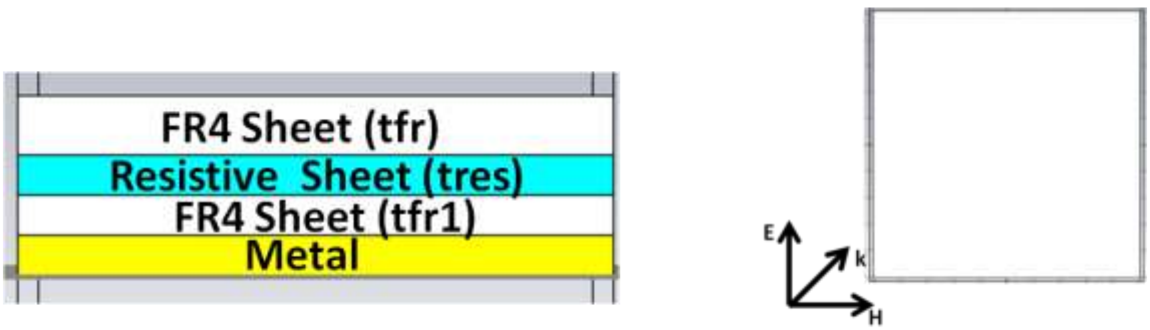
# 6: Multilayer with Engineered Square Patch

The Jaumann absorber (JA) is considered as multilayer absorber, which enhances the bandwidth by introducing additional resonance modes because of multilayer configuration. The chapter presents a design approach to improve the bandwidth of the Triple Layer Microwave Absorber using metallic square patches. TLMA (Triple Layer Microwave Absorber) consists of a metal sheet, FR4 substrate, a resistive sheet of 100 $\Omega/\mathrm{sq}$ and FR4 substrate. The fractional bandwidth for -10 dB reflection of the TLMA with the thickness of 6.13mm is 9.7 GHz (7 GHz-16.7 GHz). In comparison, the fractional bandwidth for -10 dB reflection for square patch-based TLMA is 11.2 GHz (5.6 GHz -16.8 GHz). The improved bandwidth of the designed absorber is achieved with almost the same thickness as the TLMA. The loss mechanism is revealed by field quantities and parametric analysis of the geometric parameters of the designed absorber.

The S-parameters of the proposed absorbers are simulated using CST Microwave Studio. The response of the absorbers is simulated in frequency domain solver under unit cell boundary conditions. The absorbance of the metal back absorber is calculated using the expression $A = 1 - R = 1 - |S_{11}|^2$. The performance of the absorber is analyzed and estimated for different polarization and oblique incidence angles under TE and TM components.

## 6.1 TLMA WITHOUT SQUARE PATCHES

The side and top view of the TLMA are presented in Figure 6- 1(a) and (b) along with wave vector, electric field and magnetic field directions. The TLMA is a layered arrangement of, bottom to top, a metal sheet, FR4 substrate, a resistive sheet of 100 $\Omega/\mathrm{sq}$ and FR4 substrate. The thickness of the base and top FR4 are 3.0 mm and referred to as tfr1 and tfr, respectively (Figure 6- 1(a)). The permittivity and loss tangent of FR4 is 4.2 and 0.02, respectively. The thickness of the resistive sheet (tres) is 0.13 mm. The total thickness of the TLMA is 6.13mm.




(a)

(b)

**Figure 6- 1 :** (a) Side and (b) top view of TLMA along with wave vector, electric and magnetic field directions

The equivalent circuit of TLMA is shown in Figure 6- 2(a). The equivalent circuit shows that the TLMA can be considered as a combination of two-layer configuration, by assuming the lower metal back FR4 substrate along with resistive sheet works as Salisbury screen. The equivalent impedance of TLMA is the combination of Salisbury screen and top FR4 substrate as shown by $Z_{ss}$ and $Z_d$, respectively in Figure 6- 2(a).

