Chapter 5
Theoretical Study of Equilateral Triangular Microstrip Antenna and Its Arrays

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Abstract Novel design of equilateral triangular microstrip antenna is proposed at X-band frequency. The antenna is designed, fabricated and tested for single and multiband operation. This study presents the theory developed with respect to the experimental work carried out on design and development of equilateral triangular microstrip array antenna (ETMAA). The experimental impedance bandwidth of single element conventional equilateral triangular microstrip antenna (CETMA) is found to be 5.02 %. The two, four and eight elements of ETMAA have been designed and fabricated using low cost glass epoxy substrate material. The array elements are excited using corporate feed technique. The effect of slot in enhancing the impedance bandwidth is studied by placing the slot in the radiating elements of ETMAA. The study is also made by exciting the array element of ETMAA through aperture coupling. For eight elements, maximum 33.8 % impedance bandwidth is achieved, which is 6.73 times more than the impedance bandwidth of conventional single element CETMA. The experimental impedance bandwidths are verified theoretically and they are in good agreement. The obtained experimental results and theoretical study of the proposed antennas are given and discussed in detail.

Keywords Theoretical study of ETMAA · Gap-coupled feeding technique · Slot loading technique

5.1 Introduction

A microstrip or patch antenna is a low-profile antenna that has a number of advantages over other antennas: it is light weight, low volume, low profile, planar configurations which can be made conformal, low fabrication cost, readily amenable to mass production and electronics like LNA's and SSPA's, and can be integrated with these antennas quite easily [27]. While the antenna can be a 3-D structure (wrapped

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around a cylinder, for example), it is usually flat and that is why patch antennas are sometimes referred to as planar antennas.

Global demand for voice, data and video related services continues to grow faster than the required infrastructure can be deployed. Despite huge amount of money that has been spent in attempts to meet the need of the world market, the vast majority of people on Earth still do not have access to quality communication facilities. The greatest challenge faced by governments and service providers is the "last-mile" connection, which is the final link between the individual user or business users and worldwide network [35]. Copper wires, traditional means of providing this "last-mile" connection is both costly and inadequate to meet the needs of the bandwidth intensive applications. Coaxial cable and power line communications all have technical limitations. And fiber optics, while technically superior but is extremely expensive to install to every home or business user. To overcome this wireless connection is being seen as an alternative to quickly and cost effectively meet the need for flexible broadband links.

Basically an antenna can be considered as the connecting link between free-space and transmitter or receiver [2]. Presently there exist different types of antennas. The design and development of microwave antennas are the most important task in microwave communication systems to achieve the desired radiation requirements. Among the various types of microwave antennas, the microstrip antennas (MSAs) have found one of the important classes within the broad field of microwave antennas because of their diversified applications in microwave communication.

Microstrip antenna technology has been the most rapidly developing topic in the antenna field receiving the creative attentions of academic, industrial and professional engineers and researchers throughout the world [29]. As the microstrip antenna is planar in configuration, it enjoys all the advantages of printed circuit technology. A microstrip antenna in its simplest form consists of a radiating patch, power dividers, matching networks and phasing circuits photoetched on one side of the dielectric substrate board. The other side of the board is a metallic ground plane [3].

G.A. Deschamps first proposed the concept of the microstrip antenna in 1953 [13]. However, practical antennas were developed by Robert E. Munson [26] and John Q. Howell [16] in the 1970s. As a result, microstrip antennas have quickly evolved from academic novelty to commercial reality, with applications in a wide variety of microwave systems.

The radiating patch of microstrip antenna can be of any geometry viz: rectangular, triangular, circular, square, elliptical, sectoral, annular ring etc. Among the various types of microstrip antenna configurations, the rectangular geometry is commonly used. But, one of the most attractive features of the equilateral triangular microstrip antenna is that, the area necessary for the patch becomes about half as large as that of a nearly rectangular or square microstrip antenna designed for the same frequency [36].

