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MICROMACHINED ACTIVE ANTENNA AT KA BAND

Abhishek Kumbhat, Ananjan Basu and Shiban K Koul
Centre for Applied Research in Electronics, Indian Institute of Technology Delhi,
Hauz Khas, New Delhi-110016
akumbhat@yahoo.com, ananjan_b@yahoo.com, shiban_koul@hotmail.com

1. Introduction

Silicon micromachining technology has recently been applied to microwave and millimeter-wave field to create low-loss, adaptive and multi-functional passive/active components and antennas. The motivation for fabrication of high frequency circuits using this technology is due to high levels of functionality with low power consumption, precise dimensions and repeatability of performance [1]. In particular, a rectangular patch antenna on a silicon micromachined substrate, in which silicon is removed locally underneath the patch area, results in improved antenna performance, suppressed surface waves and increased radiation efficiency of the antenna as compared to that on bulk silicon substrate [2].

New systems those are compact, easy to manufacture, adaptable and tunable are possible by integrating various transceiver components (oscillator, amplifier etc.) into antenna structure [3-5]. Using silicon micromachining technology for fabricating miniature high frequency active antenna would combine advantages of both. To-date, no active antenna on silicon micromachined substrate has been reported in the open literature. The earlier designs of active antennas [6-7] use active devices such as Gunn diodes, FET etc. mounted on the patch itself. But these designs cannot be implemented with active antenna on silicon micromachined substrate, as mounting of active device on very thin membrane supported patch antenna is not practical. Therefore, for micromachined active antennas, designs in which active devices can be placed out of patch antenna area need to be thought of [8-9]. One such design that utilizes the patch antenna as radiator cum resonator in the feedback path of an amplifier is shown in Fig.1. The authors have recently reported preliminary design and experimental results of such an active antenna at 18 GHz on RT-duroid substrate [10]. The development of Ka-band micromachined active antenna using silicon substrate is reported in this paper. This is, to the best of our knowledge, the first demonstration of millimeter wave active antenna using micromachined silicon substrate. The design uses a patch antenna as radiator cum resonator in the feedback path of an MMIC amplifier. The MMIC amplifier chip was selected such that it's gain at Ka-band (around 15 dB) is substantially higher than the transmission loss of the 2-port patch (around 6 dB). Two U-shaped transmission lines sections were introduced to adjust the effective feedback path length. The design was first verified at Ka-band on RT-duroid substrate. Finally the active antenna was successfully realized on micromachined silicon substrate. Various fabrication issues related to the prototype of the active antenna have been discussed. Such micromachined active antennas can be combined into an array along with other micromachined/ MEMS components to yield lightweight, miniature microwave and millimeter wave systems. Prototyping such an active antenna using two port micromachined patch and MMIC amplifier chip brings up lot of fabrication issues. These issues are discussed in detail in this paper.

2. Design and Fabrication Issues

For a circuit of the type shown in Fig 1 to oscillate at a specified frequency, two conditions must be satisfied: the gain of the amplifier should exceed the transmission loss of the patch antenna and the phase lag for a signal completing the full loop should correspond to a multiple of 360 at the design frequency. A more accurate analysis (e.g. Kurokawa's condition) is difficult because appropriate non-linear characteristics of MMIC amplifier chips are not normally available. The gain of the chip used (Alpha LNA AA038N1-00, physical dimension: 2.710mm × 1.355mm × 0.1mm) has been measured to be approximately 15 dB around 35 GHz, as shown in Fig 2, which is substantially greater than the transmission loss of the 2-port patch at 35 GHz (measured to be –6 dB with co-axial transitions, although the simulation in Fig 3 shows – 3.5 dB). The cross-section of the substrate on which the 2-port patch antenna is simulated is shown in Fig.4. It can be seen from Figs. 2 and 3, that the amplifier gives sufficient gain over a large band to offset the transmission loss, and in the absence of phase information

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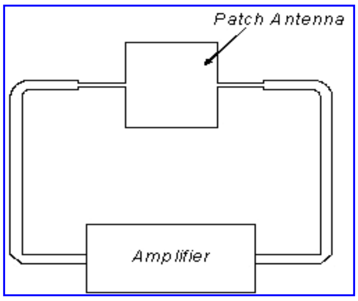

Fig. 1 Patch antenna in the feedback path of an amplifier

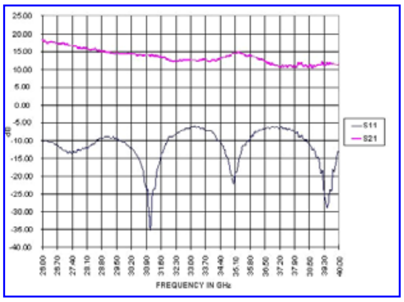

Fig. 2: Measured gain of MMIC amplifier

for the MMIC chip, it is not possible to predict the frequency of operation beforehand. For this reason, two U-shaped sections of transmission lines were inserted in the feedback path that could be manually shorted to alter the path length.

