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WIDEBAND LTCC 60 GHZ ANTENNA ARRAY WITH DUAL RESONANT SLOT AND PATCH STRUCTURE

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ABSTRACT -"A wideband LTCC 60-GHz antenna array with a dual-resonant slot and patch structure" has been designed. A multilayered low-temperature co-fired ceramic substrate of dielectric constant 7.38 was used for antenna fabrication. Using LTCC (Low temperature co-fired ceramics) system in wireless packaging applications is wide used today. The properties requirements for wireless applications are requiring low loss at high frequencies and good characteristic comparative to cost. A half-wavelength resonant slot was designed to enhance the front radiation. Micro strip antennas (MSAs) have several advantages, including that they are light weight and small-volume and that they can be made conformal to the host surface. In addition, MSAs are manufactured using printed-circuit technology, so that mass production can be achieved at a low cost.

The simulated results show that adding parasitic patches increased the resonance of the poles and improved antenna gain by 3.7dB and bandwidth by 9%.A 2X2 dual resonant slot patch antenna array was designed to further enhance the gain and bandwidth. The measured return loss showed a wide bandwidth of 23%.The measured gain for the four element antenna array war 9db with slight f fluctuations over the 57-64 GHz frequency range.

I. INTRODUCTION

Antennas are the basic components of any electric system and are the connecting link, which radiate or receive electromagnetic waves between the transmitter and free space and receiver. Thus they play a very important role in finding the characteristics of the system. An antenna is a system of elevated conductors which couple or match the transmitter or reliever to the free space wave or between a free space and a guided wave. An antenna is a specialized transducer that converts radio frequency into alternating current and vice versa. An antenna is a device to transmit and/or receive electromagnetic waves.

Basically, a transmitting antenna transmits by exciting it at the base while in a receiving antenna the applied electromagnetic field is distributed throughout the entire length of the antenna to receive the signal. The magnetic field that the transmitting antenna radiates will produce an electric current on any metal surface that it strikes.

However, if the metal that the signal strikes has a certain length relation to the wavelength the induced current will be must stronger on the object.

GENERAL CLASSIFICATION OF ANTENNAS

Antennas can be broadly classified either by the frequency spectrum in which they are commonly applied or by their basic mode of radiation. For example, employing the 'mode of radiation' basis four groups could be defined as follows: elemental electric and magnetic currents, travelling wave antennas, array antennas and radiating aperture antennas. Although these definitions are somewhat arbitrary the four groups can be broadly distinguished by the size of the antenna measured in wavelengths, which in turn can be related to the region of the spectrum in which they are commonly applied. To illustrate this division fig.2.1 shows these groupings against typical sizes and frequencies.

II. ANTENNA PARAMETERS

An antenna is characterized by a number of relevant parameters. There are radiation pattern, impedance, directivity, polarization, antenna gain, radiation efficiency, resonance frequency, and bandwidth.

a. Radiation patterns

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Antenna radiation pattern is a graphical representation in three dimensions of the radiation of the antenna as a function of direction. It provides information on the antenna bandwidth, antenna side lobes etc. The antenna patterns of most practical antennas contain a main lobe and several auxiliary lobes termed as side lobes. A side lobe occurring in space in the direction opposite to the main lobe is called the back lobe.

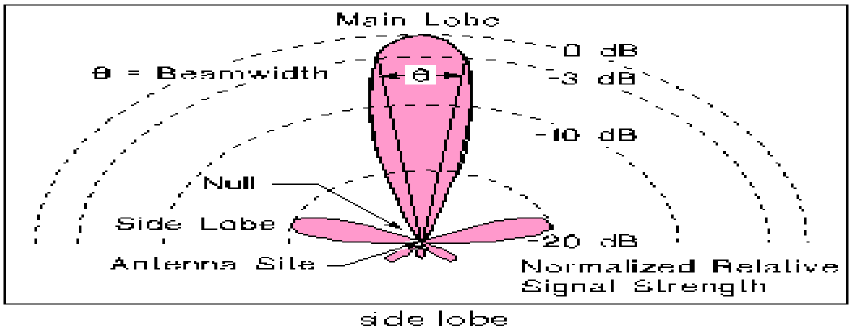

Figure 2.2: Radiation pattern

b. Impedance

The impedance of an antenna determines the efficiency with which it acts as a transducer between the propagating medium and the transmission line connecting it to the system, which it operates.

