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A REVIEW ON FERRITE-BASED COPLANAR CIRCULATOR

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***Abstract*—Due to the rapid development of microwave applications recently, it has become critical to enhance the efficiency of devices in order to satisfy the needs of the telecommunications industry. Therefore, smaller, low-cost products that operate at higher frequency ranges must be created for use in these devices. In microwave integrated circuits, a circulator with a coplanar waveguide (CPW) construction is an excellent choice Since the ground layer and the transmission line are in the exact same plane level (usually it's on the top). As a result, utilizing the lithography method, coplanar circulators may be readily and inexpensively manufactured. In this study, a thorough examination of the various coplanar circulators is provided**.

***Keywords*—Circulator, passive devices, ferrite, coplanar waveguide, self-biased, microwave component.**

I. INTRODUCTION

Because of the significant rise in the telecommunications sectors over the past many years, there’s been considerable attention to the development of non-reciprocal devices that are made of ferrite materials. The ferrite circulator has advanced significantly since its early days as a real-world example of Faraday rotation.

A. G. Fox came up with the term "circulator," and just as the term has evolved, circulators have taken on a wide variety of shapes and evaluations. Non-reciprocal devices such as isolators, circulators, and phase shifters are some of the most extensively utilized in the telecommunications industry. It transmits energy through one incident terminal to the next adjoining terminal while isolating all those other ports that use the non-reciprocal features of biased ferrite. Devices that are passively non-reciprocal are crucial parts of microwave circuits and systems. One such passive component with several applications in radar and satellite communication systems is the circulator. A circulator is a symmetric junction with three or more ports device that is loaded with ferrite. The electricity from a single port is transferred to an adjacent port in either a clockwise or a counter-clockwise fashion, while the remaining ports are isolated from each other. The device's non-reciprocal behavior is achieved by submitting a ferrite to a suitable magnetic bias field during the manufacturing process transfers energies through one incident port towards the next neighboring port using the non-reciprocal features of biased ferrite. The circulator can segregate various components of the electronic circuit and redirect energy in the desired direction thanks to all of the other non-reciprocal features. This characteristic aids in safeguarding delicate hardware in the circuits of radar systems or full-duplex communication systems. Furthermore, due to the non-reciprocity of the ferrite material, the radio signals appearing on the same antenna can be transmitted and received at the same time, so it can be used as a duplexer. Other applications include protection of the device under test (in case of mismatch) and the amplifier system.

An electronic circulator can theoretically have any number of ports, but as the number of ports increases, so do design challenges. Micro strip circulators are the circulators that are most often utilized in the industry today. Three and four-port circulators are the most commonly produced circulators in terms of practicality. Nevertheless, in recent years, the number of electronic components integrated on a single chip has risen, while the overall size of the circuit package has shrunk. As a result, there is a pressing need to miniaturize circulators. Recent advancements in the design of small circulators are based on the Coplanar Waveguide (CPW) with planar technology, this furthermore has the benefit of being easy and affordable to produce.

Due to the rapid development of microwave applications recently, it has now become essential to enhance the efficiency of devices in order to satisfy the needs of the telecommunications industry. Therefore, smaller, low-cost products that operate at higher frequency ranges must be created for use in these devices. C-Band waveguide components are frequently employed in long-distance radio telecommunications as well as high-energy physics research and development applications. For weather radar systems and satellite communications, C-Band is also used.

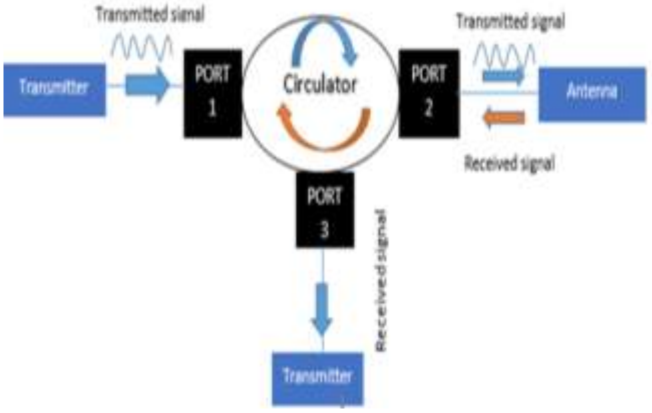


Fig. 1: 3 port circulator

The microstrip Y-junction circulator is the device that is most typically utilized in these systems. Since 1962, Bosma has defined the operational principle based on a ferrite of a non-reciprocal Y- circulator, which is a non-reversible Y-circulator, which he first disclosed in 1962 [1].

Polder tensor is utilised in this analysis to characterise the tensor permeability of the ferrite, and it is defined as A circulator having a coplanar waveguide (CPW) structure, on the other hand, Because both the line as well as the GND are placed at the similar plane and therefore are straight forward the to the pattern, it is well suited for microwave integrated circuit applications.

It was Wen [2] who was the first to investigate and create the theory of the CPW. In the following, Ogasawara [3] had demonstrated and validated the point regarding the Y-junction circulators having CPW are capable of operating satisfactorily at specific frequencies.

Many researchers have explored and developed circulators with a CPW configuration, which have since been implemented.

Zahwe [4, 5] put in a lot of effort into researching and developing the given device.

Boyajian [6] suggested made of Hexaferrite nanocomposite, a circulator, which was accepted. Having a CPW structure, a triangular-shaped circulator was proposed in our earlier paper, and of the circulator, the transmission characteristics were investigated using an Ansoft High-Frequency Simulation System.

The Helszajn's model [8,9] for strip-line structure is used to investigate the operation of such a circulator.

Later, in 2007, Zahwe conducted research on this sort of circulation[10]. Similar to a circulator strip line circulator, this machine works in much the same way. Making a micro-circulator with YIG is one of the key objectives (ferrite of 1mm thick). A low insertion loss, high-isolation, and minimal reflection levels at most of the component's port locations are required for the development process.

