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Microstrip Patch Antenna Array and its Applications: a Survey

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Abstract: *With the development of telecommunications and its applications, the design of compact antennas with high performances becomes a great necessity. Among the important requirements are: the high gain and directivity, the control of the gain pattern, the reduction of mutual coupling between elements, the multiband and broadband behavior, the reduction of reflection coefficient… The objective of this work is the presentation of the state of the art of the microstrip patch antenna array and its applications.*

Key Word*: microstrip antenna array; smart antenna; phased array antennas; beam forming antennas; electronic beam scanning antennas.*

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I. Introduction

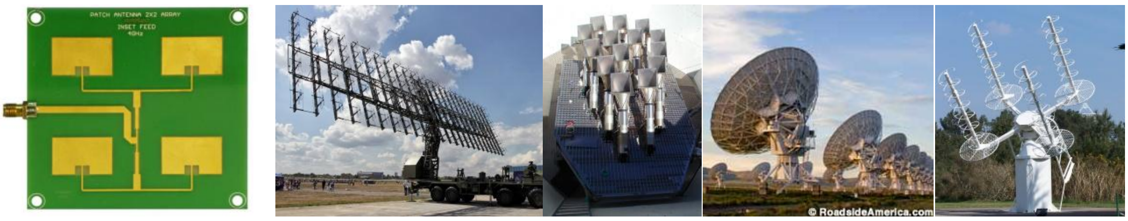
The microstrip antennas arrays have been widely used in recent years because for their robust design, presented lightweight with low cost and theirs performances are very interesting for some important applications. The microstrip array antennas are used in various fields such as personal communication systems, medical applications, mobile satellite communications, military systems (rockets, aircrafts missiles, airborne radars, Radio Navigation Systems…), wireless local area networks (WLAN), and for the 4G Radio Communication Systems. In this paper we present a survey through the literature of the different form of patch antenna array and its various applications. Also, a survey of electronic scanning antennas will be presented.

II. The antenna arrays

II.1 Overview

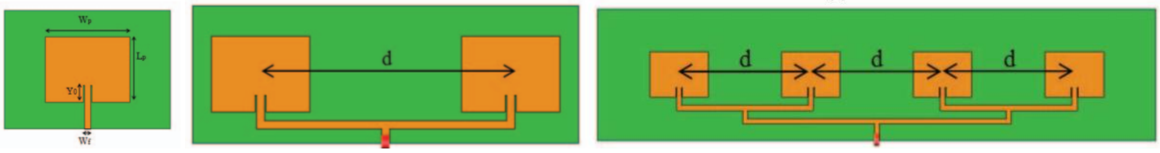
The antenna arrays, is a regular association of identical antennas to create radiation of particular shape. The radiated power is therefore greater because the number of radiating elements is multiplied. Radiation results from the in-phase addition of fields from each element. The possible combinations are thus multiple and entail a great variety of performances, which is required in the different applications. The Antenna arrays use several kinds of elements: Horns, wires, patches, parabolic, helix … (Figure 1).

It is obvious that the group of antennas occupies a larger space than the single element antenna; its radiation pattern is narrower since its directivity increases with its surface. The antenna array gain and directivity are higher compared to the single element antenna[1]. Figure2 shows an example for Microstrip Patch Antenna Array and theirs gains, when the element number increases, the HPBW (Half Power Beam Width) becomes narrow and the gain becomes high.

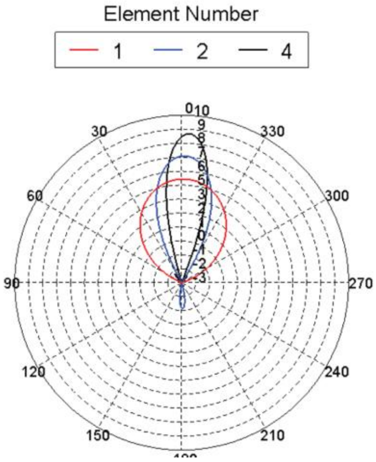


(a) Patch (b) Wire (c) Horn (d) parabolic (e) Helix

Fig.1. Different kinds of antenna arrays



(a) 1 element **(b) 2 elements** **(c) 4 elements**



(d) The gain pattern for the 3 antennas

Fig. 2.Microstrip Patch Antenna Array and theirs gains [1]

Another advantage of the antenna array is that the choice of a regular phase shift between the elements set the beam orientation, in space within certain limits of angles.

The spatial organization of the antenna array and its feeding mode, allow having a defined radiation properties. These properties are modifiable with the possibility of acting on the phase and amplitude of the power supply of each element forming the antenna array. Figure 3 shows the variation of the beam direction versus the excitation phases of antenna array elements[2].