c. Radiation efficiency

The radiation efficiency is defined as the ratio of the power that is radiated by an antenna to the power that is accepted by the antenna. The power accepted by the antenna is equal to the total power fed to the antenna through signal lines minus the power that is reflected by the antenna due to impedance mismatch.

d. Antenna gain and Directivity

Antenna gain is the ratio of maximum radiation intensity at the peak of the main beam to the radiation intensity in the same direction, which would be produced by an isotropic radiator having the same input power.

The antenna gain is also defined as the antenna directivity multiplied by the radiation efficiency. Antenna gain is important for the estimation of system performance parameters related to transmission and reception of power.

The directivity of an antenna is defined as the ratio of the radiated power per unit spatial intensity, in a given direction, to the intensity that would be obtained if the power fed to the antenna were radiated isotropically.

$$Gain = 10\log\frac{P_{out}}{P_{in}}$$

e. Resonance frequency

The resonance frequency is the frequency where the antenna works best with respect to its intended behavior, namely the conversion of guided electric signal power in to electromagnetic waves propagating through free space.

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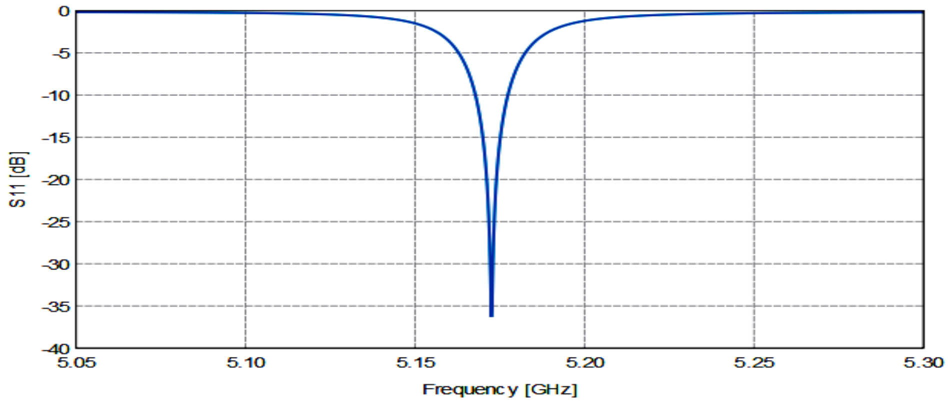


Figure 2.4: Resonant frequency

f. Return loss:

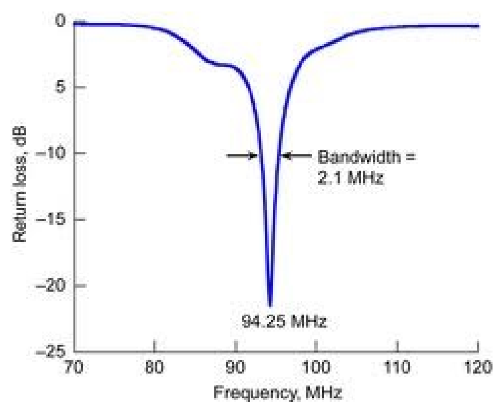
Return loss is the loss of signal power resulting from the reflection caused at a discontinuity in transmission lines or optical fiber. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. It is usually expressed as a ratio in decibels (dB).

$$RL(db) = 10\log_{10}\frac{P_i}{P_r}$$

Where *RL* (dB) is the return loss in dB, P_i is the incident power and P_r is the reflected power.

Return loss is related to both standing waves (SWR) and reflection coefficient (Γ). Increasing return loss corresponds to lower SWR. Return loss is a measure of how well devices or lines are matched. A match is good if the return loss is high. A high return loss is desirable and results in a lower insertion loss

Return loss is used in modern practice in preference to SWR because it has better resolution for small values of reflected wave.



g. Bandwidth

The bandwidth expressed in Hz, is the frequency range over which an antenna exhibits a specified behavior with respect to a relevant antenna parameter. A typical bandwidth specification is given as the frequency range where return loss is equal to or better than 10 db.

h. Polarization

The polarization of an antenna in a given direction is defined as the polarization of the wave transmitted or radiated by the antenna. When not stated, the polarization is taken to be the polarization in the direction of maximum gain. The polarization of radiated wave is defined as that

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property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric field vector.