II. CLASSIFICATION OF CIRCULATOR

A. Differential phase shift circulator

The circulator is made up of two joint pathways connecting two magic teas. A differential phase shifter is present along each coupling route. The first path's differential phase shifter is configured to create a differential phase shift that grows with frequency.

In order to create a differential phase shift that decreases with increasing frequency, the secondary differential phase shifters in the second route is configured.

The anti-phase shifter is in series with the first differential phase shifter in the first pass.

These two non-reciprocal 90 ° ferrite phase shifters are used in the differential phase circulator design together with a 3 dB directional coupler, a magic tee, and other components. A 50kW CW circulation pump that operates in the S-band has been developed.

Another circulator has been developed that operates in the C band and achieves a high power capacity of 550kW. DPS circulation uses two directional couplers with 180 ° ferrite phase or different configurations with two 90 ° ferrite phase shifters and a dielectric 90 ° phase shifter, as shown in the figure.

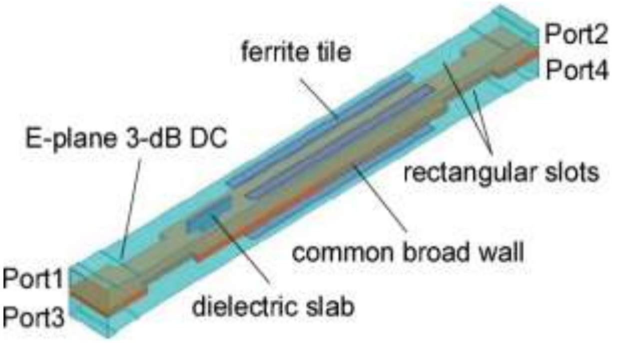


Fig. 2Differential phase shift circulator with 90° Phase shift

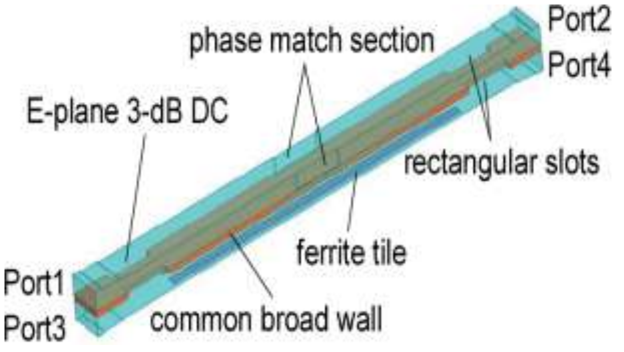


Fig. 3: Differential phase shift circulator with 180° Phase shift

B. Faraday Rotation Circulator

When a linearly polarised wave passes through a ferrite throughout the direction of bias, the polarization rotates according to the lengths of the ferrite. Faraday rotation is the name given to this occurrence. Faraday rotation is a non-reciprocal phenomenon. Figure 4 shows a 4-terminal Faraday rotary circulator.

Power approaching port 1 is transformed to the TE1,1 mode inside the circular waveguide, passes via port 3 untainted as a result, the ferrite insert rotates the electric field through 45 degrees without considerably reducing it. (the magnet is omitted for simplicity), continues past port 4, and eventually arise from port 2, just like it also do in the isolator. This form of circulator does have the same power limitations as the Faraday rotation isolator, although it is ideal for use as a low-power instrument. However, because it is larger than the Y-circulator, it is usually used at high frequencies, in the milli-meter range and higher. Its properties are comparable to those of an isolator.

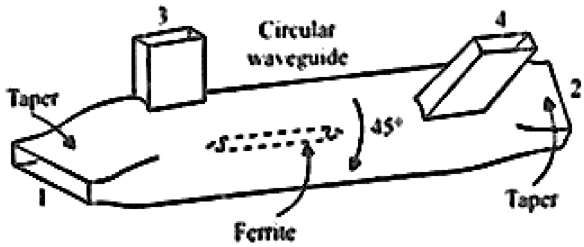


Fig. 3: Faraday rotation Circulator

Following are some of the circulator based on Farady rotation:

- Polarization Circulators:

Polarisation circulator, makes use of the Faraday rotation effect, has four output ports, one for each of the four polarizations present at either end of the device.

The polarization-circulator is a device that makes use of the 450 Faraday rotation of the plane of polarisation and is used to circulate polarisation. The construction of a second polarisation circulator has been accomplished by combining one gyrator with two magic tees

C. Junction Circulator

The ferrite junction circulator is a Powerful and flexible microwave device that is rapidly being one of the most renowned. Its flexibility may be seen in the fact that, in addition to it being a circulator, this can function as an isolator as well as switch. Instead of being a cylindrical transmission line, this has a ferrite in the middle and a junction where all of the branches meet.

Circulators with three or four ports, strip-line Y-line circulators, micro strip Y circulators, and coplanar circulators are all examples of junction circulators. Permanent magnets must be used to magnetize the ferrite in a direction perpendicular to the junction planes, and Electromagnetic fields must travel and circulates in the plane with the junction.

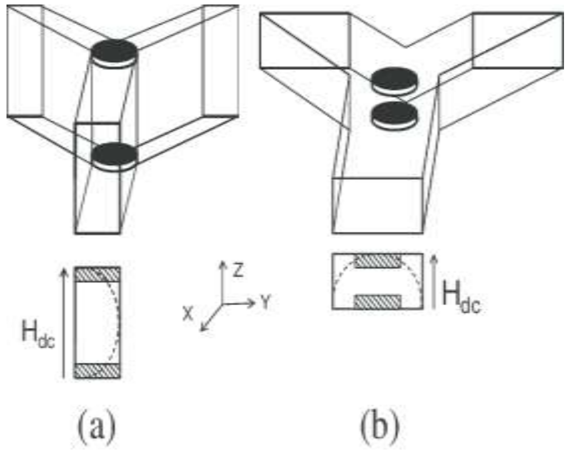
The 3-port ferrite junction circulator, often known as the Y junction circulator, is the most prevalent. It can be built as a rectangular waveguide or as a strip-line. The waveguide version is often an H-plane junction, but E-plane junction circulators are also possible. Strip-line ferrite junction circulators are typically constructed using coaxial connections and are most appropriate to UHF and low-microwave frequencies.

