

# Enhanced Performance Micromachined Patch Element for Active Monolithic Phased Array Antennas

Arun V. Sathanur, Rakesh S. Kshetrimayum and K. J. Vinoy  
Microwave Lab, Dept of Electrical Communication Engineering,  
Indian Institute of Science, Bangalore – 12  
Tel.: (80) 2293 2853, Fax: (80) 2360 0563,  
Email: kjvinoy@ece.iisc.ernet.in

## Abstract

Patch antennas with bulk micromachined GaAs substrate suitable for on-chip integration with active devices are investigated. Advantages of such integrated antennas are increased bandwidth, improved efficiency, and lower coupling between adjacent elements. The work reported here is part of a research activity towards designing a monolithic phased array antenna for space applications.

## I Introduction

It is becoming increasingly clear that various micro-electromechanical and micromachined systems and components would soon find a significant share of telecommunications equipment in the very near future [1]. Antenna is an important component in any wireless communication system, as it is an efficient interface between electronic circuits and the outside world. In keeping with the trend towards using higher frequencies in communications, (*e.g.*, space applications at around 30GHz, local multipoint distribution systems (LMDS) at 28 GHz, industrial) the antenna technology needs to meet new requirements. The *Microwave Lab.* at the Indian Institute of Science has been engaged in the development of various subsystems for such an active monolithic phased array antenna operational at 30 GHz. A previous work done in the same lab investigated the design of compact sized phase shifters at 30 GHz [2].

One antenna configuration that finds applications in several telecommunications systems is based on microstrip technology. These are low profile antennas highly preferred for space applications due to aesthetics and conformability. However, they suffer from low bandwidth and reduced radiation efficiency especially when fabricated on high dielectric constant substrates such as GaAs or Silicon. Microstrip antennas, although currently used in several microwave bands, can not be easily scaled to mm wave frequencies. Many micromachining approaches are therefore aimed at overcoming these difficulties. Micromachining assumes greater significance in the context of the high level of system integration required at the mm wave bands. As more components are integrated into circuits at chip levels, semiconductor substrates can themselves be used for antennas. The advantages of using GaAs and Silicon substrates in the context of monolithic microwave integrated circuits (MMICs) are widely understood.

Developing micromachining technology is essential as one moves towards integrating an entire communication system on a chip. Although GaAs is a good substrate for microwave circuits, antennas on them suffer from low bandwidth and degraded radiation characteristics due to its high dielectric constant [3] [4]. Most of the work internationally so far has been restricted to silicon, albeit this is not so much preferred at millimeter wave frequencies [5]. Hence in the proposed study it is planned to extend these micromachining concepts to GaAs based antenna systems.

The advantages of micromachining in microstrip patch antennas are multifaceted. In a single patch scenario, this approach can effectively reduce the effective dielectric constant of the substrate by selectively removing material (e.g., underneath the patch) and thus improve its bandwidth and radiation efficiency. In the context of antenna arrays, trenches can be micromachined below or between patches to reduce mutual coupling due to surface waves which are likely to exist on such high dielectric constant substrates especially at higher frequencies.

The current work proposes the design of a single patch antenna on micromachined GaAs substrate. The elements of the array will use these micromachined patch elements. Figure 1 illustrates the basic building blocks of such a phased array antenna.

## II Patch Antenna Design

The microstrip patch antenna consists of a metallic patch on a grounded dielectric slab such that the length of the patch including the fringing fields is half the guided wavelength. Using the expressions in [6] we designed a patch to resonate at 30 GHz on a GaAs substrate with permittivity 12.9 and of thickness 350  $\mu\text{m}$  (compatible with MMIC technology). The patch length and width are obtained as 1.21 mm and 1.91 mm, respectively. A 50 ohm microstrip line is used to feed the antenna and the matching to the input impedance of the antenna is obtained by means of an inset [6]. A commercial time domain code is used to execute the simulations. It uses adaptive meshing while maintaining at least 15 lines per wavelength at the shortest wavelength.

In the next step for the micromachined antenna, in order to obtain maximum benefits while ensuring that the wafer does not break, we design the antenna for an etch depth of 300  $\mu\text{m}$  leaving 50  $\mu\text{m}$  of GaAs. The etch profile with sloping walls inclined at 55° has been accounted for in the geometry input to the full wave simulator. The geometry (with some dimensions exaggerated for clarity) is shown in Figure 2.

For this patch design, we first need to determine the dielectric constant synthesized by the composite substrate consisting of the air and the GaAs substrate. For this purpose, quasi-static analysis assuming a series combination of two capacitors, one filled with air and the other with GaAs can be done. This model gives a  $\epsilon_{synth}$  of 1.15. However this does not account for fringing fields which contribute significantly to the capacitance. Hence this is done by simulating a microstrip on the composite substrate and deriving the synthesized permittivity from the extracted characteristic line impedance. For the above configuration of 300  $\mu\text{m}$  of air and 50  $\mu\text{m}$  of GaAs, we obtain the  $\epsilon_{synth}$  as  $1.74 \pm 0.04$  for various widths of the microstrip at 30 GHz.

Using  $\epsilon_r=1.74$  in the design expressions for the patch [1], we obtain new length and width as 3.53 mm and 4.3 mm. The cavity is made to extend beyond the patch by about twice the substrate thickness in either direction to accommodate the fringing fields [5]. Then optimization is done to tune the patch length to 3.62 mm to resonate at 30 GHz. The 50 ohm microstrip line used earlier now has a characteristic impedance of 117 ohm over the composite GaAs–air structure and thus it matches the antenna input impedance with a smaller inset.