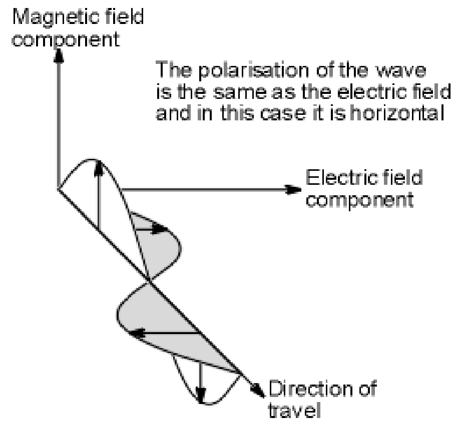

Figure 2.6: Polarization

III. LOW TEMPARATURE CO-FIRED CERAMIC (LTCC)

In the electronics the quality, reliability, operational speed, device density and cost of circuits are fundamentally determined by carriers. By the development of the manufacturing technology multichip modules have appeared, which are circuits containing several microchips. There are usually a few high-complexity microchips in these modules. These complex integrated circuits containing many inputs and outputs (I/O) need multilayer structures. There was a growing need of a technology, wherewith more than two wiring-layers are realizable.

Multilayer PWB carriers came out. The modern carrier is a multilayer printed wiring board, and passive devices are surface mounted on their terminals as discrete elements. To place an SMD element two solder bandings are necessary. With a new, modern technology it is possible to integrate passive elements (R; C) into inner layers. These passive elements (embedded resistors and capacitors) are created by film technology. The name of this technology is Embedded Passive Technology (EPT).

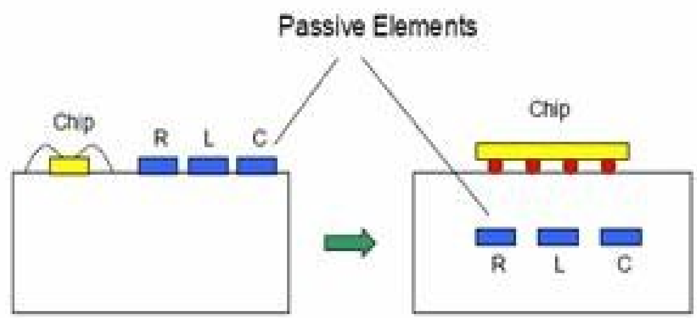

Figure 3.1Passive elements

The advantages of the circuits containing embedded passive elements against SMD devices:

- As the solder bonding are reducing, the reliability is growing,
- Less elements have to be placed and attached,
- Size of circuits are reduced,
- Speed of the signal propagation is grown,
- Better electromagnetic immunity,
- Lower prime cost.

If it is necessary to use better material than plastic carrier, it has to be made of ceramics or glass-ceramics. There are two types of raw ceramics to manufacture Multi-Layer Ceramic (MLC) substrate:

- Ceramics fired at high temperature (T ≥ 1500 °C): High Temperature Co fired Ceramic (HTCC),
- Ceramics fired at low temperature (T ≤ 1000 °C): Low Temperature Co fired Ceramic (LTCC).

The base material of HTCC is usually Al2O3. HTCC substrates are row ceramic sheets. Because of the high firing temperature of Al2O3 the material of the embedded layers can only be high melting temperature metals: wolfram, molybdenum or manganese. The substrate is unsuitable to bury passive elements, although it is possible to produce thick-film networks and circuits on the surface of HTCC ceramic.

HTCC substrates could be only manufactured by companies possessing ceramic technology. The breakthrough for electronics industry was when – mixing glass to slurry – the firing temperature of ceramic-glass substrate was reduced 850 °C, so the equipment for conventional thick-film process could be used. LTCC technology evolved from HTCC technology combined the advantageous features of thick-film technology.

