Applications of Triangular Microstrip Patch: Circuit Elements to Modern Wireless Antennas

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Abstract— **The triangular geometry of the microstrip patch is one of the most common shapes having a wide range of applications ranging from circuit elements to modern wireless antennas. Recent survey of open literature shows interesting development of this patch as novel circuit elements and antennas. In this paper, a very comprehensive review of the applications and investigations on triangular microstrip patch (TMP) has been presented.**

Index Terms— **Triangular microstrip patch.**

I. Introduction

After Deschamps proposed the idea of using the microstrip as radiator in 1953 [1], the practical microstrip antenna application took place nearly two decades later with the works by Howell [2] and Munson [3]. The triangular geometry of the microstrip patch (Fig. 1) drew the attention of the researchers in investigating the structure as planar circuit components [4]-[9] and as radiating elements in conventional [10]-[27] and multilayered configurations [28]-[31]. Compared to other patch geometries, the triangular microstrip is physically smaller having radiation properties similar to the rectangular patch but has a lower radiation loss [28]. In recent years, the TMP has found several new applications as broadband radiators [13], [32]-[39], dual frequency and multiband antennas [40]-[47], circularly polarized antennas [48]-[52] and in designing arrays [53]-[56]. Several new modified configurations due to its easy conformability are also reported in [57] and [58]. A comprehensive review of the applications of TMP as circuit elements and modern wireless antennas based on the survey of open literature is presented in this article.

II. Triangular Patch as Microstrip Circuit Elements

The first study on TMP dates back to 1977 [4]. Initial reports show that the TMP was considered as a narrow band structure owing to its high Q value. Hence, the early studies show potential applications of the TMP as oscillators, filters and circulators [4]. Almost simultaneously, Helszajn and James [5] reported theoretical and experimental investigationon equilateral TMP as disk resonator, filter and circulator. They used the cavity resonator model to determine the resonant frequencies for the $TM_{n,m,l}$ modes and also showed their respective field patterns. Design of the TMP as

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Fig. 1 A photograph of the Coax-fed Triangular Patch Antenna printed on a dielectric substrate

circulator was reported in [6]. Cuhaci [7] showed that the Q factor of triangular patch resonator is higher than that of a circular disk and hence can be used for designing low loss MICs. Sharma and Bhat [8] applied spectral domain technique to analyze isosceles triangular microstrip resonators and showed that the isosceles triangle geometry provides more flexibility compared to equilateral geometry in the design of MICs [8]. Recently, Hong and Li [9] investigated the dual-mode operation of microstrip triangular patch resonators in realizing dual-mode microwave planar filters.

III. Triangular Patch As Microstrip Radiators

After the primary investigation of Lo [10], TMP, particularly, the Equilateral Triangular Microstrip Patch (ETMP) antenna has been investigated by a number of researchers. The conventional ETMP antennas were studied in [10]-[12], [14]-[27]. The basic formulas to design ETMP antennas are presented in [16]. The ETMP has been analyzed and modeled using different techniques, namely, cavity resonator model [10],[15],[17]-[26], geometrical theory [12], Method of Moment (MoM) [22] and genetic algorithm (GA) [27]. It is apparent that most of the analyses are based on the cavity resonator model resulting in simple computer aided design formulas for determining the operating frequencies.

A tunable version of the conventional ETMP has been investigated in [14] by introducing a variable air gap between the substrate and the ground plane as shown in Fig. 2. The analysis was further modified by the present authors and a more accurate formulation is proposed in [15]. They have also conducted experiments to examine the bandwidth improvement caused by the air gaps. Some representative results reported in [15] are depicted in Fig. 3.

