Silicone Rubber Superstrate Loaded Patch Antenna Design Using Slotting Technique

Bhupinder Kaur¹, Garima Saini¹ and Ashish Saini²
¹ Department of ECE, NITTTR, Sector-26, Chandigarh-160026, India
² T.B.R.L., Defence Research & Development Organisation, Sector 30, Chandigarh-160030, India

E-mail: bhupinderk606@yahoo.com

Abstract. For the protection of antenna from external environmental conditions, there is a need that antenna should be covered with a stable, non-reactive, highly durable and weather resistive material which is insensitive to changing external environment. Hence, in this paper silicone rubber is proposed as a superstrate layer for patch antenna for its protection. The electrical properties of silicon rubber sealant are experimentally found out and its effect of using as superstrate on coaxial fed microstrip patch antenna using transmission line model is observed. The overall performance is degraded by slightly after the use of superstrate. Further to improve the performance of superstrate loaded antenna, patch slots and ground defects have been proposed. The proposed design achieves the wideband of 790 MHz (13.59 %), gain of 7.12 dB, VSWR of 1.12 and efficiency of 83.02 %.

Keywords: Bandwidth, Gain, Microstrip Antenna, Superstrate.

1. Introduction
Silicone rubber is generally non-reactive, stable and resistive to environmental changes. It has the capability of excellent adhesion to substrate materials like FR4. Its low viscosity property allows it to fill many fracture and voids in potting and sealing applications. At room temperature, this material cures to a solid form and adheres to common substrates including metals, ceramics and various plastics. The major advantage of this material is that it has the wide temperature range i.e. -65°C to 180°C [1]. In the view of these properties and its ease of application, silicone rubber is used in numerous products like automobile applications, electronic products, medical devices, implants, hardware devices and home repair devices [1].

Microstrip patch antenna is widely used by radio frequency (RF) & Microwave engineers and researchers because of its advantages like low profile, light weight and economical for bulk manufacture [2]. There have been a consistent focus of research on microstrip antenna since 1970s. However, they have the limitation of narrow bandwidth and low efficiency [3]. The patch antenna consists of a substrate, patch and a metallic ground. Both patch and ground get oxidized under extreme environment conditions like high humidity, as copper is used in them. To overcome above limitations, various attempts have been made recently to make an antenna insensitive to changing environment. Adding a superstrate layer over patch antennas or by placing the antenna under plastic covers is one of the solutions for protecting the antenna from environmental hazards like moisture and temperature [4].
Numerous superstrates and their configurations were reported by the various researchers in the literature to improve the antenna performance. This includes dielectric slabs [5], electromagnetic band gap structures (EBGs) [6], high reflective surfaces [7], metamaterials [8], fully or partially covered [9] and most recently the artificial magnetic superstrates (AMS) [10]. However, the effect of superstrate-substrate spacing and shape of superstrate can also affect the antenna performance. Various other materials like teflon, polypropylene, polystyrene and polycarbonate have been also reported as superstrate [11]. Moreover, it is desired to use material that is easily available in the market with low cost for bulk production.

All the simulations have been performed in the high frequency structural simulator HFSS version 16. C band is chosen for the operation of the patch antenna which ranges from the 4 - 8 GHz according to IEEE spectrum.

2. Dielectric properties of silicone rubber in c band

At high frequency, electromagnetic parameters of material should be known. The dielectric constant and dissipation factor value is experimentally found at high frequencies by Agilent technologies vector network analyzer (E8501C series). Silicone rubber is highly inert and does not react with the most chemicals. They exhibit excellent properties like wide temperature range, weather resistance, nontoxic, high durable and so on. In its uncured state it is highly adhesive gel type or in liquid form, in furtherance to get into a solid form/ rough rubbery solid form it must be cured [1]. In this paper the silicone rubber RS 692-542 is used. As mentioned above, the desired antenna needs to operate in the high frequency range in C (4-8 GHz) band. Therefore, the dielectric properties of the silicone rubber need to be measured in the desired frequency band. The experimental setup is shown in the figure 11 (a). The cured material is taken in the ring shape having an outer radius of $R= 7.0$ mm and inner radius of $r= 3.05$ mm as shown in figure 1 (b). The value of dielectric permittivity obtained is 2.7 shown in figure 1(c), and remains constant in the frequency range of c band. The value obtained for dissipation factor measured is 0.00019 at 5 GHz as shown in figure 1 (d). So, this material with the above dielectric properties can be used for the antenna for the protection from adverse environmental conditions.
3. Effect of silicone rubber material over patch antenna

3.1. Patch antenna design without superstrate

The dimensions of the basic patch antenna are calculated with the help of the equations using transmission line model [12]. All the dimensions are mentioned in the table 1. The geometry of the patch antenna is shown in figure 2.

| Parameters | Size  | Parameters           | Size  |
|------------|-------|----------------------|-------|
| L          | 22 mm | h                    | 1.6 mm|
| W          | 24 mm | Feed pin height      | 1.6 mm|
| l          | 12 mm | (x,y)                | (0,3) |
| w          | 16 mm | Feed pin radius      | 0.7 mm|
3.2. **Patch antenna design with superstrate**

Silicone rubber material is of thickness \( K = 1.6 \) mm is used as the superstrate which is shown in figure 3. The simulation results of antenna with and without superstrate are shown in the figure 4. The values of -10 dB bandwidth, reflection coefficient and resonant frequency can be measured. There is a slight decrease in the value of the gain. The value of VSWR should be less than 2. For both the antennas the value of VSWR is 1.12 and 1.20, respectively. The comparison results of effect of superstrate over patch antennas are shown in table 2.

