Abstract - A new dual band slot antenna has been developed using Micro- Electro- Mechanical system (MEMs) technique for millimeter wave (MMW) wireless communication application. A DC-contact switch is employed to switch the operating frequency from 38 GHz to 60 GHz. The antenna resonating frequencies including simulation and measurement are reported. The RF switch performance, such as pull in voltage, stress distribution and switching time, are also simulated and measured. The brief fabrication is also described in this paper.

Keywords: MEMs antenna, multi-band antenna, MEMs switch, system on chip

I Introduction

With the rapid development of personal wireless communication system, two significant trends are appearing. One is to apply higher frequencies, such as millimeter wave, to provide broadband for high rate data transmission, the other is to integrate multi-tasks in one system, which greatly extend the application of wireless device[1]. To meet the need of multi-band MMW applications, choice could be made from the following three type antennas: A) a single antenna showing multi-resonance characteristics for the proper frequencies. B) A very broadband antenna to cover all required frequencies, and C) a switchable antenna to operate at required frequency points. Both a multi-resonance antenna and a broadband antenna will suffer interference from another signals operating at frequencies covered, and it is reported that antenna has an impedance bandwidth (VSWR < 2) less than 50% [2,3,4], whenever using a type of slot or patch antenna. A switchable design is known as a new technology with clear design concepts and compatibility with RF circuitry. So far, many researches have been done at frequencies less than 10 GHz, using PIN diodes as switches [5,6,7]. In MMW band, the traditional PIN diodes ultimately limit the antenna efficiency, due to high insertion loss. It is very useful to develop a switchable antenna, which could provide high efficiency in MMW band.

As an example, a new slot antenna was designed to switch the operating frequency between 38GHz and 60GHz. These two frequencies have been planned in many communicate system [8,9,10]. The key features of this antenna are first, the capability of MMW dual-band operation with only one MEMs switch employed, thus allowing for use in planar phased arrays. Second, antenna is fabricated upon a cavitated GaAs substrate, which implies high antenna efficiency and MMIC compatible process.

II Antenna Structure and Fabrication

Antenna Layout

The antenna structure is illustrated in the figures 1-4 with the associated dimensions listed in the table 1. Among the antennas proposed for CPW-fed configuration in reference 11 and 12, we selected a half-wavelength center-fed slot for 38 GHz antenna working mode and a one-wavelength offset fed slot for 60GHz antenna working mode. In principle, the DC-contact switch can control the antenna resonance point from 60 GHz to 38 GHz when a DC power is added at DC port. However, CPW will suffer serious loss from the excitation of the parasitic slotline mode in asymmetric discontinuities. The conventional method for elimination the unwanted mode is the use of air-bridges[13,14,15]. In our application, the air bridge was placed 214 µm away the slot and the height is 2 µm same as the movement distance in the MEMs switch to simplify related fabrication process. In order to integrate with MMIC, a GaAs substrate is employed. The loss in substrate is reduced by etching a portion of substrate dielectric underneath the antenna [16,17].

Figure 1 top view of the switchable antenna

Figure 2 substrate with a cavity

Footnotes:
1 Agilis Communication Technologies Pte Ltd, Singapore Technologies Electronics, Singapore 569061
2 School of EEE, Nanyang Technological University, Singapore 639798
3 Shenglu Antenna Co. Ltd. P.R. China 528100
A six-mask batch process is used to fabricate the MEMs switchable antenna. Figure 5 shows the fabrication process flowchart. (a) 500/200A of Ti/Au is deposited using e-beam and electroplated Au to the thickness of 7500A and the circuit metal layer is defined via wet etch; (b) 1000A of plasma enhanced chemical vapor deposition (PECVD) silicon nitride at 300°C and etch an anchor window; (c) PECVD a 2 µm silicon oxide as a sacrificial layer; (d) a layer of 1 µm photoresist is spun, soft baked and patterned for anchor points, dimple points; (e) 3000A of Au is deposited and wet etch to define the switch structure and air bridge; (f) bake at 250°C to harden the photoresist layer to form a beam membrane, coat with AZ4620 on the both front and back side [18,19]; (g) define patterns and back side etch in H2SO4 to 50µm; (h) the sacrificial layer is removed with HF, followed by IPA.