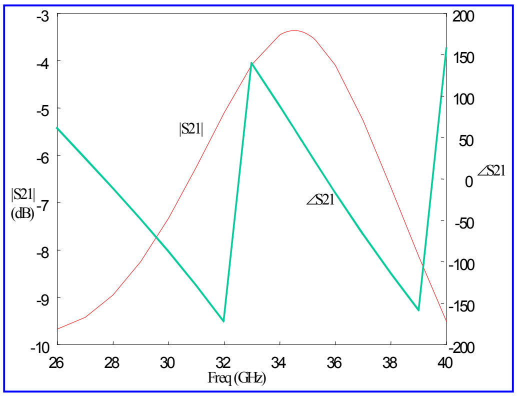

Fig. 3 Simulated magnitude and phase of S_{21} for the 2-port patch.

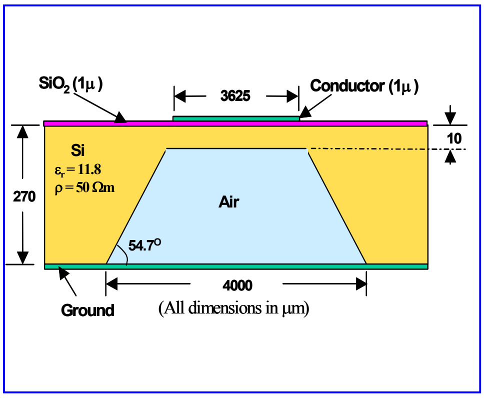

Fig. 4 Cross section of silicon substrate at patch antenna location

To interface the amplifier chip to the 2-port patch on silicon substrate (270 microns thick) a through cavity has been created by wet etching to place the MMIC LNA chip in the loop as shown in Fig. 5. Details of this interfacing are given later.

3. Circuit Layout and Measured Results

Prototyping a micromachined active antenna, using the schematic shown in Fig. 1, involves several stages. Following the verification of repeatability of the circuits on RT-duroid at 35 GHz, a 2-port micromachined patch on silicon was tested. Finally a complete micromachined active antenna on silicon at Ka band, using MMIC amplifier chip and micromachined 2- port patch, has been fabricated and tested.

2-port patch

Designing patch antenna by simple textbook formulae (using ε_{eff}) and then optimizing the dimensions for center frequency (as predicted by Ansoft HFSS simulator) to be 35 GHz, results in 3.625mm X 3.625 mm patch size on 4mm X 4mm air cavity. In this process the two high impedance sections connecting the micromachined patch antenna patch to the 50-ohm lines, were kept at the original designed values appropriate to a conventional 1-port patch antenna: 0.09 mm wide and 0.78 mm long. The micromachined patch antenna was fabricated on 10- micron thin silicon membrane (covered with 1 micron silicon dioxide) suspended on air cavity in high resistive silicon substrate (Thickness = 270 microns, resistivity = 5000 ohm-cm, orientation = [100]). The air cavity is created by standard wet etchant (KOH) yielding a 54.7^0 tapered sidewall in silicon substrate. The patch antenna conductor is one-micron thick gold printed on one-micron thick silicon dioxide dielectric layer. Simulated results for this are shown in Fig. 3. Measured $|S_{21}|$ showed a peak of –6 dB at resonance, however the resonant frequency was found to be strongly dependant on the accuracy of front-to-back alignment of the wafer.

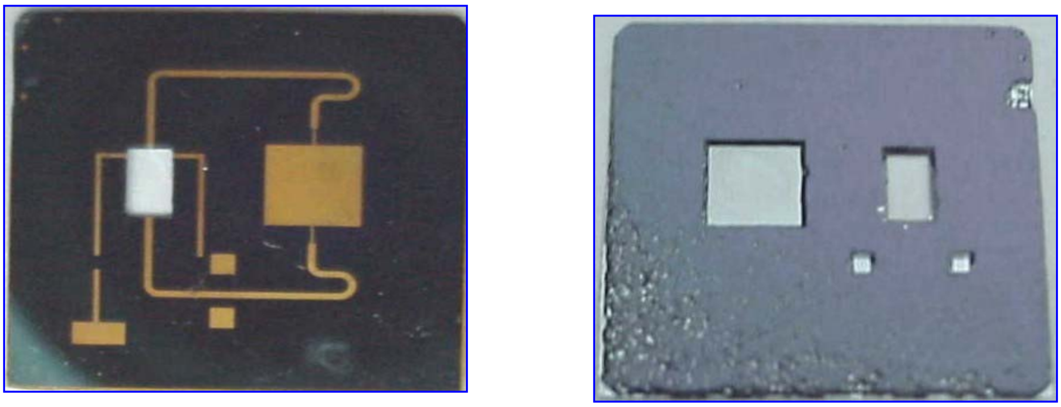
(a) (b)

Fig. 5 Micromachined Active Antenna: (a) Design layout on silicon (b) Backside aligned cavity

Micromachined Active Antenna Element (on 270µm Silicon substrate)

Figure 5 shows layout of the patch antenna with feedback path on micromachined silicon substrate and backside cavity. The U-shaped half-wavelength transmission line sections have been included in the feedback path to manually optimize effective path length. An extra through cavity in feedback path has been created for placing the MMIC amplifier chip. Additional holes were created for chip capacitors used to bias the amplifier, but a packaged capacitor was found to be satisfactory, and chip capacitors were not used.