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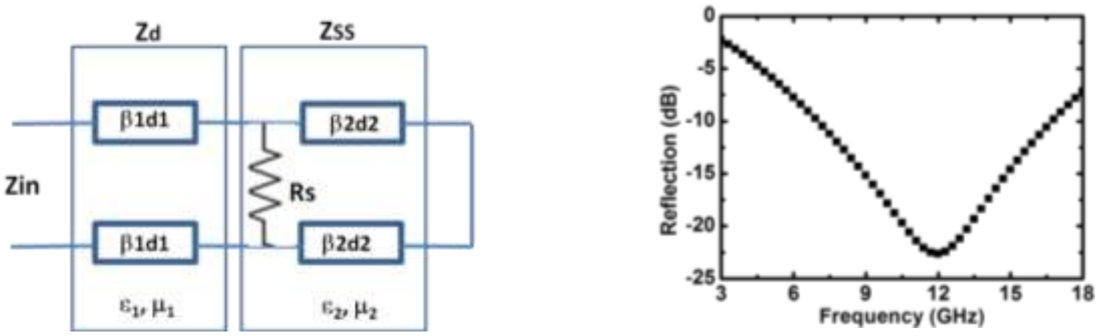
$$\frac{1}{Z_{ss}} = \frac{1}{R_s} + \frac{1}{jZtan(\beta d)} \ where\ Z = \frac{Z_0}{\sqrt{\varepsilon}} \ and\ \beta = \frac{2\pi f\sqrt{\varepsilon}}{c} \tag{1}$$

$$Z_d = Z_0\sqrt{\frac{\mu}{\varepsilon}}\tanh\left(\frac{-j2\pi f d\sqrt{\mu\varepsilon}}{c}\right) \tag{2}$$

where $Z_0$, d, f, c, μ and ε are the free space impedance, the thickness of the absorber, frequency, speed of light, permeability and permittivity of the absorber respectively. The equivalent impedance can be calculated using the equation (1) and (2) as described above. The simulated reflection of the TLMA is shown in Figure 6- 2(b), which indicates the bandwidth of 9.7 GHz (7-16.7 GHz) for -10 dB reflection. The bandwidth is attributed to the formation of Jaumann absorber [Chambers and Tennant, 1994]. The upper FR4 sheet in combination with resistive sheet works as Jaumaan configuration.

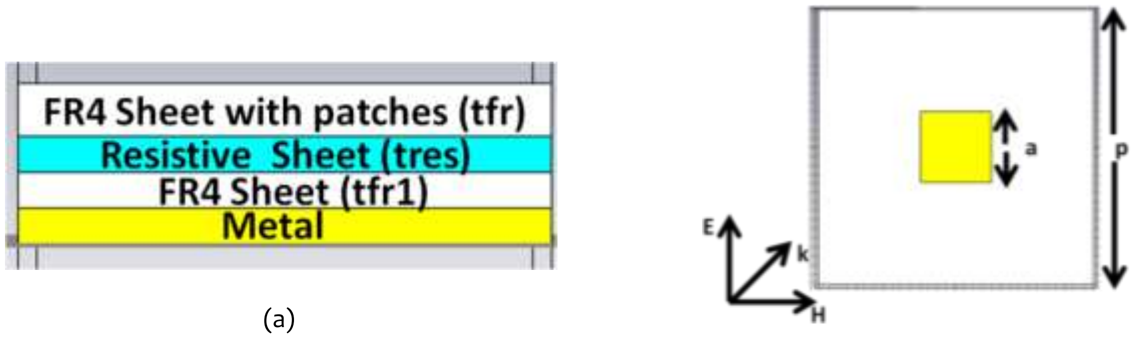



(a) (b)

**Figure 6- 2:** (a) Equivalent Circuit Model for the TLMA (b) Simulated reflection of the TLMA

## 6.2 TLMA WITH SQUARE PATCHES

The square patches are considered as capacitive element due to enhance coupling between the nearby patches. The resonant frequency of the metallic square patches can be tuned by changing the patch size, thickness and material parameters of the substrate [Luukkonen *et al.*, 2009]. The capacitive element based absorber offers enhanced bandwidth in comparison to low capacitive elements viz. cross, square loop [Costa *et al.*, 2013]. Considering the capacitive nature, ease of fabrication using low-cost screen printing technique, and tuning of the resonance frequency, the square patches are considered.




