A QUASI-OPTICAL RECEIVER WITH ANGLE DIVERSITY

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Abstract— **A quasi-optical receiver front end consisting of a 10-GHz lens amplifier antenna array and three self-oscillating grid mixers is presented. The lens amplifies incoming plane waves incident from different directions and focuses them to three points where the mixers are placed. Because of the angle-preserving nature of the amplifier, the mixers generate independent IF signals from three incident directions. The resulting angle diversity is useful for reducing multipath fading in communications.**

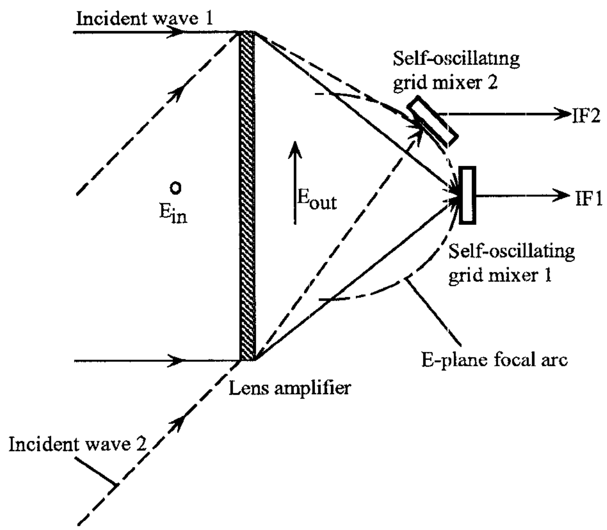

Fig. 1. A quasi-optical receiver consisting of a lens amplifier and self-oscillating grid mixers. Waves incident from different directions are received independently by mixers positioned along the focal arc, providing angle diversity. Only two of the three mixers are shown for clarity.

I. Introduction

QUASI-OPTICAL techniques have recently been proposed for realizing wireless communication components [1]-[3]. A variety of stand-alone quasi-optical components have already been demonstrated, and recent efforts have focused on integrating them into transmitters and receivers. The motivation for the work presented here is to demonstrate a quasi-optical receiver front end. This receiver consists of a lens amplifier antenna array [4] and three self-oscillating grid mixers, as shown in Fig. 1. The lens array amplifies incoming plane waves at the carrier frequency and focuses them to points along an arc where mixers are placed. The mixers are self-oscillating quasi-optical grids, so a separate local oscillator is unnecessary. The three mixers receive signals independently from three directions, resulting in a simple angle diversity scheme. This is useful for eliminating multipath fading nulls in wireless communications, since the probability of a fade from three different incident angles is low [5].

II. Receiving Lens Amplifier

The 24-PHEMT patch-antenna lens amplifier presented in [4],[6] demonstrated absolute power gain as well as beam-steering, beam-forming, and beam-switching capabilities. This amplifier was designed as a transmitting amplifier with feed points situated along a focal surface in the near field of the array, as shown in Fig. 2(a). The reciprocal nature of the passive lens allows the array to also function as a receiving amplifier, where an incident plane wave is amplified and focused to a point, as shown in Fig. 2(b). If a mixer is placed at this point, the amplifier can serve as the front end of a receiver. The measured power gain and isolation of this amplifier in both the transmit and receive modes are shown in Fig. 2(c) and confirms the reciprocity of the lens design. The maximum power gain is 5 dB and the isolation is more than 20 dB for both configurations at 9.7 GHz.

The amplifier in [4] was not designed for low noise and exhibits a noise figure of 3.4 dB at X-band. A similar amplifier array using two-stage amplifiers, where the first stage was designed for low noise, was presented in [7] with a 1.9 dB noise figure at X-band. However, the latter array was not used in this work because its operating frequency was incompatible with those of the mixers described in the next section.