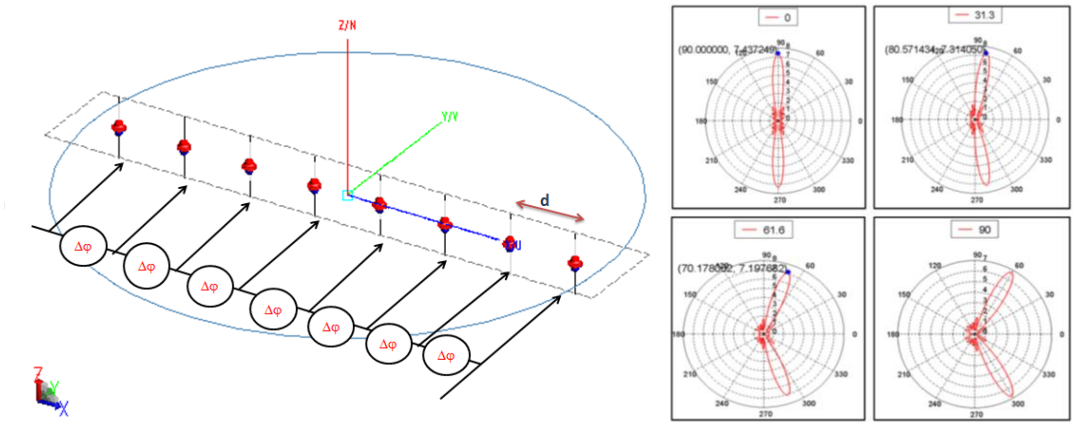


Fig. 3. Dipole Antenna Array and theirs gains pattern [2].

The coupling between the elementary antennas is a delicate point because this coupling modifies the radiation and adaptation characteristics. In particular, the bandwidth of the antenna array is higher than that of the elementary antenna because of the coupling.

II.2 The use of antenna array

The development of antenna arrays started over 100 years ago. Brown separated two vertical antennas by half a wavelength and fed them out of phase. He found that there was increased directivity in the plane of the antennas. Forest also noted an increase in gain by two vertical antennas that formed an array. Marconi performed several experiments involving multiple antennas to enhance the gain in certain directions. These initial array experiments proved vital to the development of radar. World War II motivated countries into building arrays to detect enemy aircraft and ships. The first radar for air defense was a network of radar stations named "Chain Home (CH)" built in 1940 (Figure 4). As the war progressed, better radars were needed. New radar called the SCR-270 (Figure 5) was available in Hawaii and detected the Japanese formation attacking Pearl Harbor[3].

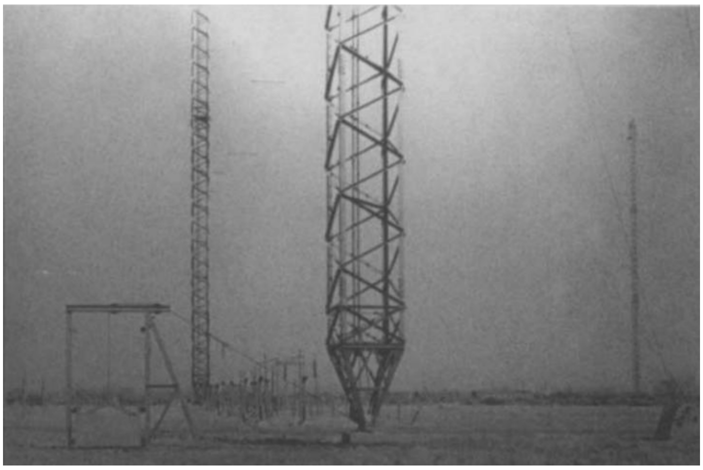


Fig.4. Chain Home antenna array [3]

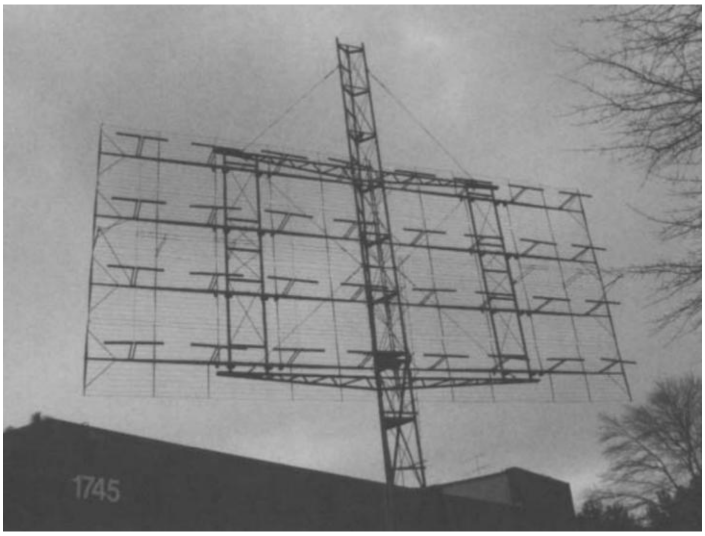


Fig. 5. SCR-270 antenna array [3]

In recent years, with the development of patch antennas, LEVINE presented in 1989 an analysis and theoretical study of the radiation and losses (dielectric, ohmic, dissipative) of microstrip arrays, he presented also a description of the radiation patterns and the surface wave excitation of 4 element array including the feed network effects. Finally the analysis has been extended to 16, 256 and 1024 elements thus giving gains, directivity and radiation patterns and this for frequency 10, 20, 30 and 35 GHz(Figure 6) [4].