(a) (b)

**Figure 6-3:** (a) Side and (b) Top view of the unit cell of the absorber along with wave vector, electric and magnetic field directions

The side and top view of the unit cell of the designed absorber are presented in Figure 6-3(a) and (b) respectively along with wave vector, electric and magnetic field directions. The proposed absorber is a layered structure which consists of, bottom to top, a metal plate, FR4 substrate, a resistive sheet of 100 Ω/sq, FR4 substrate with printed metallic square patches. The square patches are made up of copper with thickness and conductivity of 0.035 mm and 5.8 × $10^7$ S/m respectively. The design parameters are presented as p (periodicity of the unit cell) =30 mm and a (square patch dimension) = 7.7 mm and other design parameters are the same as discussed in the above subsection.

The estimated reflection from the absorber is plotted for co-polarization and cross-polarization as Figure 6-4(a). The absorber indicates the bandwidth of 11.2 GHz (5.6 GHz -16.8 GHz) for -10 dB reflection in co-polarization. The reflection is below -70dB in cross-polarization which is almost nil. The designed absorber works as an efficient absorber which absorbs the incident wave in both Co and Cross polarizations.

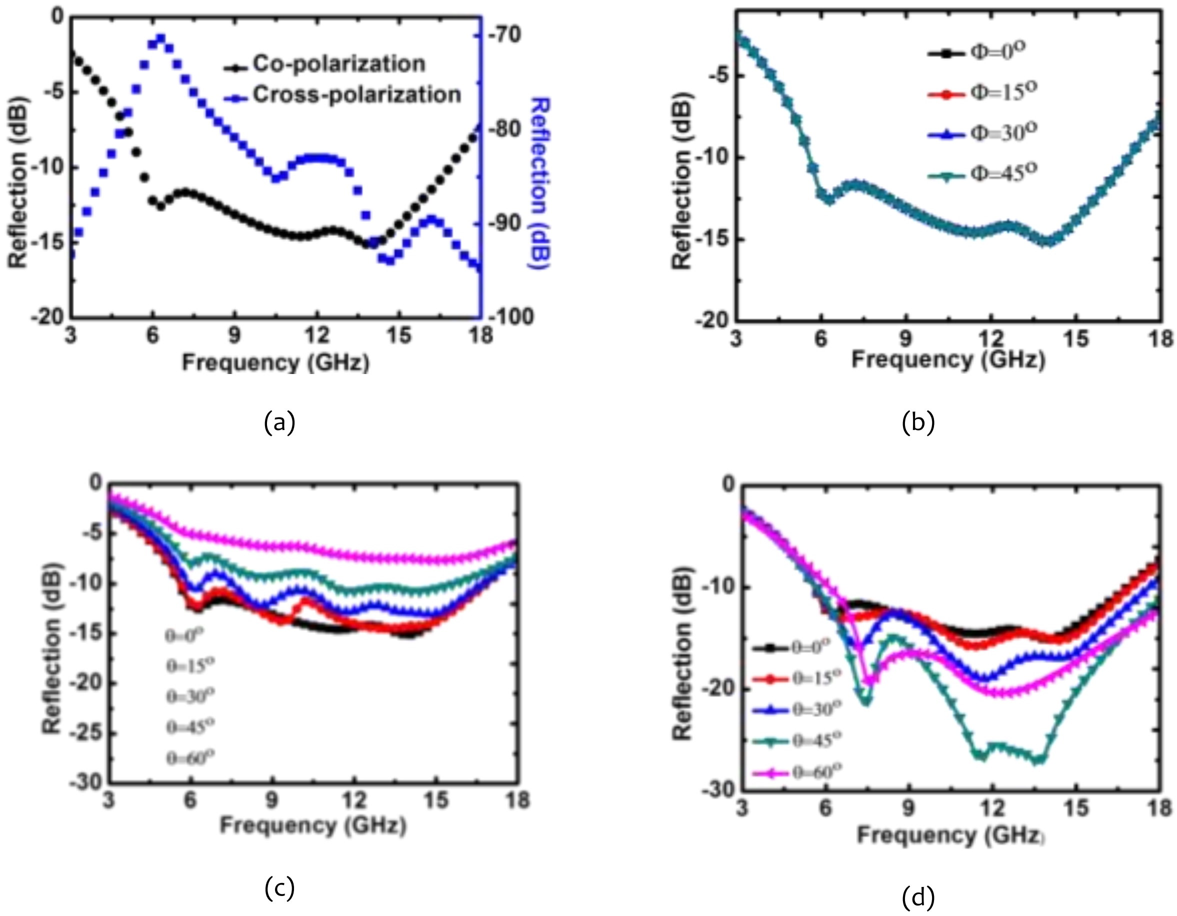



**Figure 6-4:** (a) Simulated reflection of the absorber for Co and Cross polarizations (b) Simulated results for polarization angles 0° to 45° (c) and (d) Simulated results for oblique incidence 0° to 60° under TE and TM modes respectively

The performance of the absorber is numerically evaluated for