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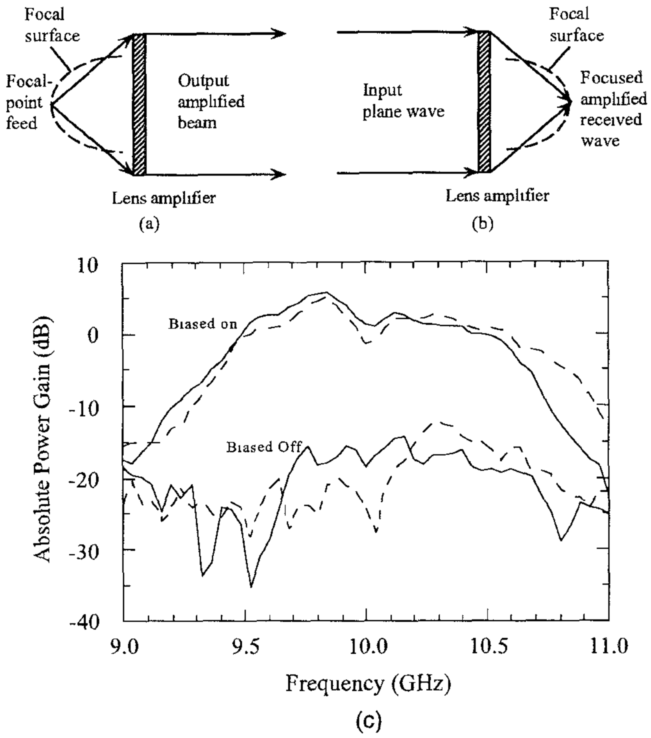

Fig. 2. The lens amplifier operating in (a) transmit mode and (b) receive mode. (c) Measured power gain and isolation of the quasi-optical lens amplifier used as a transmit lens (dashed lines) and receive lens (solid lines).

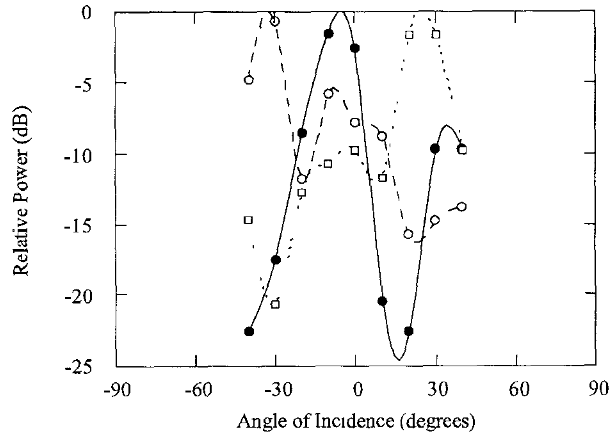

Fig. 3. Relative power measured at three amplifier focal points as the angle of incidence of a plane wave source is varied. The three focal points are located at −30° (dashed line), 0° (solid line) and +30° (dotted line) with respect to the optical axis of the lens amplifier. The maximum received power for the three receive horn locations occurs when the transmit and receive horns are co-linear.

In the angle diversity scheme presented here, the lens array amplifies and focuses incident plane waves to points along its focal arc. Plane waves incident from different directions are focused to different points along the focal arc due to the angle-preserving nature of the amplifier [8]. To demonstrate this, an X-band transmit horn is moved along an arc from $-40°$ to $+40°$ with respect to the optical axis of the lens. This provides plane waves with different incident angles to the lens amplifier. A receive horn is located at $-30°$, $0°$, and $+30°$ along the E-plane focal arc of the lens amplifier. Fig. 3 shows that the maximum received power for the three different receive-horn locations occurs when the transmit horn is located co-linearly with the receive horn. Plane waves with different angles of incidence are hence focused to independent points along the focal arc.

III. Self-Oscillating Grid Mixer

The quasi-optical grid mixer in [9] requires a separate local oscillator (LO) signal that must be radiated onto the grid. To simplify the system design, a self-oscillating mixer can be used instead, since the oscillating device generates its own LO and mixes it with the incident RF signal [10]. A quasi-optical self-oscillating mixer using two transistors was described in [11]. Here we present experimental results for a self-oscillating grid mixer using 25 PHEMTs.

Since the amplifier described above has maximum gain at X-band, an LO signal within the same frequency range is required. However, existing C-band grid oscillators [12] were used in this work. In this case, the grid functions as a subharmonic self-oscillating mixer where the second harmonic is used for the LO. A subharmonic mixer is attractive in situations where it may be more difficult to build an LO at the fundamental frequency, as in millimeter-wave receivers.

The 25-PHEMT grid oscillator has a free-running oscillation frequency of 5.36 GHz. A vertically polarized incident RF signal is received by the vertically oriented drain and gate leads of the grid oscillator and mixes with the LO. The IF signal is detected from the horizontally oriented DC bias lines. The horizontal lines contain very little of the RF and LO signals, so this provides a simple RF-IF and LO-IF isolation scheme. The grid does not provide RF-LO isolation, however, so the oscillator will function as a self-oscillating mixer only when the RF signal is outside of its injection-locking range.