### III Results of Simulations

The comparison of the two antennas with respect to the return loss is shown in Figure 3. Clearly the patch on the micromachined substrate exhibits a larger -10dB return loss bandwidth. The bandwidth is enhanced from 911 MHz (3.04 %) to 1335 MHz (4.45 %) thus representing a 46 % increase in the bandwidth.

Figures 4 and 5 show the comparison of E-plane H-plane patterns comparison of the two patches. In the plain substrate case, we can see that the maximum in the E-plane pattern is shifted to about  $40^\circ$  away from the bore-sight. This may be attributed to the surface waves bouncing off the finite ground plane edges and causing pattern distortion by interfering with space waves. This is totally absent in the micromachined case thus implying suppression of surface waves [5]. The directivity increases from 5.6 dB to 8.3 dB for the micromachined case. The radiation efficiency also improves from 69% for the plain case to 86% for the micromachined case. A reduction in the back lobe levels can also be observed. Important antenna parameters are compared in Table 1.

### IV Conclusion

In this work, micromachining concepts are applied to design a performance enhanced microstrip antenna suitable for integrating with GaAs based MMIC circuits. The substrate is undisturbed over the circuit part and over the patch antenna part it is etched from underside to synthesize a low permittivity composite substrate. The synthesized permittivity of the substrate material is obtained by simulation of microstrip transmission lines over such substrates. Full wave simulations show enhanced performance for such antennas with respect to bandwidth, efficiency and directivity.

### References

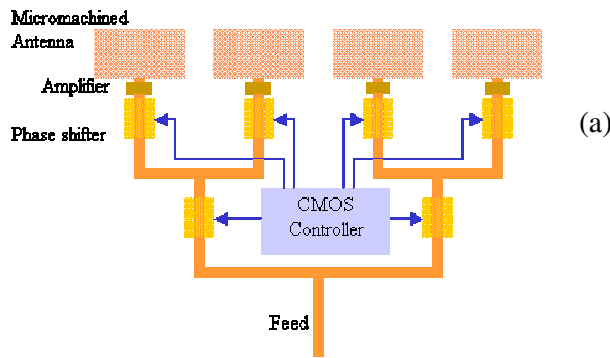
- [1] V.K. Varadan, K.J. Vinoy and K.A. Jose, *RF MEMS and their applications*, John Wiley and sons, London, 2003
- [2] I.Paul, *Design and Optimization of Micromachined Phase shifters*, Master of Technology thesis, Indian Institute of Science, Bangalore – 560012
- [3] D.M. Pozar, “Considerations for millimeter wave printed antennas,” *IEEE Trans. Antennas & Propagat.*, vol 31, pp. 740-747, 1993.
- [4] D.M. Pozar, “Rigorous closed-form expressions for the surface wave loss of printed antennas,” *Electron. Lett.*, vol. 26, pp. 954–956, 21 June 1990.

[5] Papapolymerou, I.; Franklin Drayton, R.; Katehi, L.P.B., "Micromachined patch antenna," *IEEE Trans. Antennas & Propagat.*, vol. 46, pp. 275-283, 1998.

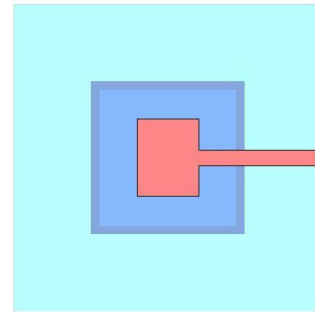
[6] C.A. Balanis, *Antenna Theory – Analysis and Design*, John Wiley and sons, New York, 1997

Table 1: Key antenna parameters

	S <sub>11</sub> Bandwidth (-10 dB)	Directivity	Efficiency	Gain	E-Plane Beam width (3dB)	H-Plane Beam width (3dB)
Plain patch	911 MHz	5.6 dB	69%	4 dB	134	84
Micromachined patch	1335 MHz	8.3 dB	86%	7.6 dB	82	77



(a)



(b)

Figure 2 The micromachined antenna geometry (a: Side view, b: top view)

Figure 1 A schematic of a phased array antenna

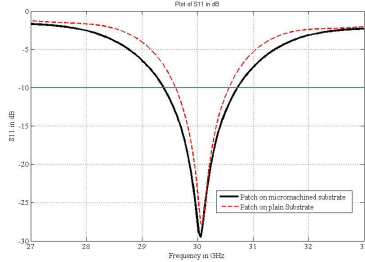


Figure 3 Comparison of return loss of plain and micromachined patch antennas

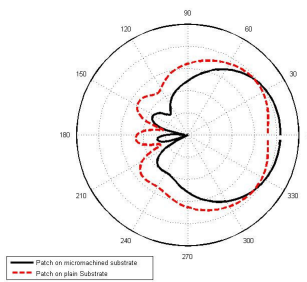


Figure 4: E-Plane pattern comparison

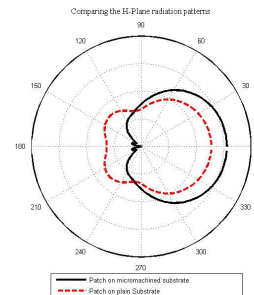


Figure 5: H-Plane pattern comparison

Legend : Solid black – Micromachined , Dashed red - Plain