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An Investigation on Antenna Substrate Materials for the Design Of 5X20 Massive MIMO Antennas

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Abstract *— The wireless technology resides at 5G global standard wireless communication. This standard enhances the network capacity, network coverage, lower latency and enormous bandwidth by increasing the operating frequencies of the communication standards. 5G standard promises to deliver a speed of 500 times faster than 4G by utilizing the technology such as massive MIMO, small cell, beam forming and full duplex technology. The higher operating frequencies leads to the path loss constrains and the device compact also one of the issues arises in the handheld wireless communication devices or massive machine type communications. To overcome these issues an effective antenna has to be designed for the new generation wireless standards. Most commonly used handheld communication devices, IoT devices and massive machine type communication uses microstrip patch antenna as radiating elements and the substrate materials associated with these antennas plays a key role for the development of an antenna. In this paper, investigations on six different substrate materials were done for the design of MIMO antenna. A rectangular microstrip antenna was designed under the operating frequency of 28 GHz using six different substrate materials such as Taconic TLY-5A, Arlon Diclad 880, Rogers Utralam, Rogers RO 3003, Rogers RO 3035 and Arlon AD 450. From this analysis an Arlon Diclad 880 substrate material is best suited for the developement of an array. An array of 10 elements and 100 elements microstrip patch antenna has been designed and simulated using CST microwave studio suite. A planar microstrip antenna array (2X5) was designed using Arlon Diclad 880 substrate material having the dielectric constant of 2.2 and a thickness of 0.127 mm, it gives a maximum gain of 13.74 dBi at 27.9 GHz, directivity of 14.29 dBi and the overall dimensions of 10×22.5×0.127 mm where as 5X20 massive MIMO antenna array gives a maximum gain of 23.66 dBi at 28.1 GHz, directivity of 24.15 dBi and the overall dimensions of 145×22.5×0.127 mm. Further slots will be introduced in the antenna for even more size reduction in the conventional microstrip patch antenna for the 5G wireless handheld communication devices and the IoT applications.*

Index Terms— *Microstrip patch antenna, Substrate Materials, 28 GHz frequency band, Compact size, 5G Wireless Technology, Massive MIMO Antenna, 5X20 Antenna elements.*

INTRODUCTION:

A. Need of antenna:

When the communication took place through the coaxial, copper cable etc., the infrastructure for implementing the communication path between the transmitting and receiving end user devices getting complicated when the end user device tries to connect more number of another end user device. It is not practically applicable for mobility through wired communication. So, the antenna or the radiating elements came into existent to overcome the mobility of end user devices. The radiating element transmits or receives the electromagnetic waves or radio waves and converts the EM waves into electrical signal and vice versa. The radio or electromagnetic waves carries the information's and propagates through free space. Antennas are the fundamental part of any wireless communication systems [1-2]. In wireless communication system, the transmitting antenna on the transmitter

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converts the electrical signal into electromagnetic waves on the other hand the receiving antenna receives the electromagnetic waves back into electrical signals. These electrical signals are guided by the transmission line. Thus the antenna serves as a transitional element between the free space and the transmission line. In other words, antenna is transducers. The electromagnetic waves are nothing but oscillating electric and magnetic field which are perpendicular to each others. The followings are the some of the important functions of antennas; they are Transducers, Impedance matching, Radiator, Sensor and Coupler. The radiation mechanisms of an antenna are quite simple. Generally, the incident energy is getting reflected back when the circuit is open. In practical, a small amount of electromagnetic energy spreads out to the free space through the aperture. When the two wires of an dipole gets closer to each other then the radiations from one wire cancel out the radiation from another parallel wire due to opposite charged particles. To increase the radiated electromagnetic waves, the aperture of a dipole should be enlarged enough to couple the incident energy to the free space. This leads to increases in the radiation efficiency and the signal transmission takes place. The important antennas parameters are as follows; Radiation pattern, Radiation efficiency, Radiation intensity, Bandwidth, Gain, Directivity, Effective aperture, Polarization etc. The operation performed by the transmitter as well as receiver may varies and also falls under the categories of transducing elements. There exist a wide number of antennas with various sizes and shapes. Also the wireless communication systems may use single radiating elements or combination of its radiating patch to improve the coverage and the capacity of the end user devices. The types of application and the frequency of operation lead the antenna to be fabricated in various sizes and shapes. It also includes linear, planar, circular polarization. The typical classification of antenna are as follows; Wire antenna, Aperture antenna, Reflector antenna, Lens antenna, Microstrip antenna, Array antenna etc.

B. 5G and Beyond:

Now, wireless communication systems are in the 5G era. 5G the enhanced global wireless standard for the mobile communication like 1G, 2G, 3G and 4G wireless communications. It brings us a new kind of features to the end user devices to connect virtually every devices and everything together which includes devices, Machines, Clouds etc. 5G wireless communications delivers higher multi Gbps data speed, low latency, high reliability, massive network capacity, enhanced availability and reliable communication to the end users [4]. It is particularly designed to connect more available devices with higher speed capabilities; latency between the devices will be neglected. 5G widely used in three types of connecting devices such as enhanced mobile broadband, mission critical communication and massive IoT devices. It is expected to be 500 percent faster than previous generation wireless communication. The peak data rate of up to 20 Gbps. Like 4G network, 5G also uses the OFDMA technology with the New Radio air interface will also enhance the much higher flexibility and reliability for the users. 5G uses the New Radio frequency band in order to increases the data rate of the communication systems and to eliminate the interference from the available frequency bands ranges below 6 GHz and to increases the network capacity [3]. The Frequency Range (FR1) which ranges below 6 GHz and the Frequency Range (FR2) includes mm waves frequency band ranges from 20 to 60 GHz.

C. mm Wave Communication:

Millimeter wave or high frequency band in 5G frequency ranges from 24 GHz to 60 GHz. The available wireless communications devices uses the below 6 GHz frequency band, when the network capacity has reached their limits, a traffic congestion may occur and corresponding frequency spectrum has a limited bandwidth and less network capacity [7]. To overcome this issue, 5G uses the mm wave frequency band [11]. Though the 5G mm wave delivers a high speed data rate but it has some limitations too. As radio frequency increases, mm wave coverage has limited to 300 to 500 feet due to the path loss associated with increases in the operating frequencies [5]. Since, the mm wave widely used in military, satellite, aerospace industries but to increases the speed and network capacity, the 5G should uses the mm wave frequency spectrum [6]. To overcome the path loss problem associated in mm waves, the 5G infrastructure creates a small cell concept to avoid limited coverage, seamless wireless communication and better user experience. The 5G small cells are low powered when it's compared to 4G high powered tower cells. Small cells can provide high speed communication and the utilization of mm wave. The cells can be deployed in indoors as well as outdoor environments.