Early experimenters discovered that waveguide T-junctions with a transversely magnetized ferrite slab properly situated in the junction may be converted into circulators with correct matching and magnetic field adjustment. The bandwidth of such devices was quite limited. Refinements resulting in better symmetry were discovered to boost bandwidth, resulting in practical devices. The following are the benefits of using a junction circulator:

- High power may be handled using a junction circulator.
- These circulators have increased operating bandwidth.
- These seem to be easy to assemble and light in weight.
- These are well Suitable for incorporation in-to the microwave circuits.

Different configurations of junction circulators:

- Waveguide Circulators: There are two different types of waveguide junction circulators. Three identical waveguides intersecting at 120 degrees to produce a symmetrical V-shaped figure are used in H-plane junctions and S-plane junctions. A ferritepost is mounted in the E-plane junction and a ferrite disc is fixed in the H-plane junction in the junction region, and the ferrites are transversely magnetised by the d.c. field.



(a) (b)

Fig.4: Waveguide Circulator

Given the geometrical symmetry of the system, it should be obvious that if RF power is applied to one of the waveguides, it will emerge at the adjacent waveguide in the direction of circulation, so isolating the third waveguide from the others. The circulation action can be achieved by selecting the appropriate ferrite rod or disc dimensions, as well as the appropriate saturation magnetization and biasing-field magnitudes, and such a device is referred to as the H-plane and E-plane waveguide circulator, depending on its configuration.

Another type of waveguide circulator, which employs slabs on either side of the three waveguides, is also available. All of the microwave energy is trapped in one of the sl ab s, resulting in what is known as an ed. It's the Ferrite dielectric mode of operation. It is then steered continually by the slab from one wave-guide to another until it reaches an adjacent one. Using symmetrical slabs of ferrite that have been transversely magnetised, Lax and Button were able to compute the field distribution.

Three identical three-port Hplane or Eplane circulators separated by approximately one-half guide-wavelength can be used to construct four-port waveguide circulator, and three identical three-port Eplane circulators can be used to construct five-port waveguide circulators.

Guide for the cross-guide 4-port circulators are constructed with four waveguides intersecting at 90 degrees, resulting in an insertion loss of 0.25 dB in the X-band region, according to the published results.

Because of the low external direct current magnetic fields employed, these waveguide circulators are smaller in size and lighter in weight than the Faraday rotation or rectangular waveguide phase type circulators.

It should be noted that in the case of 4-port waveguide circulators, the insertion-loss between adjacent ports is also 0.25 decibels, and that it is 0.50 decibels between diagonal ports. The lowest level of isolation between ports is 20 dB, and the highest level of isolation between ports land 3 is 40 dBs.

Turnstile Circulators: A 4-port circulator based on the well-known 4-arm turnstile junction, as well as Fowler's and Schang-circulators petterson's based on the 3-arm turnstile junction, have been reported by Allen. Owen-Barnes has reported a very compact turnstile circulator based on the well-known 4-arm turnstile junction.

It is common practise to employ matching turnstile junctions in these types of circulators, and the circular arm is ended by the Faraday rotator, which is located in front of an adjustable short circuit plunger.

With the device being considered to be made up of two separate parts and the Faraday rotator being assumed to be reflection less, Allen demonstrated that the circulating action could be obtained by appropriately adjusting the velocity of propagation and phase of the wave in the circular arm.

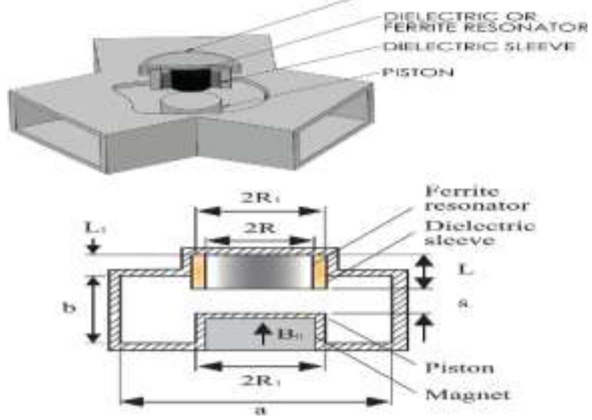


Fig.5: Turnstile Circulator

Strip line Circulators: Two ferrite discs separate a tri-plate metal connection sandwiched between two ferrite discs in a strip-line circulator. The entire assembly is then placed in a circular resonant cavity made of non-magnetic aluminium, into which three ports have been added for resonance. The flat plates at the top and bottom of the cavity serve as ground planes for the strip transmission lines that run through it. The arms of a tri-plate junction are joined to the centre by a connection plate.

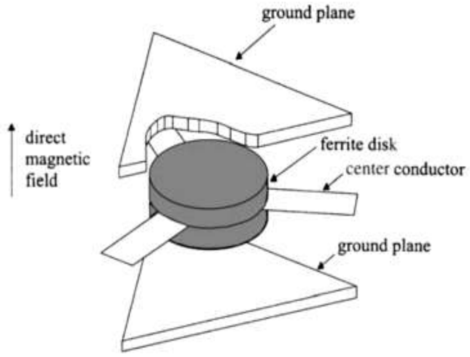


Fig.6: Strip-line Circulator

Micro-Strip Circulators: The ferrimagnetic micro-strip junction circulators designed by Hershenov and others demonstrated excellent performance characteristics in the X-band region when operated at high frequencies. These circulators were substantially smaller and lighter than the X-band waveguide circulators that are currently in use.

Microstrip transmission lines have a conductor lines solely on a single side of the substrate that has a high dielectric constant. A ferrite disc is inserted on the substrate of a basic microstrip circulator circuit and a top-mounted permanent magnet provides DC magne tic bias as shown in figure 7. These devices, which have microstrip transmission line connections, are suited for incorporation into advanced microwave integrated circuits, as well as for direct connection to other components via their microstrip transmission line connections.

