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Improving the performance of a planar UWB antenna by adding cover layers

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Abstract: In this paper, we investigate the effects of adding cover layers to the multi-layer structure of a planar UWB antenna on the antenna performance parameters. With the proposed technique, the antenna return loss can be enhanced and the matched frequency bandwidth can be increased. In some cases a multi-band antenna can achieve the performance of a wide band antenna covering all its original frequency bands and the gaps between them. With proper selection of the cover layer material, thickness, and position (on top, bottom and/or both), we can get significant improvements in the antenna return loss. In the same paper we investigate the effect of cover layer on other antenna performance parameters, such as gain, efficiency and radiation pattern. Using the solder mask as an antenna cover layer is a very useful technique that we propose. It is very economical, widely available and very easy and fast to fabricate.

[M. Y. Elhefnawy, Aladdin Assisi, Ibrahim F. Taradand Hosny Almotaafy. **Improving the performance of a planar UWB antenna by adding cover layers.** *Life Sci J* 2019;16(11):101-111]. ISSN: 1097-8135 (Print) / ISSN: 2372-613X (Online). http://www.lifesciencesite.com. 11. doi:10.7537/marslsj161119.11.

Keywords: UWB antennas, PCB cover materials, return loss, solder mask, printed monopole antenna.

1. Introduction

UWB technology is very important to many potential applications due to larger channel capacity and higher time precision etc. [1]. Moreover; increasing data rates needs more bandwidth. It is safe to state that the demand for wideband antennas increases in response to wireless communication applications requiring more and more bandwidth. The problem of using multiple antennas for a number of applications operating in handheld devices can be solved by employing UWB and SWB monopole structures in which a single antenna can cover the entire operating bandwidth; as a result, the size of the device becomes miniaturized. Both long-range and short-range communications including the ultra-wideband (UWB) range are covered by SWB antennas. A single UWB antenna can be used to cover simultaneously many communication bands such as GSM/UMTS (800/850/900/950/1800/1900/2100 MHz), GPS (1227.60/1575.42 MHz), ISM (2.4/24.25 GHz), WLAN / Wi-Fi (3.6/4.9/5/5.9 GHz), radio determination applications (4.5–7 GHz, 13.4-14 GHz) and UWB communication (3.1–10.6 GHz). A SWB antenna can cover all these bands, together with radio astronomy (22.5 GHz, 24.05–27 GHz) [2-3] and millimetric band communications. Another important advantage of using a wide antenna bandwidth is a high resilience to fading [4].

A PCB antenna has a low profile, low manufacturing costs and can easily be integrated with other parts of Monolithic Microwave Integrated Circuits (MMIC). This allows a compact module design [5]. The main drawback is its limited bandwidth. Planar monopole antenna has the same merits of planar structure, compact size and consistent radiation characteristics. At the same time, its bandwidth can be significantly increased. Therefore, it has become one of the most attractive candidates for UWB and SWB antennas [6], [7]. The state of the art UWB and SWB antenna focuses mainly on planar monopole microstrip antennas that can be directly printed onto printed circuit boards (PCBs) and have wide bandwidths that can be further extended as we are going to show in this letter.

Ideally, an UWB antenna ought to have a sufficiently wide bandwidth so as to cover the entire UWB spectral bandwidth. As demonstrated in [4], this is not an easy task to achieve. A lot of articles have been presented by several researchers across the globe related to SWB antennas. The major concern in SWB wireless handheld terminals is the design of the antenna; compact size with good radiation capability [8]. To satisfy such requirements, various types of planar antennas have been developed and several bandwidth enhancement techniques have been released such as making slots in ground plane and patch, patch tapering, reducing ground plane and defecting it [9]. A variation of the novel technique called defected microstrip structure (DMS) was employed by Peyrot-Solis et-al to enlarge the bandwidth of a planarized ultra-wide band (UWB) monopole. It was demonstrated that introducing a defect in the feeding microstrip line, the lower bandwidth limit is lowered without affecting the antenna gain and radiation pattern. The bevel technique in the ground plane near to the feeding point was used to increase the highest bandwidth limit [10]. Monopole antennas with defected ground plane are also very popular for achieving (UWB) and super wideband (SWB) [8].

One of the essential parameters of wide band planar antennas is its impedance matching and impedance bandwidth which may be significantly improved by using multilayer dielectric configuration. To achieve this, the emphasis is mainly laid on S11 enhancement factors of a multilayer patch antenna specially the physical parameters of the substrate and covered materials.

1. Effect of solder mask coating on the return loss of UWB antennas

In order to study this effect we have to simulate different models of UWB antennas and study the effect of solder mask coating on each model. The results of this study are reported in the following examples.

1.1 Octagonal antenna on a 0.78mm TLY-5 substrate

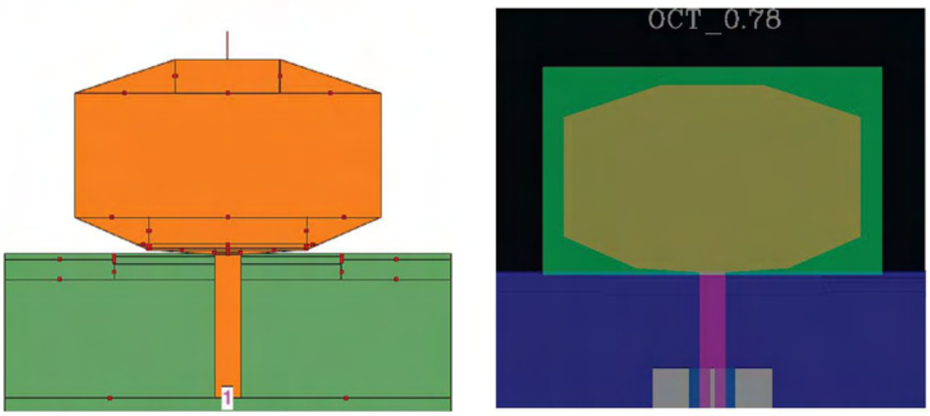


Figure 1 Geometry of the 0.78mm TLY-5 Substrate Octagonal Antenna

To allow the antenna radiation without solder mask, two equal openings are done in the TOP MASK and BOTTOM MASK layers around the octagon as shown in the layout above. The simulation of this model results in the following frequency response.