The components of the glass are chosen the way that it crystallizes at the temperature of 850 °C, it has high bend strength and good electrical parameters. During co-firing the glass melts, the conductive and ceramic particles are sintered. Figure below shows the distribution of glass particles in LTCC glass-ceramic before and after firing.

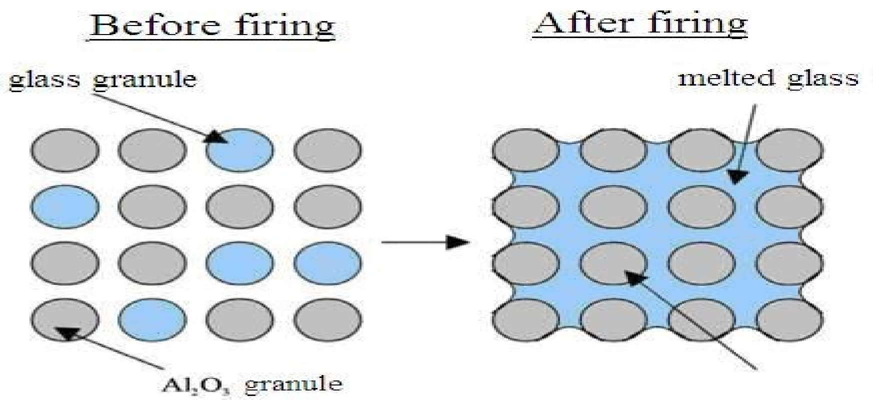

Figure 3.2.Evolving binding at melting of glass in LTCC glass-ceramic structure

On the surface of LTCC substrates hybrid integrated circuits can be realized. Passive elements can be buried into the substrate, and it is possible to place semiconductor chips in a cavity. In some application (i.e. micro fluidics applications) embedded channels are shaped. The number of layers can be as high as 40. Figure shows the structure of a complex circuit realized with the technology.

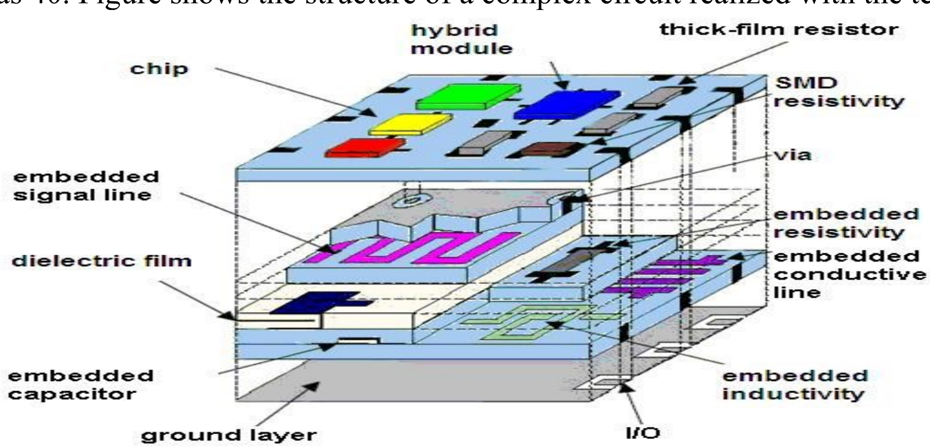

Figure 3.3 Complex LTCC circuit structure

The LTCC technology offers the following benefits:

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- More economical manufacturing process compared with the conventional thick-film technology;
- Mass production methods can be really applied (several processing steps can be automated);
- Fabrication techniques are relatively simple and inexpensive;
- Low tolerance in dielectric constant and better thermal conductivity
- Electronic circuits can be integrated, and very robust against environmental stress.
- Design and manufacture 3-dimensional circuits;
- Possibility of cutting the tape / substrate into different shapes;
- Because of the possibility to bury passive components within the substrate, it reduces the size of circuits (down to about 50 %t in comparison to the PCB);

The multilayer technology allows for the parallel stacking of up to more than 20 layers.Multilayer ceramic technology stems from the late '50th as the development of RCA Corporation. The multilayer technology allows for the parallel stacking of up to more than 20 layers. Later IBM has stroked up researches and has evolved the first multilayer ceramic substrate with the following parameters: surface 9 cm2, 33 layers, has 100 flip chips on its surface as LSI component. The substrate was fired at the temperature of 1600°C; Mo, Mo-Mn, and W were used as conductive component. From the middle '80th the development of the computers has geared, so the aim was the increase of density of conductive network on substrate. More and more thinner wirings were used, but hereby the resistance value has increased. There was a need of conductive materials with lower resistance value. These are Cu, Au, Ag, etc. The substrates had to be good thermal conductor. The high speed of the signal propagation required low permittivity of ceramic.