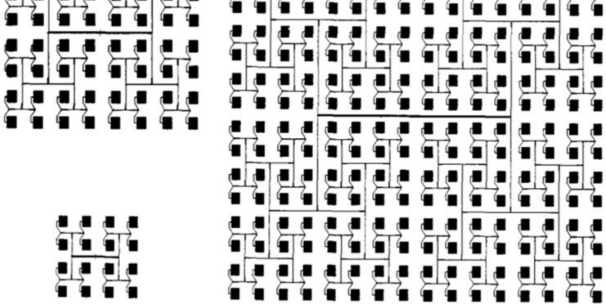
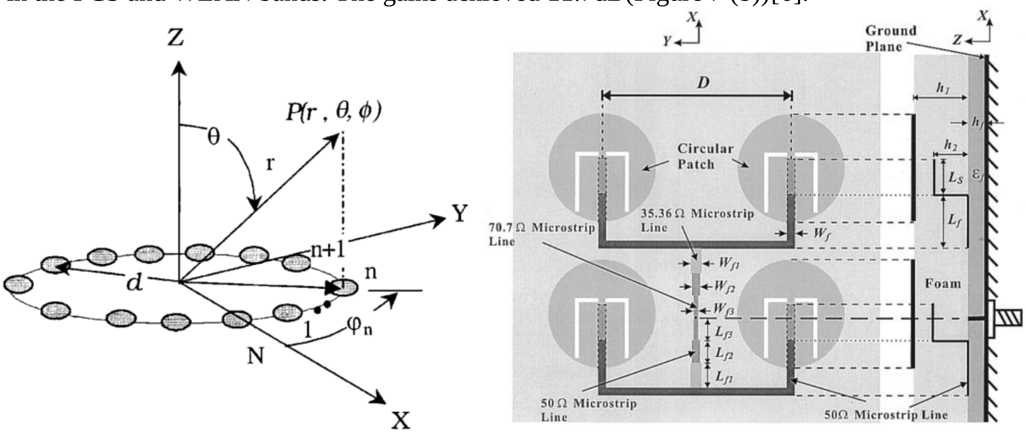


Fig. 6. Layouts of modular arrays of 16, 64, and 256 element studied by LEVINE [4]

In 2002, KARMAKAR studied the behavior of 12 elements circular patch antenna array fed by an aperture coupled feeding mode. The antenna operates in the band of 1.4 GHz - 1.8GHz (Figure 7 (a))[5]. In 2003, JUI-HAN LU designed a network of circular antennas with slots and using the coupling mode feeding, operating in the PCS and WLAN bands. The gains achieved 11.7dB(Figure 7 (b))[6].



(a) **(b)**

Fig. 7. The circular patch antenna arrays fed by aperture coupled mode studied by KARMAKAR (a) [5] and JUI-HAN LU (b) [6]

In 2006, YOUSEFZADEH proposed a new microstrip patch antenna array with fractal patches instead of conventional rectangular patches. Simulation results show that using fractal patches enhances the performance of the array. The mutual coupling between elements decreases substantially, and input return loss decreases compared to rectangular patch array [7].

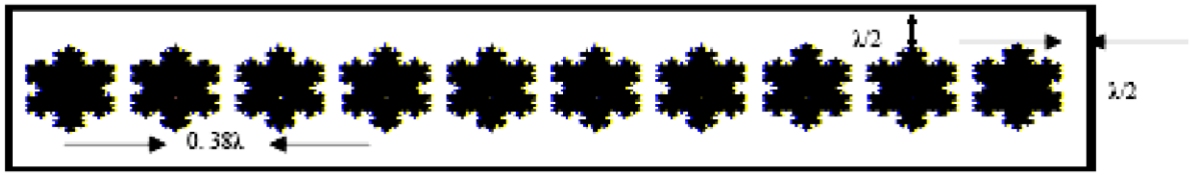


Fig. 8. The structure of the KOCH Snowflake fractal patch array antenna proposed by YOUSEFZADEH [7]

In 2008, ZULKIFLI designed a double hexagonal shape antenna composed of two element triangular microstrip antenna array. The results demonstrated that the radiation properties of the antenna with DGS (Defected Ground Structure) have better performance than the antenna without DGS. It is also shown that the geometry of the DGS has an influence towards the performance of the antenna characteristics Figure (9)[8].

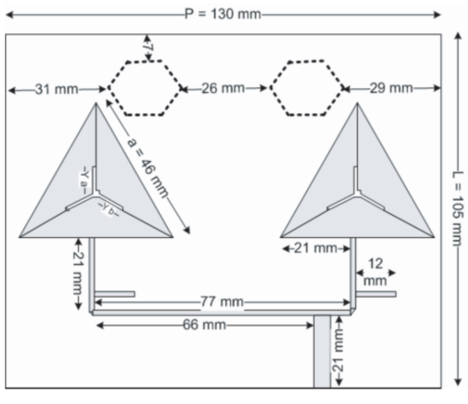
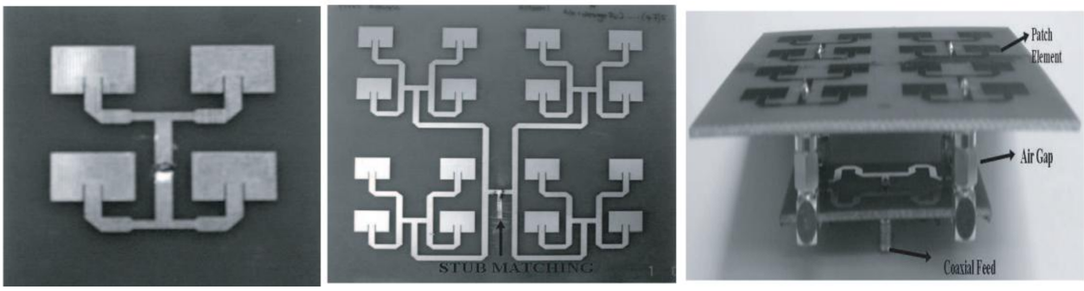