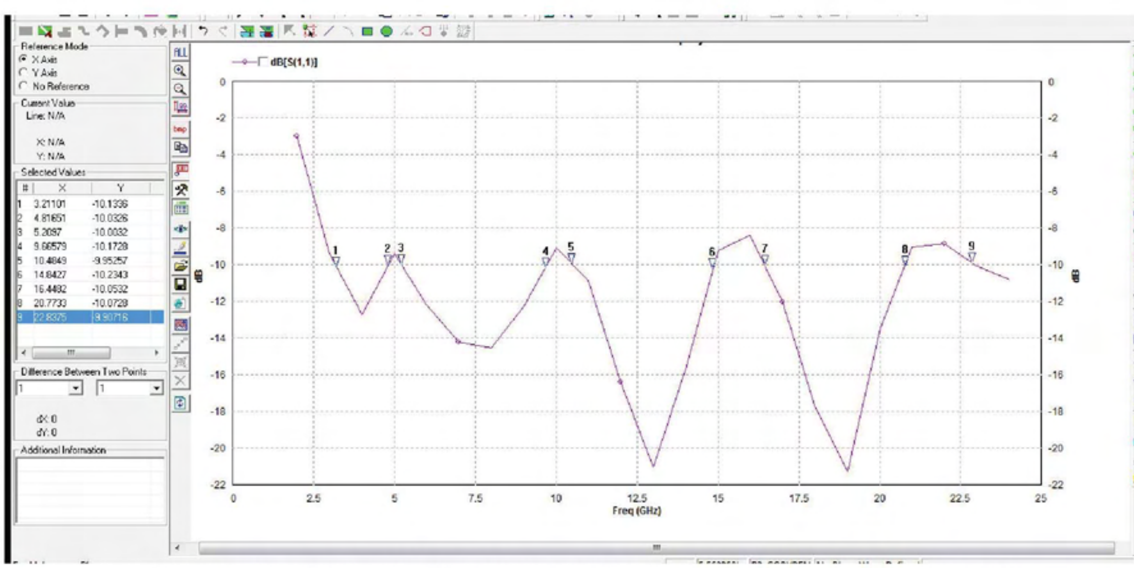


Figure 2. Simulated S11 of the 0.78mm TLY-5 Substrate Octagonal Antenna

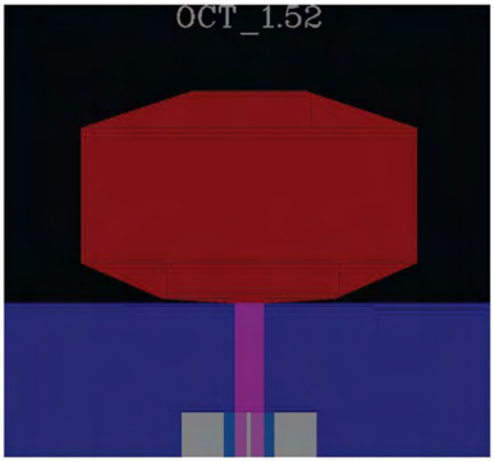


Figure 3. Geometry of the 0.78mm TLY-5 Substrate Octagonal Antenna with solder mask

It can be seen from the above frequency response that we have a multi-band antenna with gaps between its frequency bands.

1.2 Coating the 0.78mm TLY-5 Octagonal Antenna with Solder Mask

Let us study the effect of solder mask coating of the octagonal antenna. A typical relative dielectric constant of the solder mask material is 3.5 and its typical loss tangent is of the order of 0.01. The typical thickness of a solder mask is 0.02 mm. The solder mask coated antenna has a continuous solder mask layer without any opening, as shown in the following figure 3.

Two 0.02mm solder mask layers have been inserted in the IE3D Zeland simulator below the BOTTOM layer and above the TOP layer and the simulation was run with these solder mask layers. The results are the following:

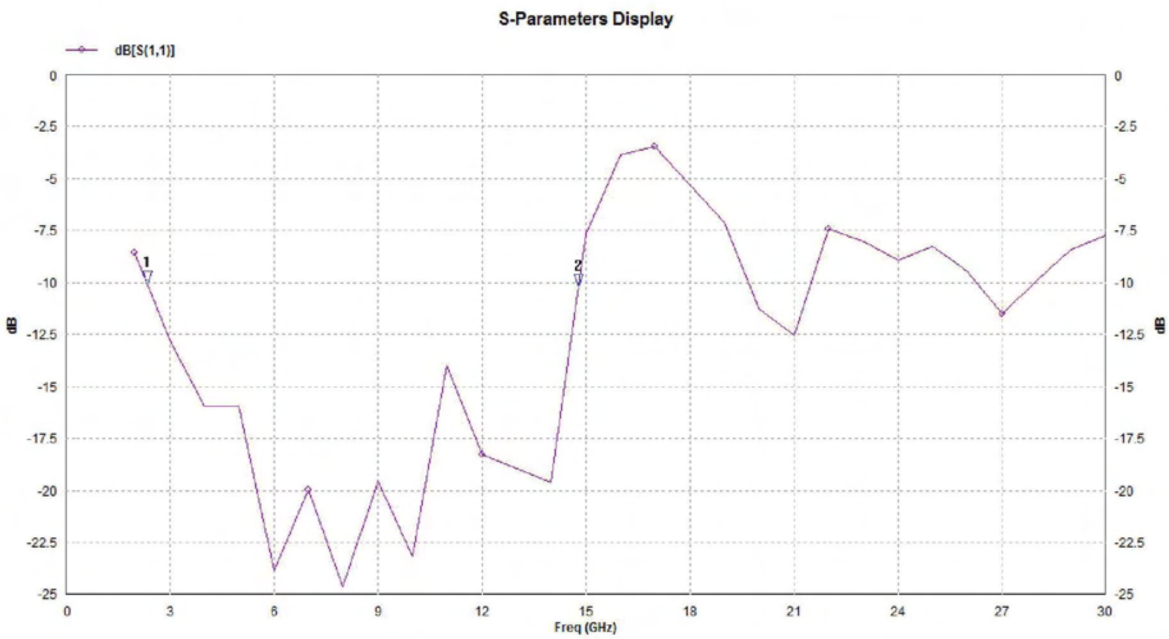


Figure 4. Simulated S11 of the 0.78mm TLY-5 Substrate Octagonal Antenna with solder mask

It is evident that the antenna with solder mask coating becomes an UWB antenna covering the frequency band 2.35 to 14.78 MHz with a very good matching.