In the beginning of the '90s a substrate was developed by American and Japanese electronic and ceramic firms, which satisfied the demands above. IBM and Fujitsu were the first companies, who applied ceramic with low permittivity and Cu conductive layer on it in their products. In the second part of decade the interest levelled at wireless applications. The high frequency Bluetooth's Wireless applications required the low expansion coefficient and low permittivity. In two tables are delineated the parameters of LTCC substrate of some relevant firm. The first table introduces the period from 1985 to 1990 the second table shows the products of current market marker. The conductive materials of it are Au, Ag, Pd, Cu and their alloys; the firing temperature is between 850 °C and 1000 °C. The second table shows loss tangent (TG d) too. The direction of advancement was the use of unleaded glass.

3.1 LTCC DESIGN FLOW

The first step of manufacturing raw glass-ceramic is mixing various kinds of materials and it is homogenized by a ball mill. Base material is alumina dust, solvent, organic binder, dispersing agent and aggregate. The main component is alumina. The adjustment of viscosity is by using organic aggregates; dispersing agent (ground glass) does a part during firing. The aggregates:

- help insertion of fired patterns
- decrease sinter-temperature
- decrease surface raggedness
- compress the structure of the ceramic
- Fix the colour.

The suspension (slurry) made from these materials is poured onto polyester foil (Mylar, Kempton) or glass-plate. After it the thickness of the wet material is set by a blade. Another possibility is to let the suspension flow through between two reels, so thus it is plane. Figure below shows this process.

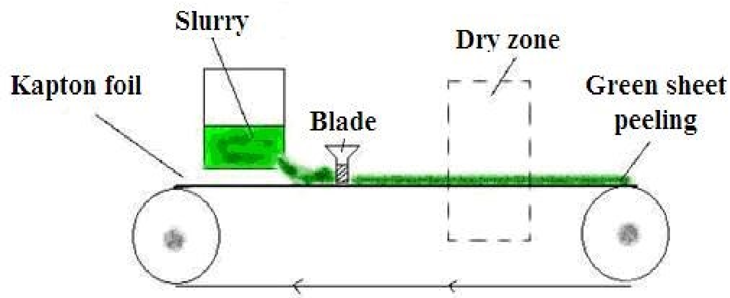


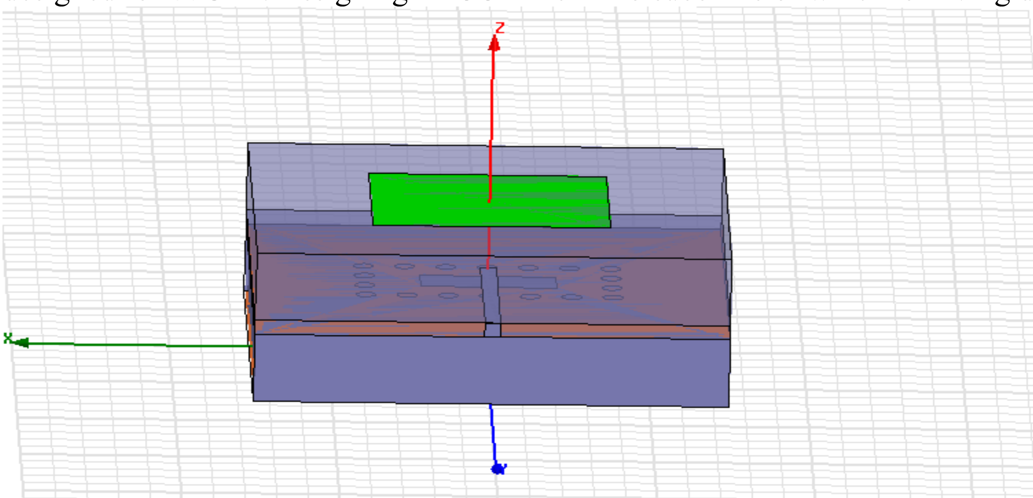
Figure 3.4. Green sheet casting onto polyester (Mylar) foil

This is followed by multistage drying when the solvents evaporate. The raw green-sheet can be peeled from the foil. The consistence of the ceramic is similar to plasticize.

