due to the difference in the path lengths between the elements of the antenna array. However, since the pilot and signal frequencies are close to each other, their phases closely match each other through space. Thus, providing the array is not too large, the phase error term $\psi_p - \psi_s$ is very small. Consequently, the outputs of each element are very nearly in phase and can be combined constructively for a maximum response.

THE EXPERIMENTAL SELF-STEERED ACTIVE ARRAY

Integrated Mixer Active Antenna Element and Array

The array element, as shown in Fig.2, consisting of a microstrip patch radiator with integrated mixer has been previously described [2]. Here an integrally matched beam-lead Schottky-Barrier diode [3] is used as the mixing element.

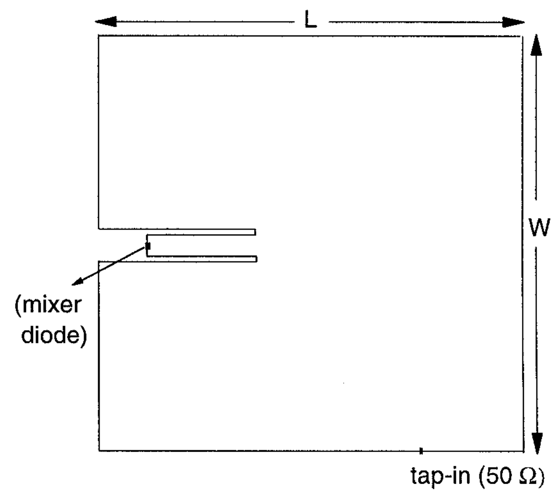

Fig.2 Schematic of the integrated mixer active antenna element

To verify the theory, an array was constructed; the signal (f_s) and pilot (f_p) frequencies were 5.2 GHz and 5.18 GHz, selected to represent a HIPERLAN application [4]. The spacing between the integrated mixer antenna elements was made one half wavelength for maximum boresight reception at normal array signal incidence.

Measurement of Phase Error

The phasing error can be measured with the experimental arrangement of Fig.3. Here, two elements of the receiving array are illuminated by a signal and a pilot carrier from a pair of signal generators situated in the far-field. The incoming signal at 5.2 GHz is down-converted to 20 MHz by a pilot frequency of 5.18 GHz.

Fig.4 shows the phase difference between the two IF outputs measured using HP 70820A Microwave Transition Analyzer, set in vector voltmeter mode.

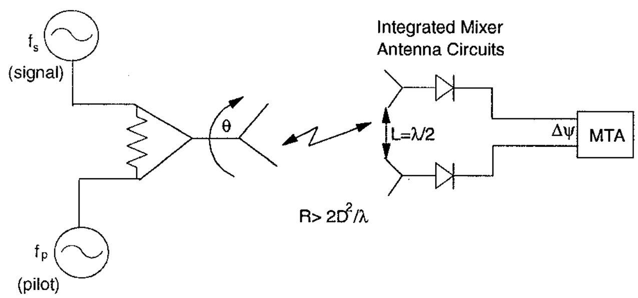

Fig.3 Schematic of the experimental set up for measurement of phase error

Such a measurement has been performed over the IF signal frequency range, 5 MHz to 50 MHz with respect to the pilot frequency, for an incident level at the array of -5 dBm on a two-element array. The signals are distributed to the two integrated mixer elements through equal path lengths. As seen from the plot of Fig.4, the two channels are matched to within 8° at 50 MHz IF frequency for $0.5\lambda_o$ element separation.

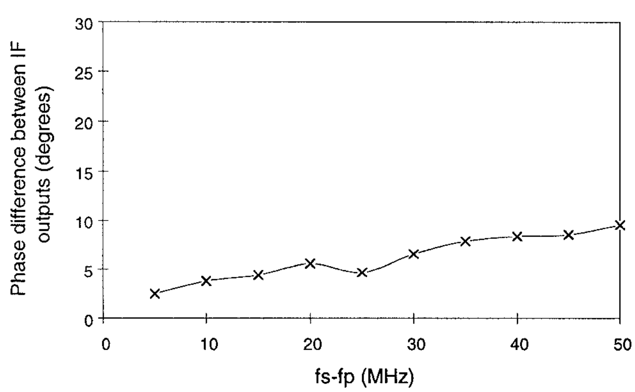

Fig.4 Phase difference between the two IF (f_s-f_p) outputs as measured using MTA

According to the principle of operation of the self-phased array, antenna elements are able to make a constructive contribution to overall array gain provided the separation between the extreme elements is small compared to a wavelength corresponding to signal-pilot difference frequency. The difference, or error in array phasing resulting from two elements spaced by a distance L projected in the direction of pilot carrier is given by

$$\Delta\psi = \frac{2\pi L(f_s - f_p)}{c}.$$

In this case, the computed phasing error is approximately 1° for a 20 MHz IF signal, measured 5°.