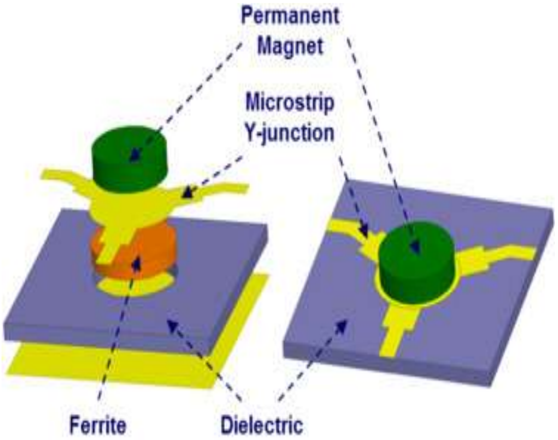


Fig.7: Strip-line Circulator

III. KEY PERFORMANCE PARAMETER OF CIRCULATOR

While choosing a Circulator, it is necessary to make sure that the device has acceptable performance criteria for the specified purpose. Circulators' basic and perhaps most essential performance metrics are insertion loss, VSWR, and isolation. These factors have a clear trade-off with bandwidth; as operational bandwidth increases, their values degrade.

- Isolation: Isolation is a measure of the separation of signal levels on neighbouring ports of a Circulator. This is expressed in decibels (dB). The greater the isolation value, the less disturbance out of a signals with one port compared to another. The isolation can be achieved by connecting a matching termination to the one of the Circulator's three ports. A Circulator's isolation is mostly determined by the two criteria listed below:

Level of termination match & Terminated port's VSWR.

Expected isolation is less than 10 dB in the situation of a bad match on the terminating port. Whenever the terminating port matches is enhanced to a VSWR = 1.10:1 by employing a good termination, the isolation increases to more than 20 dB.

- Insertion Loss: Another significant factor to consider while choosing a Circulator is known as transmission channel insertion losses. Insertion Loss is indeed the entire quantity of energy wasted while sending the RF signal from one port of the Circulator to the other. As previously indicated, the Circulator is a passive RF component, therefore any signal passing through that will be attenuated. Insertion loss usually is expressed in decibels and is the ratio of the output signal to the input signal (dB)

$$\text{Insertion} - \text{Loss} = 10\log_{10}\frac{[\text{Pout}]}{[\text{Pin}]}[\text{dB}]$$

The I.L(Insertion Loss) is the parameter that is a frequency dependent, It is proportional with frequeny as it increases with increases in operating frequency. As a result, the insertion loss of a Circulator becomes more substantial at higher frequencies due to more power being wasted as heat.

Circulator insertion loss is typically measured in the range of 0.2 to 0.4 dB.

- VSWR: It is an abbreviation for Voltage Standing Wave Ratio. The proportion of reflected power to the incident power of the standing waves caused by an impedance mis-match between both of the RF source as well as the load.

These standing waves are not desirable because the energy transmitted is reflected back and returns to the origin that is source. It has the potential to harm the Rf signal source.

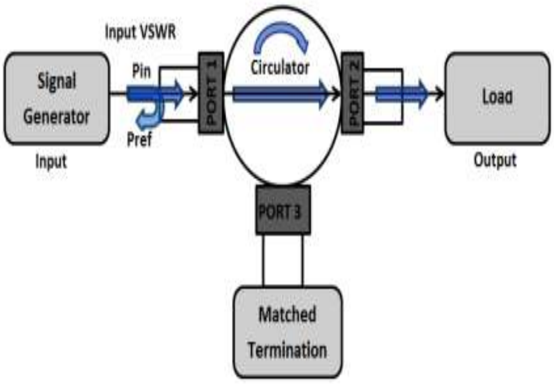


Fig 8: VSWR

The |Γ |that is magnitude of the reflection_coefficient,itdefines the reflective quality of each port of the circulator.

$|\Gamma| = \frac{\sqrt{\text{Pref}}}{\sqrt{\text{Pin}}}$= v- /v+

Where Pref is the reflected power, Pinis the incident power, V- is the reflected wave and V+ is the incident wave.

The resultant VSWR is given by the following equation:

$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

A Circulator's effective input VSWR varies with load VSWR. More energy is reflected toward the port that is terminated as the output load discrepancy increases. It is then reflected back to the input after being attenuated by isolation. As a result, the overall VSWR at the input is increasing.

IV. COPLANAR CIRCULATOR

D. Overview

When connecting an antenna to a transmitter or receiver, circulators are required. For example, circulators are required at the transmitter or receiver's input and output for connecting the antenna. Implementing ferrite materials on the other hand invariably results in a high-volume solution that is incompatible with microwave integrated circuits. With the help of coplanar technology, it is possible to create electronic circuits that behave like circulators. They may be able to take the place of ferrite circulators.

In 1962, Bosma published a paper on the strip line Y-junction circulator that was widely read. Through this investigation, it will be possible to determine the circulation conditions, thereby, to derive the critical physical parameters that will be used in the construction of strip line circulators.

The above-mentioned constraints can be solved by placing conducting components and the ground plane on the same side of the dielectric substrate. This types of integrated-circuits transmission line design is known as a coplanar waveguide. A conducting metallic strip and two ground strips are concurrently positioned adjacent to something in the construction of a coplanar- waveguide, which would be formed on an insulating slabs. This sort of transmission-line lends itself to the production of integrated circuits (ICs).

The following are some of the few benefits of a coplanar-structure:

- With cpw conducting parts, also it is simple to interconnect a shunt to that of an electrical device.
- The installation of a ferrite disc does not necessitate the drilling of a holes through all the base or substrate.

E. Numerical understanding of coplanar circulators

According to the theoretical conclusions reached by J. Helszajn,

$$r\frac{A}{2\sqrt{3}} \qquad (1)$$

The inscribed radius of the triangle resonator is represented by r, while the length of the inner triangular conductor, depicted in Figure 8, is represented by A.