D. Microstrip Antenna:

In 5G wireless mobile communications, a microstrip antenna plays an important role in the connecting end user equipments such as massive machine type communication, smart phones, access point, virtual reality etc. The end user devices are very much compact enough to handle, the microstrip antenna paved a way to the electromagnetic waves can be easily communicate with the connecting devices. Microstrip antenna commonly referred to as the patch antenna, this antenna importance increases rapidly day by day applications [9]. It can be easily integrated with other electronic circuits though the size of this antenna is very much compact and planar structure. It is a low profile antenna has its manufacturing cost is less and can be easily fabricated. Microstrip antennas are formed by etching the conducting materials on dielectric substrate materials known as patch. It comes out with various shapes and sizes it depends upon the frequency of operations. The conventional shapes are rectangular, square, triangle, circle, elliptical etc. The figure 1 shows the structure of a rectangular microstrip patch antenna using insect feeding method. The patch, the ground plane and the transmission lines are made up of high conducting materials, when the patch is excited by the electrical signal, the patch starts radiates the electromagnetic waves through its width. There are different types of feeding mechanisms are available to excite the radiating elements they are contact and non contact feedings. In contact feeding the excitation of patch is directly through strip line or through coaxial feed line. Microstrip feed lines are conducting strips, which is extremely smaller than the radiating elements and directly etched on the dielectric substrate and it is attached directly to the patch plane. Coaxial feed lines are most commonly used feeding method. In this method the outer conductor is attached to the ground plane and inner conductor is drilled and soldered to the radiating patch and the appropriate coordinates are chosen such that their impedance should be perfectly matched. In non contact feeding the excitation is indirect and the radiating elements are excited through electromagnetic coupling. Aperture coupling uses two dielectric materials separated by ground plane. The feed lines are provided through the bottom of the lower ground plane, a slot is formed in the ground plane which lies between the two substrate materials. In proximity feeding method eliminates the ground plane between the two dielectric substrate materials instead it uses the feed line for the electromagnetic coupling from the excited signal

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to the patch. The different method has various advantage and disadvantage and depends upon the frequency of operation and respective applications.

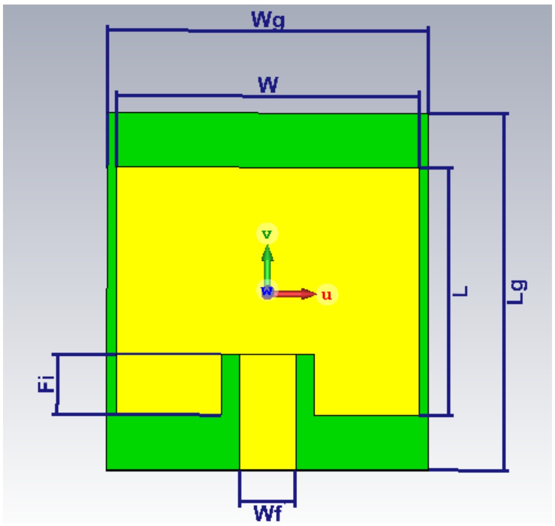

Fig. 1 Rectangular Microstrip Patch Antenna (RMPA) with insect feed

E. Antenna Design Equation

Before going into the microstrip patch antenna design, the microstrip patch antenna should meet following requirements such as dielectric substrate height should lies between $0.003\lambda \leq h \leq \lambda$, where λ is the free space wavelength. The permittivity of the substrate should lies between $2.2 \leq \varepsilon_r \leq 12$ [8].

The following design equations help to calculate the width and length of the patch.

$$W = \frac{C}{2F}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

To calculate the length of the patch, an effective dielectric constant of the substrate and ΔL should be known.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\sqrt{1+\frac{12h}{W}} \tag{2}$$

$$\Delta L = 0.412h\,\frac{(\varepsilon_{reff}+0.8)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \tag{3}$$

$$L = \frac{\lambda_s}{2} - 2\Delta L \tag{4}$$

$$\lambda_s = \frac{\lambda}{\sqrt{\varepsilon_{reff}}} \tag{5}$$

Where W = Width of the patch material
L = Length of the patch material
h = Height of the substrate material
ε_r = Dielectric Constant of the substrate material
ε_{reff} = Effective dielectric constant of the substrate material
ΔL = Variable length of the patch material
C = Velocity of light in free space
F = Resonant Frequency
λ_s = Wavelength of the substrate material
λ = Wavelength of the operating frequency

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The following equation gives the dimensions of the substrate material:

$$Ls = L+6h \tag{6}$$

$$Ws = W+6h \tag{7}$$

Where Ls = Length of the substrate material,
Ws = Width of the substrate material,
L = Length of the patch material and
H = Height of the substrate material.

SUBSTRATE MATERIALS FOR ANTENNA FABRICATION:

A. General Requirements:

To design a microstrip patch antenna, the selection of appropriate substrate materials is the foremost thing. The substrate is necessary to provide mechanical support to the radiating element. Generally, a substrate consists of dielectric material having a variant dielectric constant for different application, which will simultaneously affect the electrical properties of radiating element. The following important parameters are considered before selecting the substrate materials for the antenna design they are surface wave, dissipation and loss tangents, copper loss, temperature, humidity range, mechanical stability, manufacturing cost of the substrate materials etc. The dielectric constant of the substrate materials should lies between 2.2 to 12 and the thickness of the substrate materials should lie between $0.003\lambda \leq h \leq\lambda$, where λ is the free space wavelength. If the dielectric constant of the material increases, the size of the antenna to be designed becomes compact and vice versa. The thickness of the material also plays a major role while selecting the substrate material for design. Generally, a microstrip patch antenna has narrow bandwidth and emits surface waves. To eliminate these problems, a thicker substrate material is chosen but the gain significantly reduced. A trade of should be made and appropriate dielectric constant and substrate thickness should be chosen for the appropriate applications. For the size constrain applications, a thin substrate and high dielectric materials are to be selected. For better performance and gain, thin substrate and low dielectric constant materials is to be chosen.

B. Most Commonly Used Substrate Materials:

Substrate materials are the base of an antenna design and fabrication. This material should be low loss materials to enhance the performance of the communication systems. The demand is from the mobile phone manufacturer, base stations, IoT application, automotive industries, military applications, satellite communications etc. The substrate materials for the antenna are mainly falls under the following categories they are ceramics, organic laminates and fiber glasses. PTFE (polytetrafluoroethylene) laminates, LCP (Liquid crystal polymers), PPO (Polyphenylene oxide) and LTCC (Low Temperature Co-Fired Ceramic) substrates plays an important role in the market for the substrate development of an antenna. PTFE substrate materials are most commonly used materials in automotive radar, antennas, and microwave high speed circuitry [10]. It has low dielectric loss, low dielectric constant, high temperature resistance, volume resistivity and breakdown voltage. 5G technology uses high frequency spectrum, which increase the path loss. The antenna should be designed to overcome this transmission loss and different substrate materials are needed to meet the specifications. Thus antenna requires efficient power supply and it will generate enormous heat, the traditional polyamide substrate materials have high dielectric constant, high loss, high moisture absorption rate, higher transmission loss and unstable structures makes these materials not to meet the requirement of 5G technology. So, the modified polyamide, LCP and novel graphene materials are expected to be the most suitable materials for 5G technologies and high frequency applications. Graphene has light weight, faster thermal conduction and better stability which are suitable for 5G. And also ferrites materials are used in ceramics substrate to increase the signal transmission and also provide mechanical stability of the substrate materials [10].

C. Materials:

1. Taconic TLY-5A

Taconic TLY laminates are composed of light weight woven fiberglass and this material are more dimensionally stable material than hopped fiber reinforced PTFE laminates and it is suitable for high volume of manufacturing process [12]. The loss dissipation factor allows them to employ this material in automotive radars and other antennas in mm wave spectrum. The Taconic TLY 5A and 5 has a dielectric constant of 2.17 and 2.2, posses low loss tangent of 0.0009 and dielectric tolerance of + or – 0.02 [18]. It has low moisture absorption rate of 0.02%, thermal conductivity of 0.22 W/mK and peel of strength of 12 lbs/in. The major benefits of these substrate materials are excellent dimensional stability, high peel strength, laser abatable, consistent dielectric constant, low dielectric loss and low dielectric constant. These materials are widely used in satellite / cellular communications, automotive radar, LNA, LNCs, LNBs, power amplifiers, aerospace industries, ka, E and W band applications.

