MEMS based Top-Loaded Monopole Antenna Operating at 77 GHz for Automotive Radar Systems

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Abstract—Over a million fatalities happen in road accidents every year around the world, most of them being mainly due to human error. Besides several existing technologies used to reduce the impact of accidents (airbags, ABS, etc.), a new class of safety systems called advanced driver assistance systems (ADAS), is now being introduced to reduce human error. These systems are enabled by smart sensors based on millimeter-wave automotive radars.

Automotive radar sensors detect potential collisions and warn/alert the driver or intervene with the braking and other controls of the vehicle in order to prevent an accident. They are capable of detecting objects and obstacles surrounding the vehicle and their position and speed relative to the vehicle. But compact, simple structured automotive radars are highly in need nowadays, since it involves less fabricating complexities and cost and enables easy analysis and troubleshooting. This paper proposes one such compact and simple structured automotive radar. There are 4 major frequency bands allocated for radar applications, which can be divided into two sub-bands: 24-GHz band and 77-GHz band. A top-loaded monopole antenna based on MEMS technology, tuned to operate at 77 GHz, for automotive radar systems has been proposed. The antenna is analysed using Ansoft/HFSS.

Keywords—ADAS, millimeter-wave automotive radars, 77GHz, MEMS, top-loaded monopole antenna.

I. INTRODUCTION

A. MEMS Technology

Micro-Electro-Mechanical Systems or MEMS can be defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) which are made using the techniques of microfabrication. The physical dimensions of MEMS devices can vary from well below one micron on the lower end of the dimensional spectrum, all the way to several millimeters. These devices (or systems) sense, control and actuate on the micro scale and produce effects on the macro scale. It combines silicon-based microelectronics with micromachining technology. MEMS is being widely used in both industrial and consumer products due its advantages of low cost, small size and weight and very low power consumption. MEMS has four functional elements, microactuators, microelectronics, microsensors and microstructures.

The sensor measures information from a surrounding environment and provides an electrical output signal in response to the parameter it measured. The actuator converts an electrical signal into an action which can create a force to manipulate itself, other mechanical devices or the surrounding environment to perform some useful function. Microsensors detect changes in the system’s environment by measuring mechanical, thermal, magnetic or electromagnetic information or phenomena. This information is processed by the microelectronics which signal the microactuators to react and create some form of changes to the environment.

Using MEMS based antennas for millimeter wave circuits offers an important advantage: the suppression of unwanted substrate modes, which otherwise could lead to additional losses [6].

B. Why 77GHz Radar Band?

As frequency increases, smaller antenna size can be employed. Also by going toward higher frequencies, angular resolution can be enhanced. As the carrier frequency is increased, the Doppler frequency also increases proportional to the velocity of the target, thus achieving a higher speed resolution too. The 77-GHz band consists of two sub-bands, 76-77GHz for narrow-band long-range radar and 77-81GHz for short-range wideband radar. By using the 77 GHz band for long-range and short-range applications, there is an advantage that the same semiconductor technology may be used in the implementation of both of them. Also, recently, regulatory agencies are pushing for migration to mm-wave range by imposing restrictions on manufacturing and power emission in the 24 GHz band. Thus, as higher output power is allowed in 77 GHz band compared to 24 GHz, it is widely used nowadays.

II. AUTOMOTIVE RADARS

Automotive radar sensors play a vital role in the prevention of majority of road accidents that occur due to human error. By means of a decision-making unit, they can alert the driver about any potential danger, prevent collision by intervening with the control of the vehicle in hazardous situations, take over partial control of the vehicle and assist the driver in parking the car. The key aspects of a radar system are:

- Detection range
- Speed detection Range
- Range and velocity precision
- Angular resolution
Angular width of view

Automotive radar systems are divided into three sub-cATEGORIES: short-range, mid-range and long-range automotive radar https://openreview.net/pdf?id=HyR7cYIIC based on its key aspects.

For short-range radars, the main aspect is the range accuracy while for mid-range and long-range radar systems, the key performance parameter is the detection range. Short-range and mid-range radar systems (range of tens of meters) enable several applications such as pre-crash alerts and blind-spot detection. It can also be used for the implementation of “stop-and-go” applications in city traffic.

Long-range radars (hundreds of meter) which are utilized in adaptive cruise-control systems, can provide enough accuracy and resolution for even relatively high speeds (~120mph). The 77 GHz band consists of the sub-bands, 76-77 GHz for narrow-band long-range radar and 77-81 GHz for short-range wideband radar. The 76-77 GHz band is used for long-range detection which is typically utilized in adaptive cruise control (ACC) systems.

Recently, the 77-81 GHz band has been allocated also for short-range, high-resolution radar systems. Hence, this band also can be used for pre-crash alarm, stop-and-go and blind-spot detection.