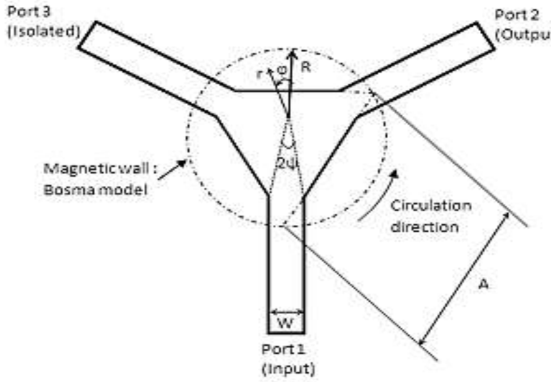


Fig.8: Configuration of the central conductor

The ferrite disk's actual radius:

$$r=R \qquad (2)$$

The equation can be used to figure out how the triangle's side A is calculated:

$$kA\frac{4\pi}{3} \qquad (3)$$

It is known as the medium's wave number, abbreviated as k:

$$k = \frac{2\pi}{\lambda}\sqrt{\varepsilon_f\mu_{eff}}$$

and

$$\mu_{eff} = \frac{\mu^2-k^2}{2}(4)$$

where μ is the effective permeability of the ferrite computed using the Polder model, and k is the relative dielectric constant.

The constituents of the tensor Polder ferrite are denoted by the letters K and μ. The authors in [6] discovered that the margins are not quite ideal magnetic walls of the resonator based on observations of the first mode's resonant frequency. The following is how they defined the effective value of the triangle side Aeff:

$$A_{eff} = A + \frac{h}{4}(5)$$

The thickness of the ferrite coating is denoted by h. Figure 1 shows the method in which the central conductor is arranged. The radius of the ferrite disc lines R and the stripline width angle W can be used to calculate the stripline conductor's width W, as illustrated in [1].

$$W = 2R\sin\Psi$$

and

$$\Psi = \frac{\pi\left(\frac{k}{\mu}\right)}{3.186\sqrt{\mu_{eff}}/\varepsilon}(6)$$

The magnetic substance used in [1] is ferrite, and it is positioned in the centre of the device to serve as a magnet. The circulator's non-reciprocity is due to the use of this magnetic substance.

Because of the polarisation along the axis of the cylinder, and the saturation of the ferrite, When the ferrite is polarised parallel to the cylinder's axis and saturated with an internal static magnetic field, the given formulas are used to calculate the field:

$$H_i = \sqrt{\frac{\lambda}{\sqrt{3}W}4\pi M_S} - 4\pi M_S \qquad (7)$$

Free space wavelength is given by λ, centre conductor radius is given by w, saturation magnetization is given by Ms, and external static field H0 are described by the following equations:

$$H_0 = \frac{\omega}{\gamma}(8)$$

The gyromagnetic factor is represented by Y and the angular frequency is represented by w

F. Circulator With Coplanar Waveguide (CPW) Structure

Due to the fact that the transmission line and GND are both positioned in the same plane in a circulator It is also an excellent contender for microwave integrated circuits because of its CPW structure (usually on the top).As a result, utilizing the lithography method, coplanar circulators may be readily and inexpensively manufactured. Figure 2. depicts a coplanar structure with a CPW structure of a hexagonal circulator that is characteristic of this kind. For the first time, Wen and Bayard [11, 12] disclosed coplanar circulators working at 7 GHz that require an internal magnetic field greater than 170 kA/m. Ogasawara demonstrated that using a CPW, Y-junction circulators could successfully function at numerous frequencies depending on the external dc magnetic fields applied perpendicularly to the ferrite surface[13]. This circulator, which includes thin layers of BaM (Barium ferrite) and a dielectric layer with a very low dielectric constant [14], has also recently been proposed and successfully tested. It was discovered in 2011 that a ferrite could be created by embedding magnetic particles into a host dielectric matrix in laboratory LT2C, and that a coplanar circulator could be constructed using this ferrite [15].

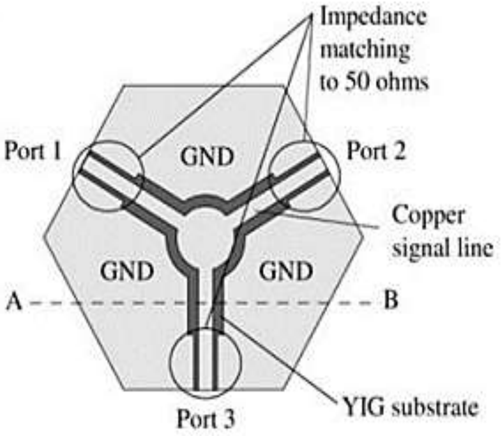


Fig 9:wit a CPW structure, a hexagonal circular

It is presented in [16] that a coplanar circulation extrapolated from the stripline circulator, which has been explored by Bosma, is presented. Because the signal line and the ground are positioned in the same plane, the device with coplanar construction is well suited for usage with microwave integrated circuits because it will be simple to interconnect with other components. Furthermore, the design that we suggest is capable of being manufactured utilising the normal lift-offff technique as well as collaborative fabrication. All of this contributes to the reduction of the overall cost of the final components produced. Ogasawara was the first to report a coplanar waveguide circulator on a ferrite substrate, which was published several years ago. His report [17] did not, however, provide any additional information on the circulator or its transmission qualities. Koshiji and colleagues [18] have developed a coplanar waveguide that incorporates a large cylindrical ferrite post. The coplanar circulator developed and tested by Oshiro et al. [19] in 2004–2005 used two substrates of YIG (each post having a 500-micron thickness) and was successfully tested. The CPW structure of a new coplanar circulator with the YIG fifilm was proposed in previous publications [20,21], and the transmission characteristics of the circulator were studied using a three-dimensional (3D) fifinite element method (FEM).