2. Arlon Diclad 880:

Diclad laminates are woven fiberglass reinforced PTFE laminates. Using precise control of the PTFE ration, it offers a wide range of lowest dielectric constant and low dissipation factor [13]. The woven fiberglass reinforced laminates provide excellent dimensional stability than non woven fiberglass reinforced PTFE laminate materials. The consistency of this PTFE fiberglass offers a wide range of dielectric constant and provides a uniform dielectric constant over frequency. The fiberglass piles in Diclad substrate materials are aligned in the same direction where as cross piles are available and named as cuclad substrates. Arlon Diclad 880 has a dielectric constant of 2.2 and has a low dielectric loss tangent of 0.0009 [19]. It has low moisture absorption rate of 0.02%, thermal conductivity of 0.261 W/mK, peel strength of 14 lbs per inch, arc resistance of >180, dielectric breakdown of >45 KV. The major benefits of this substrate material are excellent dimensional stability, low dielectric loss tangent, electrical properties are highly uniform across frequency, excellent chemical resistance, consistent mechanical performance. These materials are widely used in commercial phased array network, military radar feed network, low loss base station antennas, digital radio antennas, multi guidance systems, filters, couplers and LNAs.

3. Rogers Utralam 3850 LCP:

The Utralam 3850 composed of highly temperature resistant Liquid Crystalline Polymers (LCP). It was developed for single layer and multilayer substrate materials construction [14]. It is well suited for high speed circuits and high frequency applications in routers, switches, telecommunications networks and other high performance applications. It has low and stable dielectric constant and low dissipation factor. It offers a double copper clad laminates. Utralam has a dielectric constant of 2.9 and loss tangent of 0.0025 [20]. It has a low moisture absorption rate of 0.04%, thermal conductivity of 0.2 W/mK, peel strength of 8.52 lbs per inch, dielectric breakdown strength of 1378 KV/cm and chemical resistance of 98.7%. The major benefits of this substrate materials are stable electrical properties, excellent dimensional stability, extremely low moisture absorption, reduces break time, maintains stability in humid environments, excellent flame resistant. Its typical applications are high speed switches and routers, humid substrates, handheld and RF devices, base station antennas, chip packaging, military satellite and radar sensors.

4. Rogers RO 3000 Series:

Rogers Ro 3000 series substrate materials are ceramic filled PTFE laminates and widely used in commercial RF and microwave applications [15]. It offers excellent electrical and mechanical stability. The substrate with mechanical properties that maintains constant dielectric values this will help the designers to develop multi layers circuit boards that use variant dielectric constant substrate for separate layers without reliability problems. These are antenna grade substrate materials specially manufactured for the design of antennas. The Rogers RO 3003 material has a dielectric constant of 3.0 and dissipation factor of 0.0010 [21]. It has low moisture absorption rate of 0.04%, thermal conductivity of 0.50 W/mK, peel strength of 12.7 lbs/in and density of 2.1 gm/cubic centimeter. The Rogers RO 3035 [16] material has a dielectric constant of 3.50 and dissipation factor of 0.0015. It has low moisture absorption rate of 0.04%, thermal conductivity of 0.50 W/mK, peel strength of 10.2 lbs/in and density of 2.1 gm/cubic centimeter. The major benefits of this laminates are low dielectric loss, excellent mechanical properties, low plane expansion coefficient. Some typical applications are automotive radar, cellular telecommunication systems, global positioning satellite antennas, direct broadcast satellite, power backplanes, patch antenna for wireless communications, remote meter readers and data link on cable systems.

5. Arlon AD 450:

Arlon AD 450 substrate materials composed of woven fiber glass reinforced, ceramic filled PTFE laminates. The woven fiber glass composite provide excellent dimensional stability, thickness uniformities, better dielectric constant [17]. This substrate material replaces the FR 4 substrate materials when higher frequencies applications are performed by FR 4 with dielectric constant of 4.5. The high thermal conductivity and low LTE of this materials provide higher power design application, the temperature and heat rejection are to be considered for the design. The Arlon AD 450 has a dielectric constant of 4.50 and dissipation factor of 0.0035. It has low moisture absorption rate of 0.07 %, thermal conductivity of 0.38 W/mK, peel strength of > 10 lbs/in, density of 2.45g/cubic centimeter and dielectric breakdown of > 45 KV. The major features and benefits of these materials are readily replace of FR 4, superior PTH adhesion, heat dissipation and management, multiple board panel and large circuit formats are achievable. Typical applications are circuit board miniaturization, wideband antenna applications, replacement of FR 4 in higher frequency applications and multimedia transmission systems.

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ANTENNA DESIGN:

A rectangular microstrip patch antenna using insect feed method was designed and analysis of its performance were done using six different substrate material of different substrate thickness with the help of CST Microwave Studio Suite Electromagnetic Simulation tool.

A. Antenna Design using Taconic TLY-5A:

A rectangular microstrip patch antenna was designed using Taconic TLY-5A substrate material and analysis was made using different substrate thickness under the operating frequency of 28 GHz 5G mm wave spectrum band. The conducting plane such as patch, feed line and ground plane were designed using copper annealed. An insect feed method was employed to match impedance of the feed line and the radiating patch plane. The table I gives the dimensions of the rectangle microstrip patch antenna with different substrate thickness and the table II shows the overall simulated results of an antenna design using Taconic TLY-5A. It also shows the obtained gain, bandwidth, center frequency, directivity with respect to the different substrate thickness. The figure 2 shows the return loss plot of the antenna design using Taconic TLY-5A with different substrate thickness.

TABLE I: Dimensions of RMPA design using Taconic TLY-5A substrate material.

S. No.	Material	Dielectric constant	Loss tangent	Thickness Hs(mm)	Wp/Lp (mm)	Ws/Ls (mm)	Wf/Wc (mm)	Lf/Lc (mm)
1	Taconic TLY-5A	2.17	0.0009	0.09	4.2251	4.5	0.2797	1.72
					3.51	5	0.5594	1/0.7759
2				0.13	4.2251	4.5	0.404	1.69
					3.51	5	0.808	0.95/0.807
3				0.19	4.2251	4.5	0.5905	1.59
					3.51	5	1.181	0.85/0.91
4				0.25	4.2251	4.5	0.777	1.54
					3.51	5	1.554	0.80/0.96

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TABLE II: Obtained results of RMPA design using Taconic TLY-5A substrate material.

S. No.	Material	Thickness Hs(mm)	Directivity (dBi)	Gain (dBi)	C. Freq. (GHz)	S11(dB)	B.W(GHz)
1	Taconic TLY-5A	0.09	6.883	5.814	27.98	-37.9	0.5
2		0.13	6.741	6.187	28.08	-40.5	0.7
3		0.19	6.564	6.18	28	-52.65	1.1
4		0.25	6.403	5.863	28.14	-60.7	1.4