III. ANTENNA DESIGN

A. Outline of the Structure

This paper presents the design and analysis of a MEMS based radar antenna that is designed to operate at 77 GHz. The antenna is 3D in shape [1]. It consists of a substrate made of silicon and has a bottom ground. The radiating part is a top-loaded monopole antenna. Since usage of just a monopole antenna with the symmetric stripline produces high reflection coefficient and irregular radiation pattern, a top-loaded monopole antenna has been attempted [5]. The top-load of a monopole antenna can be a plate or an umbrella of wires and so on [2]. In this paper, plate is used as the top-load. A cavity is formed at the center of the substrate, extending till its center point (along the cross-section). The top-loaded monopole antenna is placed inside this cavity to reach the symmetric stripline, which excites the antenna.

B. Stripline and its Advantages

In this paper, stripline is used to feed the antenna [1]. The stripline is a conductor sandwiched by dielectric between a pair of ground planes. A classic stripline is usually made by etching circuitry on a substrate that has a ground plane on the opposite face and then adhesively attaching a second substrate (which is metalized on only one surface) on top to achieve the second ground plane.

The advantages of stripline are, it is non-dispersive and also stripline filters and couplers always offer better bandwidth than their counterparts in microstrip. Another advantage of stripline is that fantastic isolation between adjacent traces can be achieved (as opposed to microstrip).

A symmetric stripline is a geometry that consists of a trace running between two ground planes located in layers above and below with the same dielectric thickness and material on both sides. The symmetric stripline is shown in Fig. 1.

![Fig. 1 Cross section of a symmetric stripline](image)

Characteristic impedance of a stripline is given by Eq. 1

\[
Z_0(\Omega) = \frac{60}{\sqrt{\varepsilon_r}} \ln \left[ \frac{1.9(B)}{(0.8W + T)} \right] 
\]

Where

- W – Trace width
- \( \varepsilon_r \) – Relative dielectric constant
- B – Spacing between the two planes

The formula for spacing between the two planes is given by Eq. 2

\[
B = (2H+T) 
\]

Where

- T – Stripline Thickness
- H – Dielectric Thickness

IV. DIMENSIONS AND IMPLEMENTATION OF THE ANTENNA

A. Dimensions of the Antenna

The substrate is a 0.195 mm thick high resistivity silicon wafer, with a dielectric constant of 11.9 and conductivity 0.05 S/m. To get better reflection coefficient, \( \lambda/2 \) size substrate is used rather than \( \lambda \) size, since reduced substrate size reduces surface waves and hence better radiation is achieved [3]. The proposed antenna’s front view is shown in Fig. 2.
A ground plane is used at the bottom of the substrate. All dimensions of the antenna correspond to $\lambda/4$ at the operating frequency of 77 GHz. A 440µm x 440µm plate is used as the top-load for the monopole. The vertical pole that holds the plate has dimensions corresponding to $\lambda/24$ value. Since the microstrip line used is symmetric, it is placed exactly at the centre of the substrate’s cross section. It can be viewed clearly in Fig. 3. Short bias lines cause changes in antenna resonance frequency and as the line length increases, only minimal changes in the radiation pattern is observed [4]. Based on this, the stripline has been designed and placed.

The reflection coefficient which describes either the amplitude or the intensity of a reflected wave relative to an incident wave is an important factor for an antenna to ensure that discontinuities in the transmission line are absent and hence reflections are absent.

From Fig. 4, it is observed that the proposed antenna has good reflection coefficient. Also, from Fig.5, it is observed that the three-dimensional radiation pattern resembles the doughnut shape.

The antenna offers an impedance bandwidth of 10.65% and has a good gain of about 1.75 dB.

The two-dimensional radiation pattern is shown in Fig. 6 which depicts that the radiation of the antenna is efficient in endfire direction.

The gain obtained is 1.75 dB. The current flow on the top-loaded monopole antenna is shown in Fig. 7.
Fig. 7 reveals good current conducting abilities of the antenna, thus producing an endfire radiation. According to the top-loaded monopole antenna which is presented in this paper, the endfire radiation supports greatly for detecting the objects and obstacles surrounding the vehicle, thus avoiding potential collisions or hazardous situations.

It is important that the antenna’s feed line is impedance matched with the load. VSWR is the measure for it, which shows how well the antenna is impedance matched with the transmission line to which it is connected. The VSWR of the antenna is 1.1997 as shown in Fig. 8.

The radiated power of the antenna is shown in Fig. 9. It shows that the antenna radiates efficiently with a high radiated power of 30.1dBm.

VI. CONCLUSION

An automotive radar antenna based on MEMS technology that operates at 77 GHz has been proposed. It is compact and simple structured. A top-loaded monopole antenna is used which is excited using a stripline. The antenna produces endfire radiation. The presented results show that the proposed antenna enjoys good characteristics such as reasonable impedance bandwidth, good VSWR of 1.1997 and a radiated power of 30.106 dBm. The antenna’s three-dimensional radiation pattern resembles the doughnut shape. The antenna’s reflection coefficient is -20.8 dB, proving the design to be more convincing.

REFERENCES