1.3 The same Octagonal antenna on a 1.52mm TLY-5 substrate

Increasing the substrate thickness the antenna BW increases as shown in the following figure. We have got a wider BW (up to 35 GHz with a small exception from 15 to 15.2 GHz)

It is evident that the antenna is well matched between 2.7 GHz and more than 35 MHz, except for a small region between 15.1546 and 15.732 MHz where S11 is > -10 dB (It is of the order of -9.5 to -10 dB). Comparing with the same octagon on a 0.78mm substrate of the same material, the frequency band extended from 22 GHz to 35 GHz and the mismatch zone has become very small in width (0.6GHz) and in depth (0.5dB). The antenna can be considered an UWB antenna and not a multi-band antenna.

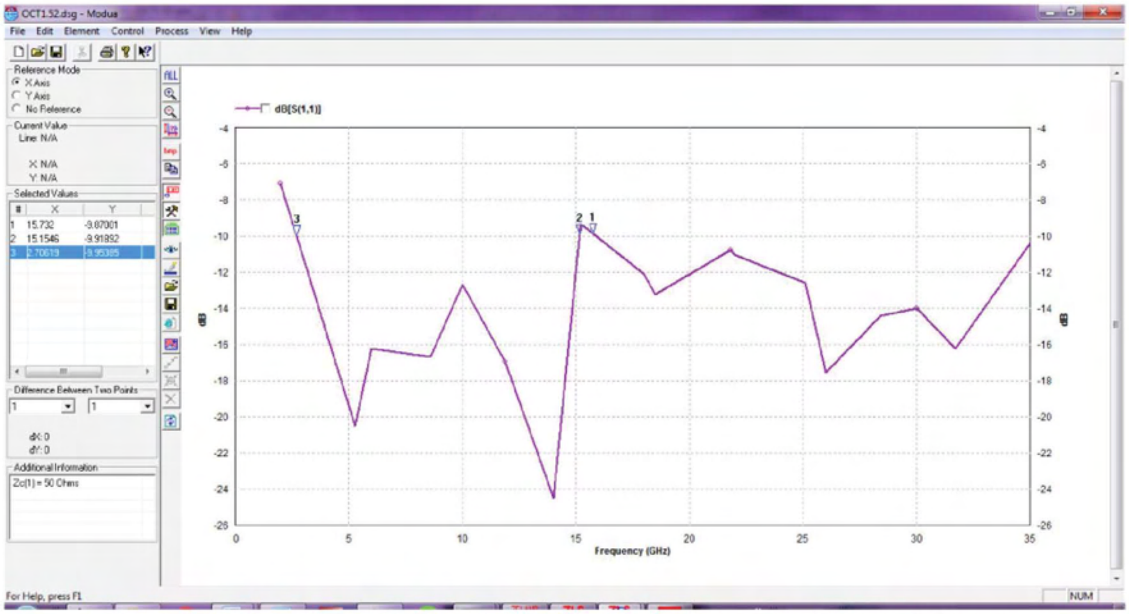
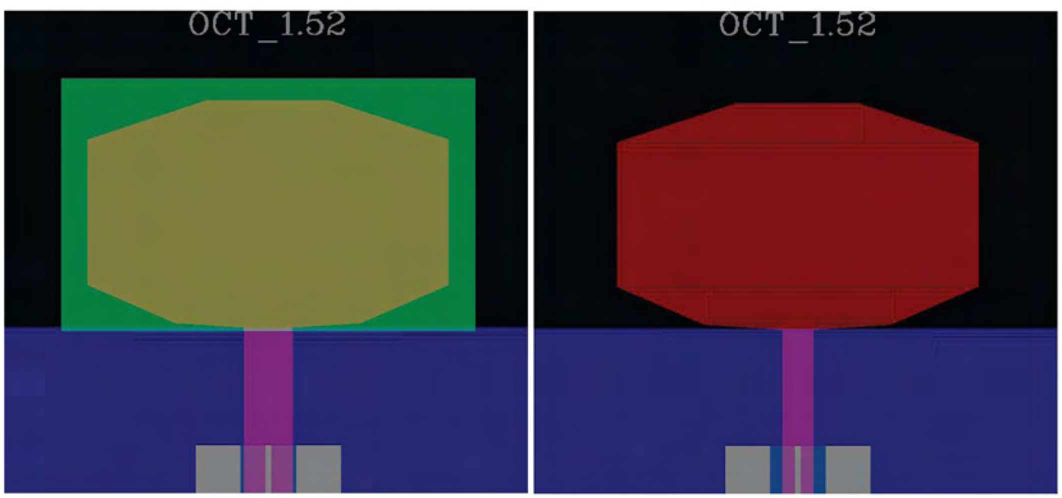


Figure 5. Simulated S11 of the 1.52mm TLY-5 Substrate Octagonal Antenna

1.4 Coating the 1.52mm TLY-5 Octagonal Antenna with Solder Mask



a. uncoated antenna **b. solder mask coated antenna**

Figure 6 Geometry of the 1.52mm TLY-5 Substrate Octagonal Antenna

Let us study the effect of solder mask coating on the 1.52mm octagonal antenna.

A typical relative dielectric constant of the solder mask material is 3.5 and its typical loss tangent is of the order of 0.01. Its typical thickness is 0.02 mm. Two 0.02mm solder mask layers have been inserted in the IE3D Zeland simulator below the BOTTOM layer and above the TOP layer and the simulation was run with these solder mask layers. The results are the following:

It is evident that the solder mask coating has enhanced the antenna performance.

As we have noted with the 0.78mm octagonal antenna, although the solder mask coating has decreased the maximum frequency from 35 to 34.27 GHz, we have got a much better matching within the band. The mismatch region completely disappears.

1.5 An Elliptic Monopole Antenna on a 0.78mm TLY-5 substrate

The simulated frequency response of this antenna is shown in the following figure. It is a multi-band antenna. It has three similar bandwidths around 7.5, 12.5 and 19 GHz.

