Active Microwave Antennas – Current Status and Future Prospects

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1. Introduction

An active antenna is defined for the purposes of this paper as a module in which a radiating element and an active device or circuit are closely integrated, such that the overall performance of the module cannot be described simply in terms of individual performance parameters of a separate antenna and a separate circuit.

Potential benefits of this level of integration include:

- Reduced overall fabrication costs.
- Improved performance compared to cascaded individual modules, for example by eliminating interface losses, parasitics and manufacturing variables.
- Reduced size, for example by eliminating redundant matching networks or using features of the antenna to provide functions which would otherwise require a circuit element.
- Integration onto semiconductors (systems on a chip) – leaving only bias and data connections, eliminating RF bondwires.

The disadvantages and difficulties with active antennas include:

- CAD issues. Full EM simulation is required for the entire module, because of antenna-circuit interactions. This is time consuming and demanding.
- EMC issues – eg LO reradiation.
- Selectivity – it is hard to form high Q structures for high rejection filters in the same medium as the antenna and the circuit.
- Measurement and diagnostics issues.

The following sections give some examples of the work in this area at Birmingham University.

2. Compact Low Noise Receiving Antenna

An example of how circuit functions can be realized within an antenna structure is provided by a quarter wavelength, inset fed patch antenna directly integrated with a low noise transistor [1].

The generic form of the structure (omitting d.c bias and d.c. blocks) is illustrated in Fig. 1. Complex impedance matching for low noise performance is provided by adjusting the inset feed point and the distance from the feed point to the gate connection. Meanwhile, the distance from the shorted edge to the source lead connection point also provides series inductive feedback. The published example [1] gave an embedded noise figure of 0.5 dB and 24 dB gain at around 1.33 GHz.

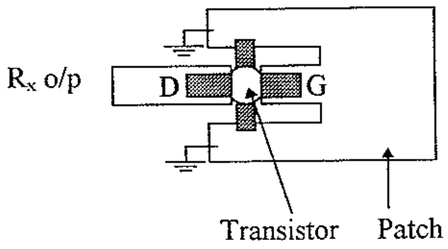

Fig. 1 Generic view of a low noise active patch antenna

3. Integration of a printed antenna and an active circulator

An active circulator, based on commercial 50Ω gain blocks, and a patch antenna were integrated together by mounting the antenna inside the closed loop of the circulator, as shown in Fig. 2. The design procedure has been described in [2].

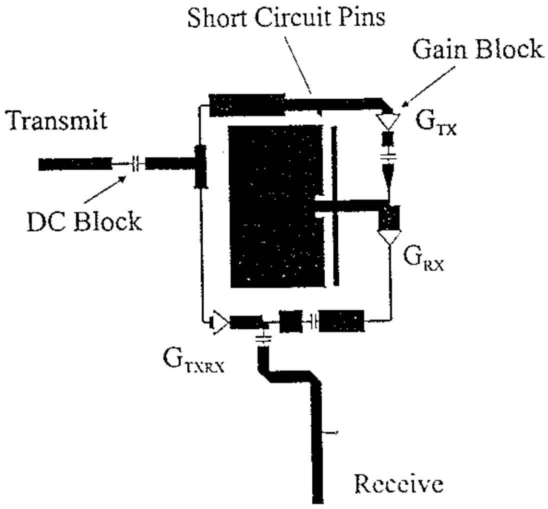

Figure 2 Active Antenna Circulator

The antenna measures 20mm x 12mm. Figures 3 and 4 show the measured S-parameters for the integrated active circulator antennas. In the transmit-receive isolation of the integrated structure (figure 4), a double hump appears because of the interaction of the active circulator with the antenna. FDTD analysis [2] is a valuable tool to study such effects. The measured isolation is better than 20dB over a 7MHz band, with a maximum of 26.9dB at 3.745GHz where the antenna operates. The measured active antenna gains are seen to have larger bandwidths (figure 4), as have the return losses (figure 3). The gain of the short circuit antenna has been measured separately as approximately 3dBi. Thus the circulator is adding approximately 4dB gain on receive and 10dB on transmit. The antenna pattern is shown in Figure 5.