Fig. 9. Configuration of double hexagonal DGS antenna proposed by ZULKIFLI [8]

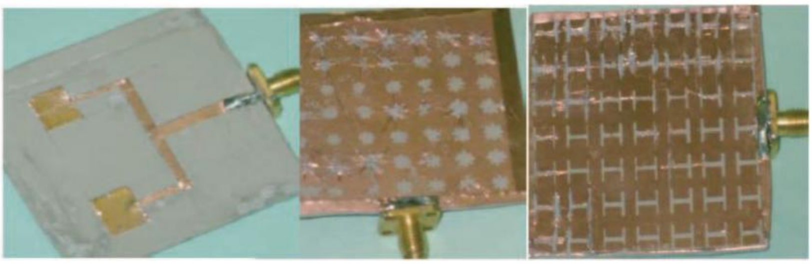
In 2009, ALI studied 2x2 and 4x4 microstrip planar antenna array with the separated feed line technique concept in order to reduce the sidelobe level and to increase the gain (figure 10)[9].



(a) (b) (c)

Fig. 10. the 2x2 (a) and 4x4 (b) microstrip planar antenna array with the separated feed line technique (c) proposed by ALI [9]

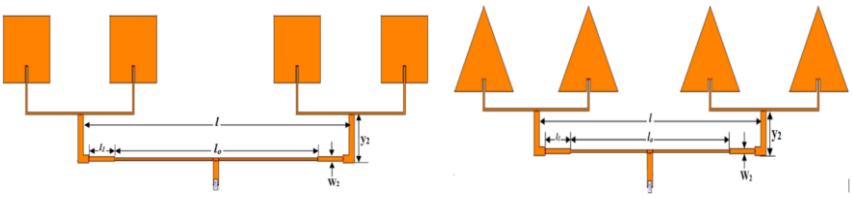
In 2010, ELSHEAKH designed a two-element microstrip array antenna integrated with 2D-EBG (Electromagnetic Band-Gap) on the ground plane. This antenna reduces the coupling between patches of the array and, hence, is useful in decreasing the maximum side-lobe level without a change in the distance between the patches(Figure 11) [10]. ATTIA studied a 4 x 1 linear microstrip patch array antenna with a magneto-dielectric superstrate constructed by split-ring-resonators to enhance its far-fleld properties. The distance between the patches and the superstrates is optimized to achieve a gain enhancement and mutual coupling reduction[11].



(a) (b) (c)

Fig. 11. Photo of the fabricated antenna (a) radiator, (b) star slot and (c) I slot proposed by ELSHEAKH[10].

In 2012, KHRAISAT compared the performances of rectangular and triangular antenna arrays. This study demonstrates that the two structures have the same performances, however, a better suppression for side lobe level is observed for the triangular structure (figure 12)[12].



(a) (b)

Fig. 12. The rectangular (a) and triangular (b) patch antenna array studied by KHRAISAT [12].

In 2013, RESLEY presented a rectangular patch end-fire array antenna. It was designed and optimized using eight elements of half-wavelength and a width 0.12λ in FR-4 substrate. Measured results showed end-fire operation with a measured maximum gain of 6.9 dBi in the end-fire direction. The antenna can be used for multiband applications(Figure 13) [13].

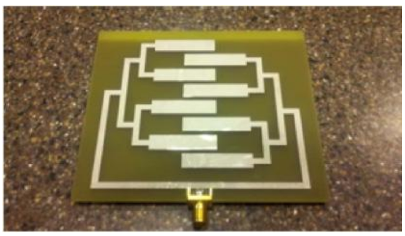
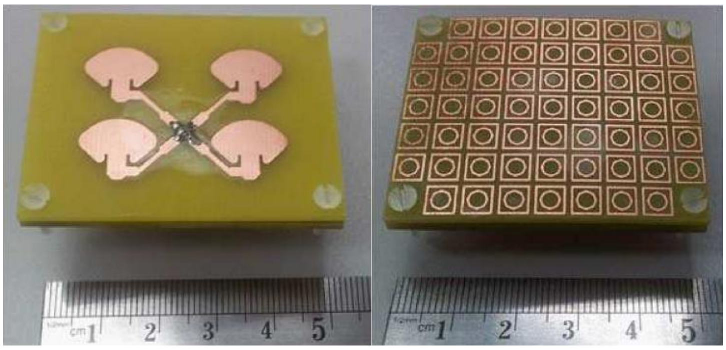


Fig. 13. photo of the multi-band end-fire antenna array designed by RESLEY [13].

RAIMI DEWAN designed a 4-element (2x2) circular patch antenna array. The implementation of DGS Ground plane allows having a high gain with a wider bandwidth. The antenna operates in the band of 5.8GHz (figure 14) [14].



(a) Top view **(b) Bottom view**

Fig. 14. The 4-element (2x2) circular patch antenna array with DGS Ground plane designed by RAIMI DEWAN [14].

