A W-band Surface Micromachined Monopole for Low-cost Wireless Communication Systems

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***Abstract* — A W-band CPW-fed 3-D quarter-wavelength monopole that is vertically mounted on a variety of substrates is reported for the first time. A transition from coplanar waveguide to vertical coaxial structure is investigated. The structure demonstrates broadband impedance matching and symmetry radiation pattern in W-band. Greater than 10 dB return loss over 19 GHz bandwidth is measured on chromium coated soda-lime glass substrate, while over 10 GHz bandwidth for silicon and sapphire substrates is also observed in simulation. As a low-cost solution without etching requirements, this idea can be easily extended to integrate with other RF front-end components and to design more compact millimeter wave systems. Experimental and numerical simulation results are provided to demonstrate the effectiveness of the idea.**

***Index Terms* — Micromachining, millimeter-wave antennas, monopole, W-band, 3-D transition.**

I. INTRODUCTION

With the growing demand for higher data rate and affordable communication modules, increasing bandwidth and reducing fabrication cost are both imperative, especially in the millimeter-wave frequency range. For this type of miniaturized systems, coplanar waveguides are widely used and act as the main interconnecting lines between different modules because they provide advantages, such as ease of connecting to surface mounting active components and fabrication simplicity [1].

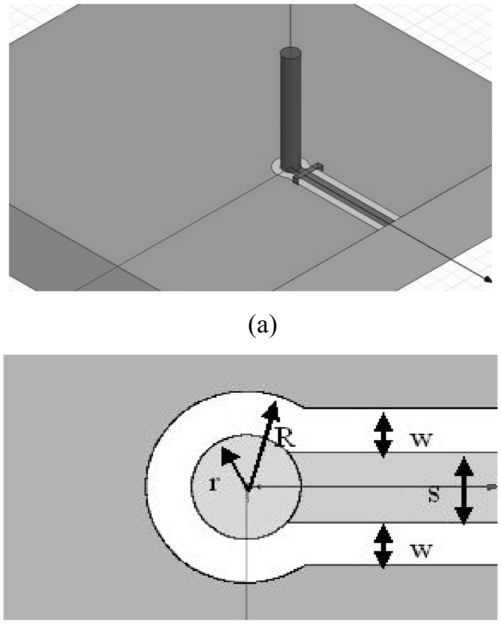
Printed circuit antennas are compatible with these coplanar transmission lines and thus often used in compact millimeter wave systems as a low-cost solution [2]. Nevertheless, microstrip patch antennas often suffer from low bandwidth, high loss and perturbation of radiation pattern caused by surface wave, which limit their application in broadband modules and have led to various bandwidth improvement techniques [3]. On the contrary, thin wire or cylindrical monopoles have broad impedance bandwidths and might be better candidates for broadband radiation. The major roadblock for their wide application is that the 3D transition from the preceding planar transmission lines to the monopole radiation structures is more complicated than those of printed circuit antennas. It is well known, that in lower frequency systems, the cylindrical monopole is usually fed from the backside by a coaxial line, requiring the use of an etching process. In compact millimeter wave systems, this process should be avoided for the reasons of cost reduction and fabrication compatibility with coplanar transmission lines. Therefore, a transition from a 2-D CPW structure to a 3-D monopole is essential for the effective realization of this concept.

In this paper, we present for the first time a novel cylindrical monopole that is vertically-mounted on glass substrate operating in W-band. The work has been enabled by surface micromachining technology and can be realized on other substrates as well. This scheme is proposed as an alternative for traditional leaky wave mode and microstrip radiators. It is via-free, and thus a low-cost solution. In the future, we expect that this structure can be easily integrated with other key RF front-end components in millimeter wave systems.

II. CONFIGURATION OF THE STRUCTURE AND FEEDING TRANSITION DESIGN

The general configuration and the illustration of key geometrical parameters are shown in Fig.1. The quarter-wavelength monopole is vertically mounted at the end of the center conductor of the CPW line. The two sides of the ground plane are connected radially to enclose the monopole bottom [4]. The radius of monopole *r*, the radius of the ground aperture *R*, the center conductor line width *s* and the gap width *w* between center conductor and ground have been optimized with Ansoft HFSS9.0.