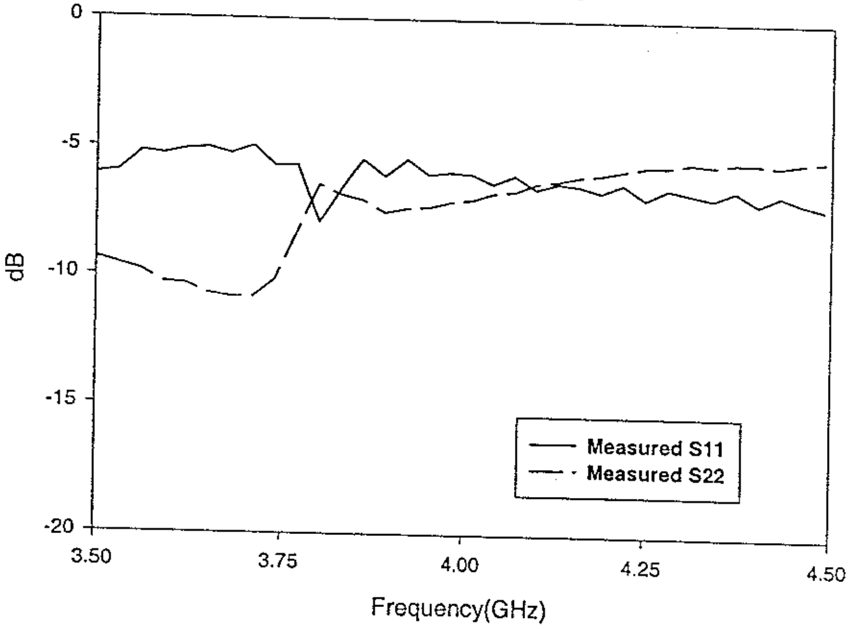

Figure 3 Input and Output S-parameters for the active circulator antenna

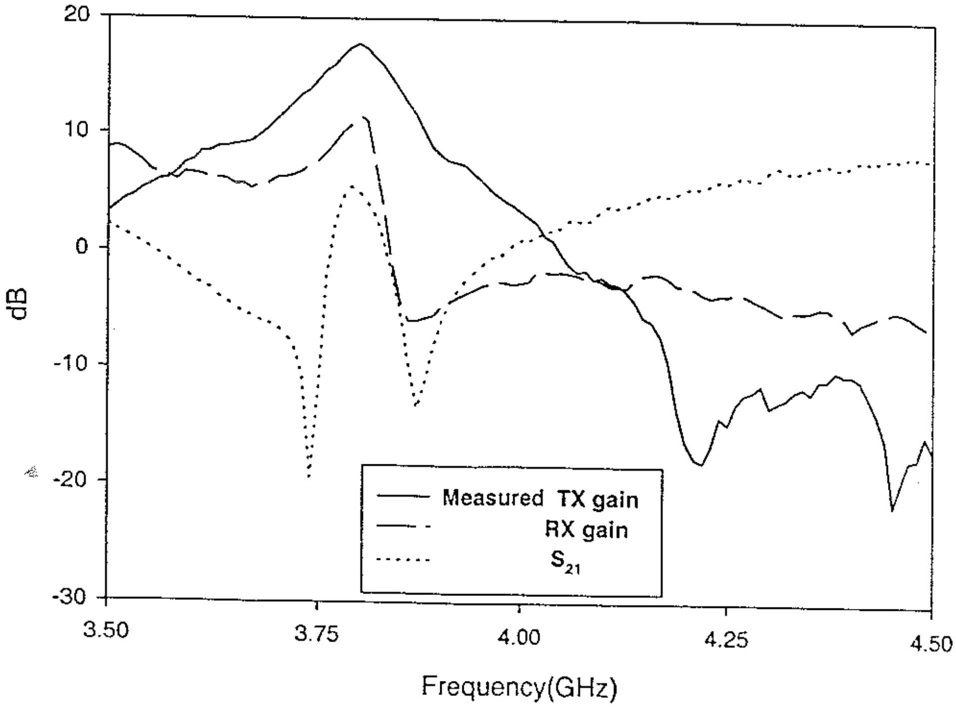

Figure 4 Transmit and Receive S-Parameters for the Active Circulator Antenna

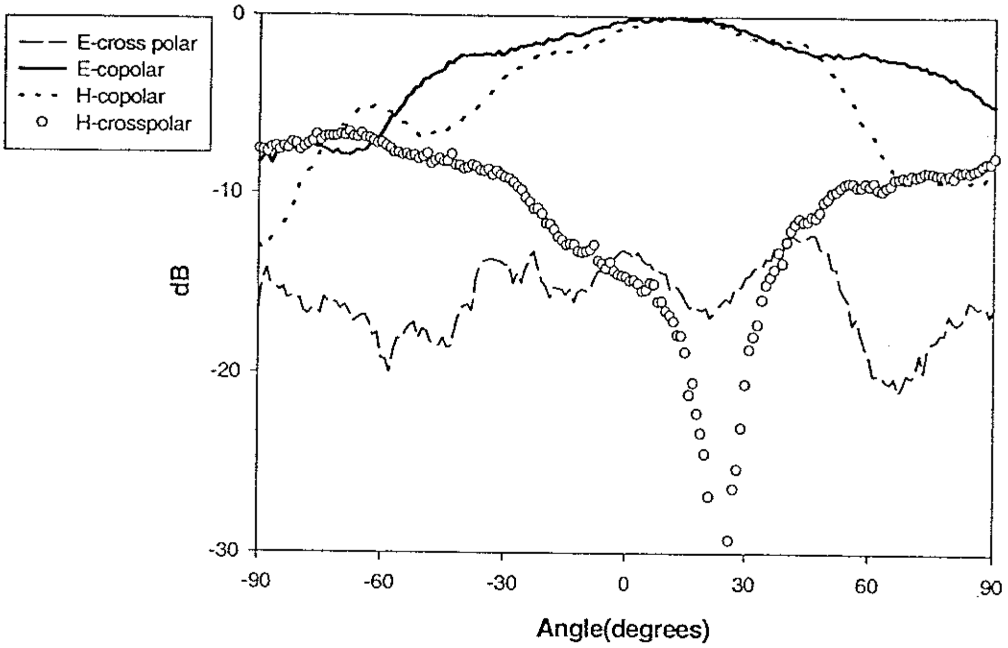

Figure 5 **Transmit Radiation Patterns for the Active Circulator Antenna**

4. An Integrated Phase-Locked Oscillator Active Antenna

An example of the way circuit functions can be achieved within the antenna geometry is provided by the active antenna PLO illustrated in Fig. 6, where a sampled output from a self oscillating patch antenna is taken from the edge opposite the active device to be fed back in to the PLL [3]. The phase noise improvements resulting from locking are illustrated in Fig. 6.

