Theory of concurrent multimode reciprocal and nonreciprocal SIW ferrite Device

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First week report

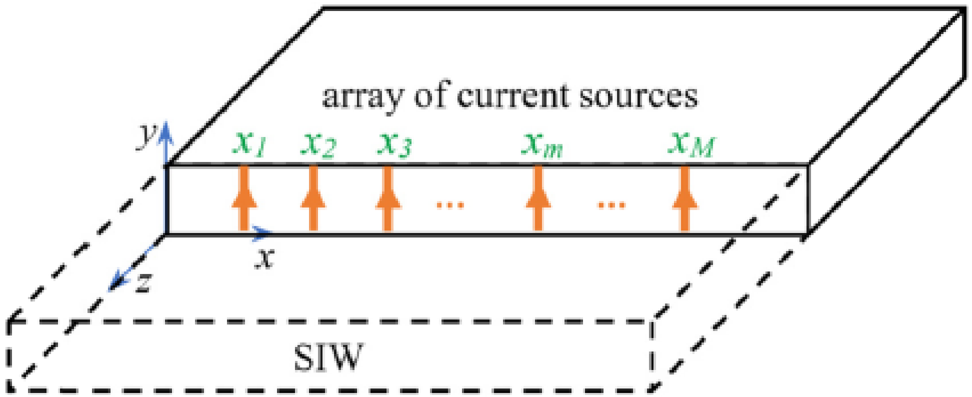


Figure 1: Multimode excitation of SIW by an array of M current sources within SIW

1 Introduction

In this paper formulate reciprocal and non reciprocal ferrite component with arbitarily concurrent multimode featuresbased on SIW technology. to design it a nonreciprocal unit cell (NRUC) defined and characterized then deploing NRUC next to each other then kernel configuration a incident wave break into sevral segment independently propagating along NRUC. A dual mode circulator and triple mode gyrator fabricated and measurement with simulation.This technology deploying and integrarting ferrite material to realize various loaded SIW component isolator and circulator.

1.1 Excitation With Multimode with SIW

In tjis secton we wil devlop a generalized theoretical foundation to excite mode within SIW. TEno mode exixt within the SIW, and for Z directed wave field expression can be written as

$$E_y^n = A_n e_n e^-(j\beta_n z) = \hat{y} A_n sin(\frac{n}{a} \tag{1}$$

$$H_x = A_n h_n e^-(j\beta_n z) = -\hat{x}\frac{A_n}{Z_n} sin(\frac{n}{a}) \tag{2}$$

where n is the mode number, A$_n abdB_n iatheamplitudeeachmodeaisthewveguidewidth.$ Assuming f$_{end} isthemaximumoperationalfrequencybandNpropagatingwavewithinTheSIW.$

$$a < \frac{C(N+1)}{2f_{end}\sqrt{\epsilon_r}} \tag{3}$$

consider a current element amplitude I$_m atpositionx_m awayfromoriginsuchacurrentmathematicallyexpressed$

$$J_m = \hat{y} I_m \delta(X - X_m)\delta(z) \tag{4}$$

Amplitude of each excited wave is the superposition of of all sources

$$A_n = \frac{Z_n}{A_n} \sum_{n=1}^{\infty} sin(\frac{n\pi x}{a}) \tag{5}$$

since source may be constructive or destructive so leading or cancellation of the source within the SIW. we want to find out complete set of solution there will be N sources for propagating modeso $X_m and I_m of each source variable$

To solve it first SIW divided into n segment and element of current source placed at the centre

$$X_m = \frac{(2m-1)a}{2N} \tag{6}$$

$$I_m^n = I_o^n sin \frac{n\pi(2m-1)a}{2N} \tag{7}$$

substituting in equation (5) we get

$$I_O^n = \frac{A_n a}{Z_n a} \tag{8}$$

the amplitude distribution of current array is calculated in table 1 where up to four mode are shown. it can be noted that dot product of each two rows is zero current arrays are orthogonal and also how the current distribution for even and odd modes is symmetrically and antisymmetrically.

TABLE I

AMPLITUDE DISTRIBUTION OF CURRENT SOURCES FOR ARBITRARY SINGLE-MODE EXCITATION IN A MULTIMODE SIW

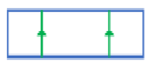
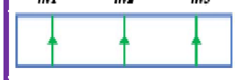
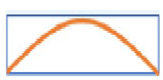
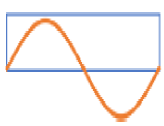
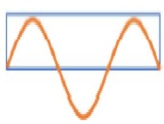
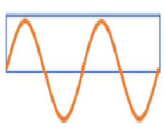
Mode to be excited (TE_{n0})	Amplitude of current-source elements: $I_m^{(n)*} A_n a/Z_n$								
	Dual-mode SIW		Triple-mode SIW			Quad-mode SIW			
	m1	***m2***	***m1***	***m2***	***m3***	***m1***	***m2***	***m3***	***m4***
									