Microstrip antennas despite their potential advantages also have some drawbacks compared to conventional microwave antennas. One of the major drawbacks is its narrow impedance bandwidth i.e. 1–2 %. Increasing the impedance bandwidth of microstrip antennas has become an important task and is the major thrust of research in microwave communication. Various techniques have been reported in the literature for enhancing the impedance bandwidth of microstrip antennas. But equilateral triangular microstrip antenna found handful of investigations. The literature study shows that, there is still void and hence requires further investigation to enhance its impedance bandwidth.

In the present investigation, work is mainly concentrated on the enhancement of impedance bandwidth of equilateral triangular microstrip array antennas using:

i. Corporate feed technique,
ii. Slot-loading technique,
iii. Aperture-coupled feeding technique, and
iv. Gap-coupled technique.

The conventional equilateral triangular microstrip antenna (CETMA) is designed and fabricated using glass-epoxy substrate material. The two, four and eight elements equilateral triangular microstrip array antennas (ETMAAs) are constructed using the same substrate material. The antenna elements are excited through corporate feed technique. The change in impedance bandwidth is studied for these antennas. Further, by loading slot in the radiating elements, the effect of slot in enhancing the impedance bandwidth is studied. The elements of slot loaded antennas are excited through aperture coupled feeding. The comparative study of impedance bandwidth is made between corporate fed slot loaded and aperture coupled equilateral triangular microstrip array antennas. The impedance bandwidths of these antennas are studied comparatively.

5.2 Types of Microstrip Antennas

The approaching maturity of microstrip antenna technology, coupled with the increasing demand and applications these antennas are mainly classified into three basic categories [3]:

1. Microstrip patch antennas,
2. Microstrip traveling wave antennas,
3. Microstrip slot antennas.

The present study is carried out experimentally for microstrip patch antennas and microstrip slot antennas. Theory for the proposed antennas is also developed for validation of experimental results of the antennas. This chapter presents the theoretical calculation of impedance bandwidth of conventional equilateral triangular microstrip antenna (CETMA) and equilateral triangular microstrip array antennas (ETMAAs). The impedance bandwidth is determined separately for corporate and aperture coupled fed ETMAAs.

Several techniques have been developed and found quite useful to enhance the impedance bandwidth of microstrip antennas (MSAs), such as use of stacked technique [5–7, 22], use of corporate feed technique [12, 15], use of parasitic elements [1], use of thick dielectric substrate [4, 6, 12], use of additional resonator [18], use of aperture-coupled technique [11, 28], use of electromagnetically coupled technique [17], use of L-shaped probe [25], use of a resonant slot inserted in the main patch [21, 23, 31, 33], etc.

Various theoretical analyses are available in the literature to validate the experimental impedance bandwidth of MSAs. Joseph Helszajn and David S. James [14] have described theoretical and experimental results on planar resonators of equilateral triangular resonators having magnetic sidewalls. The TM fields in such resonators with magnetic boundary conditions are obtained by duality from the TE modes with electric boundaries. The theoretical description includes the cutoff numbers of the first few modes. The performance of a microstrip circulator using a triangular resonator is also described by them.

Girish Kumar et al. [18] have verified the theoretical bandwidth of MSA consisting of additional resonator gap-coupled to the radiating edges of resonant patch. They have verified the theoretical bandwidth using Green's function approach and the segmentation method.

Kai Fong Lee et al. [20] have analyzed the equilateral triangular patch antenna by means of the cavity model. They have given the theoretical formulas and the characteristics obtained from the theory including radiation patterns, percentages of power radiated, total Q factors, input impedances and their variations with feed position. They opined that, the equilateral triangular patch can be designed to function as a triple frequency antenna.

Wei Chen et al. [10] have presented a critical study of the resonant frequency of the equilateral triangular patch antenna. They compared their results with experimental results reported by other scientists using the moment method and the Gang's hypothesis analysis.

Qing Song and Xue-Xia Zhang [34] have verified the theoretical bandwidth of two element gap-coupled microstrip array antenna by using the spectral dyadic Green's function for a grounded dielectric slab and the moment method.