IV. RESULTS AND DISCUSSION

. DESIGN OF SINGLE PATCH ANTENNA USING HFSS

The antenna substrate of thickness 0.5mm and length and width of 3mm and 3mm has been designed for 60GHz. Assigning LTCC material to substrate of which is having dielectric constant 8.



4.1 . Design of single patch antenna

Rectangular Patch has been designed on the top of the substrate with the dimensions of length 1.5mm and width 1.4mm.To get more band width all patches should radiate in one phase (angle). Slot has been designed with the dimensions of length 0.86mm and width is 0.3mm.To get more band width substrate height has to be increased. But every substrate has some specific height if height is increased above the specific height antenna will stop radiating. So in order to increase the height of substrate vias are used with the radius of 0.0625mm and height 0.5mm has been designed between the substrate ground planes. Feed line is designed with the impedance of 50 ohms to match antenna impedance of 50 ohms the dimensions are of 1.52mmx0.1mm has been used designed. If impedance is mismatched the input power which is transferring to antenna will reflect back and power loss will be happened.

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4.1 . RETURN LOSS PLOT OF SINGLE PATCH ANTENNA

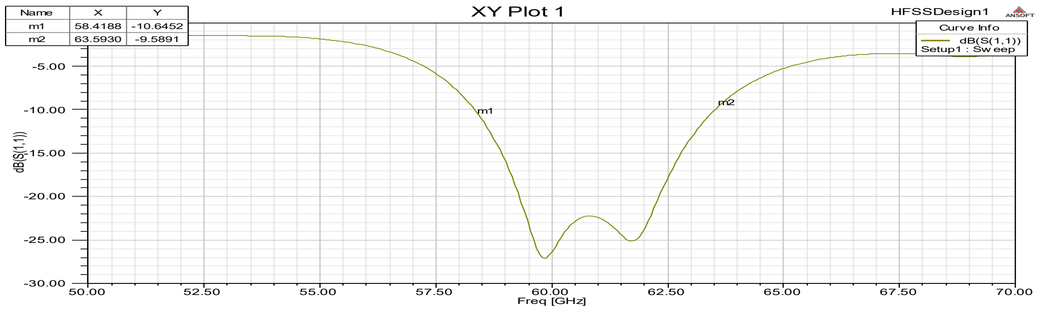

Figure 4.2. Return loss plot of single patch antenna

The above figures shows that return loss is -27dB .that means the power which has been given to antenna is reflecting very less. Band width is 5GHz.7.1.4 3D POLAR PLOT OF SINGLE PATCH ANTENNA

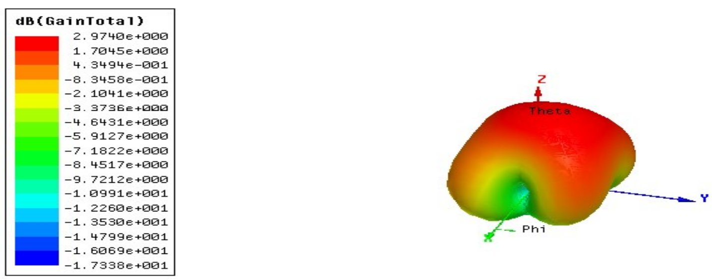

Figure 4.3 3D polar plot of single patch antenna

The red color in the above figure shows the highest radiation towards the z axis that means patch radiates above the substrate .Green color shows power loss the table shows the maximum radiation 2.94db.In order to increase the gain we should go for array.

