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Integrated Active Antennas with Full Duplex Operation

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Abstract

This paper discusses two types of active integrated antenna. Firstly, results are presented for a novel two element active transmit-receive array using dual linear polarisation and sequential rotation. Each element includes an integrated oscillator and amplifier mounted on orthogonal edges of a square patch, such that transmit and receive paths are isolated and polarisation duplexed. The array gives in excess of 55dB transmit-receive isolation at 3.77GHz. Link budget calculations are used to show expected system performances. Secondly, an active circulator is integrated with a patch antenna to produce a same polarisation fully duplexed transceiver. The active circulator antenna is shown to have 14dBi transmit gain and 7.4dBi receive gain with a transmit-receive isolation of 26.9dB. These active antennas have potential uses in both short range communication and radar systems.

Introduction

An active antenna integrates an active device into a printed antenna to improve its performance or combine functions within the antenna itself. Such antennas are of increasing interest [1] as system designers require more complex functions to be implemented in reduced space. New, high volume millimetric applications such as vehicle collision avoidance radar, wireless LAN and electronic tagging are driving costs lower and putting further constraints on size and weight. This work aims to address these demands by taking further steps in the integration of active antennas by combining both transmit and receive functions into a single antenna.

Section I : Sequentially Rotated Active Antennas

This work uses a square microstrip patch antenna, resonant at 4.0GHz, with a MESFET mounted centrally on the edge of the patch to form an oscillator [2] and another MESFET, configured as an amplifier on the orthogonal edge to act as the first stage in a receiver. The inherent isolation of the centre points of orthogonal edges of a square patch is used as the basis for the transmit-receive isolation. This transceiver is linearly polarised with transmit and receive channels on orthogonal polarisations. The channels can be same frequency or offset depending on the application. A method to improve the isolation of the single patch is that of sequential rotation [3]. Here the receiver outputs are taken from opposite edges of the two patches and the phases of the direct feedthrough signals from transmit to receive are adjusted so that they are 180° out of phase which on combining will cancel. The received signals are forced to be 180° out of phase by the positions of the receiver outputs, thus when combined they will add in phase. This method can increase the isolation by 20 to 30dB.

Results

The basis for the transmit-receive isolation is the orthogonal positioning of the oscillator and amplifier. Measurements were carried out to assess the levels of isolation obtainable. Using a passive patch and wire bond connections isolations in excess of 40dB were obtained. Having established good isolation for a passive patch, the active components are added. A schematic of the array is shown in figure 1(a). All FETs are of type ATF-26884. The drain of the oscillator FET is connected to the centre of the patch and a short circuit transmission line is connected to the source. The gate is also connected to a short circuit transmission line. The source and gate terminations provide the negative resistance at the drain port required for oscillation conditions [4]. The amplifier FET is mounted in a 50Ω transmission line with d.c. blocks and choke coils for biasing. At this stage no matching circuits have been implemented.

To form the array two elements are spaced by approximately $3\lambda_0/4$. The size of each substrate was 90mm square. The outputs from the two amplifiers were connected to a power combiner through lines with 180° phase difference. A variable phase shifter was used to offset the small phase differences in the amplifiers. The oscillators lock together by mutual coupling and power combining occurs in the far field. Frequency tuning is performed by adjusting the oscillator drain and gate bias voltages and the tuning bandwidth was found to be 47MHz, centred on 3.77GHz. Cancellation of the transmit signals breaking through into the receiver was achieved by control of both the phase shifter and the amplifier gains. We found that small differences in the wire bond positions and oscillator output powers produced differences in the two signals of as much as 5dB and this was offset by reducing the gain of one of the amplifiers. Because of this the receive performance was not optimised. Despite the problems isolation better than 50dB was achieved from the array as figure 1(b) shows.

The output power of the oscillator was calculated from the effective isotropic radiated power (EIRP) and measurements of the gain of an identical passive array. Figure 1(b) shows the oscillator output power together with the isolation signal after cancellation. A maximum array output power of +17.7dBm (58.9mW) was obtained at 3.787GHz with a d.c. to r.f. efficiency of 21.4%. The isolation signal has a minimum at 3.77GHz of -45.5dBm, this is equivalent to 55.7dB isolation. The isolation is better than 30dB across the whole band and this could be improved by using broadband, constant phase shift networks, such as Schiffman phase shifters.

Link budget calculations were performed to estimate the levels of isolation required for a typical communications link. For a signal to noise ratio of 10dB at a range of 1Km, an 8 x 8 array of elements with 63dB isolation is required. These systems are envisaged for the millimetric bands were such arrays would be very small and light weight.