The characteristic impedance of CPW lines on silicon, sapphire and glass has been calculated as a function of normalized center conductor width, using LineCalc of Agilent ADS, and is depicted in Fig.2. The gap width is fixed to 50 μm for these curves and the ground is assumed to be infinite. In order to get compatibility with both fabrication process and measurement facilities, the center conductor width and gap width have been chosen appropriately.



(a)

(b)

Fig.1 (a) Configuration of the structure (b) illustration of the key geometrical parameters

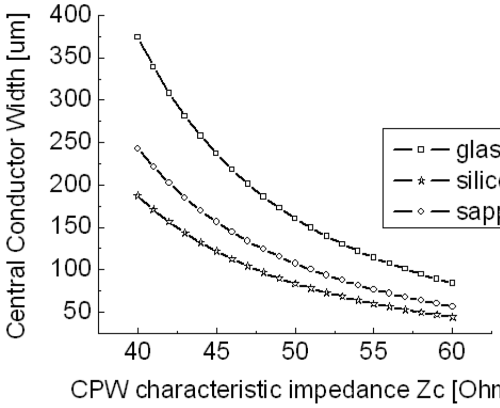


Fig.2 CPW dimensions vs. characteristic impedances on different substrates (Gap width fixed to 50 micron)

The theoretical input impedance of the quarter-wave length monopole is 36.5 Ohm at resonance. On some substrates, the width of center conductor for 50 Ohm characteristic impedance will be comparable to and even significantly larger than the diameter of the monopole. On other side, in order to get a symmetrical radiation pattern, the transition discontinuity should be only a small portion of the circumference of the ground aperture. Considering this, we have two alternative choices for the feeding: (A) use a thinner line width to feed the monopole and transform it to wider lines with the aid of different types of matching networks; (B) From Fig. 2, we can observe that the characteristic impedance is still around 50 Ohm when using a narrow line width of 80 μm, if the diameter of the monopole is 100 μm. Therefore, simply connecting the CPW line without other impedance transforming techniques would also be a reasonable choice. These two schemes have been simulated and compared.

For scheme (A), we can use either a linear tapered line transformer, or open and short stub matching networks. However, these matching techniques can introduce more discontinuities to the structures and thus more parasitic radiation [5]. The maximum directivity of a quarter-wave length monopole is not high--about 1.7 dB theoretically, thus the parasitic radiation can easily perturb the desired monopole radiation pattern because its main radiation axis is parallel with the axis of monopole. Based on comparison between simulation results, we decided to test first the scheme (B).

In our design, the central operating frequency for the monopole is chosen as 85 GHz and the theoretical height of the monopole is 800 μm. Simulation results with Ansoft HFSS 9.0 are shown in Figs. 3-6. Fig. 3 shows S11 for silicon and sapphire substrates, while radiation patterns for silicon and sapphire substrates are given in Fig. 4. Figs. 5-6 are the results for soda-lime glass substrate.

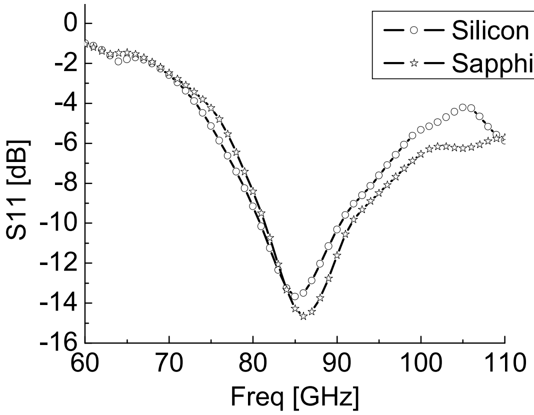
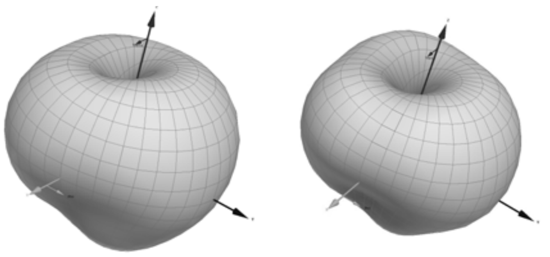