7.1.5. RADIATION PATTERN OF SINGLE PATCH ANTENNA

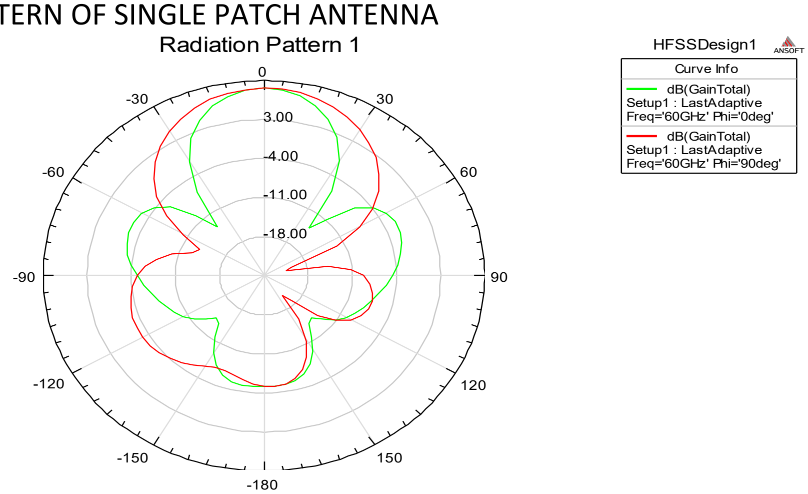

Figure 4.4. Radiation pattern of single patch antenna

Red curve indicates the radiation pattern of the antenna at phi is 90 degrees. Green curve indicates the radiation pattern of the antenna at phi is 0 degrees. Gain of the antenna can be calculated from this pattern.

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DESIGN PARAMETERS OF 2X1 ANTENNA ARRAY

SUBSTRATE	
LENGTH	6.64mm
WIDTH	4mm
THICKNESS	0.5mm
SUBSTRATE TYPE	LTCC
RELATIVE PERMITIVITY Er	7.38
DIELECTRIC LOSS TANGENT	0.01
RELATIVE PERMIABILITY	1

SLOT	
LENGTH WIDTH	1.07mm 0.3mm

PATCH	
LENGTH	1.7mm
WIDTH	1.6mm

Figure 4.5 Parameters of 2X1 antenna array

4.2 DESIGN OF 2X1 ANTENNA

The antenna of substrate thickness 0.5mm and length and width of 6.64mm and 4mm has been designed for 60GHz. Assigning LTCC material to substrate of which is having dielectric constant 7.38.

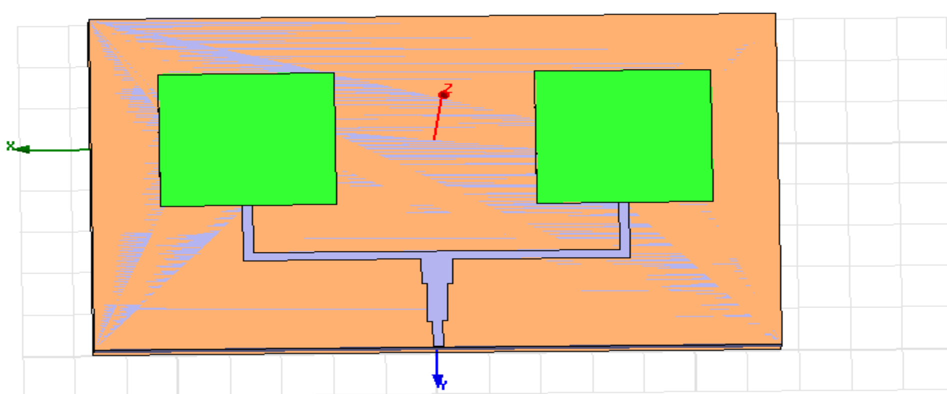

Figure 4.5 Design of 2X1 antenna array

Rectangular Patch has been designed on the top of the substrate with the dimensions of length 1.7mm and width 1.6mm.To get more band width all patches should radiate in one phase (angle). Slot has been designed with the dimensions of length 1.07mm and width is 0.3mm.To get more band width substrate height has to be increased. But every substrate has some specific height if height is increased above the specific height antenna will stop radiating. So in order to increase the height of substrate vias are used with the radius of 0.0625mm and height 0.5mm has been designed between the substrate ground planes. Feed line is designed with the impedance of 50 ohms to match antenna impedance of 50 ohms and the dimensions are of 1.41mmx0.1mm has been used designed. If impedance is mismatched the input power will be reflected .so power loss will be happened. Power divider has been used to transfer equal power to all patches.7.2.3. RETURN LOSS PLOT OF 2X1 ANTENNA ARRAY

