DESIGN OF SUBSTRATE INTEGRATED WAVEGUIDE COMPONENTS BY USING CST SOFTWARE

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Abstract – The project presents the design, simulation and fabrication of Substrate Integrated waveguide (SIW) technology based microwave components, such as Rectangular SIW (RSIW), Power divider, directional coupler. The main objective of this project is to design an SIW components.

Microstrip based devices can be used up to certain frequencies by using K-band frequency (18 -26.5). The conventional microwave components which are heavy, bulky in size, high cost. In order to overcome these draw-backs we have chosen substrate integrated waveguide as an approach. The results will be obtained from the CST software.

Index Terms – Microstrip, Substrate Integrated Waveguide, Power Divider, Directional Coupler, Rectangular substrate integrated waveguide.

I. INTRODUCTION

At high frequencies waveguide devices are preferred; however their manufacturing process is difficult. Therefore a new concept emerged: substrate integrated waveguide. SIW is a transition between microstrip and dielectric-filled waveguide (DFW). Dielectric Filled waveguide is converted to substrate integrated waveguide (SIW)by the help of vias for the side walls of the waveguide. Because there are vias at the sidewalls, transverse -magnetic (TM) modes do not exist;TE_{10} therefore is the dominant mode. SIW Devices can be thought as a form of dielectric filled waveguide (DFW), therefore the starting point can be DFW for TE_{10} mode the dimension "b" is not important as it does not affect the cutoff frequency of the waveguide the substrate can be at any thickness; it only affects the dielectric loss.

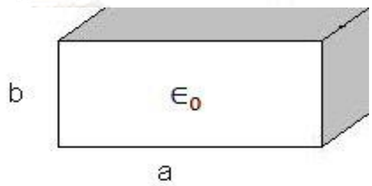

Fig.1 Dimension definition of rectangular waveguide

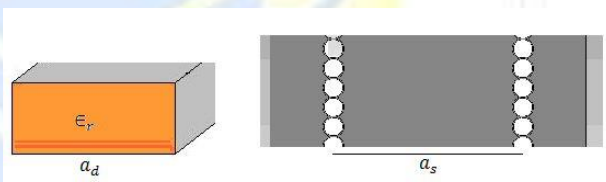

Fig.2 Dimensions for DFW and SIW

For a rectangular waveguide, cut off frequency of arbitrary mode is found by the following :

$$f_c = \frac{c}{2a}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$

Having determined the dimension "a" for the DFW, the design equations for SIW.:

$$a_s = a_d + \frac{d_2}{0.95_p}$$

II. EXISTING METHOD

Conventional Waveguide

A microwave circuit (or a system) is, in general, an interconnection of many fundamental microwave devices such as filters, couplers, power divider/combiners, etc. However, an essential requirement in all these devices is the ability to transfer signal power from one point to another as efficient as possible (i.e., with minimum amount of loss)[1]. This requires the transport of electromagnetic energy in the form of a propagating wave. Therefore, all the aforementioned fundamental microwave devices are designed and manufactured in the form of a guiding structure so that electromagnetic waves can be guided from one point to another without much loss.

Fig. 3 Rectangular Waveguide

In this mode, only the electric field components on y-axis direction vary. The vertical solid lines in the x-y plane represent the E-field components of y axis. The dash loops inside the waveguide show the magnetic field. The crosses represent E-field components with a downward direction, and the dots represent those with an upward direction.

Microstrip Line:

A microstrip is a type of transmission line that consists of a conductor fabricated on dielectric substrate with a grounded plane. It is easily miniaturized and integrated with microwave devices making it a popular choice of transmission line. A microstrip line consists of a conductor of width W, a dielectric substrate of thickness d and permittivity $\boldsymbol{\varepsilon_r}$.The presence of the dielectric concentrates the field lines in the region between the conductor and the ground plane, with some fraction being in the air region above the conductor, leading to quasi -TEM modes of propagation in which dispersion occurs as a function of wavelength as shown in Fig.

The characteristic impedance of the line changes slightly with frequency (again, even with a non-dispersive substrate material). The characteristic impedance of non-TEM modes is not uniquely defined, and depending on the precise definition used, the impedance of microstrip either rises, falls, or falls then rises with increasing frequency.[10] The low-frequency limit of the characteristic impedance is referred to as the quasi-static characteristic impedance, and is the same for all definitions of characteristic impedance.