In 2014 CHENG designed a large-scale high-gain planar integrated array antenna operating at W-band (91 - 97 GHz), which employs SIW (Substrate Integrated Waveguide) as the feeding network. The 32×32 array of patch antennas are divided into a number of 2×2 sub-arrays, each of which is fed through a longitudinal slot etched on the top conductor surface of the SIW feeding line(figure 15) [15].

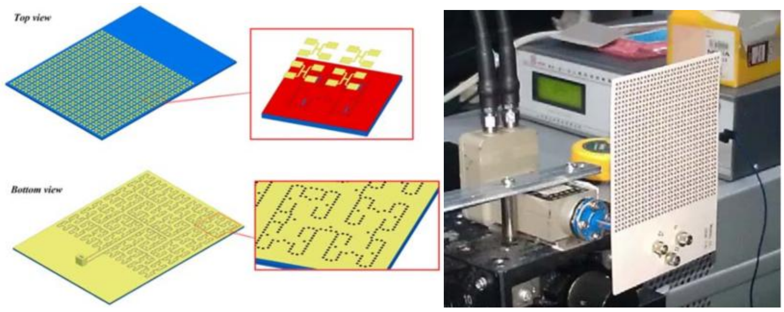


Fig. 15. The 32×32 patch antenna array with Feeding mechanism proposed by CHENG [15].

In 2015, Huang studied a new directional antenna array aperture, based on LSA (Long Slot Antenna) array technology, and associated feeding structure were designed, fabricated, and tested. The complex feeding structure of the antenna array was simplified with a novel metallic patch design using 50-60 Ohms microstrip lines. The antenna have a gain of 16 dBi and a bandwidth of 4-6 GHz (figure 16) [16].

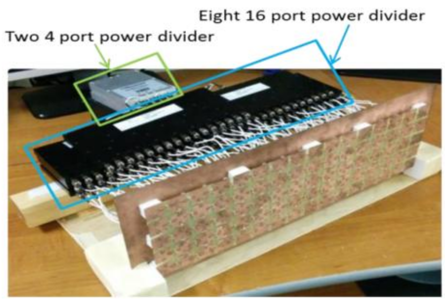
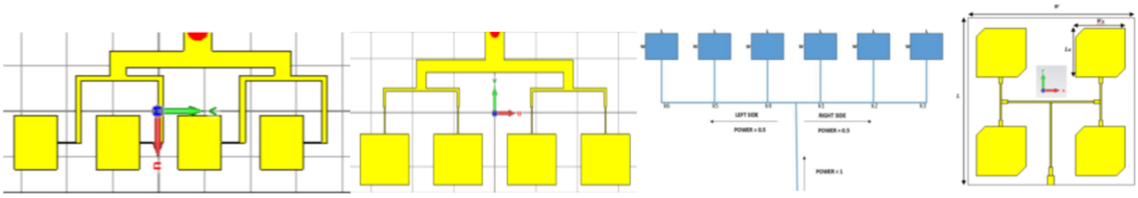


Fig. 16. The patch antenna array with Feeding mechanism proposed by Huang [16].

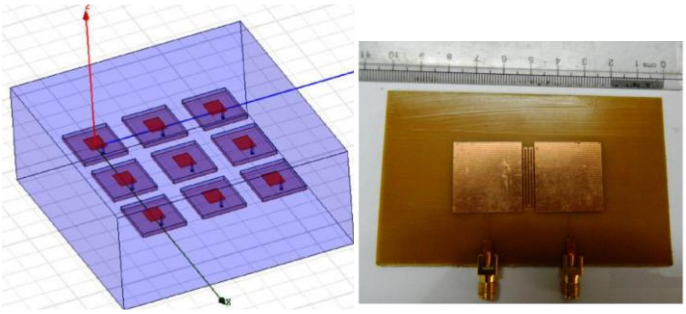
DINESH RANO designed a multiple configurations of linear patch antenna array with very high gains. These antennas are adequate for 10GHz applications (figure 17 a and b) [17]. HADZIC studied a microstrip patch antenna array with six elements. The antenna has a high gain (15.1 dBi) and a very small sidelobes. The designed antenna can be applicable in many fields such as radar applications(figure 17 c) [18]. JAIS designed a 2x2 patch array high gain antenna for 2.45 GHz ISM (Industrial, Scientific and Medical) band application. With air gap configuration, the antenna is able to increase bandwidth percentage of up to 46.15% and realized gain of 19.29 dBi (figure 17 d) [19].



(a) (b) (c) (d)

Fig. 17. The patch antennas array studied by DINESH RANO (a, b) [17] and HADZIC (c)[18]and JAIS (d)[19]

In 2016, MIDASALA designed a 3x3 rectangular patch antenna array operating at the frequency of 13.3GHz with a gain of 17.29 dBi (figure 18 a)[20]. GHOSH succeeded in reducing the mutual coupling of a rectangular patch antenna array (2x1) with using meander line resonator between the two patch antennas (figure 18 b)[21].



(a) (b)

Fig. 18. The patch antennas array studied by MIDASALA (a) [20] and GHOSH [21]

In 2017, GHARBI studied two rectangular patch array antennas 4x1 and 2x2 for 5G applications (28GHz), the gains reached 13.3dBi (figure 19)[22].