different polarization and oblique incidence angles under TE and TM components (Figure 6-4). The orientation of incident wave, electric field and magnetic field for different polarization and oblique incidence are discussed in [Bhattacharyya, 2016]. The performance of the absorber is almost invariant for different polarization angles due to four-fold rotational symmetry (Figure 6-4(b)). The performance of the absorber for oblique incidence angles 0° to 60° under TE, and TM modes are plotted in Figure 6-4(c) and (d) respectively. The oblique incidence performance of the absorber is almost stable up to 15° and 60° under TE and TM modes, respectively. The less angular stability of the absorber under TE mode is attributed to the decrease of the capacitive strength [Costa *et al.,* 2013].

## 6.3 PARAMETRIC ANALYSIS OF DIMENSION PARAMETERS

The parametric analysis of the design parameters is shown in Figure 6-5. The effect of square patch size is plotted as Figure 6-5(a). As the patch size increases the absorbing peak at 6 GHz (a=7.7mm) shifts towards the lower frequency region. The shifting of reflection dip to a lower frequency is attributed to the increased coupling between the square patches. The effect of tfr1(upper FR4 sheet) and tfr (base FR4 sheet) on reflection are plotted as Figure 6-5(b) and (c) respectively. It indicates the requirement of the FR4 thickness to optimize the reflection for -10dB. Figure 6-5(d) presents the variation of reflection level with periodicity (p). It indicates that the minimum coupling between the square patches is required for bandwidth enhancement.