Girish Kumar and K.P. Ray [19] have given the expressions for calculating the percentage impedance bandwidth of rectangular microstrip antenna (RMSA). In this study theoretical determination of impedance bandwidth of ETMA and ETMAAs has been made with the help of the equations given by Girish Kumar and K.P. Ray [8: pp.13] by replacing [3, 8] W/L ratio with ($n \times Se$) where, S_e is the effective side length of the equilateral triangular radiating patch and n is the number of equilateral triangular radiating patches. The impedance bandwidth of single element conventional equilateral triangular microstrip antenna (CETMA) is determined by this method.

The equations given by Girish Kumar and K.P. Ray have been extended to determine the impedance bandwidth of ETMAAs. The extended equations are applied to determine the impedance bandwidth of two, four and eight element ETMAAs. As the number of array elements increases in ETMAAs the multiplying factor S_e also increases accordingly.

The theoretical impedance bandwidth of ETMA and ETMAAs computed on the basis of the above theory is compared to the experimental impedance bandwidth for the validation.

5.2.1 Theoretical Impedance Bandwidth

The conventional equilateral triangular microstrip antenna (CETMA) and equilateral triangular microstrip array antennas (ETMAAs) have been designed for TE10 mode.

The expression derived by Girish Kumar and K.P. Ray [19] for the calculation of percentage impedance bandwidth are in terms of patch dimensions and substrate parameters. The expressions are, [19],

$$Impedence\ bandwidth(\%) = \left[\frac{A \times h}{\lambda_0 \sqrt{\varepsilon_r}}\right] \times \sqrt{\frac{W}{L}}, \quad (5.1)$$

where:
h - thickness of the substrate,
ε_r - relative permittivity of the substrate,
W - width of the patch,
L - length of the patch,
λ_0 - free-space wavelength,
A - correction factor.

The correction factor A changes as the value of $\left[\frac{A \times h}{\lambda_0 \sqrt{\varepsilon_r}}\right]$ changes [19], which is given by:

$$A = 180 \text{ for } \left[\frac{A \times h}{\lambda_0 \sqrt{\varepsilon_r}}\right] \leq 0.045,$$

$$A = 200 \text{ for } 0.045 \leq \left[\frac{A \times h}{\lambda_0 \sqrt{\varepsilon_r}}\right] \leq 0.075,$$

$$A = 220 \text{ for } \left[\frac{A \times h}{\lambda_0 \sqrt{\varepsilon_r}}\right] \geq 0.075.$$

In the present investigation the value of correction factor A is taken as 180 because the calculated value of $\left[\frac{A \times h}{\lambda_0 \sqrt{\varepsilon_r}}\right]$ for CETMA and ETMAAs is less than 0.045 determined for the known value of h, λ_0 and ε_r.

The expression (5.1) given by Girish Kumar et al. [19] is for RMSA. But in the present study the geometry of radiating elements are equilateral triangular in shape. Therefore the Eq. (5.1) is converted for equilateral triangular microstrip antenna and arrays by replacing [3, 14, 19] the W/L ratio with $(n \times S_e)$. The modified equation for CETMA is given by

$$Impedence\ bandwidth(\%) = \left[\frac{A \times h}{\lambda_0 \sqrt{\varepsilon_r}}\right] \times \sqrt{n \times S_e}, \quad (5.2)$$

where:
S_e - effective side length of the equilateral triangular radiating patch, and
n - number of equilateral triangular radiating patches.

In Eq. (5.2) the value of S_e is given by the formula, [19],

$$S_e = S + \frac{4h}{\varepsilon_e}, \tag{5.3}$$

where:
S - side length of the equilateral triangular microstrip patch,
ε_e - effective dielectric constant.