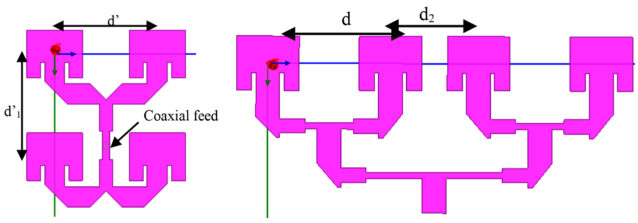


Fig. 19. The patch antennas array studied by GHARBI [22]

HUI LI designed a 4-element antenna array fed by employing U-shaped and M-shaped feedlines to excite a quasi-cross-shaped coupling aperture. The antenna operates at 5.4 -5.6GHz band, for OAM (Orbital Angular Momentum) applications (figure 20)[23].

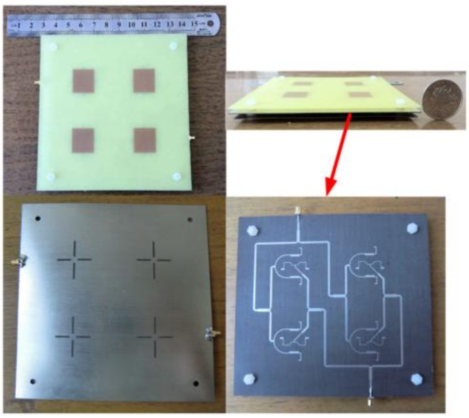
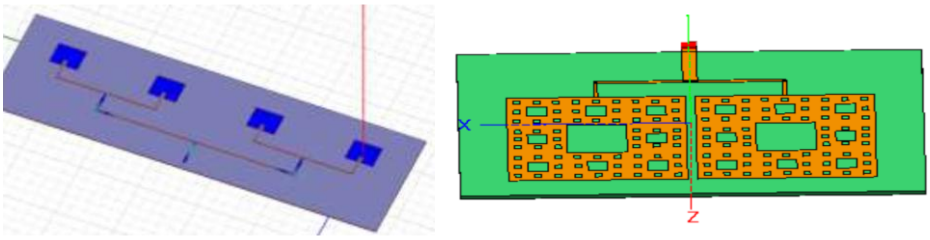


Fig. 20. The patch antenna array designed by HUI LI [23]

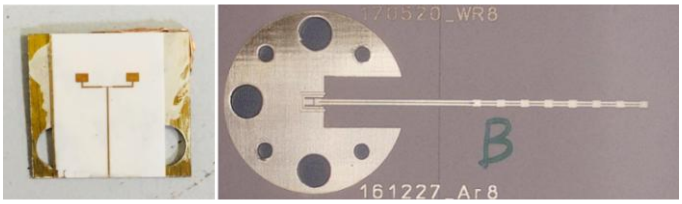
DATTO designed a 1x4 rectangular antenna array that operates at 2.4GHz and has a gain of 14.45 dBi (figure 21 a)[24]. MATHPATI designed a Sierpinski carpet fractal antenna array (2x1). The antenna is broadband operating at 4 GHz frequency but has very low gains (figure 21 b)[25].



(a) **(b)**

Fig. 21. The antennas array studied by DATTO (a) [24] and MATHPATI [25]

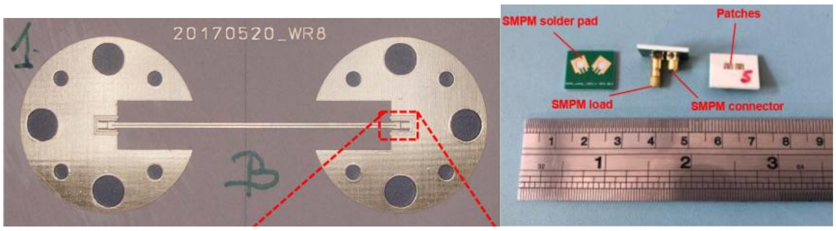
In 2018, JAISWAL designed a two-element microstrip patch antenna array using recessed ground at 60GHz with a wide bandwidth and high gain (figure 22 a)[26]. HASAN designed a differential microstrip patch antenna array that operates at 122 GHz and is suitable for radar applications. The antenna is composed of 8-element series-fed array and it provides an impedance bandwidth of 14 GHz and a gain of around 13.74dBi at 122 GHz (figure 22 b)[27].



(a) **(b)**

Fig. 22. The antennas array designed by JAISWAL (a) [26] and HASAN [27]

In 2019, HASAN designed a differential microstrip patch antenna array and a rectangular waveguide to couple differential microstrip line transition operating at 122 GHz. The antenna array is realized in series-fed topology architecture and is very suitable for MIMO radar applications (figure 23 a)[28]. SHEN proposed a miniaturized two-element microstrip antenna array for 5G wireless communication systems (26,5 – 29,5 GHz). A surface EBG is applied as the ground for two closely packed patch antennas (figure 23 b)[29].



(a) **(b)**

Fig. 23. The antennas array designed by HASAN (a) [28] and SHEN [29]

All the presented works aims to design Microstrip Patch Antenna Array in order to improve gain and directivity while reducing mutual coupling and rear and side lobes. In the next section, electronic scanning antennas will be presented.

III. Electronic beam scanning antennas

III.1 Overview

One of the advantages of the antenna array is to steer the maximum radiation to a selected direction or create multiple lobes simultaneously by the excitation of the different sources by signals having specific phases.