Fig. 3 Simulated input return loss for the monopole on silicon substrate and sapphire substrate



(a)

(b)

Fig. 4 Simulated radiation pattern for the monopole on (a) silicon substrate (b) sapphire substrate

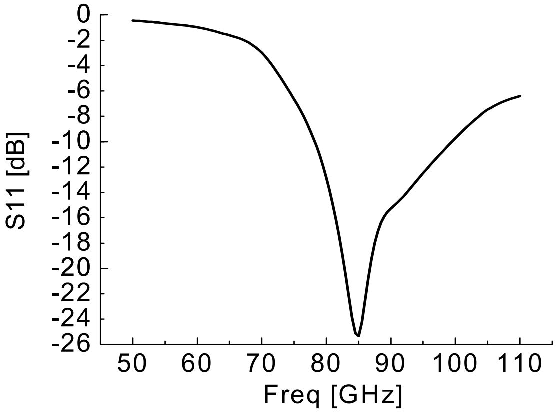


Fig. 5 Simulated input return loss for the monopole on glass substrate

As for the radiation performance, a symmetrical far field pattern has been achieved for all three substrates. The far field radiation parameter calculation tool in HFSS 9.0 was utilized to estimate the radiation efficiency and led to the observation that most of the energy is radiated from the monopole.

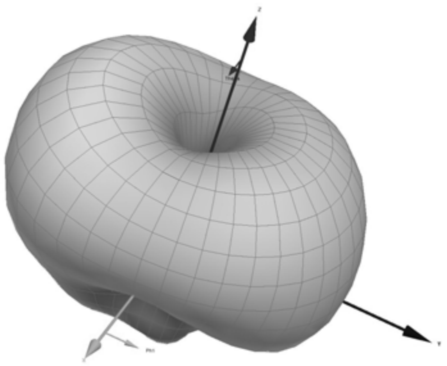


Fig.6 Simulated radiation pattern for the monopole on glass substrate

III. FABRICATION

The fabrication was done on glass substrate this time. A polymer core conductor fabrication technique [6] has been adopted for the high aspect ratio monopole structure. A photodefinable epoxy, SU-8 (Microchem, Inc.), which is favorable to high aspect ratio micro patterning [7], is used for the monopole backbone and electroplated gold for the electrical conductive path.

A thick overcoat gold layer is required for the conductive path to minimize the RF conductor loss. In general, 5 times skin depth is considered to be sufficient, which is approximately 1.5 μm for the gold in w-band.

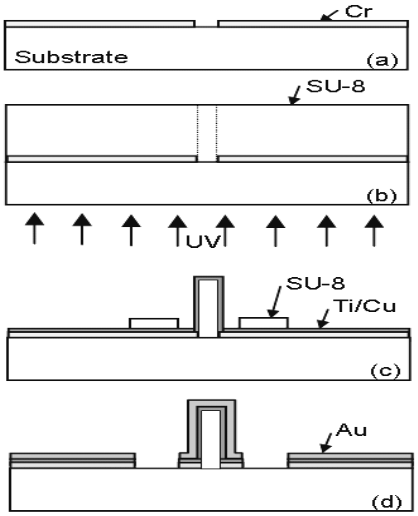
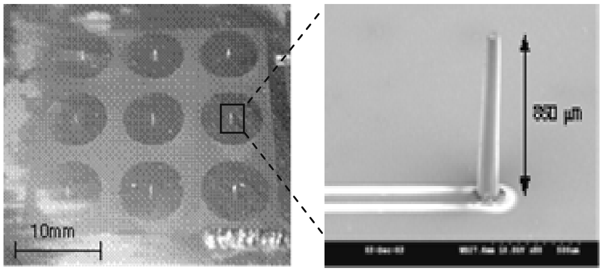