The value of S and ε_r are determined using the following Eqs. (5.4), [30], and (5.5), respectively.

$$S = \left(\frac{S_{eff1} + S_{eff2}}{2}\right), \tag{5.4}$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{s}\right) -^{\frac{1}{2}}. \tag{5.5}$$

The Eq. (5.2) is extended to calculate the impedance bandwidth of corporate fed two, four and eight element array antennas. Further, (5.2) is also used to determine the impedance bandwidth of aperture-coupled fed four and eight element array antennas by considering the aperture coupled parameters. During the calculations of percentage impedance bandwidth of array elements the patch dimensions [19] in terms of area i.e. the area of the equilateral triangular radiating patch (A_t), area of slot loaded equilateral triangular microstrip radiating patch (A_{sp}) and capacitance of the slot (C_s) are taken into consideration. The capacitance of the slot C_s is calculated with the help of the transmission line model [3]. This analytical technique [19] is based on equivalent magnetic current distribution around the patch edges (similar to slot antennas).

5.2.1.1 Calculation of Impedance Bandwidth of CETMA

The CETMA is fed by 50 microstripline, which is connected at the center point C_p of the side length of the equilateral triangular microstrip patch. Between the equilateral triangular microstrip patch and 50 feed line a matching transform is used to avoid the mismatch. For CETMA, n is taken as 1 in Eq. (5.2) as CETMA consists of only one radiating element. Hence Eq. (5.2) reduces to,

$$Impedence\ \ bandwidth(\%) = \left[\frac{A \times h}{\lambda_0\sqrt{\varepsilon_r}}\right]\sqrt{S_e}. \tag{5.6}$$

Therefore, the theoretical impedance bandwidth of CETMA is calculated using the above equation which is found to be 5.35 %. This impedance bandwidth is recorded in Table 5.1. From this table it is seen that, the theoretical impedance bandwidth is in close agreement with the experimental value.

5.2.1.2 Calculation of Impedance Bandwidth of T-ETMAA

The two element equilateral triangular microstrip array antenna i.e. T-ETMAA is fed by corporate feed arrangement. The area of equilateral triangular radiating element (A_t) is taken into consideration [19] for calculating the impedance bandwidth of T-ETMAA. The value of A_t is determined using the basic formula of equilateral triangular element, which is given by

$$A_t = \frac{\sqrt{3}}{4} S^2, \tag{5.7}$$

where S is the side length of the equilateral triangular radiating element. The value of A_t is multiplied to Eq. (5.2) to find impedance bandwidth of T-ETMAA.

The value of n is taken as 2 in Eq. (5.2) as T-ETMAA consists of two radiating elements. Hence the extended formula for the determination of impedance bandwidth of T-ETMAA is given by

$$Impedence\ bandwidth(\%) = \left[\frac{A \times h}{\lambda_0 \sqrt{\varepsilon_r}}\right] \times (\sqrt{2 \times S_e}) A_t. \tag{5.8}$$

Table 5.1 shows the theoretical and experimental impedance bandwidths of T-ETMAA.

5.2.1.3 Calculation of Impedance Bandwidth of TS-ETMAA

The rectangular slots are loaded at the center of the radiating elements of two element slot-loaded equilateral triangular microstrip array antenna i.e. TS-ETMAA. Therefore the area of the slot loaded patch (A_{sp}) [19] and capacitance of the slot (C_s) [3] are considered during the calculation of impedance bandwidth of TS-ETMAA. Slot also resonates along with patch, which enhances the impedance bandwidth. The capacitance parameter C_s associated to the slot is responsible for its resonance. This C_s is evaluated using the transmission line model [3]. According to transmission line model, the C_s is given by

$$C_s = \frac{\Delta l \sqrt{\varepsilon_{eff}}}{c \times Z_0}, \tag{5.9}$$

where $\triangle l$ is the extension length and ε_{eff} is the effective dielectric constant. The value of $\triangle l$ and ε_{eff} are evaluated from (5.10) and (5.11), respectively. For these calculations ε_e is taken from (5.5).