	$+\frac{\sqrt{2}}{2}$	$+\frac{\sqrt{2}}{2}$	$+\frac{1}{3}$	$+\frac{2}{3}$	$+\frac{1}{3}$	$+\frac{\sqrt{2-\sqrt{2}}}{4}$	$+\frac{\sqrt{2+\sqrt{2}}}{4}$	$+\frac{\sqrt{2+\sqrt{2}}}{4}$	$+\frac{\sqrt{2-\sqrt{2}}}{4}$
	$+\frac{1}{2}$	$-\frac{1}{2}$	$+\frac{\sqrt{3}}{3}$	0	$-\frac{\sqrt{3}}{3}$	$+\frac{\sqrt{2}}{4}$	$+\frac{\sqrt{2}}{4}$	$-\frac{\sqrt{2}}{4}$	$-\frac{\sqrt{2}}{4}$
	x		$+\frac{1}{3}$	$-\frac{1}{3}$	$+\frac{1}{3}$	$+\frac{\sqrt{2+\sqrt{2}}}{4}$	$-\frac{\sqrt{2-\sqrt{2}}}{4}$	$-\frac{\sqrt{2-\sqrt{2}}}{4}$	$+\frac{\sqrt{2+\sqrt{2}}}{4}$
	x		x			$+\frac{1}{4}$	$-\frac{1}{4}$	$+\frac{1}{4}$	$-\frac{1}{4}$

Figure 2: Caption

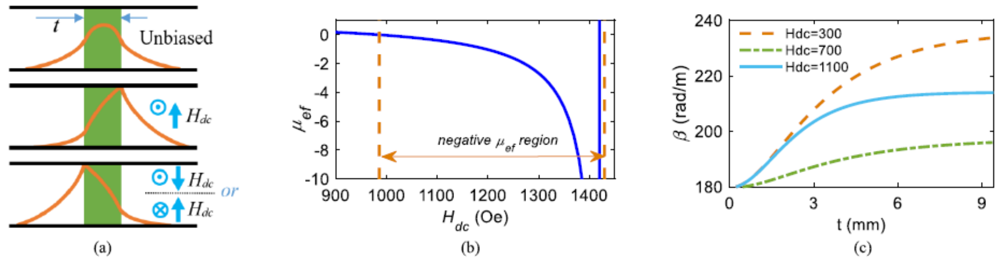


Figure 3: (a) Behavioral illustration of nonreciprocal propagation in a transversely biased ferrite slab for a TE mode wave. Crossed and dotted circles indicate forward- and reverse-directed waves, respectively. (b) Negative region of effective relative permeability plot versus internal magnetic bias. (c) Propagation constant of unit cell versus ferrite width for different biases, with $\epsilon_f = 14 and \epsilon_r = 2.94$.

1.2 Nonreciprocal Unitcell

consider a ferrite slab embeded within substrated integrated waveguide where the surrounding low dielectric constant. sice the ferrite permitivity is high so ferrite slab becomes dielectric waveguide TEno wave confined within the ferrite slab field outside the ferrite slab is evanescent and deccaying outward impedance is imaginary..now if the transverse magnetic bias is applied to ferrite it will exhibits nonreciprocal by displacing electromagnetic field in forwad and reverse direction of propagation(when the direction of magnetic bias is reversed) as shown in figure 2(a) Now by applying boundary condition the equation

$$K_f = \sqrt{(\omega/c)^2 \mu_e \epsilon - \beta^2} \tag{9}$$

$$K_d = j\sqrt{\beta^2 - (\omega/c)^2 \epsilon_d} \tag{10}$$

where $\epsilon_d and \epsilon_f are the dielectric constant of substrate and ferrite$

Negative permebelity will localize more electromagnetic wave at one interface of the ferrite. then effective permeability can be expressed in terms of poles and zero.

$$\mu_e = \frac{\mu_o(H_{dc} - H_{z1})(H_{dc} - H_{z2})}{(H_{dc} - H_{p1})(H_{dc} - H_{p2})} \tag{11}$$

$$H_{z2} = -M_s + f/\gamma \tag{12}$$

$$H_{p2} = 0.5(-M_s + \sqrt{M_s^2 + 4(f/\gamma)^2}) \tag{13}$$

In figure 2(b) the relative permeability in the negative region is strongly nonlinear therefore the centre frequency of the lower side in the negative region broader bandwidth performance of the unit cell the most importnt point is that if the ferrite is too narrow it will loosely interaction with magnetic field as such waveguide will propagate inside the waveguide is slightest perturbation due to ferrite