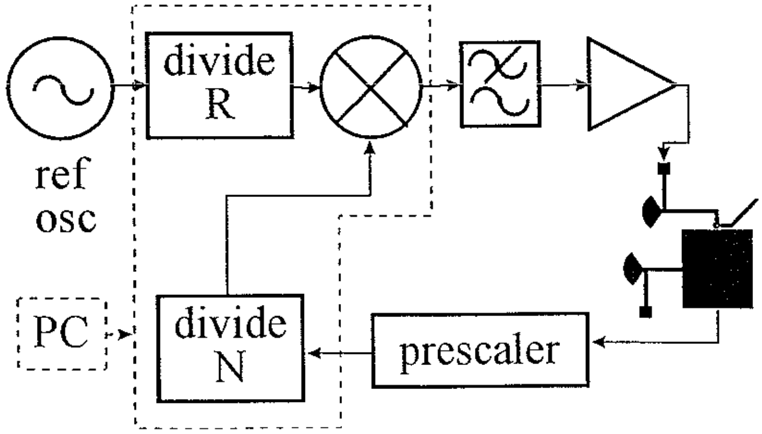

Figure 6. **Active Antenna PLO**

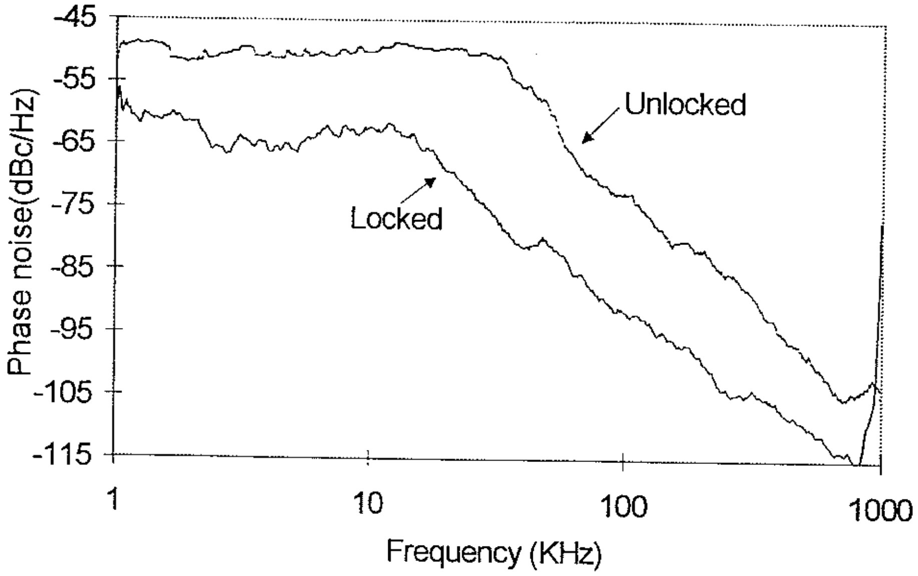

Figure 7 Phase Noise of Locked and Unlocked Self Oscillating Patch Antenna

5. A 35 GHz Self Oscillating MMIC Patch Antenna

The feasibility of integrating a mm-wave patch antenna onto a commercial HEMT MMIC has been demonstrated by producing a 35 GHz self oscillating antenna chip using the GMMT H40 Process. The frequency can be tuned over a range of 1.9 GHz, with a maximum EIRP of over 15dBm. The chip layout, tuning response and normalized radiation pattern are shown in Figures 8 to 10.