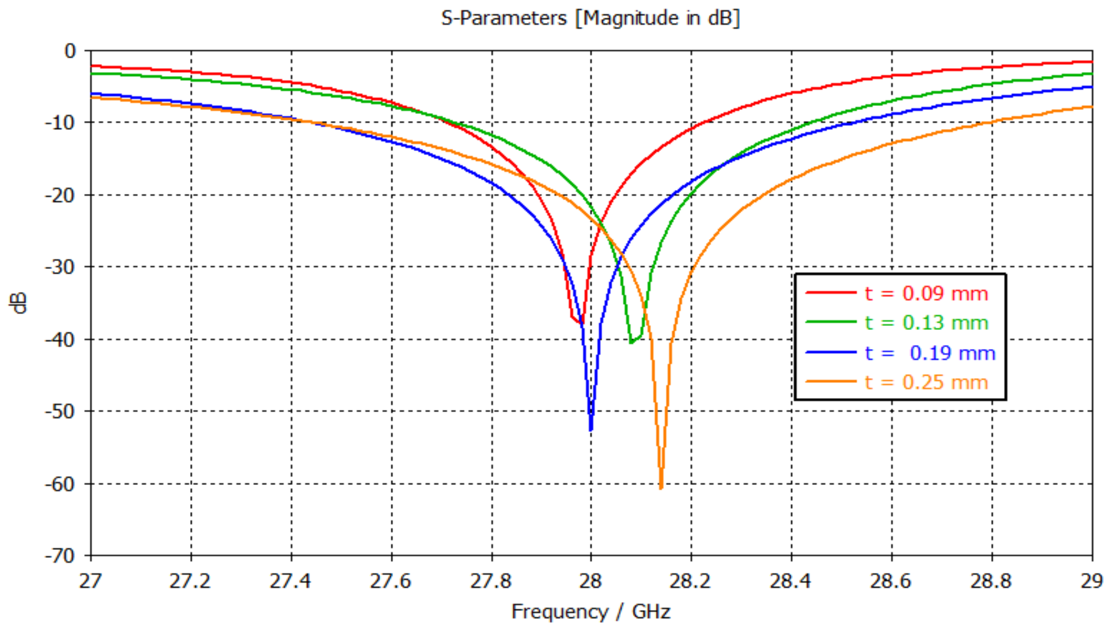

Fig. 2 Return loss plot of the antenna design using Taconic TLY-5A

B. Antenna Design using Arlon Diclad 880:

A rectangular microstrip patch antenna was designed using Arlon Diclad 880 substrate material and analysis was made using different substrate thickness under the operating frequency of 28 GHz 5G mm wave spectrum band. The conducting plane such as patch, feed line and ground plane were designed using copper annealed. An insect feed method was employed to match impedance of the feed line and the radiating patch plane. The table III gives the dimensions of the rectangle microstrip patch antenna with different substrate thickness and the table IV shows the overall simulated results of an antenna design using Arlon Diclad 880. It also shows the obtained gain, bandwidth, center frequency, directivity with respect to the different substrate thickness. The figure 3 shows the return loss plot of the antenna design using Arlon Diclad 880 with different substrate thickness.

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TABLE III: Dimensions of RMPA design using Arlon Diclad 880 substrate material.

S. No.	Material	Dielectric constant	Loss tangent	Thickness Hs(mm)	Wp/Lp (mm)	Ws/Ls (mm)	Wf/Wc (mm)	Lf/Lc (mm)
1	Arlon Diclad 880	2.2	0.0009	0.127	4.2351	4.5	0.3913	1.69
					3.5	5	0.7826	0.94/0.8113
2				0.254	4.2351	4.5	0.7826	1.61
					3.4691	5	0.13	0.85/0.887
3				0.381	4.2351	4.5	1.1739	1.77
					3.5	5	1.7	1.02/0.727
4				0.508	4.2351	4.5	1.5623	1.85
					3.56	5	2.25	1.13/0.649

TABLE IV: Obtained results of RMPA design using Arlon Diclad 880 substrate material.

S. No.	Material	Thickness Hs(mm)	Directivity (dBi)	Gain (dBi)	C. Freq. (GHz)	S11(dB)	B.W(GHz)
1	Arlon Diclad 880	0.127	6.751	6.156	28	-40.7	0.7
2		0.254	6.383	5.836	28.12	-50.9	1.3
3		0.381	6.308	4.903	28.12	-51.7	1.4
4		0.508	6.029	3.93	27.82	-51.7	1.4

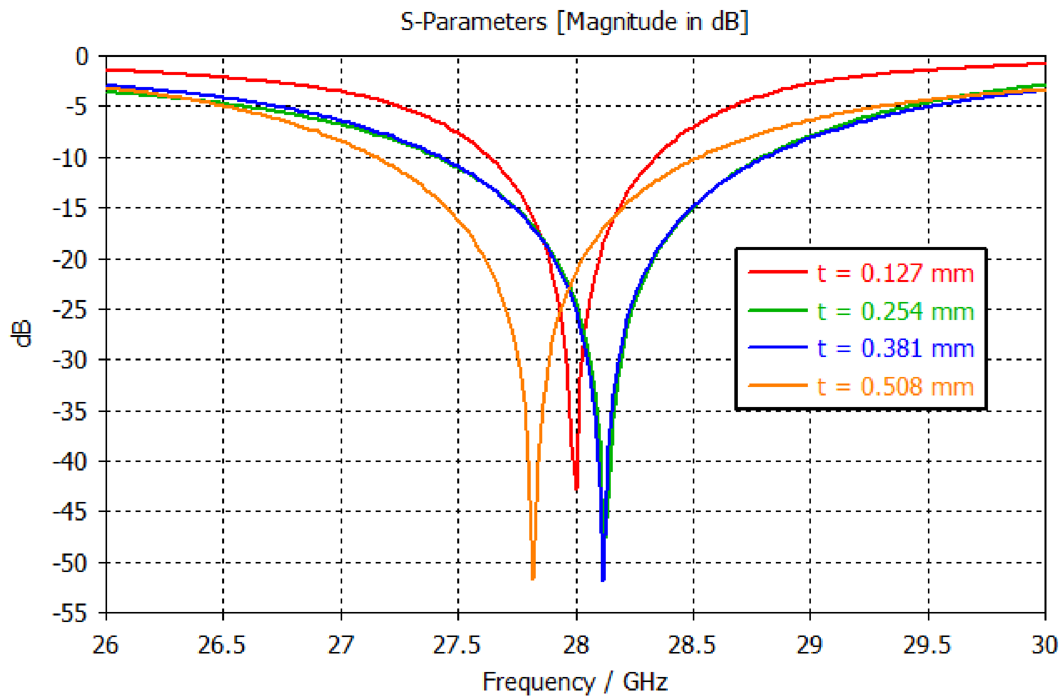

Fig. 3 Return loss plot of the antenna design using Arlon Diclad 880

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C. Antenna Design using Rogers Utralam 3850:

A rectangular microstrip patch antenna was designed using Rogers Utralam 3850 substrate material and analysis was made using different substrate thickness under the operating frequency of 28GHz 5G mm wave spectrum band. The conducting plane such as patch, feed line and ground plane were designed using copper annealed. An insect feed method was employed to match impedance of the feed line and the radiating patch plane. The table V gives the dimensions of the rectangle microstrip patch antenna with different substrate thickness and the table VI shows the overall simulated results of an antenna design using Rogers Utralam 3850. It also shows the obtained gain, bandwidth, center frequency, directivity with respect to the different substrate thickness. The figure 4 shows the return loss plot of the antenna design using Rogers Utralam 3850 with different substrate thickness.

TABLE V: Dimensions of RMPA design using Rogers Utralam 3850 substrate material.

S. No.	Material	Dielectric constant	Loss tangent	Thickness Hs(mm)	Wp/Lp (mm)	Ws/Ls (mm)	Wf/Wc (mm)	Lf/Lc (mm)
1	Rogers Utralam	2.9	0.0025	0.101	3.8	4	0.257	1.8
2					3.05	5	0.5	0.83/0.6969

TABLE VI: Obtained results of RMPA design using Rogers Utralam 3850 substrate material.