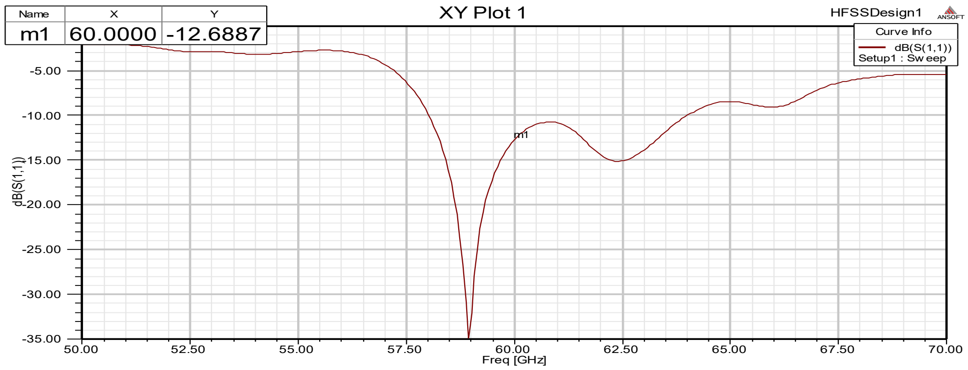

Figure 4.6 Return loss plot of 2X1 antenna array

The above figures shows that return loss is -35dB .that means the power which has been given to antenna is reflecting very less. Band width is 6GHz

3D POLAR PLOT

Figure 4.7 3D polar plot of 2X1 antenna array

The red color in the above figure shows the highest radiation towards the z axis that means patch radiates above the substrate .Green color shows power loss the table shows the maximum radiation 5.64db.As compared to single patch antenna Gain is increased from 2.71 to 5.64, i.e. 2.95db more gain is obtained.

7.2.5. RADIATION PATTERN PLOT

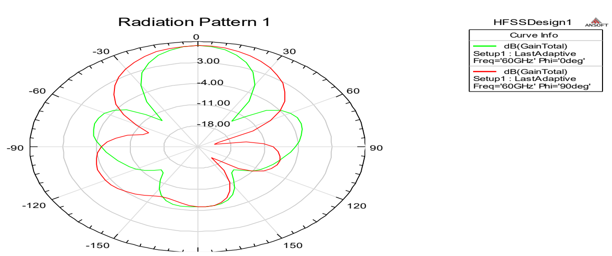

Figure 4.8 Radiation pattern of 2X1 antenna array

Red curve indicates the radiation pattern of the antenna at phi is 90 degrees. Green curve indicates the radiation pattern of the antenna at phi is 0 degrees. Gain of the antenna can be calculated from this pattern.

V. CONCLUTION AND FUTURE SCOPE

The study of a dual resonant slot patch antenna array that functions around 60GHz on LTCC substrate with the center fed micro strip structure was designed for easy feeding and impedance matching. The parasitic path placed at a certain height above the substrate can enhance front radiation, antenna gain and bandwidth effectively. Single patch antenna, 2x1 antenna array and 2x2

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antenna array are designed for wireless personal area network (WPAN) applications. It provides a wider bandwidth.

The gain of the single patch antenna is 2.97GHz. More gain can't be obtained by single patch antenna .So in order to get more gain, array should be designed .Return loss -27db is obtained by single patch antenna that is less than -10db so power loss is very less. Band width of the single patch antenna is 5GHz.

The 2x1 antenna array has been designed to get more gain .By comparing 2x1 antenna array with single patch antenna the gain of the antenna is increased from 2.97 to 5.64 i.e.3.67GHz is the improved by 2x1 antenna array .Return loss -35db is obtained that is less than -10db so power loss is very less. Band width of the antenna is 6GHz.

The 2x2 antenna array has been designed to get more gain .By comparing 2x2 antenna array with 2x1 patch antenna array the gain of the antenna is increased from 5.64GHz to 8.71GHz i.e.3.7GHz is the improved by 2x2 antenna array .Return loss is -21 that is less than -10db so power loss is very less. Band width of the antenna is 9GHz.

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