Three GSG coplanar probes are coupled to a vector network analyzer in this study, and the transmission properties of the circulator produced with only 65 m ferrite film are measured. This circulator is based on the design studies in [20,21].

V. FERRITE BASED CIRCULATOR

Magnetism has been recognised for thousands of years, since since the Greeks discovered naturally magnetic rocks known as lodestones, which could attract any iron that came too close [2]. However, considering its rarity, this was little more than a curiosity until lately. The characteristics remained opaque and intangible.

In, the engineering work began in earnest. Polder [3] used ferrimagnetics to determine what is now known as the Polder permeability.

The tensor specified the relationship between magnetic flux density and magnetic field intensity as a function of the material's DC biassing, the field strength at which the material's magnetic saturation occurs, and the device's frequency of operation. Devices The use of ferrimagnetic materials, which may claim electrical properties, began to arise. Such materials have a di-electric loss tanδ (tangent) of the order of 10^{-4}.

Ferrite based circulators are available on the market through numerous of suppliers throughout the world in a range of formats and specifications. Many different transmission line media employ circulators, such as Faraday rotation circulators, DPS (differential phase-shift) circulators, Okada circulators, and switching circulators. Nonreciprocal transmission in a ferrite-loaded T-junction was the first to be seen. In [22] and [23,24], a strip line device arrangement was the subject of the first phenomenological theory for the circulator. Since that time, circulators have been made in virtually every transmission line geometry, including waveguide, strip line, coaxial, micro strip, coplanar waveguide, and so on. When no external magnetic field is supplied, the ferrite-loaded junction performs effectively as a symmetrical power splitter[25,26].

It allows 2 counter—rotating, degenerative mode which join together to form a standing-wave form with a void with in center of an intersection in the smallest approximation.

When such an external mag-netic field is introduced, the magnetic moments in the ferrite start to precess, and the 2 counter wise-rotating mode engage with the ferrites to varying degrees. As a result, the degeneracy is lifted, resulting in differing resonance frequencies for the 2 counter-rotating modes[27,28,29].

This causes the standing wave pattern to rotate. The secondary requirement in the development of a ferrite based circulator is that the input impedance match the feeding transmission line impedance across the frequency range of interest.

- Ferrite Materials: Such materials have a di-electric loss tanδ (tangent) of the order of 10^{-4}. Over the centuries, a variety of ferrimagnetic materials have been studied to aid in the development and manufacturing of circulators as well as other devices operating at RF, microwave, and millimeter-wave frequencies and with a variety of insertion losses, ability to handle power, excellent thermal stability, and bandwidth requirements. Ferrites from the garnet group, such as yttrium iron garnet (YIG) and calcium vanadium garnet(CVG), have the least dielectric and magnetic losses.

Because YIG and CVG are far less susceptible to mixed valence states and other flaws, they have very small dielectric loss[30,31].

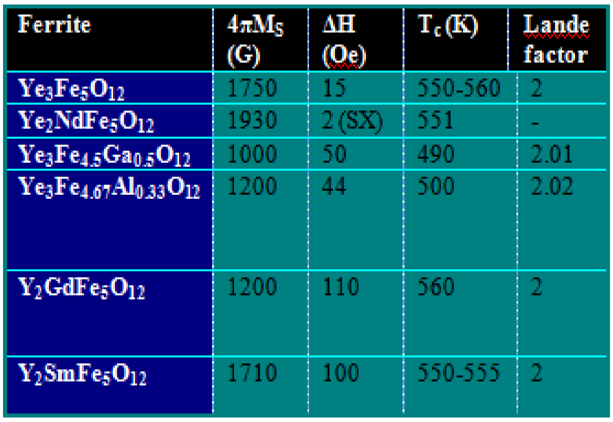
However, the saturation magnetization of such material remains restricted to roughly 2,000 G. As a result, YIG as well as CVG are helpful for broadband circulators or other device applications in the L, S, even C bands. Spinel ferrites are utilised to attain higher frequency range, such as X, Ku, and higher bands[32].

The ferrite lattice, whether spinel, garnet, or hexa-ferrite, has a close - packed of oxygen anions as its structural backbone.

A) Granets: Whenever it comes to cubic ferrites, garnets stand out because it offer outstanding insulating qualities. As a result, these are suitable materials for applications where minimising conduction losses is critical[33,34,35].

Designers confine their discussion in this study to compositions that it have special significance at UHF, RF, and microwave frequencies, with an emphasis on the production of important YIG.

Table I[36,37] displays the magnetic, electrical, & microwaves features of several garnets.



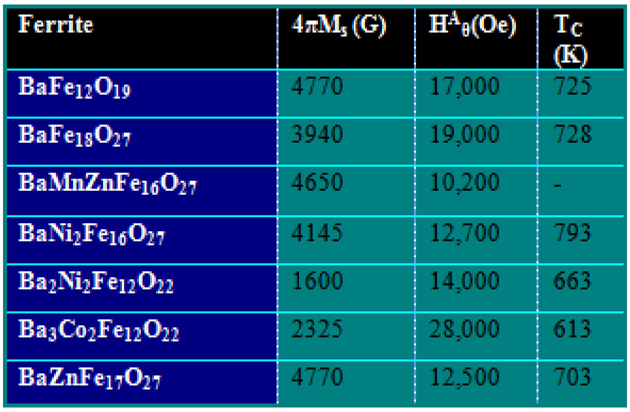
Ferrite	$4\pi M_S$ (G)	ΔH (Oe)	T_c (K)	Lande factor
$Ye_3Fe_5O_{12}$	1750	15	550-560	2
$Ye_2NdFe_5O_{12}$	1930	2 (SX)	551	-
$Ye_3Fe_{4.5}Ga_{0.5}O_{12}$	1000	50	490	2.01
$Ye_3Fe_{4.67}Al_{0.33}O_{12}$	1200	44	500	2.02
$Y_2GdFe_5O_{12}$	1200	110	560	2
$Y_2SmFe_5O_{12}$	1710	100	550-555	2

Table 1: Garnets with its micro-wave properties

B) Hexaferrites: Unlike garnet and spine ferrites, hexa-ferrites possess hexagonal lattice structure[39,40], which results in high magneto crystalline anisotropic energies & magnetic anisotropy fields (Ha) therefore, as a result, high FMR frequency. Those generated from BaM -type (or BaM) hexaferrite, $BaFe_{12}O_{19}$, are one of the most popular microwaves hex ferrites.