$$\triangle l = 0.412h \left[\frac{(\varepsilon_e + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_e - 0.258)\left(\frac{W}{h}\right) + 0.8}\right], \tag{5.10}$$

$$\varepsilon_{eff} = \varepsilon_r - \frac{\varepsilon_r - \varepsilon_e}{1 + G\left(\frac{f_r}{f_p}\right)^2}, \tag{5.11}$$

where

$$G = \left(\frac{Z_0 - 5}{60}\right)^{\frac{1}{2}} + (0.004 \times Z_0), \tag{5.12}$$

$$f_p = \frac{Z_0}{2\mu h}, \tag{5.13}$$

$$\mu_0 = 4\pi 10^{-9}, \tag{5.14}$$

$$Impedence\ \ bandwidth(\%) = \left[\left(\frac{A \times h}{\lambda_0 \sqrt{\varepsilon_r}}\right) \times \sqrt{2 \times S_e \times A_{sp}}\right] + C_s, \tag{5.15}$$

where:
A_{sp} - area of the slot loaded patch excluding the area of rectangular slot, and
C_s - capacitance of the slot.

Hence the value of A_{sp} in (5.15) is calculated by the formula

$$A_{sp} = A_t - A_s. \tag{5.16}$$

In the above equation the value of A_t is calculated with the help of (5.7) and A_s is the area of rectangular slot which is given by

$$A_s = L_s \times W_s, \tag{5.17}$$

where:
L_s - length of the rectangular slot,
W_s - width of the rectangular slot.

The impedance bandwidth of TS-ETMAA is calculated using (5.15) and is recorded in Table 5.1.

5.2.1.4 Calculation of Impedance Bandwidth of FS-ETMAA

The radiating elements of TS-ETMAA are increased from two to four to construct four element slot-loaded equilateral triangular microstrip array antenna i.e. FS-ETMAA. The value of n is taken as 4 in (5.2) for FS-ETMAA as FS-ETMAA consists of four radiating elements and a slot at their centre. The total capacitance effect caused by slots in two radiating elements of FS-ETMAA is minimized by the capacitance effect of slots produced by the remaining two elements of FS-ETMAA. The slot in the elements acts as series capacitances and hence C_s decreases. The two set of elements in FS-ETMAA are resonating independently and gives two operating

Table 5.1 Verification of impedance bandwidth of corporate fed and aperture-coupled fed ETMA and ETMAAs

Antennas	Impedence bandwidth (%)		Error(%)
	Theoretical	Experimental	
CETMA	5.35	5.02	6.57
T-ETMAA	4.76	4.50	5.77
TS-ETMAA	7.12	7.35	3.12
FS-ETMAA	6.62	6.68	0.89
F-ETMAA	9.44	9.11	3.62
ES-ETMAA	9.96	10.20	2.35
FA-ETMAA	13.47	13.75	2.03
FAS-ETMAA	22.98	23.74	3.20
EAS-ETMAA	32.50	33.80	3.84

bands [30]. Therefore the total C_s due to slot in FS-ETMAA is subtracted as shown in the following Eq. (5.18)

$$Impedance\ \ bandwidth(\%) = \left[\left(\frac{A \times h}{\lambda_0\sqrt{\varepsilon_r}}\right) \times \sqrt{4 \times S_e \times A_{sp}}\right] - C_s. \quad (5.18)$$

The values of A_{sp} and C_s in (5.18) are determined with the help of (5.16) and (5.9), respectively. The obtained theoretical impedance bandwidth of FS-ETMAA is tabulated in Table 5.1.

5.2.1.5 Calculation of Impedance Bandwidth of F-ETMAA

The F-ETMAA is the extension of T-ETMAA. The radiating elements of T-ETMAA are increased from two to four to construct four element equilateral triangular microstrip array antenna i.e. F-ETMAA. The (5.8) used for the calculation of impedance bandwidth of T-ETMAA, is also used here for the impedance bandwidth calculation of F-ETMAA. But the value of n is taken as 4 in this case (i.e. 2 is replaced by 4) as F-ETMAA consists of four radiating elements. From the experimental results of the proposed antennas [30], it is clear that the antenna is resonating for four bands of frequencies. This indicates that each element of F-ETMAA is resonating independently. The coupling effect caused by the total radiating area (A_t) of the two adjacent elements in F-ETMAA if subtracted as shown in the following Eq. (5.19), and the obtained overall impedance bandwidth now becomes equal to the experimental impedance bandwidth of F-ETMAA. Hence (5.8) becomes

$$Impedence\ \ bandwidth(\%) = \left[\left(\frac{A \times h}{\lambda_0\sqrt{\varepsilon_r}}\right) \times \sqrt{4 \times S_e}\right] - 2A_t. \quad (5.19)$$

The value of A_t is calculated using (5.7). The impedance bandwidth of F-ETMAA obtained from (5.19) is recorded in Table 5.1.