S. No.	Material	Thickness Hs(mm)	Directivity (dBi)	Gain (dBi)	C. Freq. (GHz)	S11(dB)	B.W(GHz)
3	Rogers Utralam	0.101	6.2	5.2	28.16	-54	0.7

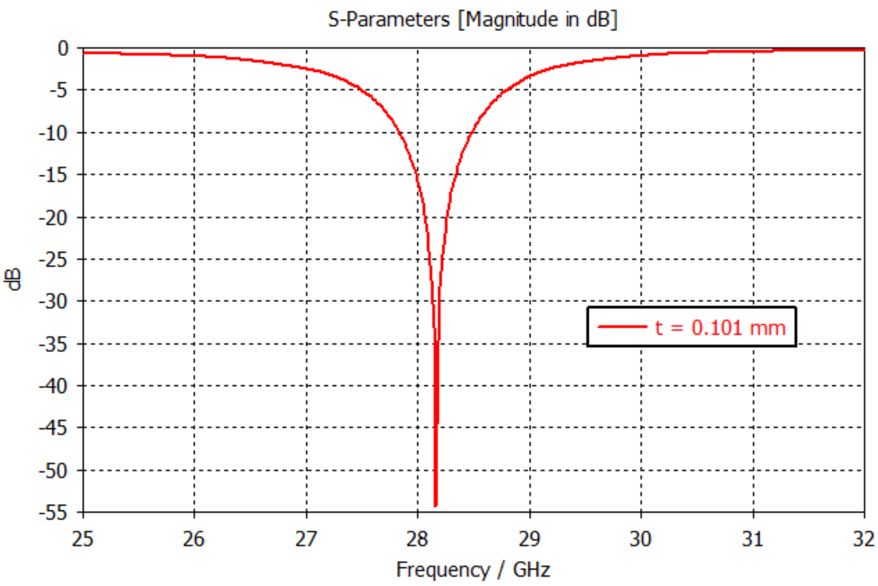

Fig. 4 Return loss plot of the antenna design using Rogers Utralam 3850

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D. Antenna Design using Rogers RO 3003:

A rectangular microstrip patch antenna was designed using Rogers RO 3003 substrate material and analysis was made using different substrate thickness under the operating frequency of 28GHz 5G mm wave spectrum band. The conducting plane such as patch, feed line and ground plane were designed using copper annealed.

TABLE VII: Dimensions of RMPA design using Rogers RO 3003 substrate material.

S. No.	Material	Dielectric constant	Loss tangent	Thickness Hs(mm)	Wp/Lp (mm)	Ws/Ls (mm)	Wf/Wc (mm)	Lf/Lc (mm)
1	Rogers RO 3003	3	0.001	0.13	3.78	4	0.3267	1.75
					3	5	0.7	0.78/0.75
2				0.25	3.78	4	0.6284	1.83
					2.97	5	0.99	0.82/0.669
3				0.5	3.78	4	1.256	1.92
					3.07	5	2.2	0.96/0.58

TABLE VIII: Obtained results of RMPA design using Rogers RO 3003 substrate material.

S. No.	Material	Thickness Hs(mm)	Directivity (dBi)	Gain (dBi)	C. Freq. (GHz)	S11(dB)	B.W(GHz)
1	Rogers RO 3003	0.13	6.18	5.6	28.2	-49.6	0.8
2		0.25	6	5.5	28.13	-52.5	1.4
3		0.5	5.7	3.7	28	-54.6	1.5

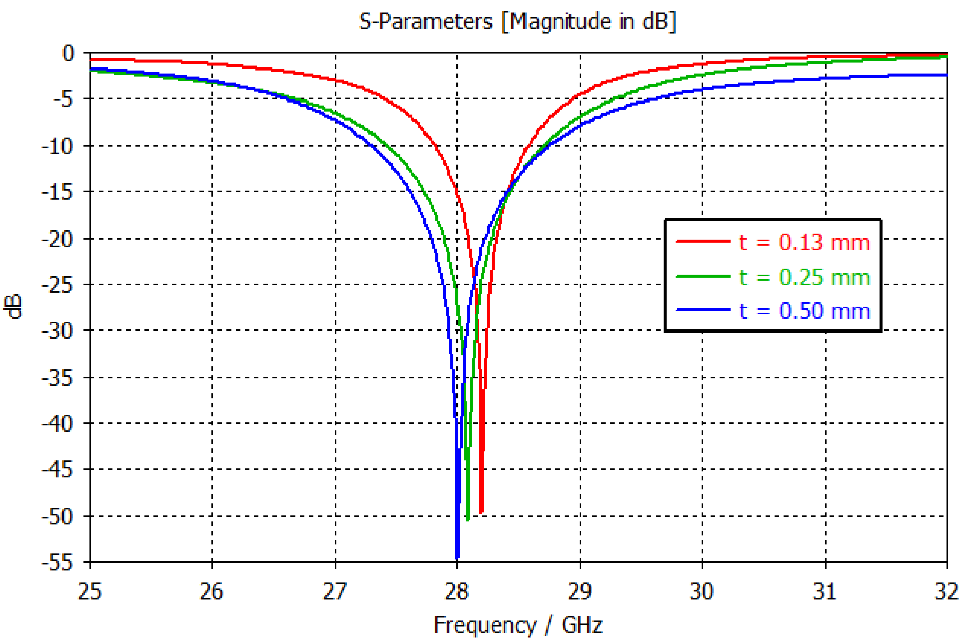

Fig. 5 Return loss plot of the antenna design using Rogers RO 3003

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An insect feed method was employed to match impedance of the feed line and the radiating patch plane. The table VII gives the dimensions of the rectangle microstrip patch antenna with different substrate thickness and the table VIII shows the overall simulated results of an antenna design using Rogers RO 3003. It also shows the obtained gain, bandwidth, center frequency, directivity with respect to the different substrate thickness. The figure 5 shows the return loss plot of the antenna design using Rogers RO 3003 with different substrate thickness.

E. Antenna Design using Rogers RO 3035:

A rectangular microstrip patch antenna was designed using Rogers RO 3035 substrate material and analysis was made using different substrate thickness under the operating frequency of 28GHz 5G mm wave spectrum band. The conducting plane such as patch, feed line and ground plane were designed using copper annealed. An insect feed method was employed to match impedance of the feed line and the radiating patch plane. The table IX gives the dimensions of the rectangle microstrip patch antenna with different substrate thickness and the table X shows the overall simulated results of an antenna design using Rogers RO 3035. It also shows the obtained gain, bandwidth, center frequency, directivity with respect to the different substrate thickness. The figure 6 shows the return loss plot of the antenna design using Rogers RO 3035 with different substrate thickness.

TABLE IX: Dimensions of rectangular microstrip patch antenna design using Rogers RO 3035 substrate material.

S. No.	Material	Dielectric constant	Loss tangent	Thickness Hs(mm)	Wp/Lp (mm)	Ws/Ls (mm)	Wf/Wc (mm)	Lf/Lc (mm)
1	Rogers RO 3035	3.6	0.0015	0.13	3.552	4	0.2879	1.42
					2.73	4	0.5758	0.79/0.577
2				0.25	3.552	4	2.5537	1.22
					2.715	4	1.1074	0.58/0.78

TABLE X: Obtained results of Rectangular Microstrip Patch Antenna design using Rogers RO 3035 substrate material.

S. No.	Material	Thickness Hs(mm)	Directivity (dBi)	Gain (dBi)	C. Freq. (GHz)	S11(dB)	B.W(GHz)
1	Rogers RO 3035	0.13	5.9	5.2	28	-41.2	0.9
2		0.25	5.633	5.113	28	-52.76	1.8