Section II : Active Circulator with integrated antenna

Active circulators have been of interest for many years with their inherent advantages of size and weight over conventional ferrite devices [5, 6]. They are also highly compatible with monolithic technology and are being used as part of complete microwave transmit-recieve front-ends [7]. This work presents a novel, hybrid, active circulator based on a phase cancellation technique integrated with a microstrip antenna forming a fully duplexed transciever module. Arrays of these elements could over come the power handling problems that limit the performance of current active circulators. A circulator is in general a three port device in which signals pass from one port to another in one direction only. They are often used to separate transmit and receive paths in communication systems or radars. In this work three gain blocks (HP MGA-86576) are connected in a ring such that signals can pass from the transmitter to the antenna, from the antenna to the receiver, and from the transmitter to the receiver. Thus there are two signal paths from the transmitter to the receiver, one via the antenna and a direct path. The phase lengths of these paths can then be adjusted so that phase cancellation occurs at the receiver. Ayasli [6] uses non-reciprocal phase shifters to obtain a similar cancellation effect, however, insertion loss is present in all the signal paths, whereas here measurements of a non-integrated circulator have shown receive gains of 4.0dB.

Figure 2 shows a schematic of the transceiver circuit. Sections of low and high impedance transmission lines are used to obtain simultaneous matching and isolation. A short circuit, inset matched microstrip antenna is placed in the centre of the ring, this optimizes circuit area and would allow arrays of these elements to be formed. The antenna measures 20mm x 12mm and the whole circuit occupies less than 50mm x 40mm. The circuit is fully planar, with only dc bias coils placed on the underside of the board. Figure 3 shows measured S-parameters, transmit and receive gains. The isolation is seen to be quite narrow band, as expected for a cancellation technique, giving better than 20dB over a 7MHz band, with a maximum of 26.9dB. The gains are seen to have larger bandwidths, as have the return losses. The gain of the short circuit antenna has been measured separately as approximately 3dB, thus the circulator is adding approximately 4dB gain on receive and 10dB on transmit. It is felt that with further optimisation of the matching circuits broader band isolation could be obtained. The antenna patterns have been measured and are shown in figure 4. The patterns are seen to be reasonable considering the proximity of the patch to the surrounding circuitry. The cross-polar level was typically better than -10dB at boresight, being degraded at wider angles due to the radiation from the microstrip lines and components, but also by the inherent poor cross-polar of a short circuit patch.

Conclusion

A novel simultaneous transmit-receive active array has been described using dual linear polarisation and sequential rotation to achieve very high values of transmit-recieve isolation. The sequential rotation technique, while leading to increased isolation, has been found to require very repeatable active patches and this can be difficult to achieve in practice. A best case transmit-receive isolation of 55dB has been obtained with an array output power of 10dBm. An active circulator antenna has been presented which gives 26.9dB of transmit-receive isolation with transmit and receive gains of 14dBi and 7.4dBi respectively at 3.745GHz and is implemented in less than 50mm x 40mm of substrate area. These results show the possibility of using larger arrays of this type in the millimetric bands for short range communication or radar systems. At these frequencies the advantages of quasi-optical power combining and no feeder losses on transmit for the sequentially rotated active antenna make this a viable alternative to conventional single transmitter systems. Furthermore the use of millimetrewave monolithic integrated circuits would enable both the techniques presented in this paper to be implemented with high repeatability, at very low cost and in large volumes.

References

[1] T. Itoh, "Quasi-Optical Microwave Circuits for Wireless Applications" *Microwave Journal* Vol. 38, No. 1, pp64-85, Jan. 1995

[2] V. F. Fusco, "Series Feedback Integrated Active Microstrip Antenna Synthesis and Characterisation", *Electronics Letters* Vol. 28, No. 1. pp89-90, Jan. 1992.

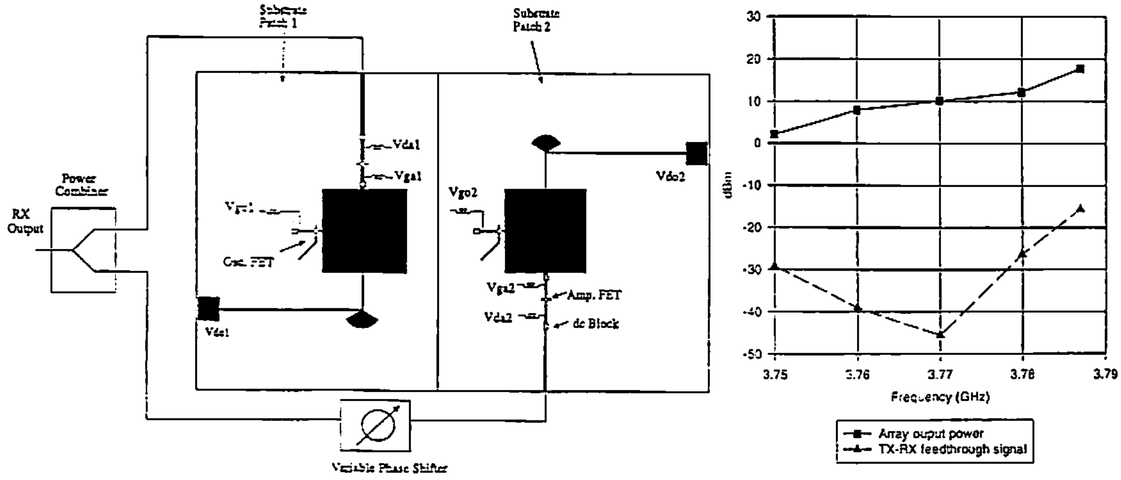
[3] P. S. Hall, "Dual Circularly Polarised Sequentially Rotated Microstrip Array with High Isolation" *Microwave and Optical Technology Letters* Vol. 5, No. 5, May 1992, pp. 236-239.