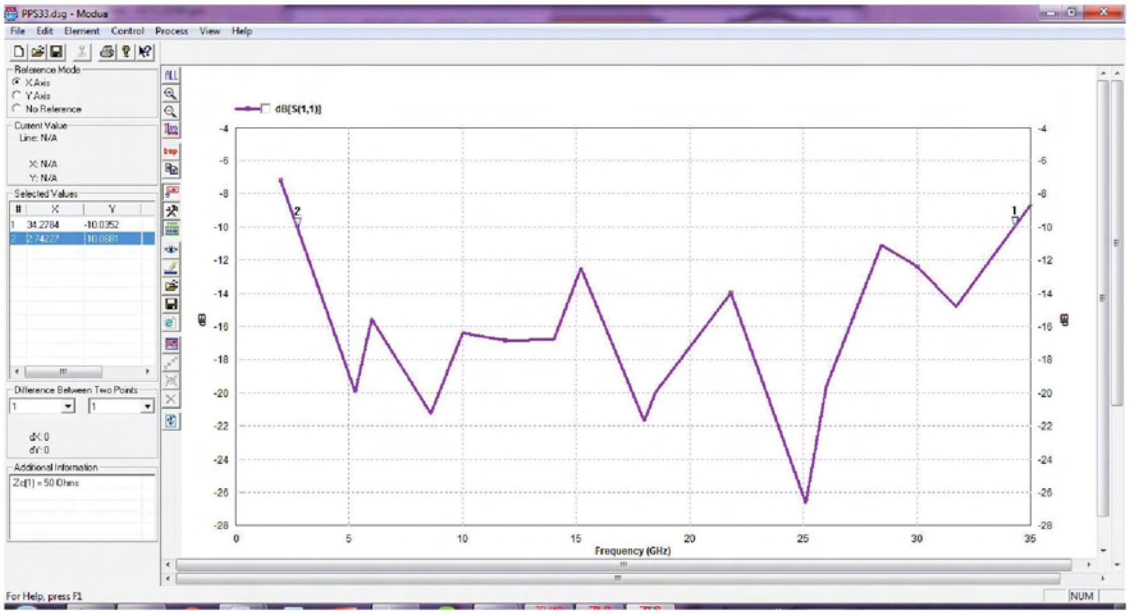


Figure 7. Simulated S11 of the 1.52mm TLY-5 Substrate Octagonal Antenna with solder mask

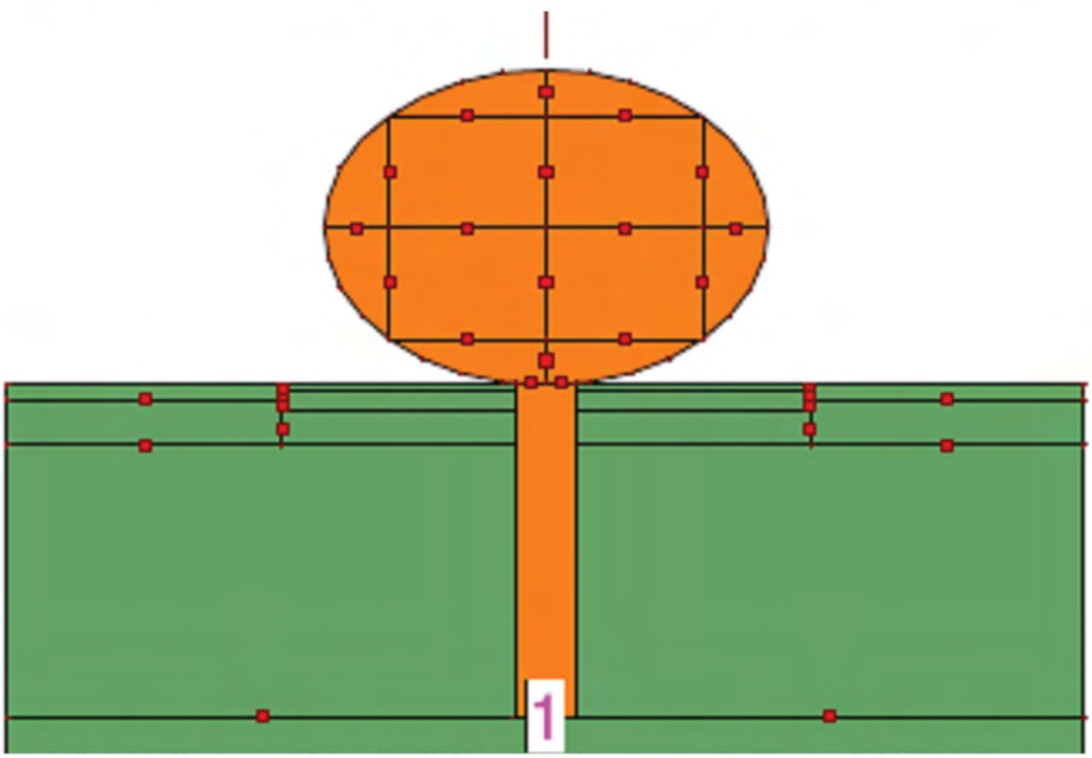


Figure 8. Geometry of An Elliptic Monopole Antenna on a 0.78mm TLY-5 substrate

1.6 The same elliptic antenna on a 1.52mm TLY-5 Substrate

As with the octagonal mnopole antenna, increasing the substrate thickness increases the anttenna bandwidth. The following S11 vs. frequency shows an enhanced performance.

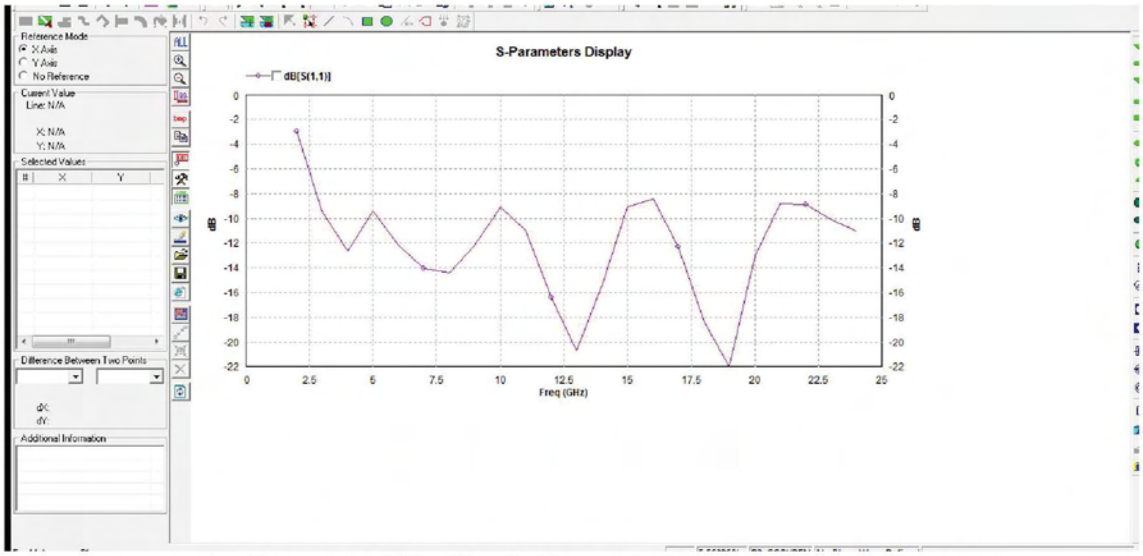


Figure 9. Simulated S11 of the 0.78mm TLY-5 Substrate elliptic Antenna

1.7 The same elliptic antenna on a 1.52mm TLY-5 Substrate

As with the octagonal mnopole antenna, increasing the substrate thickness increases the anttenna bandwidth. The following S11 vs. frequency shows an enhanced performance.