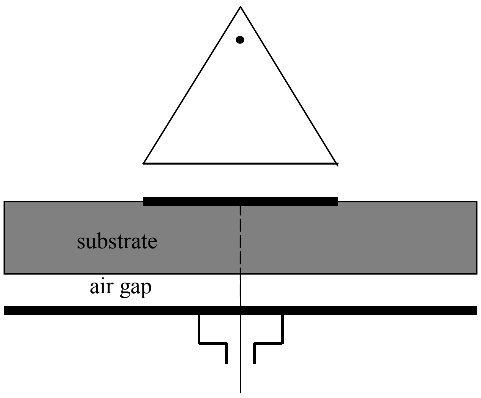

Fig. 2. Coax-fed TMP with an air gap between the substrate and the ground plane

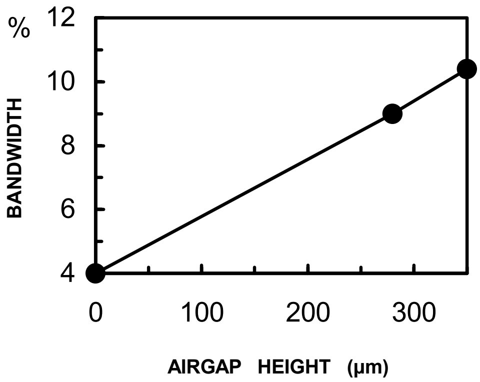

Fig. 3. Measured SWR<2 bandwidth of an ETMP antenna with different air gap heights below the substrate. Side length = 15.5 mm, substrate height = 0.508 mm, dielectric constant = 2.2 [15].

The multilayered configuration of the triangular patch with a superstrate loading as shown in Fig. 4, was first studied by Hassani *et. al.* [28]. A full-wave spectral domain technique is used to analyse the superstrate loaded triangular patch antennas. The complex full wave analysis was further simplified using a cavity resonator model by Biswas *et. al*. in [29] and [30]. Another multilayered analysis conducted in [31] propose simple and accurate closed-form expressions to compute the resonance frequency of an ETMP antenna on suspended substrates with permittivity ε_r ranging from 1.09 to 10.5.

Though broadband characteristic of the ETMP antenna is achieved by tuning the air gap as reported in [15], recent survey of literature shows several novel techniques in improving its impedance bandwidth. Jang [13] developed a new broadband antenna employing an ETMP with about 99% SWR<2 bandwidth. This approach may be of thought as a remarkable achievement since TMP is inherently a narrowband structure. However, in general the increase in bandwidth is associated with lowering in the antenna gain and as such these widedband TMPs loose their normal directivity. An application oriented design of for UMTS and ISM bands (1.92–2.48 GHz) having broadband characteristics is reported in [32]. This is achieved by placing two shorting walls at the opposite edges of a tip-truncated triangular patch

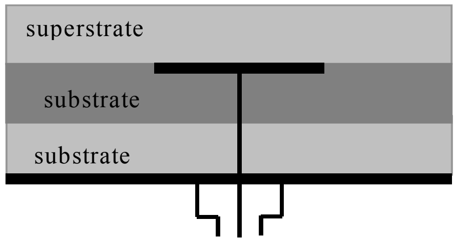

Fig.4. TMP Antenna in Multilayered Media

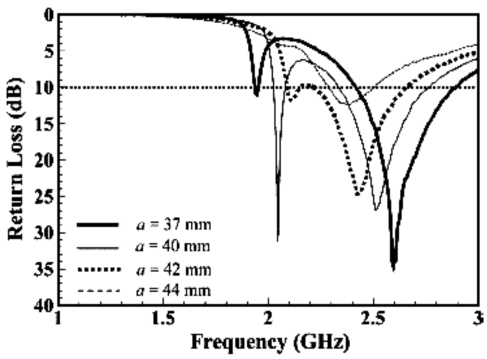

Fig. 5. Return loss versus frequency for various distance of the V-slot tip from the shorting wall [32].)

antenna with a V-shaped slot thereby exciting two resonant modes simultaneously. The result shows more than 25% impedance bandwidth with antenna height less than 0.06 λ_0. A representative plot of the return loss characteristic of this antenna is shown in Fig. 5. Another broadband configuration of the TMP employing a folded shorting wall is proposed by Li *et. al.* in [33]. Antenna gain of 6.4 dBi over a bandwidth of 28.1% is reported using this structure. The antenna configuration and its return loss characteristic is shown in Fig. 6. It also exhibits miniaturization and bandwidth enhancement when compared with the rectangular patch. Such an improvement in bandwidth of a TMP over a rectangular patch was earlier suggested by Jeon in [34]. In this report wideband patch antennas applicable to PCS and IMT-2000 were designed using an electromagnetically coupled feeding structure and the relative study shows higher impedance bandwidth (32.83%) when compared with the rectangular patch (30.36%). Several more designs for broadband operations of an ETMP are achieved by loading properly arranged slots on the patch surface [35], [36], by using an L-shaped probe [37] resulted in 42% impedance bandwidth and 6 dBi gain and by chip resistor loading [38], [39]. Dual-frequency operation of an ETMP is demonstrated by loading two pair of narrow slots in the triangular patch [40] and [41], using shorting pins [42], using a pair of spur lines [43], using a V shaped slot [44], using a slit [45] and also using stacked patches [46]. A novel design for compact multi-band single feed triangular microstrip antenna with a gain greater than 8 dBi is presented in [47].