Table 2 shows the stoichiometric ratio of all these molecules and also respective saturation magnetization & corresponding anisotropy fields for room temp, demonstrating plainly the capacity to adjust anisotropic and magnetization by provided as part[41].

Table 2: Hexa-ferrites with its microwave properties



Ferrite	$4\pi M_s$ (G)	$H^A{}_\theta$(Oe)	T_C (K)
$BaFe_{12}O_{19}$	4770	17,000	725
$BaFe_{18}O_{27}$	3940	19,000	728
$BaMnZnFe_{16}O_{27}$	4650	10,200	-
$BaNi_2Fe_{16}O_{27}$	4145	12,700	793
$Ba_2Ni_2Fe_{12}O_{22}$	1600	14,000	663
$Ba_3Co_2Fe_{12}O_{22}$	2325	28,000	613
$BaZnFe_{17}O_{27}$	4770	12,500	703

VI. CONCLUSION

This study discusses in detail the ferrite-based coplanar circulator. CPW circulators with a very thin layer may be produced with performance that is well suited for industrial applications in the RF and microwave bands. It is seen that With CPW it is simple to interconnect a shunt to that of an electrical device. Measures are needed to create compact circulators with low insertion loss in order to fulfil the ever-increasing demand in mobile and communication systems, and circulators with coplanar waveguide structures have the potential to outperform conventional circulator designs in this regard.

VII. REFERENCES

[1]. Bosma, H., 1962. On the principle of stripline circulation. Proceedings of the IEE-Part B: Electronic and Communication Engineering, 109(21S), pp.137-146.

[2]. Wen, C.P., 1969. Coplanar waveguide: A surface strip transmission line suitable for nonreciprocal gyromagnetic device applications. IEEE Transactions on Microwave Theory and Techniques, 17(12), pp.1087-1090.

[3]. Oshiro, K., Mikami, H., Fujii, S., Tanaka, T., Fujimori, H., Matsuura, M. and Yamamoto, S., 2005. Fabrication of circulator with coplanar wave guide structure. IEEE transactions on magnetics, 41(10), pp.3550-3552.

[4]. Zahwe, O., Sauviac, B., Samad, B.A., Chatelon, J.P. and Rousseau, J.J., 2009. Numerical study of a circulator using YIG thin film with a coplanar structure. Progress In Electromagnetics Research C, 6, pp.193-207.

[5]. Zahwe, O., Sauviac, B. and Rousseau, J.J., 2009. Fabrication and Measurement of a Coplanar Circulator with 65 µm Yig thin Film. Progress In Electromagnetics Research Letters, 8, pp.35-41.

[6]. Boyajian, T., Vincent, D., Le Berre, M. and Neveu, S., 2011. Study of a coplanar circulator based on a barium Hexaferrite nanocomposite. Progress In Electromagnetics Research, 1329.

[7]. H. Bosma, On stripline Y -circulation at UHF, IEEE Transaction on Microwave Theory and Techniques, Vol. 12, 1964, 61-72.

[8]. Helszajn, J., 1998. Fabrication of very weakly and weakly magnetized microstrip circulators. IEEE transactions on microwave theory and techniques, 46(5), pp.439-449.

[9]. Helszajn, J., James, D.S. and Nisbet, W.T., 1979. Circulators using planar triangular resonators. IEEE Transactions on Microwave Theory and Techniques, 27(2), pp.188-193..

[10]. Zahwe, O., Sauviac, B., Chatelon, J.P., Dehlinger, A.S., Leberre, M. and Perrot, S., 2007, October. Towards a miniaturized circulator with magnetic thin film. In 2007 European Microwave Conference (pp. 274-277). IEEE.

[11]. Wen, C.P., 1969. Coplanar waveguide: A surface strip transmission line suitable for nonreciprocal gyromagnetic device applications. IEEE Transactions on Microwave Theory and Techniques, 17(12), pp.1087-1090.

[12]. Bayard, B., Vincent, D., Simovski, C.R. and Noyel, G., 2003. Electromagnetic study of a ferrite coplanar isolator suitable for integration. IEEE transactions on microwave theory and techniques, 51(7), pp.1809-1814.

[13]. Ogasawara, N. and Kaji, M., 1971. Coplanar-guide and slot-guide junction circulators. Electronics Letters, 9(7), pp.220-221.

[14]. Wang, Y., Peng, B. and Zhang, W.L., 2010, May. Simulation of self-biased coplanar circulator using barium ferrite thin films. In 2010 International Conference on Microwave and Millimeter Wave Technology (pp. 543-546). IEEE.

[15]. Boyajian, T., Vincent, D., Neveu, S., LeBerre, M. and Rousseau, J.J., 2011, June. Coplanar circulator made from composite magnetic material. In 2011 IEEE MTT-S International Microwave Symposium (pp. 1-4). IEEE.

[16]. Zahwe, O., Sauviac, B. and Rousseau, J.J., 2009. Fabrication and Measurement of a Coplanar Circulator with 65 µm Yig thin Film. Progress In Electromagnetics Research Letters, 8, pp.35-41.

[17]. Ogasawara, N. and Kaji, M., 1971. Coplanar-guide and slot-guide junction circulators. Electronics Letters, 9(7), pp.220-221.

[18]. Koshiji, K. and Shu, E., 1986. Circulators using coplanar waveguide. Electronics Letters, 19(22), pp.1000-1002.