The electronic beam scanning is the change of direction of the main beam without moving mechanically the antenna (Dynamic Phase Array) or the change of position of the antenna without moving the beam position (Fixed Phase Array).

Smart antennas are particular case of antenna arrays with smart signal processing algorithms used to steer the maximum radiation to one or more particular directions or to identify spatial signal signature such as the direction of arrival (DOA) of the signal.

As any technology, the electronic beam scanning as smart antennas have some disadvantage such as: circuit complexity, imposed frequency range, limited scanning space and others. For example, an array patch antenna fed by Butler Matrix Feeding System covers a limited zone. Also, the feeding system is complicated[28]–[32].

An antenna array is a set of elementary antennas designed in a way to satisfy a number of specific radiation requirements (gain, directivity, radiation pattern, Side Lobe Level (SLL), Half Power Beam Width (HPBW), and others). We can respond to some specifications by controlling the constructive recombination and destructive depending on the spatial relocation of radiating sources. There are several geometric configurations of antenna arrays which can be grouped as follows:

- Linear network
- Planar network
- Circular network
- Volume network

The formation of the beam depends on several factors such as: the geometry and the position of antenna elements, the distance between them, their excitation phases, and the radiation pattern of a single element.

For example, the linear array antenna is composed of N linear radiating elements, placed in the same axe and spaced with regular distance (d). Figure 24 shows an example of linear array antenna fed by a group of sources having the same magnitude and their phases are shifted by Δϕ.

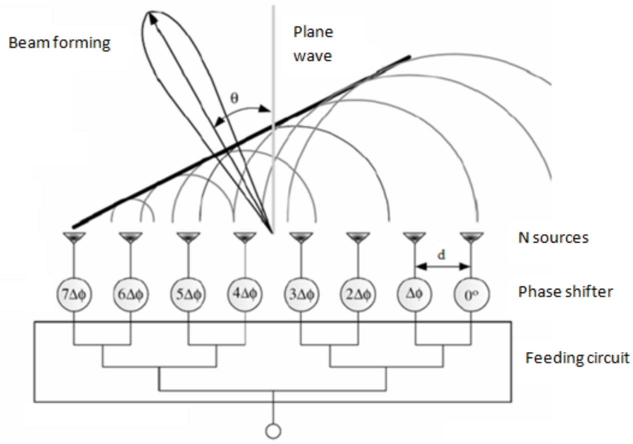


Fig. 24.Phased array antenna.

The total far field radiated by the combination of N elements, assuming no coupling between the elements, is given by the equation 1.

$$E_t = \frac{E_0 I_0}{r} \cdot \frac{\sin\left(\frac{N\varphi}{2}\right)}{\sin\left(\frac{\varphi}{2}\right)} \qquad (1)$$

With:

$$\varphi = kd\cos(\theta) + \Delta\emptyset \qquad (2)$$

And

$$F = \frac{1}{N} \frac{\sin\left(\frac{N\varphi}{2}\right)}{\sin\left(\frac{\varphi}{2}\right)} \qquad (3)$$

F is the array factor.

A variation of $\Delta\phi$ causes that of θ: "the principle of phased array antennas".

The relationship between θ and $\Delta\phi$ is given by the equation (4)

$$\theta = cos^{-1}\left(\frac{\lambda\ \Delta\emptyset}{2\pi d}\right) \qquad (4)$$

With λ is the wave length.

III.2 The use of electronic beam scanning antennas

In the last two decades, several researchers have treated electronic beam scanning antennas in their research. In 2002, VARLAMOS studied a switched parasitic smart antenna that achieves electronic beam steering by choosing the appropriate combinations of active and parasitic elements. The studied antenna is composed of ten-element linear array[35]. SHAFAI studied a technique using reconfigurable microstrip patches to generate the required inter-element phases in phased array antennas. Using the proposed technique, the beam scanning was carried out by about 14.5° without the use of phase shifters (figure 25) [36].

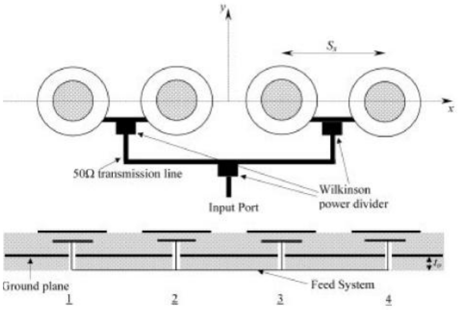


Fig. 25. The patch antenna array proposed by SHAFAI [36]

In 2003, MURAKAMI has investigated the possibility of using self-driving matrices for secure cross links in pico-satellite networks. This is a technique used for the automatic control of radiation patterns to solve the problem of energy consumption (figure 26) [37].

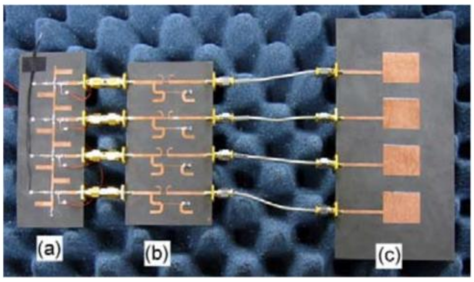


Fig. 26. The patch antenna array designed by MURAKAMI [37]

In 2005, SCHAER introduced a new design of an electronic beam scanning antenna with parasitic reactive elements. The antenna in composed of a group of circular dipoles (figure 27) [38].