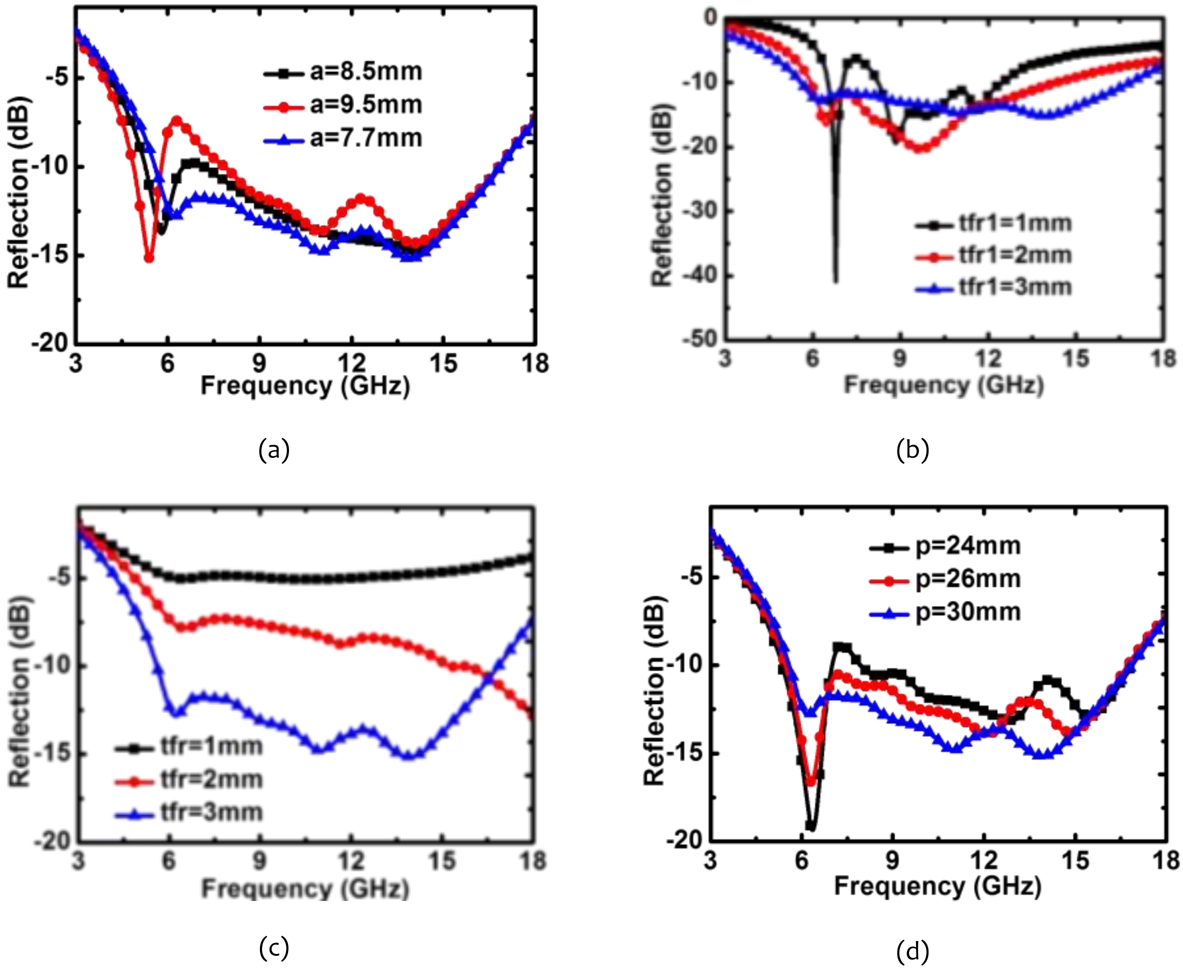



**Figure 6-5:** Parametric analysis of the design parameters (a) square patch size (p = 30 mm, tfr = 3 mm = tfr1) (b) thickness of base FR4 sheet (tfr1) (p = 30 mm, tfr = 3mm, a = 7.7mm) (c) thickness of the upper FR4 sheet (tfr) (p = 30 mm, tfr1 = 3 mm, a = 7.7mm) and (d) periodicity (a=7.7 mm, tfr =3 mm = tfr1)

## 6.4 PHYSICAL INSIGHT

The electric field and power loss density are numerically estimated and plotted in Figure 6-6 to present the physical insight of the absorber. The quantities are simulated at absorbing frequencies 6 GHz and 14 GHz. The electric field at 6 GHz is confined at the square patch due to the formation of the resonating structure (Figure 6-6(a)). The power loss density at 6 GHz indicates that loss distribution is attributed to the square patch (Figure 6-6(c)). The electric field at 14 GHz is located at FR4 sheets (Figure 6-6(b)). The power loss density at 14 GHz suggests that the loss density is confined in the upper and lower FR4 sheets owing to the formation of Jaumann configuration (Figure 6-6(d)).