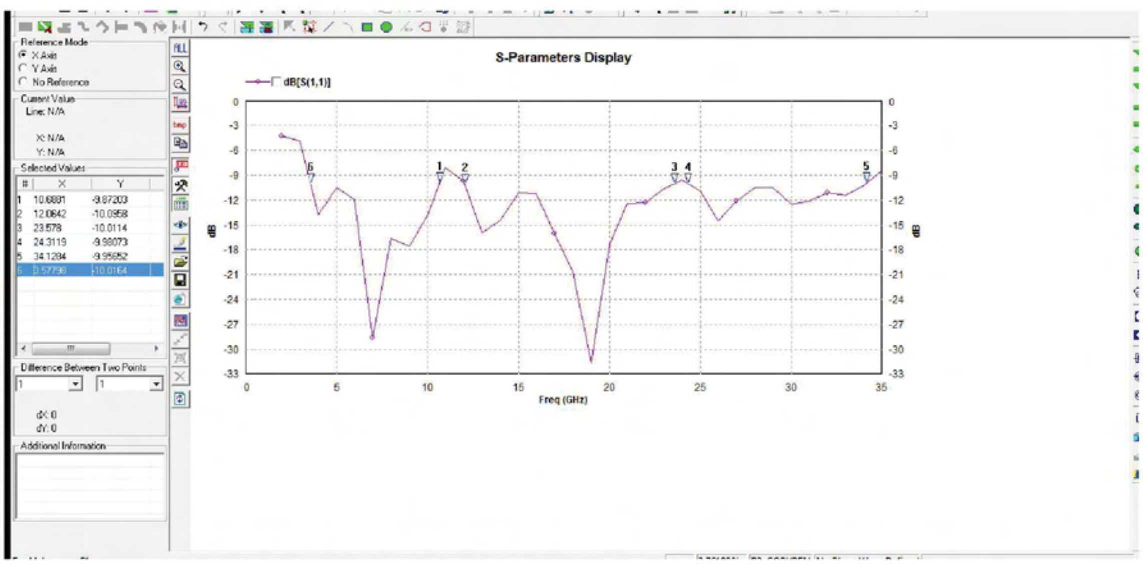


Figure 10 Simulated S11 of the 1.52mm TLY-5 Substrate elliptic Antenna

It is nearly an UWB antenna, from 3.6 GHz to 34 GHz, except for two small regions, between 10.69 and 12 GHz and between 23.6 and 24.3 GHz.

1.8 Coating the 1.52mm TLY-5 Elliptic antenna with Solder Mask

Let us study the effect of solder mask coating on the elliptic antenna. Two 0.02mm solder mask layers have been inserted in the IE3D Zeland simulator below the BOTTOM layer and above the TOP layer and the simulation was run with these solder mask layers. The results are the following:

Comparing the results with the last simulation, it is evident that the solder mask enhanced the performance of the UWB antenna. Again, instead of a multi-band antenna, we have got an UWB antenna with a33 GHz continuous bandwidth.

Figure 11. Geometry of the 1.52mm TLY-5 Substrate Elliptic Antenna with solder mask

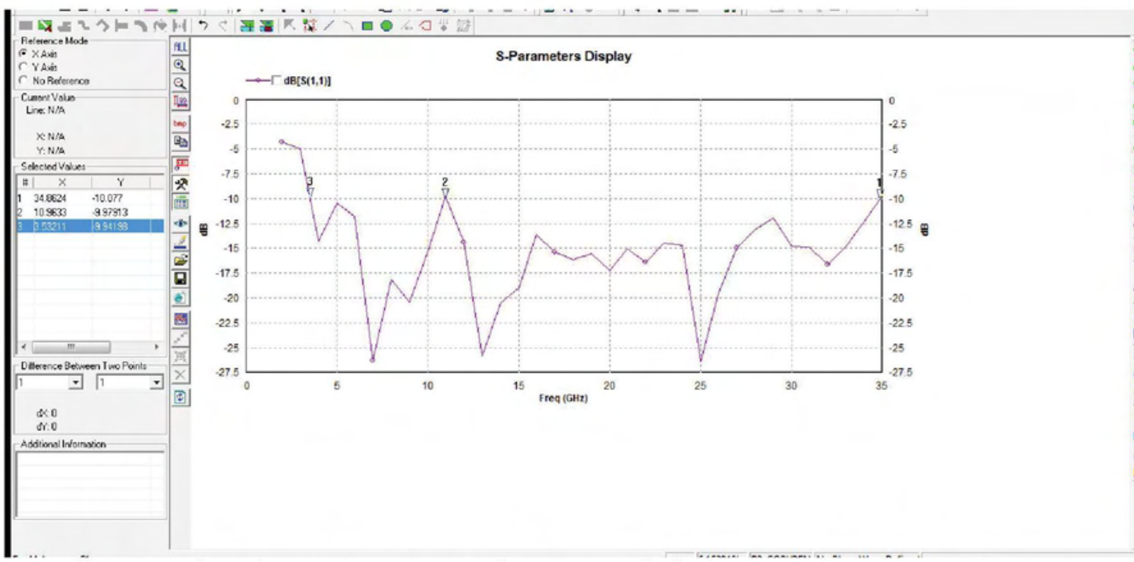


Figure 12. Simulated S11 of the 1.52mm TLY-5 Substrate Elliptic Antenna with solder mask

2. Effect of solder mask coating on the return loss of SWB antennas

We have designed a planar SWB printed monopole antenna covering the frequency band (2.18 GHz-44.5 GHz) which makes it appropriate for many wireless communication systems, medical applications, electronic warfare systems and SWB radar systems. The model antenna has been designed and implemented on a Taconic TLY-5 substrate with a low dielectric constant (DK=2.17), low loss tangent (DF=0.0009) and substrate thickness 1.52 mm. The proposed antenna was successfully implemented on this material and the simulated results showed reasonable correlation with the measured results. The model antenna bandwidth was 2.18 to 45 GHz frequency where S11 <-10 dB and VSWR< 2.