5.2.1.6 Calculation of Impedance Bandwidth of ES-ETMAA

The eight element slot-loaded equilateral triangular microstrip array antenna i.e. ES-ETMAA is the extension of FS-ETMAA. The number of radiating elements is increased from four to eight. The value of n is taken as 8 in (5.18) (i.e. 4 is replaced by 8) for ES-ETMAA as this antenna consists eight radiating elements. By comparing the graphs of the experimental results of the said antennas [30], it is clear that, ES-ETMAA resonates for four bands of frequencies by increasing elements from four to eight. But the overall impedance bandwidth is more in this case when compared to FS-ETMAA. The capacitance effect due to slot is similar in this case also as explained in Sect. 5.2.1.4. The equation used to determine the impedance bandwidth of ES-ETMAA is given by

$$Impedance\ bandwidth(\%) = \left[\left(\frac{A \times h}{\lambda_0\sqrt{\varepsilon_r}}\right) \times \sqrt{8 \times S_e \times A_{sp}}\right] - C_s. \quad (5.20)$$

The value of A_{sp} is calculated using (5.16) and the value of C_s is calculated with the help of (5.9). The impedance bandwidth of ES-ETMAA is determined using (5.20) and is recorded in Table 5.1.

5.2.1.7 Calculation of Impedance Bandwidth of FA-ETMAA

The F-ETMAA is fed by aperture-coupling to construct four element aperture-coupled equilateral triangular microstrip array antenna i.e. FA-ETMAA. The radiating elements of FA-ETMAA are excited through coupling slots. The coupling slot resonates nearer to the patch resonance [33]. The total area A_t of radiating elements becomes virtually twice the actual area. Hence the basic Eq. (5.2), if multiplied by $2A_t$, now predicts the impedance bandwidth of FA-ETMAA. Hence (5.2) becomes

$$Impedence\ bandwidth(\%) = \left[\left(\frac{A \times h}{\lambda_0\sqrt{\varepsilon_r}}\right) \times (\sqrt{4 \times S_e})\right] \times (2A_t). \quad (5.21)$$

The value of n in (5.2) is taken as 4 as FA-ETMAA consists of four radiating elements. The value of A_t is calculated using (5.7). The impedance bandwidth of FA-ETMAA is calculated using (5.21) and is given in Table 5.1.

5.2.1.8 Calculation of Impedance Bandwidth of FAS-ETMAA

The four element aperture-coupled slot-loaded equilateral triangular microstrip array antenna i.e. FAS-ETMAA is the extension of FS-ETMAA. The radiating elements of FS-ETMAA are fed by aperture-coupling to construct FAS-ETMAA. The equation used for calculating the impedance bandwidth of FS-ETMAA is taken in this case to determine the impedance bandwidth of FAS-ETMAA. But in FAS-ETMAA the coupling slots are kept exactly below the slot etched in the radiating elements of FAS-ETMAA separated by a substrate material. The coupling slot and slot in the radiating elements are resonating independently [8]. Capacitance C_s associates for each slot is in parallel, and hence C_s doubles the actual value. Therefore, $2C_s$ is multiplied to modified equation of (5.2) as in (5.18) to now predict the impedance bandwidth of FAS-ETMAA. Hence, the basic Eq. (5.6) for FAS-ETMAA becomes,

$$Impedance\ \ bandwidth(\%) = \left[\left(\frac{A \times h}{\lambda_0\sqrt{\varepsilon_r}}\right) \times (\sqrt{4 \times S_e \times A_{sp}})\right] \times 2C_s. \quad (5.22)$$

The impedance bandwidth of FAS-ETMAA is calculated using the above formula (5.22) and is tabulated in Table 5.1.