[4] K. Kurokawa, "Injection Locking of Microwave Solid-State Oscillators", *Proc. IEEE*, Vol. 61, No. 10, Oct. 1973, pp. 1386-1410.

[5] S. Tanaka, N. Shimomura and K. Ohtake, "Active Circulators-The Realization of Circulators using Transistors", *Proc. IEEE*, Vol. 53, No. 3, March 1965, pp. 260-267.

[6] Y. Ayasli, "Field Effect Transistor Circulators", *IEEE Trans. on Magnetics*, Vol. 25, No.5, September 1989, pp. 3242-3247.

[7] P. Katzin, Y. Ayasli, L. Reynolds, Jr. and B. Bedard, "6 to 18 GHz MMIC Circulators", *Microwave Journal*, May 1992, pp. 248-256.



(a)

(b)

Figure 1: (a) Sequentially rotated two element active array
(b) Array output power and transmit-receive feedthrough signal

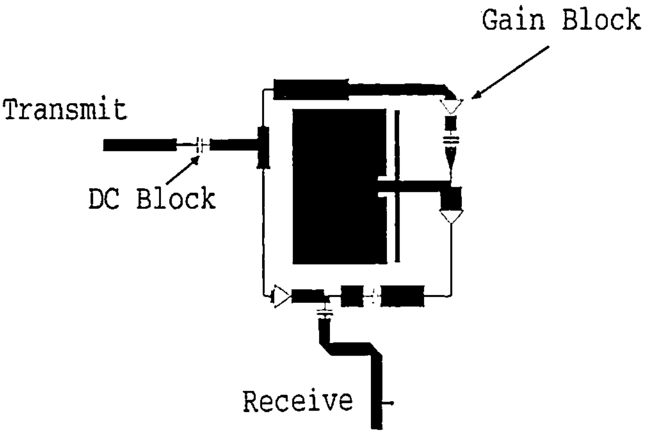


Figure 2 : Schematic layout of active circulator antenna

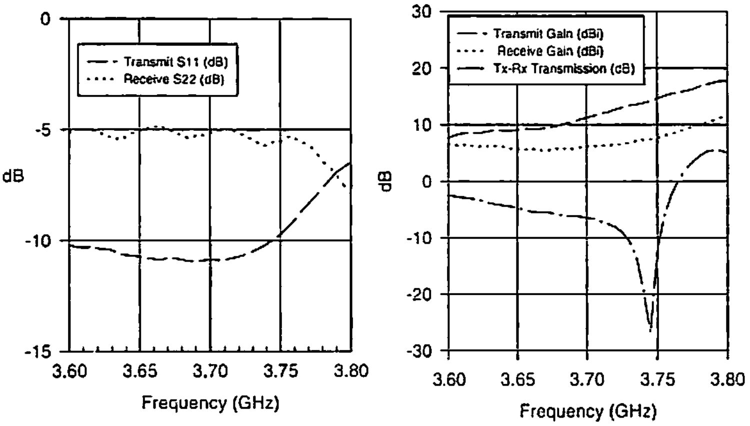
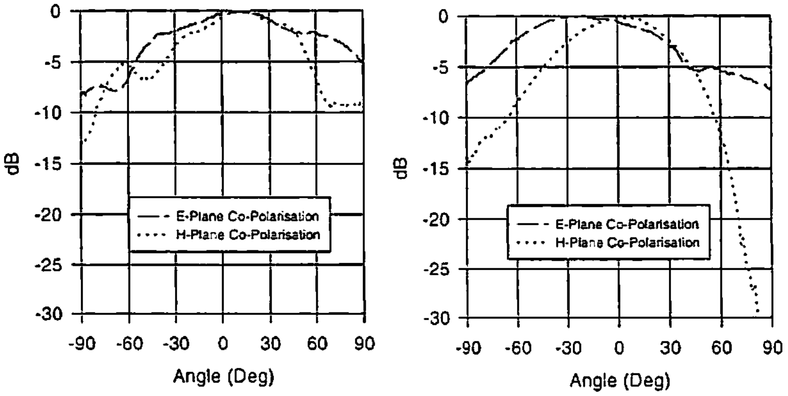


Figure 3 : Measured S-parameters, transmit and receive gains for an active circulator antenna



(a) Transmit

(b) Receive

Figure 4 : Measured transmit and receive radiation patterns for an active circulator antenna