The same SWB antenna has been simulated with solder mask cover on top, bottom and both layers. The cover material is the solder mask of series Elpemer 2467 with dielectric constant of 3.7, tangent loss of 0.029 and thicknesses 0.01, 0.02 and 0.03 mm. We have varied the solder mask thickness in the three situations to study its effect. The results are summarized in the following figures.

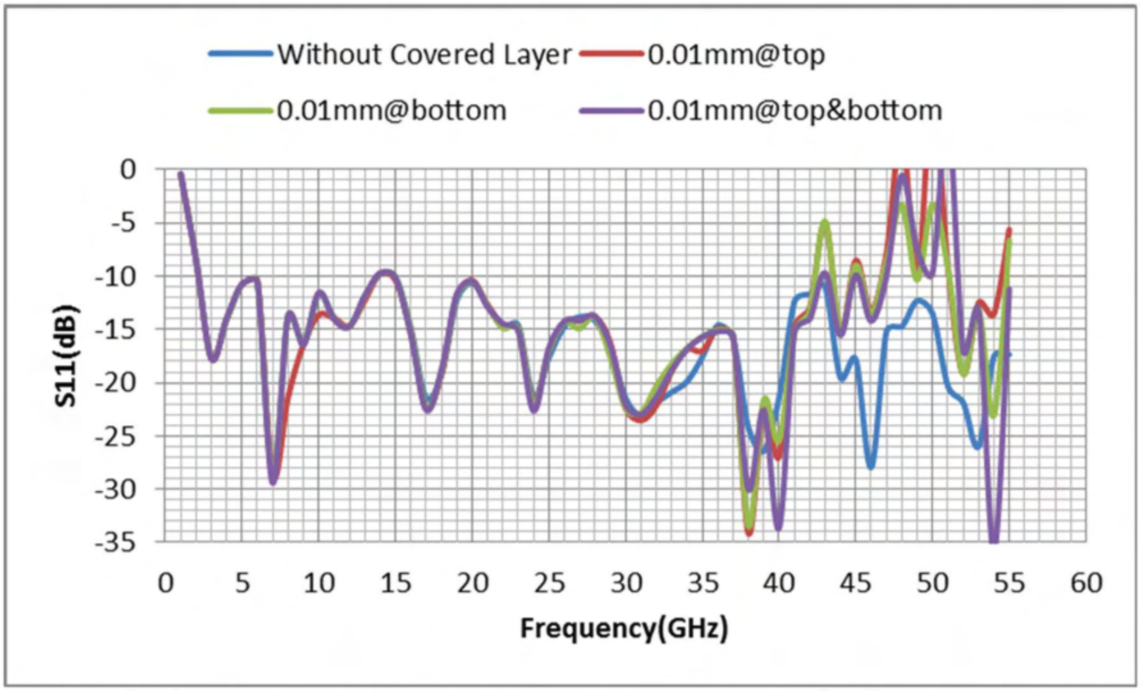


Figure 13. The S11 for the antenna without covered layer and the antenna with Covered solder mask layer of thickness of 0.01mm

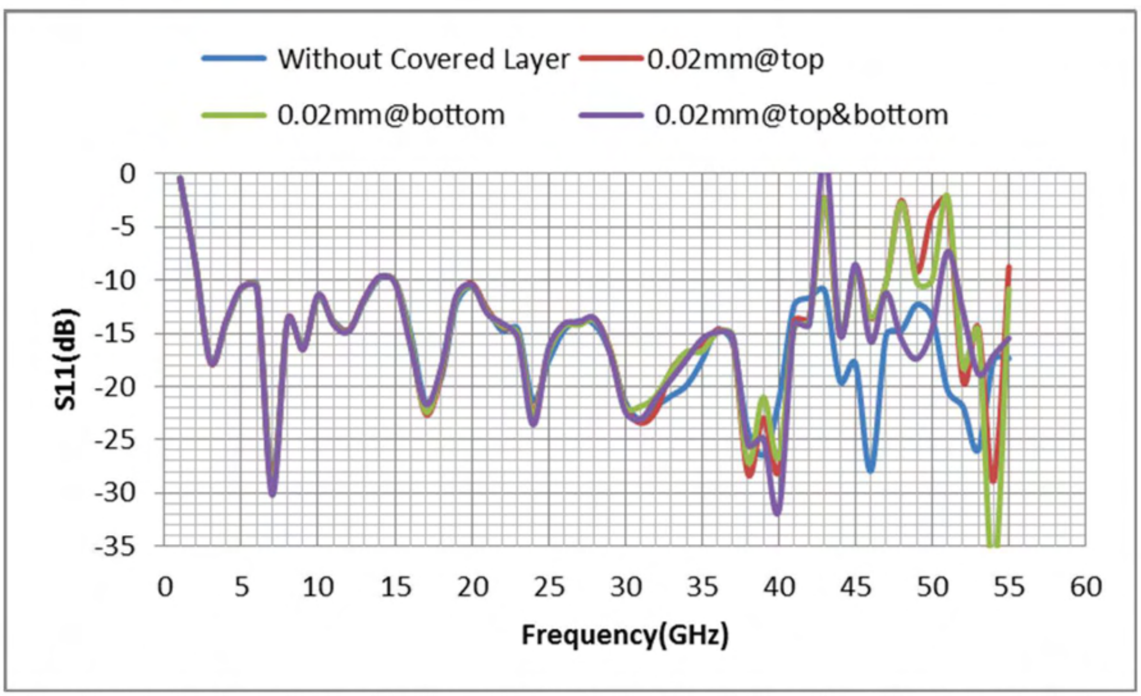


Figure 14. The S11 for the antenna without covered layer and the antenna with Covered solder mask layer of thickness of 0.02mm