The change in phase with azimuthal variation, θ, for various strengths of the pilot signal is shown in plot of Fig.5. Here the maximum pointing error is about 7° for 80° incidence.

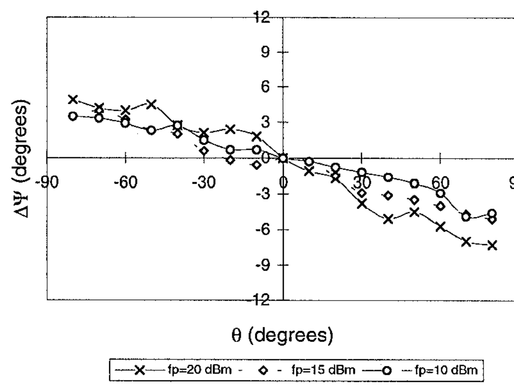

Fig.5 Measured change in phase with the angle of rotation for various strengths of the pilot signal

Radiation Patterns obtained with a Two-Element Array & Demonstration of Beam Steering

The purpose of this measurement is to confirm the ability of the self-phased array to steer a beam in the required direction utilizing, to maximum effect, the signals from a pair of elements. Each individual element has its maximum response in the broadside direction. Fig.6 shows the radiation patterns obtained with the two element array obtained as result of the self-phased combination of the element outputs. The off-frequency pilot tone causes the array to squint; measured and predicted squint values are 10° and 7° respectively. When pilot and signal are simultaneously applied, the zero squint condition is restored. This indicates that when the element outputs are combined using self-phased techniques, the signal phases are compensated by the pilot carrier so that the element outputs sum in correct phase for normal boresight operation. These results also show a satisfactory agreement with the expected theoretical performance. This indicates that the self-phasing is being successfully performed.

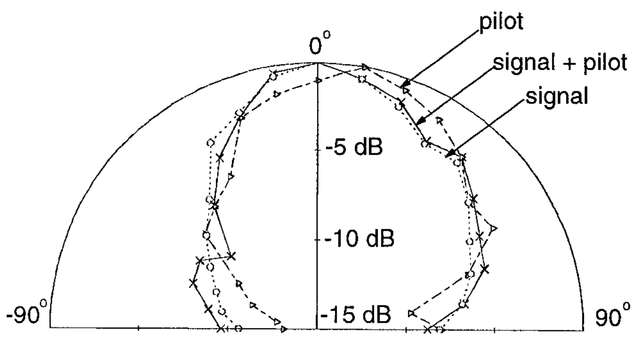

Fig.6 Measured radiation patterns obtained with the two element array obtained as result of the self-phased combination of the integrated mixer element outputs

To demonstrate the self-beam steering, the pilot carrier is switched off at various angles of rotation, and the values of change in phase is noted; the results are shown in Fig.7.

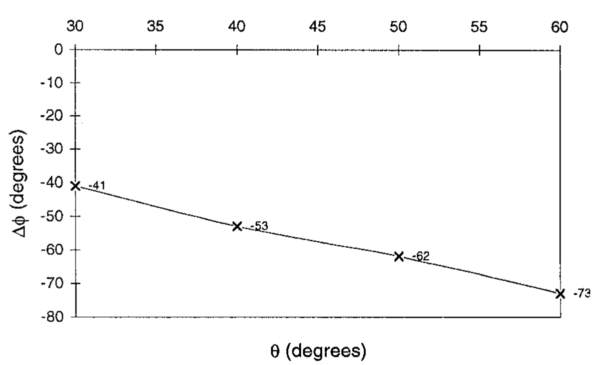

Fig.7 Demonstration of beam steering by the self-phased integrated active antenna receive array

CONCLUSIONS

A self-phased integrated mixer active antenna receive array is described for automatic beam steering at low IF frequencies by the use of an in-band pilot carrier in addition to the signal. An experimental array based on this technique has been constructed to verify the principles involved. Experimental results on self-mixing and self-phased performances illustrate the automatic beam steering capability of this type of array. This approach has many advantages over the existing techniques. The benefits immediately recognizable are the elimination of phase shifters, adaptive control (feedback) loop, and so on. An investigation of the effects of multiple pilot tones on self-tracking behaviour is underway.

ACKNOWLEDGMENT

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