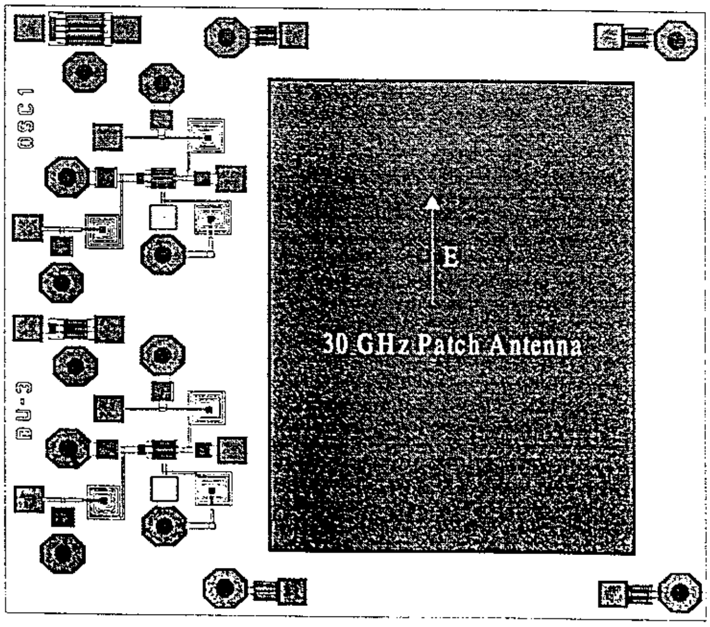

Figure 8 Self Oscillating 35 GHz MMIC Chip Layout

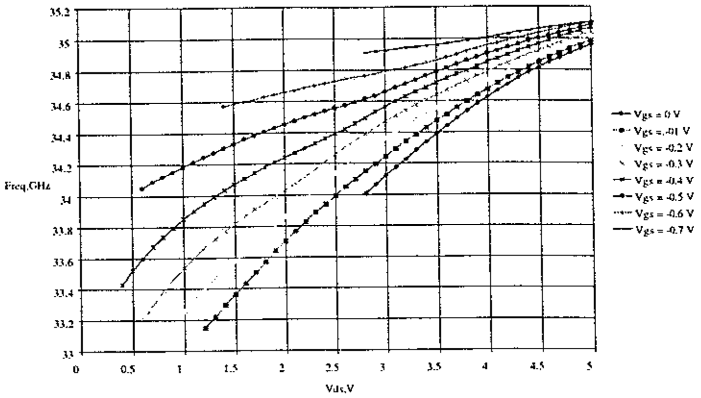

Figure 9 Tuning Response of the MMIC Oscillator Chip.