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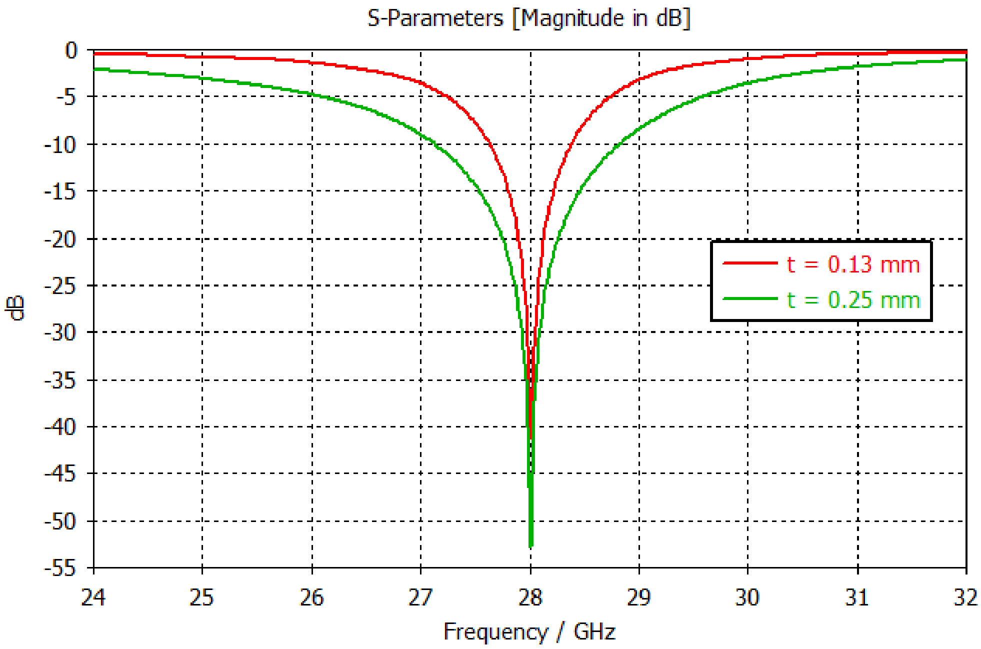

Fig. 6 Return loss plot of the antenna design using Rogers RO 3035

F. Antenna Design using Arlon AD 450:

A rectangular microstrip patch antenna was designed using Arlon AD 450 substrate material and analysis was made using different substrate thickness under the operating frequency of 28GHz 5G mm wave spectrum band. The conducting plane such as patch, feed line and ground plane were designed using copper annealed. An insect feed method was employed to match impedance of the feed line and the radiating patch plane. The table XI gives the dimensions of the rectangle microstrip patch antenna with different substrate thickness and the table XII shows the overall simulated results of an antenna design using Arlon AD 450. It also shows the obtained gain, bandwidth, center frequency, directivity with respect to the different substrate thickness. The figure 7 shows the return loss plot of the antenna design using Arlon AD 450 with different substrate thickness.

TABLE XI: Dimensions of RMPA design using Arlon AD 450 substrate material.

S. No.	Material	Dielectric constant	loss tangent	Thickness Hs(mm)	Wp/Lp (mm)	Ws/Ls (mm)	Wf/Wc (mm)	Lf/Lc (mm)
1	Arlon AD 450	4.5	0.003	0.254	3.23	4	0.4775	0.61
					2.446	4	0.955	1.39/0.6101
2				0.508	3.23	4	0.995	1.45
					2.6	4	2.5	0.75
3				0.762	3.23	4	1.43251	1.58
					2.53	4	2.3	0.85/0.42

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TABLE XII: Obtained results of RMPA design using Arlon AD 450 substrate material.

S. No.	Material	Thickness Hs(mm)	Directivity (dBi)	Gain (dBi)	C. Freq. (GHz)	S11(dB)	B.W(GHz)
1	Arlon AD 450	0.254	5.544	4.88		-44.11	1.49
2		0.508	5.264	3.1	27.9	-50.19	1.6
3		0.762	4.698	1.708	27.98	-23.4	1.8

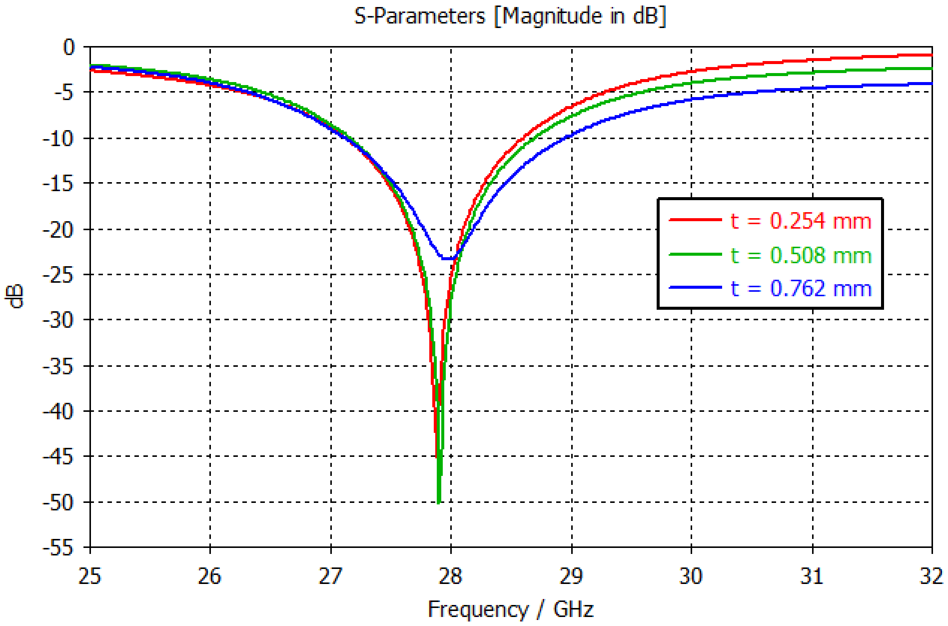

Fig. 7 Return loss plot of the antenna design using Arlon AD 450

COMPARITIVE ANALYSIS OF DIFFERENT SUBSTRATE MATERIALS:

From the comparative analysis of different substrate materials with their thickness, the Taconic TLY-5A substrate material gives a maximum gain of 6.187 dBi at 28.08 GHz and the directivity of 6.741 dBi with substrate height of 0.13 mm and the overall dimensions of 5×4.5×0.13 mm. When compared to Arlon Diclad 880 substrate material, it gives a maximum gain of 6.156 dBi at 28 GHz, directivity of 6.751 dBi, substrate thickness of 0.127 mm and the overall dimensions of 5×4.5×0.127 mm. The antenna compactness is an important parameter to be considered for the design. Hence, the Arlon Diclad 880 substrate materials with the substrate thickness of 0.127 mm gives a compact dimensions of an antenna design and acceptable gain, directivity and bandwidth, it will be used for the design of 2X5, 5X20 antenna array due to the reduced substrate thickness of 0.127 mm.

A. Proposed Microstrip Patch Antenna Array (2X5):

A planar microstrip antenna array (2X5) was designed using Arlon Diclad 880 substrate material having the dielectric constant of 2.2, and a thickness of 0.127mm. The figure 8

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shows the planar structure of proposed microstrip patch antenna array (2X5). Arlon Diclad 880 substrate material contains 0.0009 of loss tangent respectively. Patch, feed line and ground planes are designed using copper (annealed) conducting material. The table XIII gives the dimensions of the rectangle microstrip patch antenna with different substrate thickness and the table XIV shows the overall simulated results of an antenna design using Arlon Diclad 880. It also shows the obtained gain, bandwidth, center frequency, directivity respectively. The figure 9 shows the return loss plot of the antenna array (2X5), figure 10 shows the 2D and 3D gain plot of the proposed microstrip patch antenna array (2X5) and figure 11 shows the 2D and 3D directivity plot of the proposed microstrip patch antenna array (2X5).

TABLE XIII: Dimensions of RMPA array of size 2X5

S. No.	Material	Dielectric constant	loss tangent	Thickness Hs(mm)	Overall Dimensions(mm)	No. of Elements
1	Arlon Diclad 880	2.2	0.0009	0.127	10X22.5x0.127	10

TABLE XV: Simulated results of RMPA array of size 2X5.