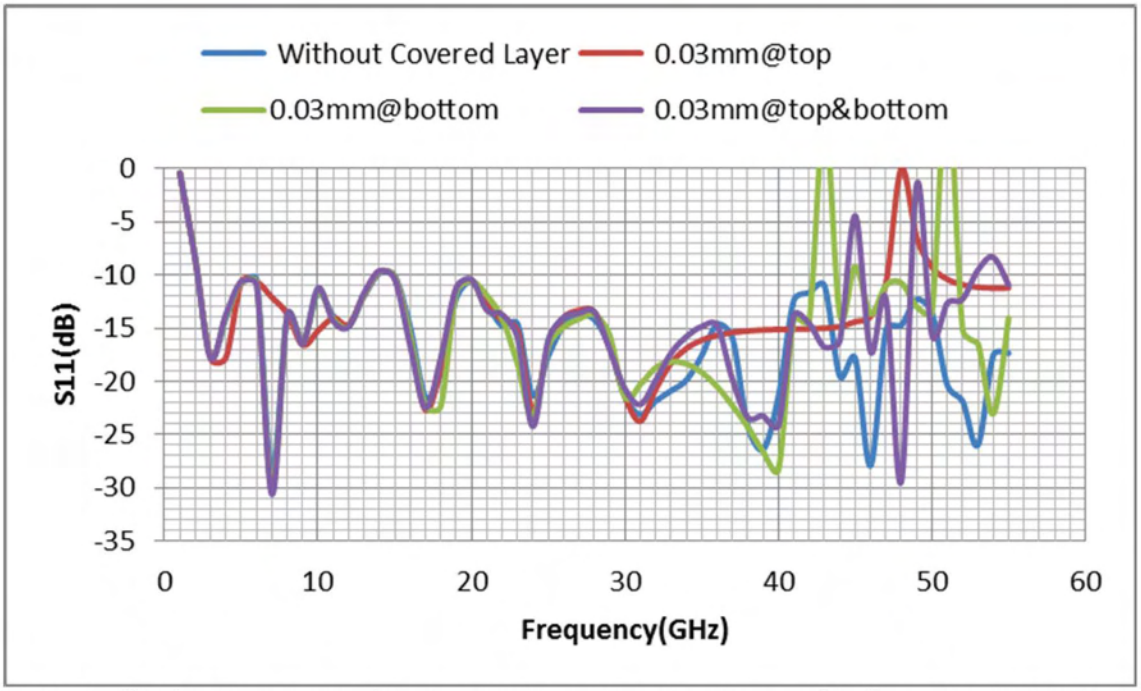


Figure 15. The S11 for the antenna without covered layer and the antenna with Covered solder mask layer of thickness of 0.03mm

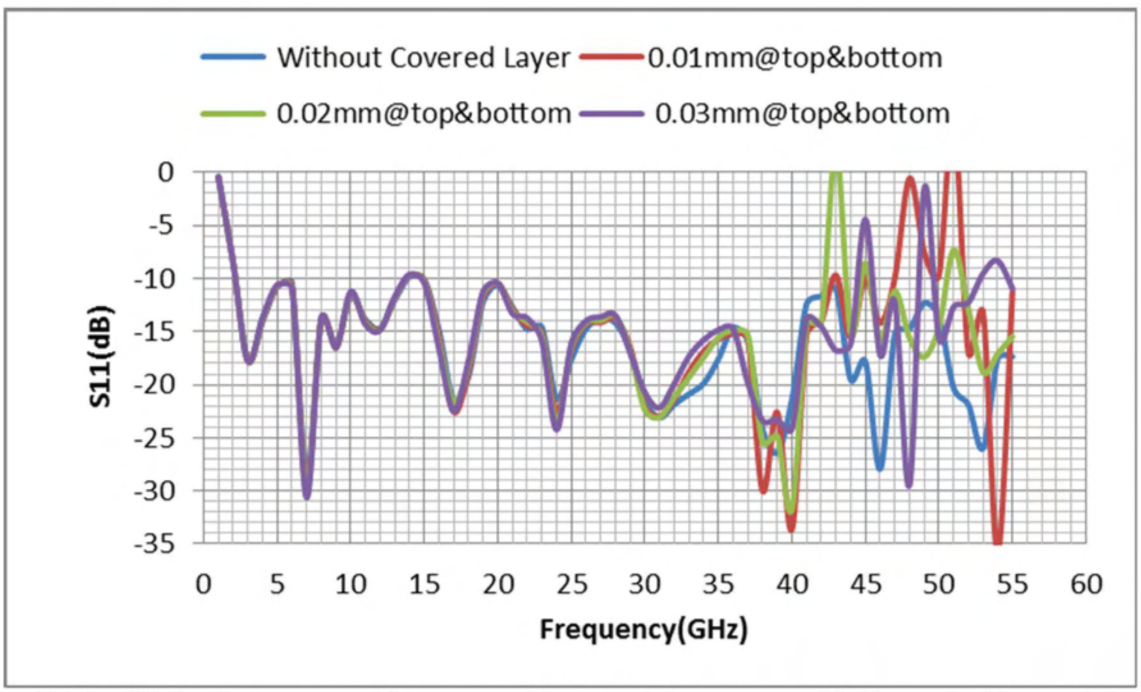


Figure 16. The S11 for the antenna without covered layer and the antenna with Covered solder mask layer of all thickness

It can be seen from the above figures that:

- The solder mask cover enhances the return loss of the SWB antenna.
- Two cover layers (top and bottom) give better performance than a single layer.
- Increasing the cover layer thickness increases the return loss.

3. Effect of solder mask coating on other antenna parameters

To study the effects of solder mask coating on these parameters, we have run ten extensive simulations at the entire SWB frequency band from 2 GHz up to 50 GHz.

We have simulated ten different cases of the SWB antenna:

a. The SWB antenna without coating.

b. The same antenna with top 0.01mm solder mask coating.

c. The same antenna with bottom 0.01mm solder mask coating.

d. The same antenna with top and bottom 0.01mm solder mask coating .

e. The same antenna with top 0.02mm solder mask coating .

f. The same antenna with bottom 0.02mm solder mask coating.

g. The same antenna with top and bottom 0.02mm solder mask coating .

h. The same antenna with top 0.03mm solder mask coating .

i. The same antenna with bottom 0.03mm solder mask coating.

j. The same antenna with top and bottom 0.03mm solder mask coating.

We have got a huge size of data describing the SWB antenna performance parameters at every frequency point in the ten different cases.

We shall take some samples of the results to give an idea of the coating effects on the SWB antenna parameters. The results are summarized in the following tables. We have taken four sample frequencies at which the main antenna performance parameters are compared.

Table 1. describes the Effect of solder mask coating in 10 different cases (of thickness and orientation) on other antenna parameters at 10GHz.