[19]. Oshiro, K., Mikami, H., Fujii, S., Tanaka, T., Fujimori, H., Matsuura, M. and Yamamoto, S., 2005. Fabrication of circulator with coplanar wave guide structure. IEEE transactions on magnetics, 41(10), pp.3550-3552.

[20]. Zahwe, O., Sauviac, B. and Rousseau, J.J., 2009. Fabrication and Measurement of a Coplanar Circulator with 65 µm Yig thin Film. Progress In Electromagnetics Research Letters, 8, pp.35-41.

[21]. Zahwe, O., Sauviac, B., Samad, B.A., Chatelon, J.P. and Rousseau, J.J., 2009. Numerical study of a circulator using YIG thin film with a coplanar structure. Progress In Electromagnetics Research C, 6, pp.193-207.

[22]. Helszajn, J., 1998. Fabrication of very weakly and weakly magnetized microstrip circulators. IEEE transactions on microwave theory and techniques, 46(5), pp.439-449.

[23]. Yamamoto, S., Shitamitsu, K., Kurisu, H., Matsuura, M., Oshiro, K., Mikami, H. and Fujii, S., 2004. Circulator with coplanar waveguide structure. physica status solidi (b), 241(7), pp.1769-1772.

[24]. Yamamoto, S., Shitamitsu, K., Kurisu, H., Matsuura, M., Oshiro, K., Mikami, H. and Fujii, S., 2004. Circulator with coplanar waveguide structure. physica status solidi (b), 241(7), pp.1769-1772.

[25]. Oshiro, K., Mikami, H., Fujii, S., Tanaka, T., Fujimori, H., Matsuura, M. and Yamamoto, S., 2005. Fabrication of circulator with coplanar wave guide structure. IEEE transactions on magnetics, 41(10), pp.3550-3552.

[26]. Zahwe, O., Sauviac, B. and Rousseau, J.J., 2009. Fabrication and Measurement of a Coplanar Circulator with 65 µm Yig thin Film. Progress In Electromagnetics Research Letters, 8, pp.35-41.

[27]. Zahwe, O., Abdel Samad, B., Sauviac, B., Chatelon, J.P., Blanc Mignon, M.F., Rousseau, J.J., Le Berre, M. and Givord, D., 2010. YIG thin film used to miniaturize a coplanar junction circulator. Journal of Electromagnetic Waves and Applications, 24(1), pp.25-32..

[28]. E.-B. Rahmouna and F. Salah-Belkhodja,2014, “Miniature triangular circulator with coplanar waveguide structure,” International Journal of Electronics and Electrical Engineering.

[29]. Al-Yasiri, J.H. and Babichev, R.K., 2017, June. Simulation of a coplanar circular circulator with a ferrite film. In 2017 Radiation and Scattering of Electromagnetic Waves (RSEMW) (pp. 368-371). IEEE.

[30]. Al-Yasiri, J.H. and Babichev, R.K., 2017, June. Simulation of a coplanar circular circulator with a ferrite film. In 2017 Radiation and Scattering of Electromagnetic Waves (RSEMW) (pp. 368-371). IEEE.

[31]. Wang, Y., Peng, B., Zhang, W.L. and Tan, K., 2010. CPW Circulators with Barium Ferrite Thin Films. Journal of Electronic Science and Technology, 8(4), pp.351-355.

[32]. Boyajian, T., Vincent, D., Neveu, S., LeBerre, M. and Rousseau, J.J., 2011, June. Coplanar circulator made from composite magnetic material. In 2011 IEEE MTT-S International Microwave Symposium (pp. 1-4). IEEE.

[33]. Kiani, E., 2017. Designing a self-biased CPW circulator based on strontium hexaferrite thick film. Journal of Electronic Materials, 46(8), pp.5089-5093.

[34]. Zhou, W., Um, J., Stadler, B. and Franklin, R., 2018, January. Design of self-biased coplanar circulator with ferromagnetic nanowires. In 2018 IEEE Radio and Wireless Symposium (RWS) (pp. 240-242). IEEE.

[35]. Joseph, S., Lebourgeois, R., Huang, Y., Roussel, L. and Schuchinsky, A., 2019, September. Low-Loss Hexaferrite Self-Biased Microstrip and CPW Circulators. In 2019 Thirteenth International Congress on Artificial Materials for Novel Wave Phenomena (Metamaterials) (pp. X-372). IEEE.

[36]. Joseph, S.D., Huang, Y., Schuchinsky, A., Lebourgeois, R. and Roussel, L., 2020, July. Self-biased CPW circulator with low insertion loss. In 2020 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP) (pp. 1-3). IEEE.

[37]. Kitajima, K., Nakano, H., Koshiji, K. and Shu, E., 1998. Improvement in the Operating Bandwidth of Coplanar Waveguide Circulator. Journal of the Magnetics Society of Japan, 22(S_1_ISFA_97), pp.S1_360-362..

[38]. Neidert, R.E. and Phillips, P.M., 1993. Losses in Y-junction stripline and microstrip ferrite circulators. IEEE transactions on microwave theory and techniques, 41(6), pp.1081-1086.

[39]. Benevent, E., Larrey, V., Vincent, D. and Dehlinger, A.S., 2006, September. Losses' origins in a 40 GHz stripline circulator with 10 µm thick barium hexagonal ferrite films. In 2006 European Microwave Conference (pp. 208-211). IEEE.

[40]. Zahwe, O., Nasser, W. and Harb, H., 2018, November. Analytical, Numerical and Experimental Study of an Original Design for a Coplanar Circulator/Isolator Based on Thick and Thin Ferrite Film. In 2018 International Arab Conference on Information Technology (ACIT) (pp. 1-8). IEEE.

[41]. Dehlinger, A.S., Le Berre, M., Chatelon, J.P., Bènevent, E., Vincent, D., Givord, D., Larrey, V. and Rousseau, J.J., 2006. Towards the integration of barium ferrite sputtered films for coplanar isolators and circulators in the millimeter wave range. MRS Online Proceedings Library (OPL), 969.