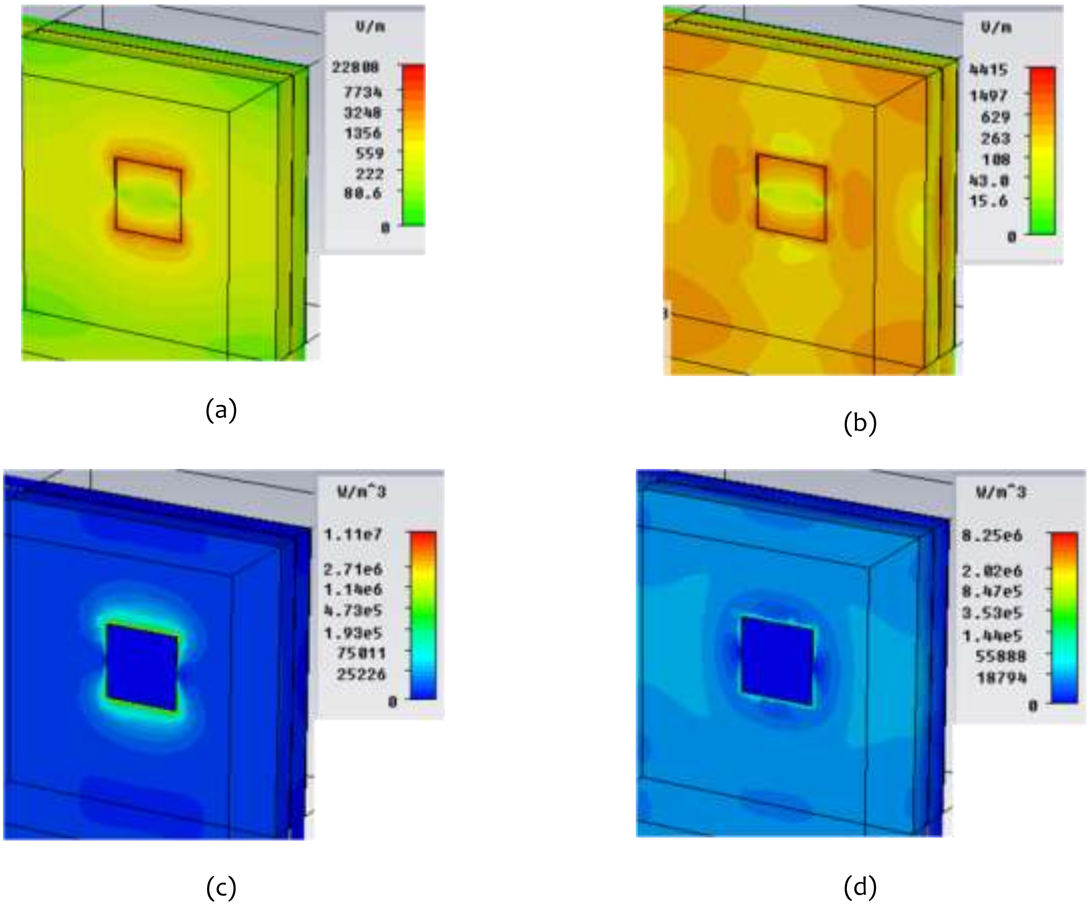



**Figure 6-6:** Simulated electric field and power loss density for the proposed absorber (a) and (b) Electric field at 6 GHz and 14 GHz respectively (c) and (d) Power loss density at 6 GHz and14 GHz respectively

## 6.5 FABRICATION AND MEASUREMENT RESULTS

The two absorbers, namely, Triple Layer Microwave Absorber (TLMA) without and with square patches, are fabricated and characterized to support the design of the proposed absorber. The fabricated TLMA without and with the square patches are shown in Figure 6-7(a) and (d) respectively, with the dimensions of 150 x 150 x 6.13 mm.

The thickness FR4 sheets are physically realized by joining the 1.5mm FR4 sheets using epoxy-based adhesive. Due care has been taken to avoid any peel-off due to poor/improper adhesion. The schematic of the measurement setup is shown in Figure 6-7(c). The performance of the absorber is measured in an anechoic chamber using Vector Network Analyzer and pair of horn antennas as described in [Cheng and Yang, 2010], [Li *et al.*, 2010].