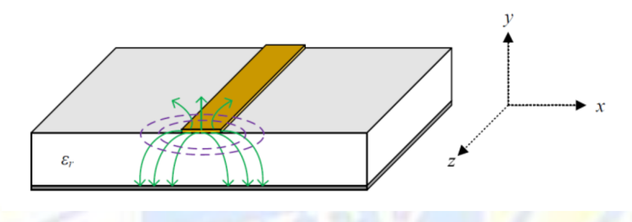

Fig.4 Microstrip line

The Phase Velocity and propagation constant is given by:

$$v_p = \frac{c}{\sqrt{\varepsilon}}$$

$$\beta = k_0\sqrt{\varepsilon e}$$

With the effective dielectric constant,ε_e of the microstrip line satisfying the relation.

$$1 < \varepsilon_e < \varepsilon_r$$

Directional Coupler

One key feature of directional couplers is that they only couple power flowing in one direction. In this way, power entering the output port is coupled to the isolated port but not to the coupled port. RF directional couplers can be implemented using a variety of techniques including strip line, coaxial feeder and lumped or discrete elements. They may also be contained within a variety of packages from blocks with RF connectors, solder pins or they may be contained on a substrate carrier, or they may be constructed as a part of larger unit containing other units.

Fig.5 Directional Coupler

While specific ports are given labels on a device, this is normally more physical constraints as some ports will be manufactured to carry higher powers than others. In fact any port can be the input, and this will result in the directly connected ports being the transmitted port, the adjacent port being the transmitted port, and the diagonal port being the isolated port. The main line is the one between ports 1 and 2. Normally this may be more suited to carry high power levels and it may have larger RF connectors, if it is a unit with RF connectors. The other ports on the directional coupler are normally more suited for lower powers as they are only intended to carry a small proportion of the main line power. Ports 3 and 4 may even have smaller connectors to distinguish them from the main line ports of the RF coupler. Often the isolated external matched load which would typically be 50 ohms.

Power Divider

power dividers provide equal amplitude and equal phase splitting as is depicted in figs. Notice that for both power dividers, the input signal at port 1 splits equally between output ports 2 and 3. In a resistive power divider, both output signals are 6db lower than the input signal, and they are in phase. In Wilkinson power dividers, the output signals are 3dB below the input signal, and they are also in phase (i.e. 0 degree phase shift between the outputs). The extra 3dB of path loss in the resistive divider is caused by the extra voltage drops across the 16.7 ohms resistors. The main difference between resistive power dividers and Wilkinson power dividers have 3dB lower loss and posses ports. Practically speaking, Wilkinson power dividers are limited in their low frequency range (flow)to a few hundred MHZ while resistive power dividers reach to DC .

Fig.6 Power Divider.

once the waveguide's one end is excited then the field can be generated. In general, the fields within the waveguide & free space will transmit in a similar way. But, in the case of propagation with the waveguide, the propagating field can be controlled through the waveguide walls so the field will not pass spherically as this is not the case through free-space.

III. Proposed Method

A substrate-integrated waveguide (SIW) also known as post wall waveguide or laminated waveguide is a synthetic rectangular electromagnetic waveguide formed in a dielectric substrate by densely arraying metallized posts or via holes that connect the upper and lower metal plates of the substrate. The waveguide can be easily fabricated with low-cost mass-production using through-hole techniques, where the post walls consists of via fences. SIW is known to have similar guided wave and mode characteristics to conventional rectangular waveguide with equivalent guide wavelength.

Since the emergence of new communication technologies in the 1990s, there has been an increasing need for high-performance millimeter - wave systems. These need to be reliable, low-cost, compact, and compatible with high-frequencies. Unfortunately, above 10 GHz, the well known microstrip and coplanar lines technologies cannot be used because they have high insertion and radiation losses at these frequencies[5]. The rectangular waveguide topology can overcome these issues, as it offers an excellent immunity against radiation losses and presents low insertion losses. But in their classical form, rectangular waveguide is not compatible with the miniaturization required by modern applications.

The concept of SIW was developed in the early 2000s by Ke Wu to reconcile those requirements. The authors presented a platform for integrating all the components of a microwave circuit inside a single substrate, with a rectangular cross-section. Using a single substrate guarantees a limited volume and a simplicity of manufacture, while the rectangular cross-section of the line provides the advantages of the waveguide topology in terms of losses.

To compare the field distribution of SIW vs conventional waveguide, X band simulations were done. Figure 1 compares the field distribution of SIW and conventional waveguide. We can see striking similarities between the two in particular the electromagnetic field distribution is TE_{10} like[6].