Fig. 7 Fabrication Process

Fig. 7 details the fabrication process. A chromium coated soda-lime glass (Telic Co.) is used as substrate. Chromium is patterned for the monopole column definition using a standard photolithography (Fig. 7a). A SU-8 epoxy (800 μm thick) is coated on the substrate to a thickness that will define the monopole height ultimately. (800 μm theoretically)UV source is exposed from the substrate side to get a relatively uniform column latent pattern. Alternatively, a front side exposure can be used for the opaque substrates such as Si or GaAs etc. (Fig. 7b). Metal deposition of titanium and copper using a DC sputterer is performed to have a conformal seed layer. Thin SU-8 (5 μm) is spin-coated on it and patterned for the definition of signal path as well as ground pads using a proximity photolithography due to uneven surface patterning (Fig. 7c). Gold up to 2 μm is electrodeposited through the bottom mold as well as column surface uniformly. The thin SU-8, a seed layer, and bottom chromium layer are removed sequentially to complete the process (Fig. 7d).



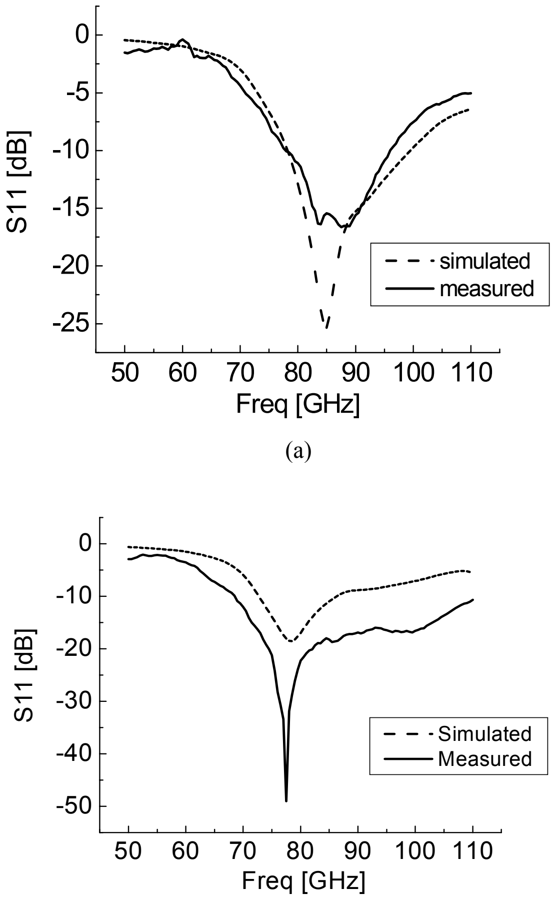
(a) (b)

Fig. 8 (a) a photomicrograph of 3X3 monopole array, (b) an SEM image of a single monopole antenna

Fig. 8a and Fig. 8b show a photomicrograph of a fabricated monopole antenna array (3X3) and an SEM image of a single monopole antenna, respectively. The fabricated structures were measured to be approximately 850 μm high, which usually vary between from 800 μm to 880 μm.

IV. MEASUREMENT

In the characterization of the structure, an Agilent 8510X vector network analyzer connected to a Cascade GSG 150 probe station that was calibrated with a standard SOLT scheme between 50GHz and 110GHz.



(a)

(b)

Fig.9 Measured S11 on two samples with comparison with simulated monopole height of (a) 800 μm and (b) 880 μm

Measurements were performed on two samples with different heights (800 μm and 880 μm) and the results are shown in Fig. 9a and Fig. 9b, respectively, where good agreement with simulation can be observed. The difference of resonant frequencies between Fig. 9a and 9b is attributed to fabrication tolerance in the monopole height. Upper-band loss shown in Fig. 9b is still under investigation and probably caused by the variation of the conductive path thickness and slot-line mode loss.

V. CONCLUSION

A W-band micromachined monopole, which is vertically mounted on a variety of substrates, is reported for the first time. A 2-D to 3-D feeding scheme is also proposed and optimized. Both the simulation and measurement results demonstrate the broadband nature of this kind of structure. Return loss of 16 dB and 50 dB were measured for two monopoles resonating at 85 GHz and 77.5 GHz respectively. Radiation pattern measurements are currently under way. This micromachined monopole can be used in low-cost broadband compact millimeter-wave communication systems.

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