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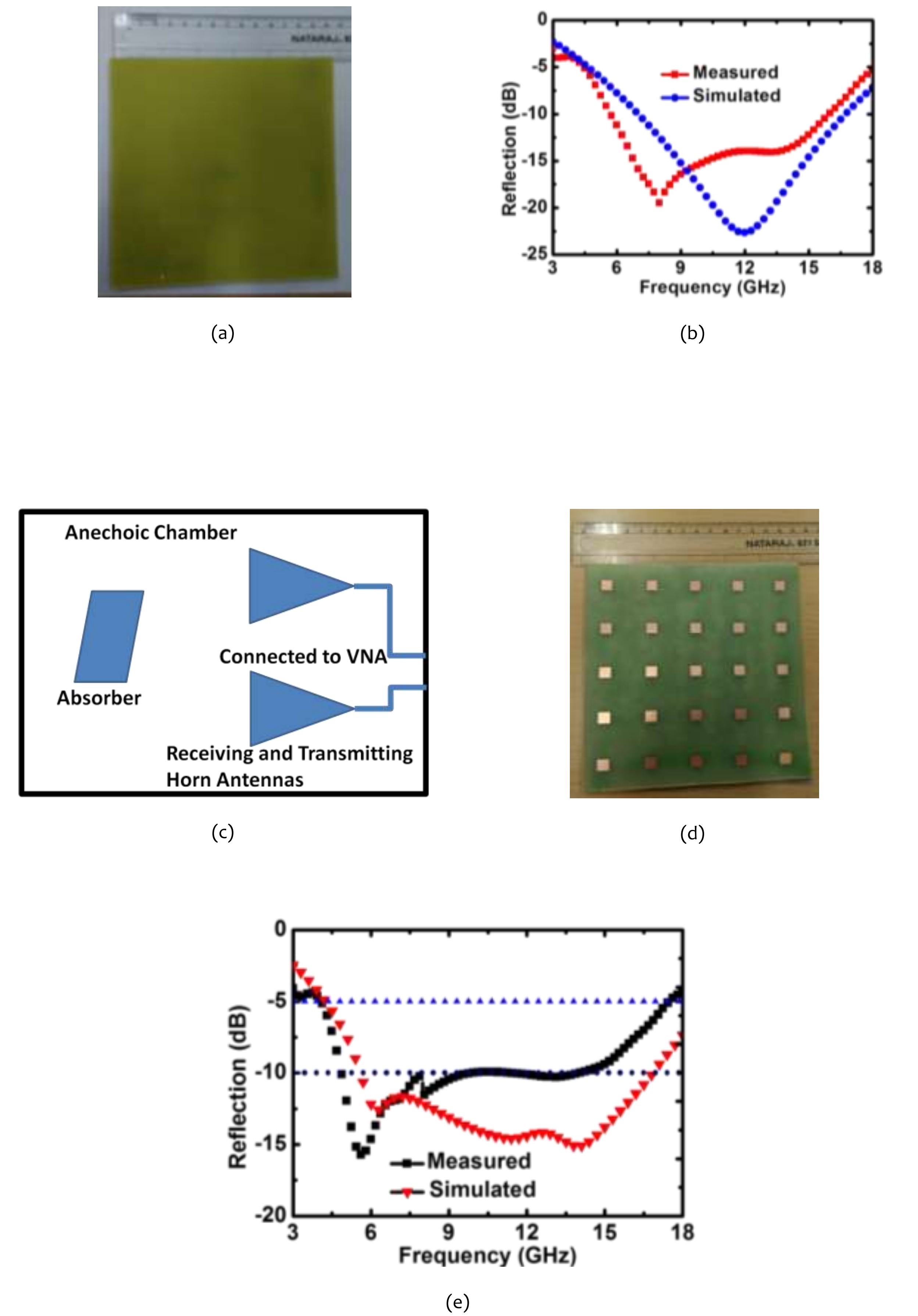


**Figure 6-7**: (a) Fabricated TLMA without the square patch (b) Simulated and measured data of the TLMA (c) Schematic of measurement setup (d) Fabricated TLMA with the metallic square patch (e) Simulated and measured data of TLMA with a metallic square patch

The simulated and measured data for TLMA and TLMA with the square patch are shown in Figure 6-7(b) and (e), respectively. The good agreement between the measured and simulated data have been observed for both the absorbers. The slight shifting of measured data to the lower frequency region is attributed to the increased thickness of the absorbers due to the joining of multiple FR4 sheets.

The performance of the absorber is investigated for a varied aspect angle (-90° to +90°) at different frequencies and compared with metal, as shown in Figure 6-8. The aspect angle is the angular position of the absorber with respect to the fixed antenna position. Figure 6-8(a) to (d) indicate that the reflection from the absorber is lower than the metal for a wide aspect angle. The difference of the reflection between the metal and absorber indicates the effectiveness of the absorber at the given frequency for different aspect angle. The asymmetric reflection pattern is observed for the absorber because of thickness variation.