Hybrid integration of MMIC chip with antenna fabricated on silicon wafer is the most critical issue to be taken care of. Thickness of Silicon wafer is 270 microns, while that of MMIC amplifier chip (Alpha) is around 100 microns. For proper wire bonding, top surface of the silicon wafer and the MMIC chip have been brought to the same level by placing MMIC chip on a metallic bump of approximately 170 microns height. The MMIC amplifier chip is mounted on the metallic bump, with conducting epoxy, as shown in Fig. 6. For this particular MMIC, solder perform is not suitable, although that would be the preferred technique in a finished product.

As a next step, the silicon wafer is bonded to the housing using epoxy. Care was taken to ensure proper alignment of the silicon wafer with respect to the bump carrying the chip. Figure 7 shows photograph of the micromachined active antenna on silicon substrate with MMIC chip and external biasing circuits. Various dimensions of the fabricated circuit are given in Fig.8. Although the MMIC amplifier chip used requires two power supplies for biasing that may be independently operated for optimum performance, in the present case, the chip was biased using a single power supply.

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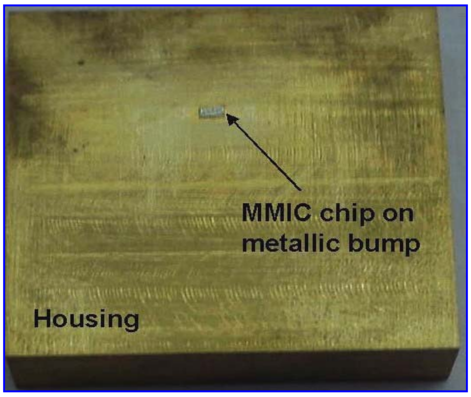

Fig. 6 MMIC amplifier chip on metallic bump

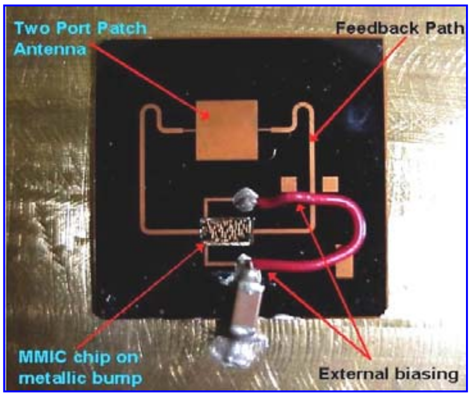

Fig.7 Final Antenna circuit with biasing circuit

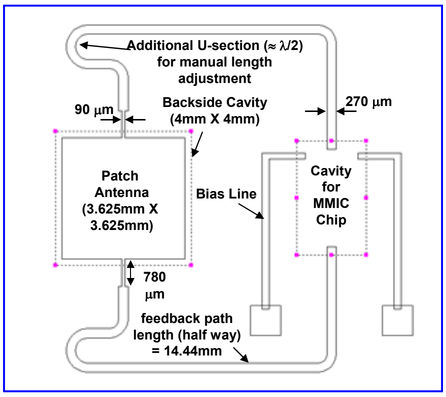

Fig.8 Layout of the circuit, with all dimensions

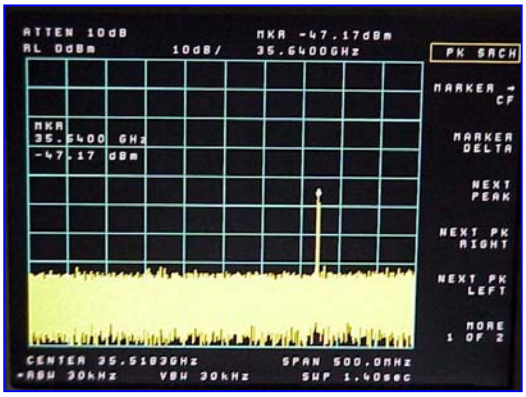

Fig. 9: Measured spectrum of the active antenna element

The oscillation from the fabricated micromachined active antenna sensed through a horn suspended above was observed at 35.64 GHz with -47.17dBm power output on spectrum analyzer as shown in Fig. 9. Measured spectrum is clean and stable. The cross polarization power is almost 20 dB down from that of co-polarization fields as desired. Manual trimming of the path length, to bring the frequency to exactly 35 GHz is possible.

4. CONCLUSION

Active antenna at Ka-band on micromachined silicon substrate has been reported for the first time. Experimental results show a stable and clean spectrum. Array of such micromachined active antennas would be used in miniaturized, lightweight and high performance phased array radar systems. Future goal is to increase power output from a single active antenna element, and to fabricate an array of such antennas.

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