Rectangular waveguide SIW

The concept of integrated rectangular waveguide substrate is based on electrical side walls synthesized by rows of metalized holes. The substrate of permittivity is sandwiched between two metal plates placed on top and bottom to allow propagation of all modes TE_{n0}. If the RSIW is properly designed by optimal parameters, a width, a diameter d of the holes, and a spacing p between two consecutive holes, its electrical behaviour is similar to that of a conventional rectangular waveguide filled with the same dielectric of width w_{eq}. Indeed, the current lines along the side walls of the RSIW are vertical, the fundamental mode TE_{10} can propagate efficiently. This means that the propagation modes, the characteristic impedances and the dispersion characteristics are almost identical with negligible radiation losses.

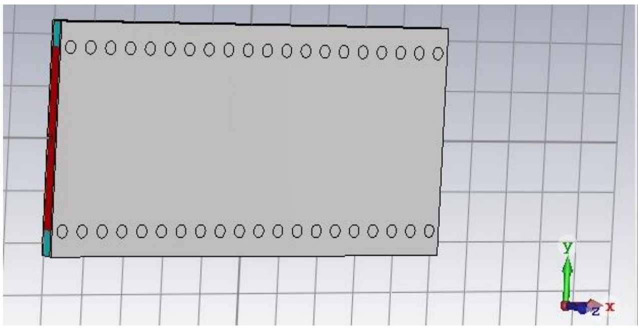

Fig.7 Rectangular Substrate Integrated Waveguide

Dielectric material is integrated between two perfect dielectric materials and the three layers are connected through via's. Waveguide Port s are allotted on both sides of the rectangular waveguide. The structure was simulated and 1D results i.e..scattering parameters was observed and by 2D/3D results electric field was observed.

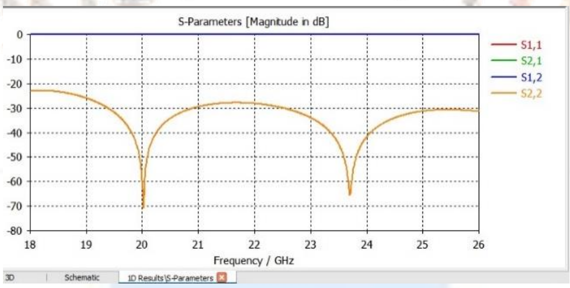

Fig.8 S-parameters of RSIW

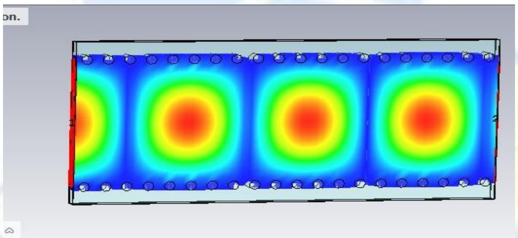

Fig.9 E-field of RSIW

SIW Microstrip Line

In this study, a microstrip transition (taper) is used to interconnect RSIW to the planar transmission lines. There is a tapered section which is used to match the impedance between a Ω microstrip line and the RSIW. The Ω microstrip line, in which the dominant mode is quasi-TEM, can excite well the dominant mode TE10 of the RSIW, as their electric field distributions are approximate in the profile of the structure.

Initial parameters and of the taper are determined from several formulas given in following by an optimization using the CST. The optimal parameters are presented in Table II. Fig4.3 shows the proposed configuration of two back-to-back of microstrip line to RSIW. It allows the design of a completely integrated planar circuit of microstrip and waveguide on the same substrate without any mechanical assembly.

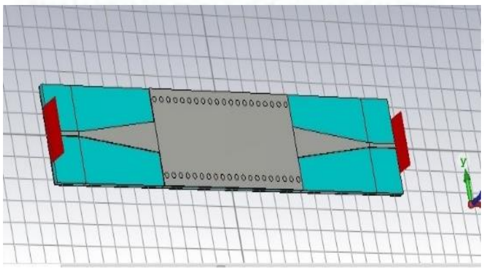

Fig.10 Microstrip line

Microstrip transition is used to interconnect RSIW to the planar transmission lines. Here Tapered section is used for impedance matching between Microstrip line and RSIW.On RSIW we design taper section and after microstrip line was designed. Microstrip lines are used for transmission lines in RF and Microwave circuits. By using tapered section we can integrate both planar microstrip and waveguide on the same substrate.