Recently, various circularly polarized (CP) designs with a TMP using single feed have been reported. The techniques used for achieving CP are by loading a narrow tuning stub at the triangle tip or at the center of the bottom edge of the triangular patch [48], by embedding a narrow slot or cross slot of unequal slot lengths [49] and by using stub/ slot in various configurations in [50]-[52].

IV. TRIANGULAR PATCH FOR ARRAY DESIGNS

Promising use of the triangular patch as array is recently reported in [53]. It is used for the Engineering Test Satellite VIII (ETS-VIII) launched by Japan Aerospace Exploration Agency to support the next generation of mobile satellite communications. The antenna comprises of three equilateral triangular patches operating at 2.50 and 2.65 GHz having 5 dBi gain.

More array application include design of a planar array of 6-triangular patches forming a circular antenna as shown in Fig. 7 and intended to use for angular diversity at 5.1 GHz (HIPERLAN) [54]. Use of TMP as phased array is demonstrated in [55]. Another application for indoor communication using a bowtie antenna formed by equilateral triangular patches is reported in [56].

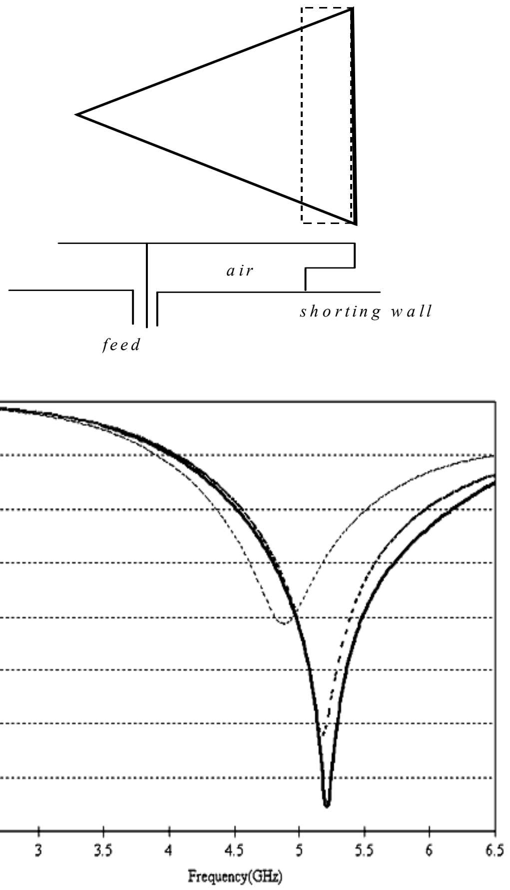

Fig. 6. TMP with a folded shorting wall and its return loss characteristics [33]

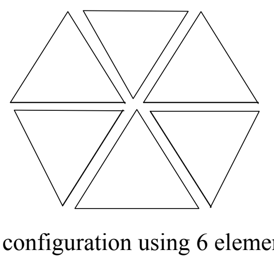

Fig.7. Array configuration using 6 element TMP [54].

Triangular shaped metal strip is also used in several antenna configurations. The bat-ear shaped antenna developed in [57] is one representative example where the directivity of a monopole is increased up to 14.7 dBi with improved side lobe performance. Another TMP printed on a cylindrical substrate is reported in [58]. This cylindrical microstrip structure offers conformability and can find applications on curved surfaces like aircraft and missile.

V. CONCLUSION

A brief review of research on triangular microstrip patch (TMP) has been presented in the limited scope. The review shows that the application of TMP varies from circuit elements to broadband radiators. Several techniques are demonstrated to overcome its inherent disadvantage of narrow bandwidth. As much as 99% SWR<2 bandwidth is reported. Application of the TMP in modern wireless systems covering UMTS, ISM and PCS bands is widely demonstrated. The conformal shape and geometry makes it an attractive element to be used for array designs.

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