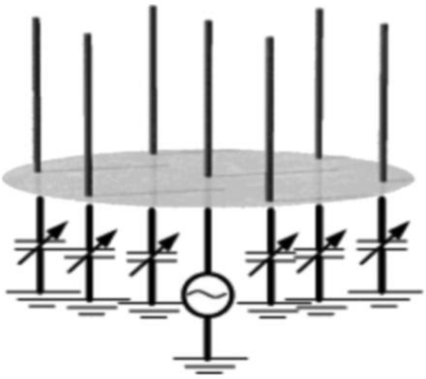
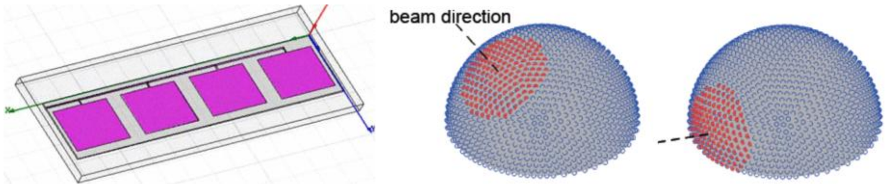


Fig. 27. The antenna array designed by SCHAER [38]

In 2011, GOEL designed a patch antenna array for radar and space applications (10GHz), the antenna is printed on a substrate with a phase shifter allowing to perform an electronic beam scanning from 0 to 10 degrees. The phase shifter is a special mechanism based on microstrip lines (figure 28 a)[39]. In 2012, CHENG investigated electronic beam steering via antenna arrays as a substitute for large parabolic tracking antennas. This kind of antennas is used for the terrestrial sector of satellite systems. The activation of the radiating elements depends on the desired direction (figure 28 b)[40].



(a) **(b)**

Fig. 28. The antennas array designed by GOEL (a) [39] and CHENG [40]

In 2013, DEROSE designed a miniaturized electronic scanning antenna array fed by a miniaturized optical system[41]. In 2015, SHI designed a PLL Circuit (Phase-locked loop) to control the power phases of a patch network in order to perform an electronic beam scanning. The antenna is operational for the W band (76-77 GHz) (figure 29) [42].

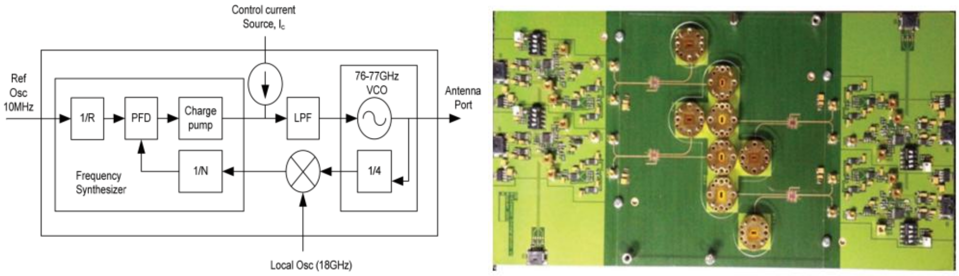


Fig. 29. The PLL circuit designed by SHI [42]

FERREIRA designed an active power supply circuit for antenna arrays with a reconfigurable radiation pattern. The circuit topology is composed of phase shifters and variable gain amplifiers allowing the dynamic control of the amplitudes and phases of the excitations of the network (figure 30) [43].

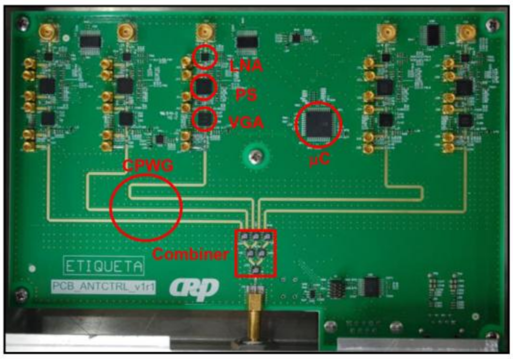


Fig. 30. The active power supply circuit for antenna arrays designed by FERREIRA [43]

In 2018, MALEK studied several antenna array configurations to have an electronic beam scanning. The chosen antenna is a dipole; the distribution of the elements is made of 3 ways (Uniform, Chebyshev and Binomiale). A comparison was made and it showed that the binomial distribution allows having a very high gain against a very large 3dB aperture[44].

IV. Conclusion

The microstrip antennas arrays are the best solution to design low profile antennas with high performances: High gain and directivity, low mutual coupling between the array elements and low side and rear lobes. They can be in different forms: rectangular, circular, and fractal. Placed in different ways: linear, circular, and planar. Fed in several ways: coaxial probes, microstrip lines, proximity-coupled, and coplanar wave guide (CPW). Their radiation properties can be improved with the implementation on the ground plane some techniques such as: Defected Ground Structure (DGS), the Air Gap (AG), the Electromagnetic Band-Gap (EBG), and the Substrate Integrated Waveguide (SIW). The ways in which the different elements of microstrip patch antenna array are fed allow having an electronic beam scanning or a beam forming. The microstrip patch antenna arrays are used in several applications, the most important are: the RADAR applications, the new generation of mobile communication systems (4G/5G), the IOT (Internet Of Things), and the satellite applications.

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