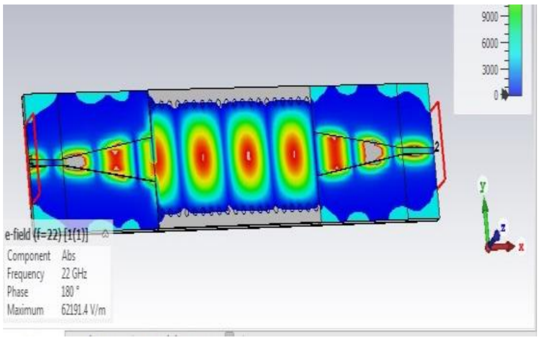

Fig.11 E-Field of Microstrip Line

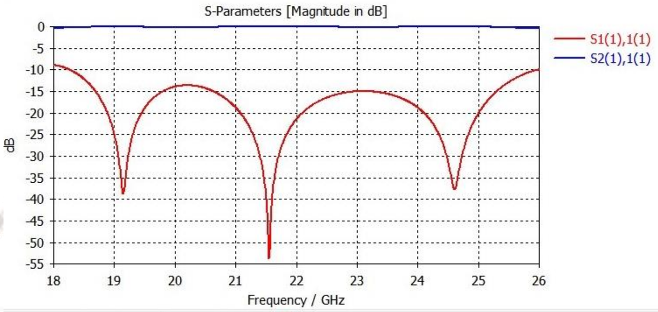

Fig.12 S-parametrs of Microstrip Line

SIW Directional coupler

The SIW directional coupler is a type of directional coupler that uses SIW technology to achieve high performance and integration. It Consists of two parallel SIW lines coupled together through a small gap in the substrate. The Signals are coupled through the gap and in opposite directions, allowing for the measurement of the forward and reverse power of the signals. The SIW directional coupler has several advantages over other types of directional couplers. It has a compact size , Low insertion loss ,and wide bandwidth.

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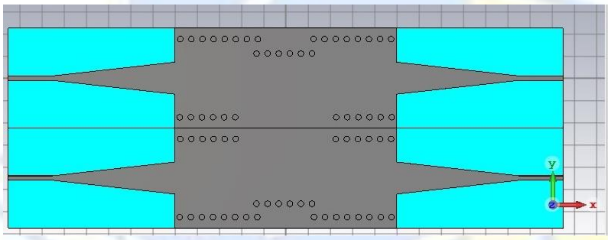

Fig.13 SIW Directional Coupler

By Using microstrip line rectangular wave guide we design directional coupler. By combining two microstrip rectangular waveguides we get directional coupler by adjusting its Via’s. Copy the waveguide with microstrip line and paste it with the width y= -W and rotate it with 180 degrees.

Couplers which have been widely used as key components in many systems have been intensively studied for decades. In the antenna beam-forming networks, the directional coupler is generally an important element in power dividing/combining networks, so great interest and effort have been directed to the development of different types of directional couplers. The RSIW directional couplers are extensively investigated.

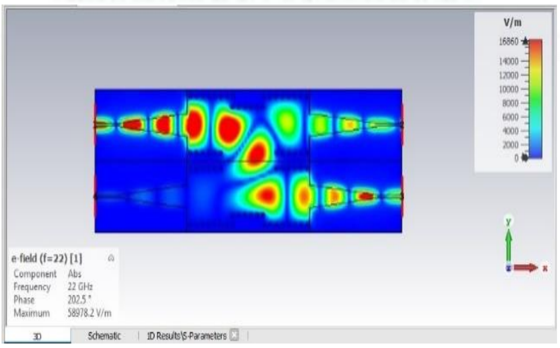

Fig.14 E-Field of Directional Coupler

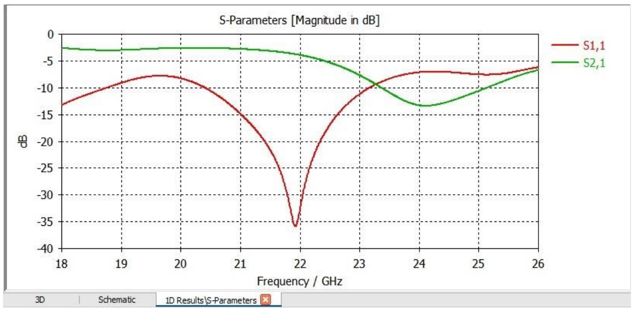

Fig.15 S-parameters Of Directional coupler

SIW Power Divider

One advantage of SIW power dividers is that they have low insertion loss and high isolation between the output ports, which makes them suitable for high performance applications. They also have a wide operating frequency range, which makes them flexible in terms of system design. SIW power divider are designed to split a single input signal into multiple output signals with equal or unequal power distribution. They are widely used in applications. Such as radar systems, communication systems and satellite systems.