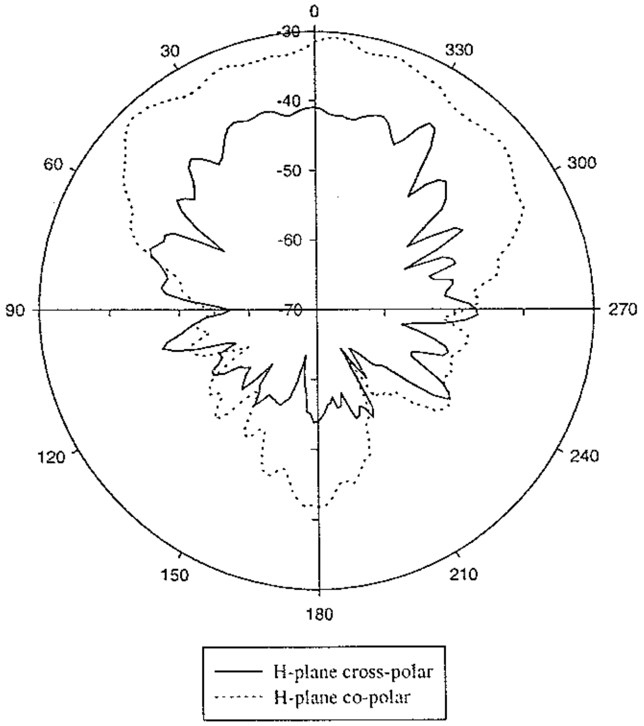

Figure 10 Normalised Radiation Pattern of the 35 GHz Oscillator Chip

6. Frequency Doubling Active Transponders

Another example of the way in which circuit functions can be merged with the antenna comes from the frequency doubling active transponder [4]. Here, two outputs from points equidistant from the center line of a half wavelength patch antenna are used to generate received signals which are π radians out of phase. When fed into a non-linear circuit, these signals generate harmonics. The odd harmonics are out of phase, but the even harmonics are in phase. Thus a frequency doubling effect can be achieved. A 10/20 GHz version based on hybrid circuits has been reported [4]. A 30/60 GHz MMIC version has also been designed, as illustrated in Fig. 11.

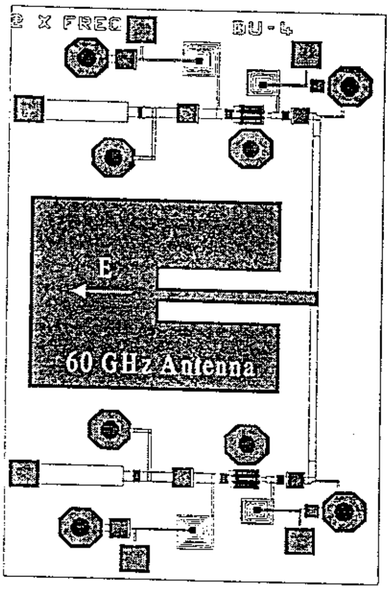

Fig. 11 30/60 GHz frequency doubling transponder MMICs.

7. Reduced Size MMIC Antennas for the Low Microwave Frequency Range

A problem which arises with incorporating conventional patch antennas onto semiconductors is that the sizes involved make this approach uneconomical for low microwave frequencies. An approach to solving this problem is to produce reduced size, semi-lumped resonant structures on MMICs. This inevitably involves a compromise in the antenna gain, but the approach may still be viable for short range communications.

A MMIC antenna resonant at 5.8 GHz is illustrated in Fig. 12. The overall size is 4.05 x 2.1 mm. The layout illustrates how the space created by making the central section inductive, to reduce the length, can be used to accommodate active devices, in this case GaAs FETS for Tx/Rx switching. Further details of the antenna design and test results have been given in [5]. The antenna gain at resonance is only -9.4 dBi, because of the size reduction. This can be improved by using the chip as a feeding structure for a larger externally mounted parasitic antenna.

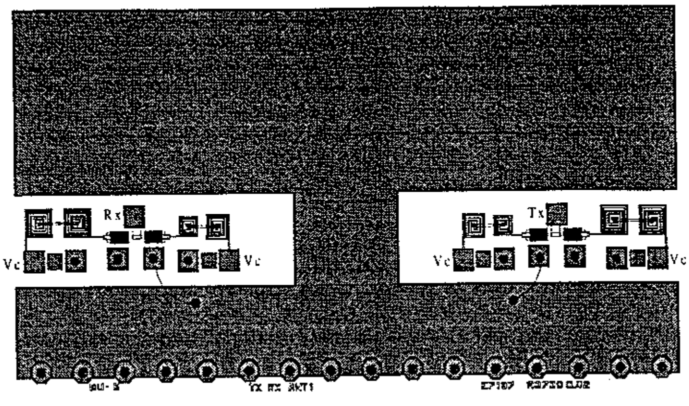

Fig. 12 5.8 GHz MMIC H-antenna

8. Conclusions

Active microwave antennas offer some significant advantages for future highly integrated communications systems. Significant research challenges remain before these benefits can be realized in practical systems. These include:

- Transfer of the MMIC ideas discussed onto silicon, to allow integration with important technologies, such as BiCMOS, SiGe BiCMOS, which are likely candidates for future highly integrated systems.
- Frequency selectivity/duplexing. Isolation of transmit and receive functions on a single chip requires high degrees of selectivity and therefore high Q structures, which are not realizable in current commercial processes.
- Analysis techniques. FDTD provides a useful tool for studying antenna circuit interactions, but dramatic increases in speed of computation will be needed to make this a viable technique for complex integrated structures.

References

1. T.D.Ormiston, P. Gardner and P.S.Hall, "Compact low noise receiving antenna," IEE Electronics Letts., Vol. 34, pp. 1367-1368, July 1998.
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5. D. Singh, P. Gardner and P.S.Hall, "Miniaturised Patch Antenna for MMIC applications," IEE Electronics Letts, Vol. 33, pp. 1830-1831, October 1997.