### Table 1

<table>
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<tr>
<th>L</th>
<th>4150</th>
<th>H</th>
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<th>L2</th>
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<td>L1</td>
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**Processing**

The MEMS switch is modeled in Figure 6 to show its mechanical activity. When a DC bias is applied, the electrostatic force $F_e$ can be represented by

$$F_e = \frac{A V^2}{2 (\frac{g_0}{\varepsilon_0} + \frac{g_s}{\varepsilon_s})}$$

Where $A$ is the effective area of actuation plate, $V$ is the voltage between the plates, $g_s$ is the height (air gap) of the switch above the bottom electrode, $g_0$ is the thickness of beam membrane, $\varepsilon_0$ and $\varepsilon_s$ are the permittivity of air and photoresist, respectively.

Using the standard second order ordinary differential equation
A switchable MEMs antenna for 38/60 GHz millimeter wave communications

and boundary conditions \( z(0)=g_0 \) and \( z'(0)=0 \) for spring mass system with (1) as a forcing function, the motion equation is given as

\[
m \frac{d^2 z}{dt^2} + c \frac{dz}{dt} + k z = \frac{AV^2}{2 \varepsilon_0} \left( \frac{g_0 - z}{\varepsilon_0} + \frac{g_i}{\varepsilon_i} \right)
\]

Where \( k \) is the spring constant, \( c \) is the damping coefficient and \( m \) is the mass of actuation plate. Assuming \( F_e \) is a constant during a very short period of the start of switch movement, we have the pull down voltage \( V_p \) and hold down voltage \( V_h \).

Switching time can be derived with assuming an average \( F_e \) is applied

\[
T_s = \frac{2cg_0^3}{\varepsilon_0 AV_i^2}
\]

Since the switch is employed for a slot antenna, the key features of the switch is replaced with the pull down voltage and the switching time instead of the \( S \) parameter for a normal switch. The actuation plate area is also constrained in order to keep a little effect on antenna radiation performance. Therefore, the long cantilever springs has been designed to achieve a low spring constant. The choice of gold as the material is also important due to its low Young's Modulus (\( E = 80 \text{ GPa} \)). Square holes 10µm are included in the actuation plates design in order to decrease the squeeze film damping of air and help in removing the sacrificial layer during wet etching process.

The distributions of stress and displacement along the switch are simulated using the MEMS CAD tools Coventor. When applying bias voltage up to 16.5V on the electrode pads, the movement is observed and the maximum field stress occurs at the anchor end shown in figure 7.

Some separated switches are also included in the wafer together with calibration kits for measurement. The actuation voltage measurements were performed using a HP 4275A Multi-Frequency LCR meter with an internal bias option. The RF response of the system has been measured using a GGB C-4 SOLT calibration standard with an 8510C Net-work Analyzer and A Lessi Probe Station and GGB 150µm pitch coplanar probes. The contact resistance is measured about 0.2 ohms when switch is in the ON position with bias voltage of 23.03V. The detail performance of switch is summarized in table 2.

The computation of the slot antenna was performed using Sunnet and shown it resonance performance in the figure 8. When the MEMS switch is turned on, the antenna resonance is switched from 38 GHz to 60 GHz. The input return loss was measured with a network analyzer HP8510C and a probe station described above. The measured return loss of the patch antenna with the MEMS switch in the ON and OFF states are shown in Figure 9. It is observed that when the switch is in the OFF state the patch resonates at about 59.3 GHz. When the switch is in the ON state, the frequency shifts to 38.2 GHz. It proves the antenna can be switched to operate at two different bands.
Conclusion

A novel slot antenna is presented in this paper. By controlling the bias voltage of a MEMs switch, the antenna can switch between 38 GHz and 60 GHz. Furthermore, the switches are simple to fabricate and also compatible with array antennas.

At the present time, the switchable antenna is being tried in an array environment to reconfigure not only the resonant frequency but also the radiation patterns.

Reference

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