Performance parameters	Un-covered	0.01 mm Top	0.01 mm Bot	0.01 mm Top/ Bot	0.02 mm Top	0.02 mm Bot	0.02 mm Top/ Bot	0.03mm Top	0.03mm Bot	0.03mm Top/ Bot
Radiation Eff. %	54.6	56	54	53.6	53.6	53.5	52.7	55	53	51.87
Total Eff. %	50.9	53.8	50.4	49.9	49.7	49.8	48.9	52.85	49.3	47.8
maximum gain dB	2	2	2	1.98	1.97	1.98	1.9	1.997	1.94	1.84
Directivity dB	4.98	4.76	4.99	5	5	5	5	4.77	5	5
Max. gain angle [°]	60, 10	60, 20	60, 10	60, 10	60, 10	60, 10	60, 10	60, 20	30, 10	60, 10
3dB beam width [°]	37, 69.5	35.7, 69.1	37.3, 69.5	37.5, 69.5	37.5, 69.5	37.5, 69.5	37.3, 69.5	35.3, 69.4	37.5, 69.5	36.9, 69.5

Table 2. describes the Effect of solder mask coating in 10 different cases (of thickness and orientation) on other antenna parameters at 20GHz

Performance parameters	Un-covered	0.01 mm Top	0.01 mm Bot	0.01 mm Top/ Bot	0.02 mm Top	0.02 mm Bot	0.02 mm Top/ Bot	0.03mm Top	0.03mm Bot	0.03mm Top/ Bot
Radiation Eff. %	52.2	52.5	51.3	51.6	53	50.6	51.4	56.8	49.9	51.4
Total Eff. %	47.6	47.7	46.7	46.97	48	46	46.7	53.8	45.5	46.7
maximum gain dB	2.7	2.4	2.44	2.29	2.4	2.3	2.3	2.72	2.2	2.36
Directivity dB	5.93	5.6	5.75	5.56	5.6	5.67	5.62	5.4	5.6	5.67
Max. gain angle [°]	45, 90	45, 90	45, 90	60, 0	60, 170	45, 90	60, 170	60, 10	45, 90	60, 170
3dB beam width [°]	17.6, 30.3	17.7, 31.8	17.6, 31.1	0, 0	29.5,56.5	17.6, 32.65	8.8, 54.4	26.4, 87	17.7, 34.5	28.28, 51.7

Table 3. describes the Effect of solder mask coating in 10 different cases (of thickness and orientation) on other antenna parameters at 30GHz

Performance parameters	Un-covered	0.01 mm Top	0.01 mm Bot	0.01 mm Top/ Bot	0.02 mm Top	0.02 mm Bot	0.02 mm Top/ Bot	0.03mm Top	0.03mm Bot	0.03mm Top/ Bot
Radiation Eff. %	73.4	78.4	65.5	75.7	79.2	74.9	76.5	78.3	73.2	73.1
Total Eff. %	73	77.98	63.44	75.22	78.8	74.4	74.5	77.7	72.7	72.49
maximum gain dB	6.7	6.9	6.8	6.7	7.26	6.8	4.9	7.1	6.77	6.81
Directivity dB	8	7.99	8.8	7.8	8.3	8	6.17	8.2	8.15	8.2
Max. gain angle [°]	60, 270	60, 270	65, 270	60, 270	45, 270	60, 270	140, 90	60, 270	60, 270	60, 270
3dB beam width [°]	17, 28	20, 27	13.9, 17	20.6, 27.27	23.2, 44.4	19.6, 25.8	16.9, 29.5	20.45, 26.1	19.5, 25.2	21, 26.4

We can deduce the following from the four comparison tables:

- Radiation efficiency of a covered antenna is always better than that of uncovered antenna. This result is very important; since it demonstrates that the increase of return loss results in better radiation efficiency.
- We can get the best radiation efficiency when the top layer is coated with solder mask. A thicker cover layer gives better radiation efficiency.
- The total antenna efficiency is enhanced with coating. It is difficult to say the coating thickness/location combination that gives the highest antenna efficiency at all frequencies.

- A thick top coating increases the antenna gain and directivity at higher frequencies.
- Even the antenna spatial coverage (expressed by the 3dB beam width at different frequencies) increases with coating. It is difficult to find a certain combination of cover layer thickness and location that gives better spatial coverage at all frequencies.

Table 4 describes the Effect of solder mask coating in 10 different cases (of thickness and orientation) on other antenna parameters at 40GHz

Performance parameters	Un-covered	0.01 mm Top	0.01 mm Bot	0.01 mm Top/ Bot	0.02 mm Top	0.02 mm Bot	0.02 mm Top/ Bot	0.03mm Top	0.03mm Bot	0.03mm Top/ Bot
Radiation Eff. %	100	100	100	100	100	100	100	100	100	100
Total Eff. %	99.3	99.8	95.6	99.96	95.59	99.78	99.93	96.7	99.85	99.6
maximum gain dB	10.9	11.8	9.19	11.87	8.6	12.3	12	9.2	12.53	11.93
Directivity dB	10.97	11.8	9.39	11.9	8.8	12.3	12	9.3	12.54	11.95
Max. gain angle [°]	45, 270	45, 270	35, 240	45, 270	120, 100	45, 270	45, 270	30, 270	45, 270	45, 270
3dB beam width [°]	8, 31.5	8.6, 19	6.4, 10.8	8.8, 17.2	16.2,39	8.4, 16.7	8.54, 14.89	5.65, 8.38	8.26, 15	8.7, 13.9

4. Conclusion

We can conclude the following:

- Coating a planar printed antenna with a top/bottom combination of cover layers enhances the antenna performance.
- The return loss of the printed antenna is increased with increasing the cover layer thickness. The maximum cover layer thickness that still increases the return loss has to be studied and determined through further simulation and measurement studies.
- With one or two cover layers, a multi-band antenna can be transformed to a wideband antenna by covering frequency gaps between its adjacent bands. This is a big advantage for antenna and RF system designers.
- Another study is needed to investigate the effects of coating material parameters; namely dielectric constant and loss tangent, on the antenna return loss and other parameters.
- Antenna cover layers not only enhance the antenna matching, but also the antenna radiation and total efficiencies. It enhances the antenna gain and spatial coverage at the same time. Further studies are required to investigate these effects and determine how to select the most appropriate coating materials and thicknesses for best performance.
- It is advisable to utilize the commercial solder mask materials already used in printed circuit manufacture to coat printed antennas and enhance their performance.

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11/5/2019