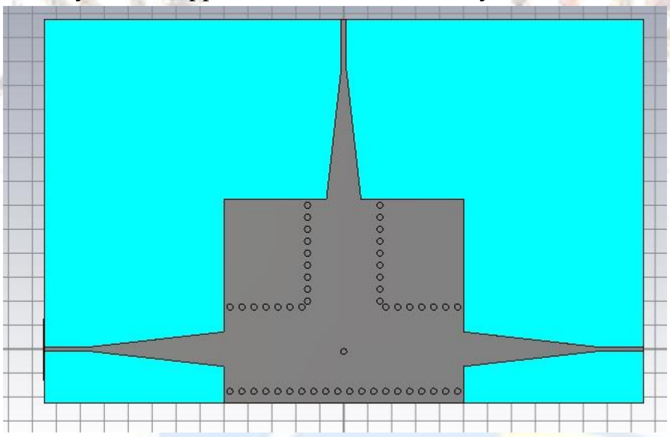

Fig.16 SIW power Divider

The transmission coefficients S21, S31 and the reflection coefficient S11, respectively. This power divider RSIW is designed by metal rods of square section with a side d equal to the diameter of the cylindrical rods used above. Fig. Indicates that S11 is less than -15 dB between 19.3 GHz and 25.02 GHz, which is more than 25.81% of the bandwidth. Power Divider is a circuit that divides a signal into two or more equal or unequal parts.

The SIW power divider consists of a waveguide splitter and two or more output ports. The waveguide splitter divides the input signal into multiple output signals of equal or unequal amplitudes. The main advantage of using SIW power divider design is its compatibility with other planar transmission line components, such as filters , couplers ,and antennas.

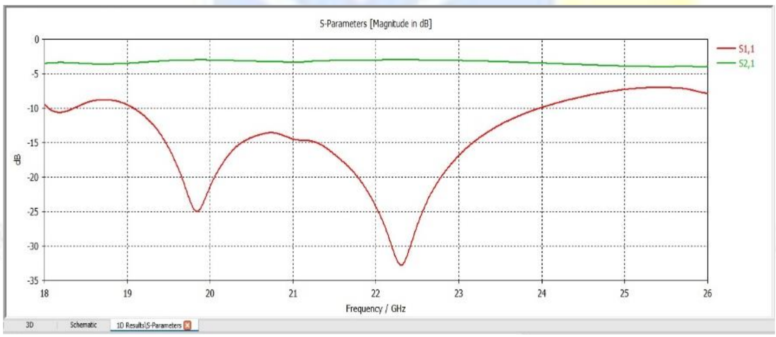

Fig.17 S-parameters Of SIW power Divider

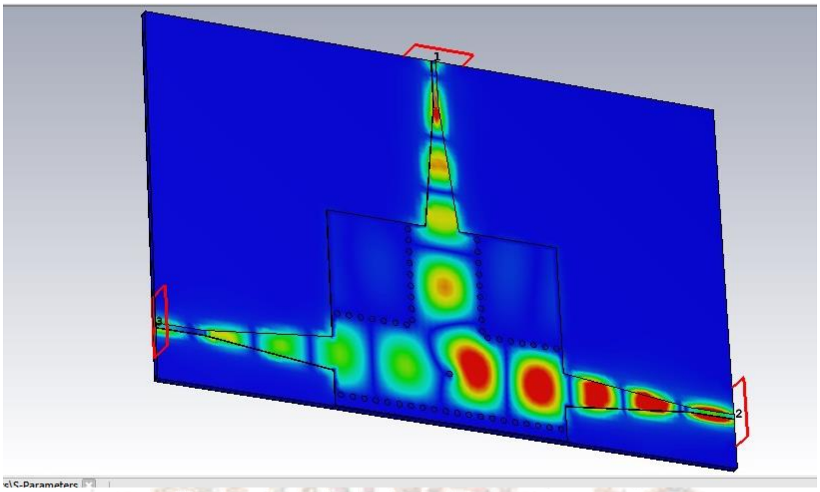

Fig.18 E-Field of SIW Power Divider

IV Conclusion

In this letter a new technology was used for designing of microwave components that operate in K-band frequency range(18-26.5) in TE_{10} Mode. The proposed method has Compact Size, low size, Low Cost and High Gain with high frequency and high speed.

V References

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