![Figure 3. Patch antenna design with superstrate (a) Top view and (b) Side view.](image)

![Figure 4. Simulation results of antenna with and without superstrate.](image)

![Table 2. Comparison results of effect of superstrate over patch antennas.](image)
Figure 4. Simulation result of antenna without superstrate and antenna with superstrate (a) reflection coefficient v/s frequency, (b) smith chart, (c) radiation pattern and (d) VSWR v/s frequency.

Table 2. Effect of superstrate over patch antenna

| Performance parameters       | Patch antenna without superstrate | Patch antenna with superstrate |
|------------------------------|-----------------------------------|-------------------------------|
| Bandwidth                    | 5.50 % (300 MHz)                  | 5.07 % (260 MHz)              |
| Gain                         | 6.59 dB                           | 6.50 dB                       |
| VSWR                         | 1.12                               | 1.20                          |
| Resonant Frequency           | 5.45 GHz                           | 5.12 GHz                      |
| Reflection Coefficient       | -24.5 dB                          | -20.8 dB                      |
| Efficiency                   | 78.62 %                            | 78.62 %                       |

4. Proposed patch antenna design

The performance parameters of the patch antenna with superstrate material are degraded slightly i.e. gain is 6.59 dB without superstrate or conventional patch antenna whereas with superstrate gain is 6.60 dB. So to improve the performance, there was a need to modify the design and optimize patch antenna for high value of gain and bandwidth with superstrate. Hence, in this paper the patch sloting technique is used. Further to enhance the bandwidth, the ground defects are introduced. The geometry of the patch antenna is shown in figure 5. All the dimensions of the proposed patch antenna design are shown in table 3. The slots results in redistribution of current of antenna which leads to increase in gain and bandwidth.
Figure 5. Proposed patch antenna design with superstrate (a) 3D view and (b) Top view.

**Table 3. Dimensions of proposed patch antenna**

| Parameters | Size      | Parameters | Size      |
|------------|-----------|------------|-----------|
| Ground size | 24 mm x 22 mm | K          | 1.6 mm    |
| L          | 12 mm     | l_4        | 4 mm      |
| W          | 16 mm     | w_1        | 18 mm     |
| l_1        | 4 mm      | w_2        | 20 mm     |
| l_2        | 4 mm      | w_3        | 4.1 mm    |
| l_3        | 4 mm      | w_4        | 3.1 mm    |

The simulation results are compared in the following graphs shown in the figure 6.
Figure 6. Simulation result of proposed antenna design and antenna with superstrate (a) Reflection coefficient v/s frequency, (b) Smith chart, (c) Radiation pattern and (d) VSWR v/s frequency.

Table 4. Comparison of proposed antenna design and patch antenna with superstrate

| Performance parameters | Patch antenna with superstrate | Proposed antenna design |
|------------------------|--------------------------------|-------------------------|
| Bandwidth              | 5.07 % (260 MHz)               | 13.59 % (790 MHz)       |
| Gain                   | 6.50 dB                        | 7.12 dB                 |
| VSWR                   | 1.20                           | 1.12                    |
| Resonant frequency     | 5.12 GHz                       | 5.81 GHz                |
| Reflection coefficient | -20.8 dB                       | -39.65 dB               |
| Efficiency             | 78.62 %                        | 83.02 %                 |

The performance parameters of the proposed patch antenna and the patch antenna with superstrate are shown in the table 4. With the new proposed design the gain is increased by the 0.62 dB and efficiency is also increased by the 4.4 %. A bandwidth of 790 MHz was also achieved in the proposed design. The value of VSWR is also improved to 1.12 from 1.20. There is a shift in resonant frequency towards right side of the spectrum of frequency with slots in ground and patch which can be taken care by slightly reducing the size of patch resulting in miniaturisation also.

5. Conclusions
The electrical characteristics of silicone rubber material i.e. relative permittivity of 2.7 and loss tangent of 0.00019 were measured. The effect of this material over the patch antenna performance is checked.
The results show a very small reduction in the performance parameters. To further improve the performance of rectangular patch antenna with superstrate layer, the ground defects and patch slots are presented. The parameters are improved in the proposed design and the same also results in slight miniaturisation of antenna over conventional one.

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