5.2.1.9 Calculation of Impedance Bandwidth of EAS-ETMAA

The eight element aperture-coupled slot-loaded equilateral triangular microstrip array antenna i.e. EAS-ETMAA is the extension of ES-ETMAA. The radiating elements of ES-ETMAA are fed by aperture-coupling to construct EAS-ETMAA. The impedance bandwidth of this antenna is calculated by using (5.22). But the value of n is taken as 8 (i.e. 4 is replaced by 8 in (5.22)) as EAS-ETMAA consists of 8 radiating elements. The obtained impedance bandwidth of EAS-ETMAA is given in Table 5.1.

Figure 5.1 gives the clear view of the comparison of theoretical and experimental impedance bandwidth of proposed antennas. From the graph it is clear that, theoretical and experimental results are with close agreement. From Table 5.1 it is clear that, the theoretical impedance bandwidth of CETMA, corporate and aperture coupled fed ETMAAs are in good agreement with the experimental results. The last column of the Table 5.1 clearly tells that, the percentage errors between experimental and theoretical results are minimum, which validate that the developed theory is with good agreement with the designed equilateral triangular microstrip antennas and its arrays.

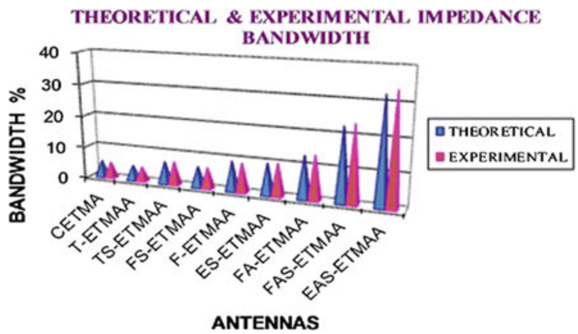

Fig. 5.1 Graph showing the comparison of theoretical and experimental impedance bandwidth of proposed antennas

5.3 Conclusion

The antennas reported in this study have been designed at X-band frequency of 9.4 GHz and are fabricated using low-cost glass epoxy dielectric substrate material. From the return loss [32] graph of CETMA, it is clear that, antenna resonating very close to the designed frequency of 9.4 GHz. This validates the design of CETMA. The dual band operation of antenna is easily achieved by simply increasing the array elements of TS-ETMAA from two to four. This newly obtained antenna FS-ETMAA is more useful for SAR application [24]. The multiband operation of antenna is achieved by increasing the array elements in T-ETMAA from two to four (F-ETMAA) with wider impedance bandwidth of 9.11 %. This multiband operation can be used in mobile computing network applications [32]. Further, the multiband impedance bandwidth is enhanced from 9.11 % to 10.20 % by increasing array elements of F-ETMAA from four to eight and by using slot in the radiating elements i.e. ES-ETMAA. This show that by increasing number of array elements, use of optimum slot in array elements and use of corporate feed arrangement is more effective in enhancing the impedance bandwidth and for converting single band into dual and multiband operation of antenna.

The triple band operation of FA-ETMAA can be converted into dual wide bands by inserting the slot at the center of radiating elements i.e. FAS-ETMAA which is 1.73 times more when compared to the impedance bandwidth of FA-ETMAA. The dual impedance bandwidth of FAS-ETMAA can be converted into a single wide band of magnitude 33.80 % by increasing array elements of FAS-ETMAA from four to eight i.e. EAS-ETMAA. This shows the effect of slot and aperture coupling is quite effective in enhancing the impedance bandwidth of ETMAAs. The impedance bandwidth of EAS-ETMAA is 3.07 times more than found earlier [9]. Further, this antenna is simple in design, fabrication uses low cost substrate material and is compact as it uses only eight array elements when compared to similar study in which the antenna consisted of sixteen array elements arranged in four rows and four columns to get nearly 11 % impedance bandwidth by [9]. From Table 5.1 it is seen that the experimental impedance bandwidths of CETMA, corporate and aperture coupled fed ETMAAs are in good agreement with the theoretical impedance bandwidths.

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