Fig. 4 shows the performance of the grid as both a harmonic and subharmonic self-oscillating mixer. The relative IF power is plotted as a function of the difference between the RF and LO frequencies. Since the second harmonic of the grid is approximately 30 dB lower than the fundamental, the IF power is much lower for the subharmonic case. The shape of the curve is possi-

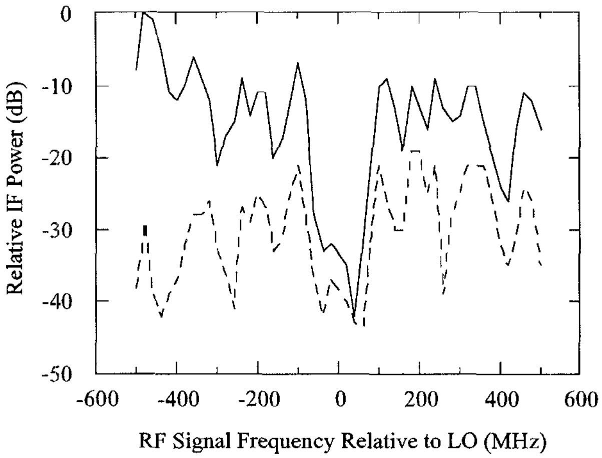

Fig. 4. The measured IF power as a function of the frequency difference between the RF incident wave and grid oscillator fundamental (solid line) and second harmonic (dashed line) LO signals.

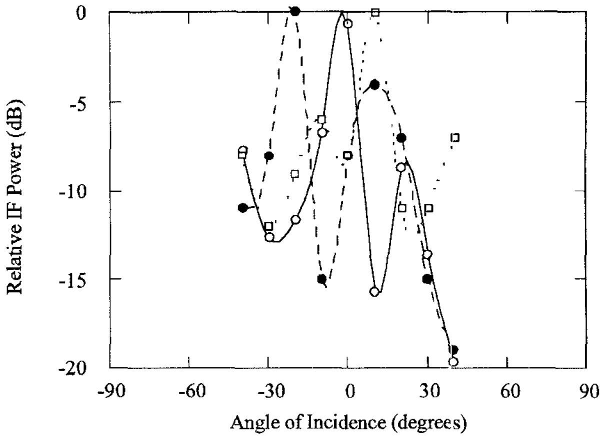

Fig. 5. The measured IF power from three mixers positioned at −30° (dashed line), 0° (solid line) and 30° (dotted line) along the focal arc of the amplifier, as the incident angle of the source is varied. The IF frequency is 600 MHz.

bly due to the nonlinearities in the circuit, and a complete understanding would require further analysis [13]. As expected, the IF power is negligible in the regime where the RF signal injection-locks the grid oscillator, which is about 200 MHz for the power levels used in this measurement. This self-oscillating grid mixer was not specifically designed for low conversion loss or low noise, but rather to simply demonstrate the use of grid oscillators as mixers.

IV. Quasi-Optical Receiver with Diversity

Multipath fading in wireless communication systems results from scattered, uncorrelated signals from different directions adding at the receiver. An angle diversity scheme combats this effect by using several directional antennas, each one responding independently to a wave propagating at a specific angle of incidence. Since the signals arriving at each angle are uncorrelated, the probability of a fade at each one is low [5].

The focusing and angle-preserving properties of the lens amplifier make it suitable for this kind of diversity scheme. As illustrated in Fig. 1, an RF signal generated by a source in the far field is amplified, rotated in polarization, and focused onto self-oscillating grid mixers. Waves incident from different directions are received by different mixers.

To demonstrate the idea, three self-oscillating grid mixers, each with free-running oscillation frequencies within 1% of each other, are placed at angles of −30°, 0°, and +30° along the E-plane focal arc of the amplifier. An RF source in the far field is moved along an arc of fixed radius in the H-plane of the amplifier, providing waves of varying angles of incidence. Fig. 5 shows the IF power from each mixer versus the incident angle of the source. The received IF signals from different directions are seen to be relatively independent. It is interesting to compare Fig. 3 and Fig. 5. The dependence of the IF power on incidence angle is very similar in shape to that of the lens amplifier at the carrier frequency.

V. Conclusion

An *X*-band quasi-optical receiver front end consisting of a 24-element lens amplifier and subharmonic self-oscillating grid mixers is presented. The focusing and angle-preserving properties of the lens amplifier allow waves incident from different directions to be received independently by the mixers. The resulting angle diversity is useful for reducing multipath fading in wireless communications.

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