S. No.	Material	Thickness Hs(mm)	Directivity (dBi)	Gain (dBi)	C. Freq. (GHz)	S11(dB)	B.W(GHz)
1	Arlon Diclad 880	0.127	14.29	13.74	27.9	-38	0.7

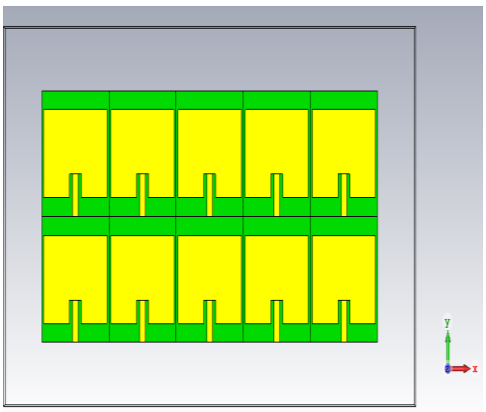

Fig. 8 Proposed RMPA array (2X5)

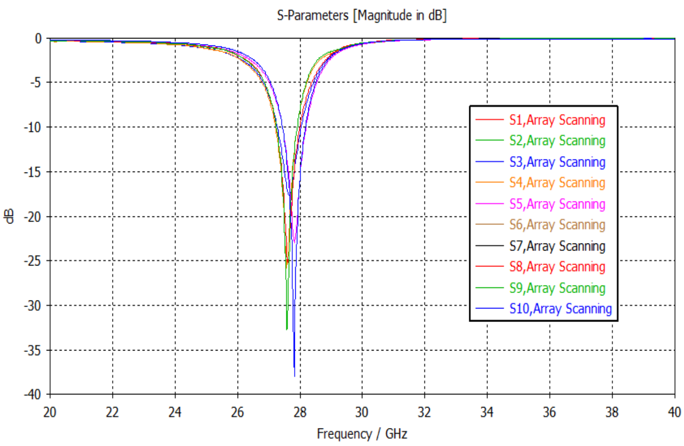

Fig. 9 Return loss plot of the proposed RMPA array (2X5)

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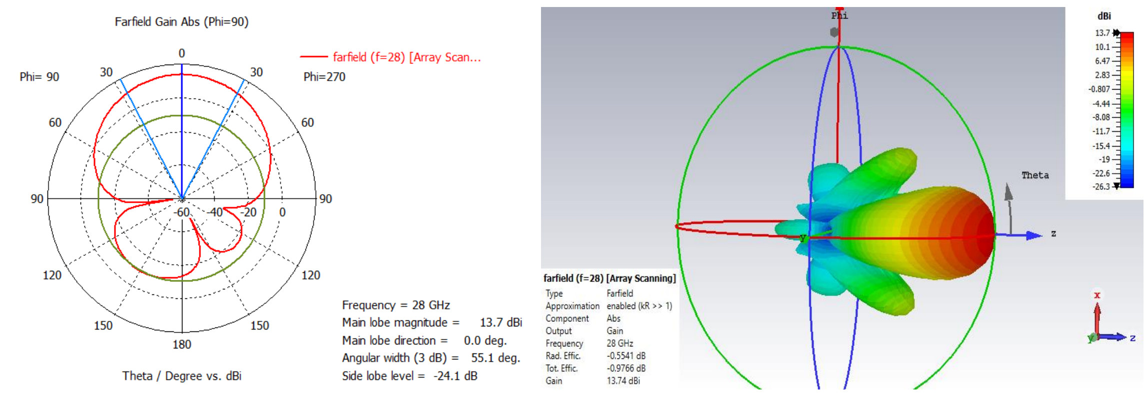
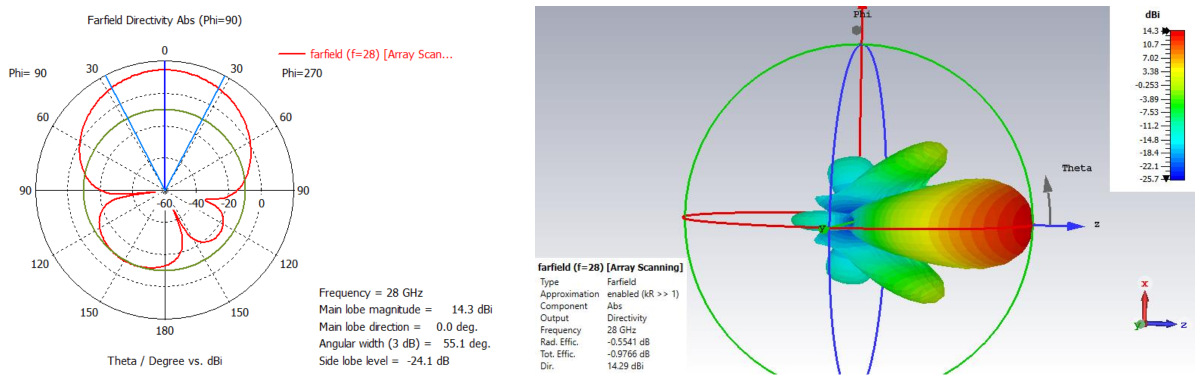


(a) (b)

Fig.10 (a) 2D Gain plot of the proposed RMPA array (2X5) (b) 3D Gain plot of the proposed RMPA array (2X5)



(a) (b)

Fig. 11 (a) 2D Directivity plot of the proposed RMPA array (2X5) (b) 3D Directivity plot of the proposed RMPA array (2X5)

B. Proposed Microstrip Patch Antenna Array (5X20):

A planar microstrip antenna array (5X20) was designed using Arlon Diclad 880 substrate material having the dielectric constant of 2.2, and a thickness of 0.127mm. The figure 12 shows the planar structure of proposed microstrip patch antenna array (5X20). Arlon Diclad 880 substrate material contains 0.0009 of loss tangent respectively. Patch, feed line and ground planes was designed using copper (annealed) conducting material. The table XVI gives the dimensions of the rectangle microstrip patch antenna with different substrate thickness and the table XVII shows the overall simulated results of an antenna design using Arlon Diclad 880. It also shows the obtained gain, bandwidth, center frequency, directivity respectively. The figure 13 shows the return loss plot of the antenna array (2X5), figure 14 shows the 2D and 3D gain plot of the proposed microstrip patch antenna array (5X20) and figure 15 shows the 2D and 3D directivity plot of the proposed microstrip patch antenna array (5X20). The table XVIII shows the comparison between 10 element and 100 element antenna array.

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TABLE XVI: Dimensions of RMPA array (5X20)

S. No.	Material	Dielectric constant	loss tangent	Thickness Hs(mm)	Overall Dimensions(mm)	No. of Elements
1	Arlon Diclad 880	2.2	0.0009	0.127	145X22.5x0.127	100

TABLE XVII: Simulated results of RMPA array (5X20)

S. No.	Material	Thickness Hs(mm)	Directivity (dBi)	Gain (dBi)	C. Freq. (GHz)	S11(dB)	B.W(GHz)
1	Arlon Diclad 880	0.127	24.15	23.66	28.1	-38	0.845