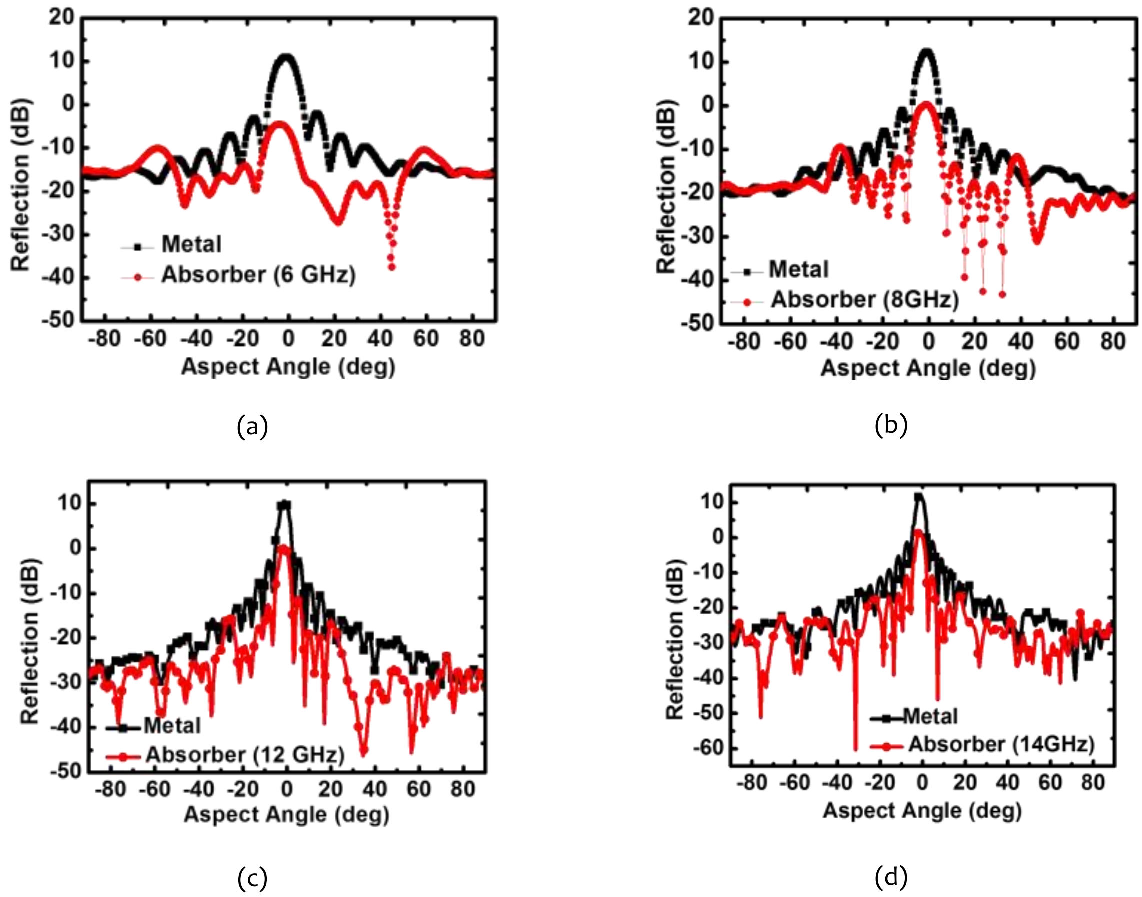


**Figure 6-8:** Measured reflection from a metal plate and the absorber for varied aspect angle at different frequencies (a) 6 GHz (b) 8 GHz (c) 12 GHz (d) 14 GHz

In summary, the chapter presents the design methodology to improve the bandwidth of Triple Layer Microwave Absorber using the metallic square patch. The methodology indicates the requirement of the minimum coupling between the square patches to enhance the bandwidth of TLMA. The good degree of correlation between the simulated and measured data has been observed.