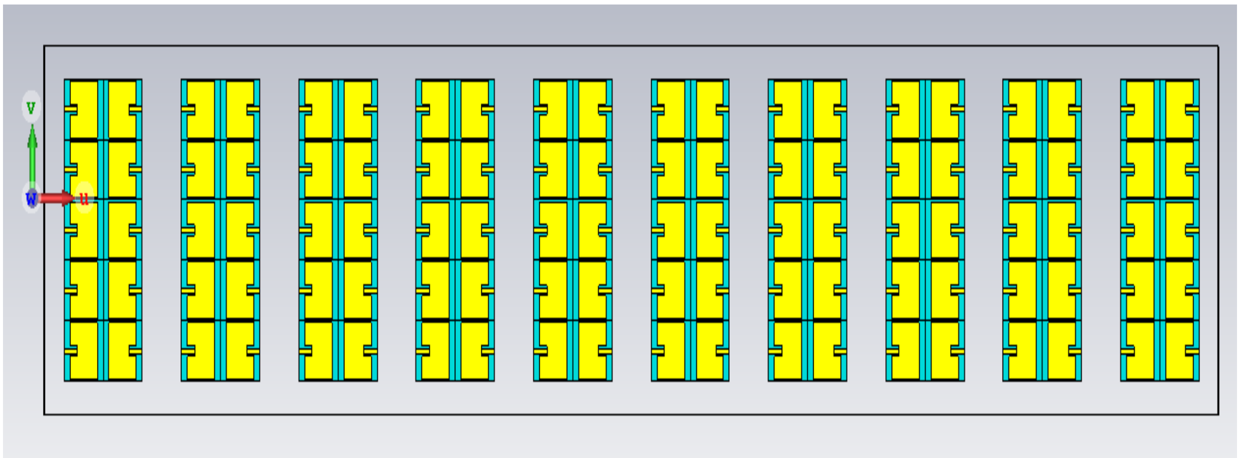

Fig. 12 Proposed microstrip patch antenna array (5X20)

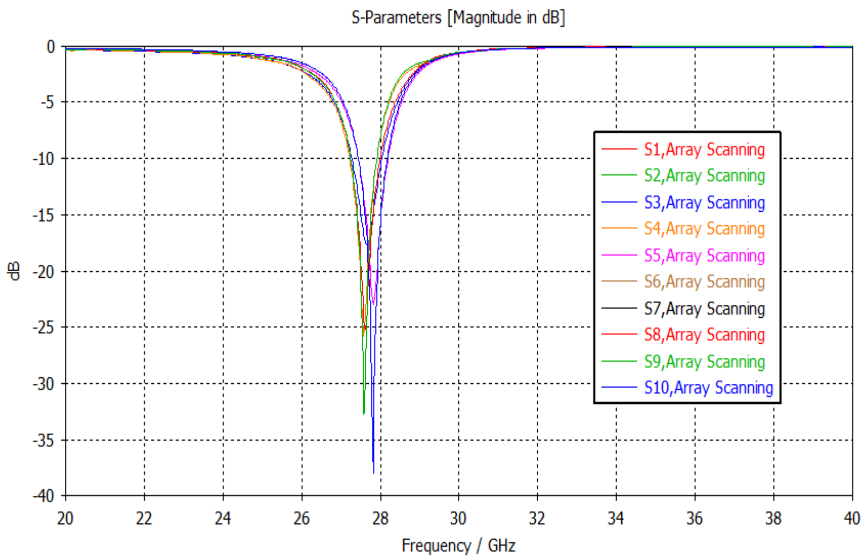

Fig. 13 Return loss plot of the proposed microstrip patch antenna array (5X20)

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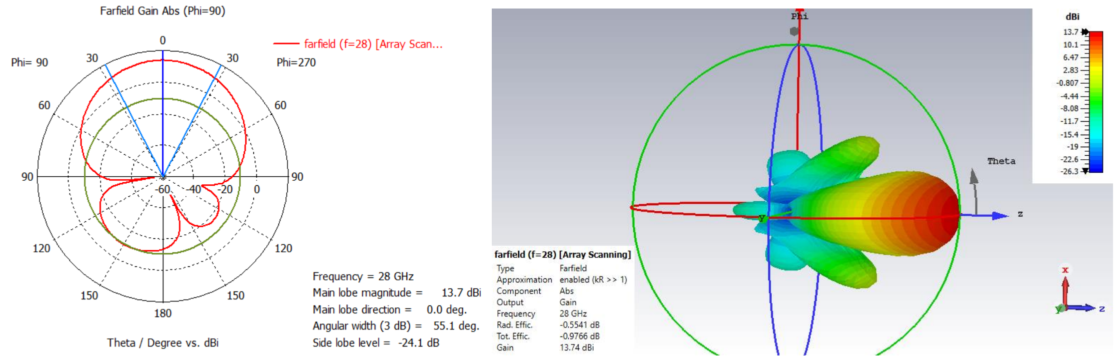
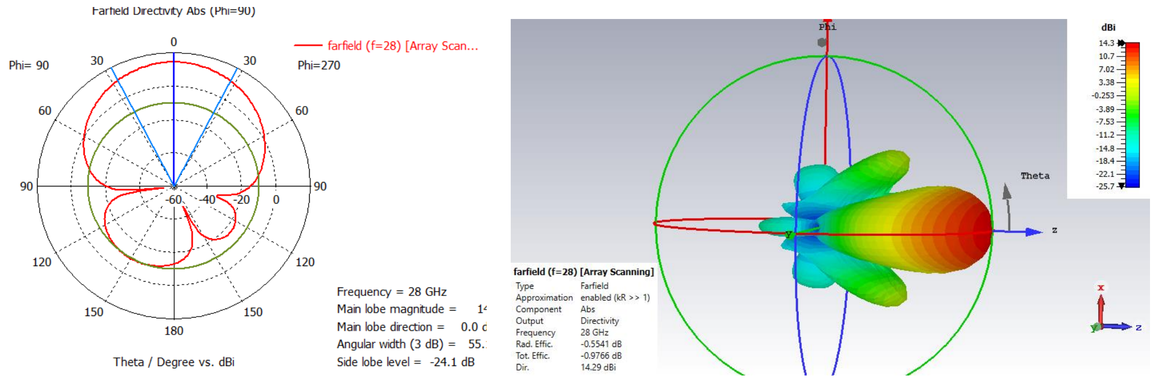


(a) (b)

Fig.14 (a) 2D Gain plot of the proposed RMPA (5X20) (b) 3D Gain plot of the proposed RMPA array (5X20)



(a) (b)

Fig. 15 (a) 2D Directivity plot of the proposed RMPA array (5X20) (b) 3D Directivity plot of the proposed RMPA array (5X20)

TABLE XVIII: Comparison between 10 and 100 element microstrip patch antenna array.

Parameters	2X5 Array	5X20 Array
Dimensions (mm)	**10×22.5**	**145x22.5**
No. Of Elements	**2X5**	**5X20**
Resonant frequency (GHz)	**27.9**	**28.1**
Return loss (dB)	**-38**	**-38**
Bandwidth (GHz)	**0.7**	**0.845**
Gain (dBi)	**13.74**	**23.66**
Directivity (dBi)	**14.29**	**24.15**

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CONCLUSION:

This research work mainly focuses on the investigation of six different substrate materials such as Taconic TLY-5A, Arlon Diclad 880, Rogers Utralam, Rogers RO 3003, Rogers RO 3035 and Arlon AD 450 for the development of microstrip patch antenna. The antenna size compactness is one of important key parameter analyzed in this research. If the size of substrate thickness increases, impedance and bandwidth will be increased and reduces the gain and directivity of an antenna. If the size of substrate thickness decreases, the gain increases and it reduces the path loss associated with increases in the operating frequency. From the investigation of different substrate materials, Arlon Diclad 880 substrate having a dielectric constant of 2.2 and the loss tangent of 0.0009 gives a maximum gain of 6.156 dBi at 28 GHz, directivity of 6.751 dBi, substrate thickness of 0.127 mm and the overall dimensions of 5×4.5×0.127 mm, which is suitable for the design of 2X5 MIMO antenna and 5X20 Massive MIMO antenna. A planar microstrip antenna array (2X5) was designed using Arlon Diclad 880 substrate material having the dielectric constant of 2.2 and a thickness of 0.127 mm, it gives a overall dimensions of 10×22.5×0.127 mm where as 5X20 massive MIMO antenna array gives a overall dimensions of 145×22.5×0.127 mm. Further slots will be introduced in the antenna for even more size reduction in the conventional microstrip patch antenna for the 5G wireless handheld communication devices and the IoT applications.

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