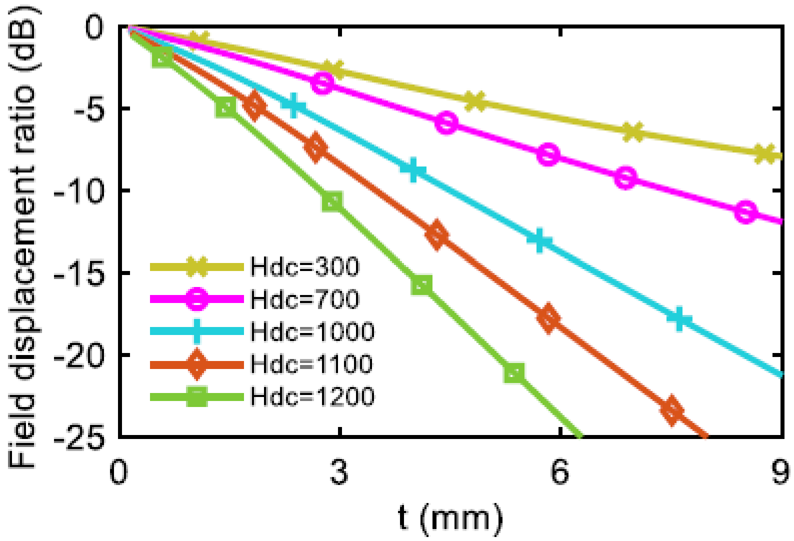


Figure 4: Field displacement ratio (in dB) versus ferrite thickness in a unit cell, for various magnetic bias points.

slab ,so incresing the thickness of ferrite salb will be leading more confinement wave within the ferritesince field are exponential within the ferrite slab it would be diminished from one interface to other so more increasing thickness is unnecessary the propagation constant should be the function of ferrite thicknes In figure 2(c) positive and negative value of permeability $\beta reachessaturationvalue$

1.3 Determinig The Ferrite Width

since displacement within the ferrite due to forward and reverse directed wave there is maximum and minimum field so the field displacement ratio is the minimum field to the maximum field that can be achieved within the unit cell the field displacement ratio is calculated in db as a function width(t)

$$fielddisplacementratio = |\frac{min(E(x=-t), E(x=0))}{max(E(x=-t), E(x=0))}| \tag{14}$$

for the positive value of effective permeability(Hdc=300 and 700 oe) the field displacement ratio is smaller due to sinusoidal field and for incresing in negative value of permeability field displacement gets more pronounced as shown figure 4

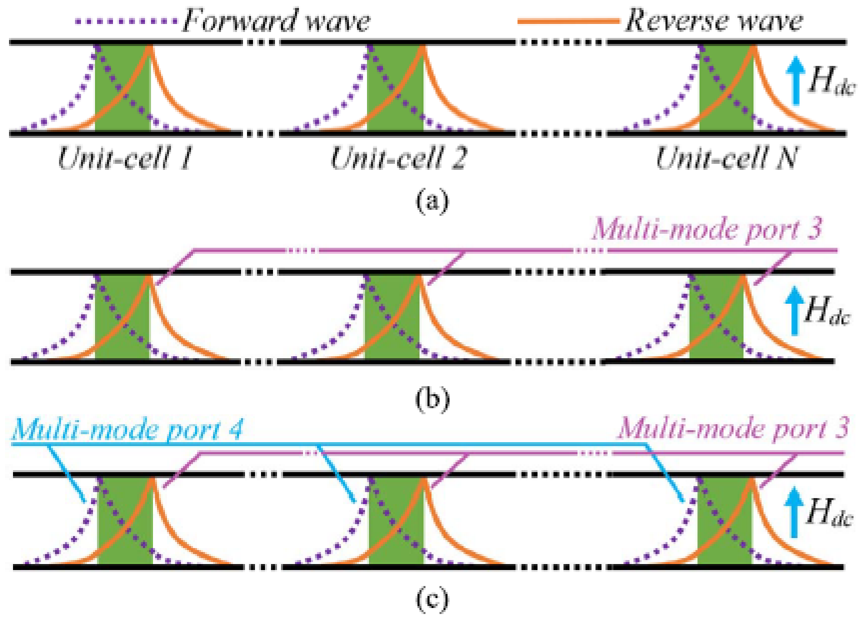


Figure 5: Parallel NRUCs as a basis to synthesize multimode nonreciprocal (a) two-, (b) three-, and (c) four-port devices. In (b) and (c), additional ports are introduced from the top (or bottom) to excite corresponding modes.

1.4 Nonreciprocal wave propagation through N parallel NRUC

Consider N parallel NRUC that ate placed to each other as shown in figure 5(a) so that do not interfare each other and do not disturbed any other boundary condition .A distinct and unique channel created within the ferrite slab so that it separated forward and reverse directed wave. In the forward field are concentrated at left interface and reverse directed wave concentrated on right interface

the most important point is that unique non reciprocal field distribution allowing perturbing the configration creative in such away that it beenefit to non reciprocal behaviour for example it is possible to introduce amplitude or phase in one side perturbation of ferrite slab to multimode phase shifter or isolator further more 3 port circulator adding multimode port interfare one side of ferrite slab to non reciprocal circulate in the desired directon

1.5 mathematicall Model for mu;tiferrite Loaded SIW

consider configuration 6(a) and 6(b) SIW ferrite loaded with NRUC even and odd number of ferrite respectively as shown in figure

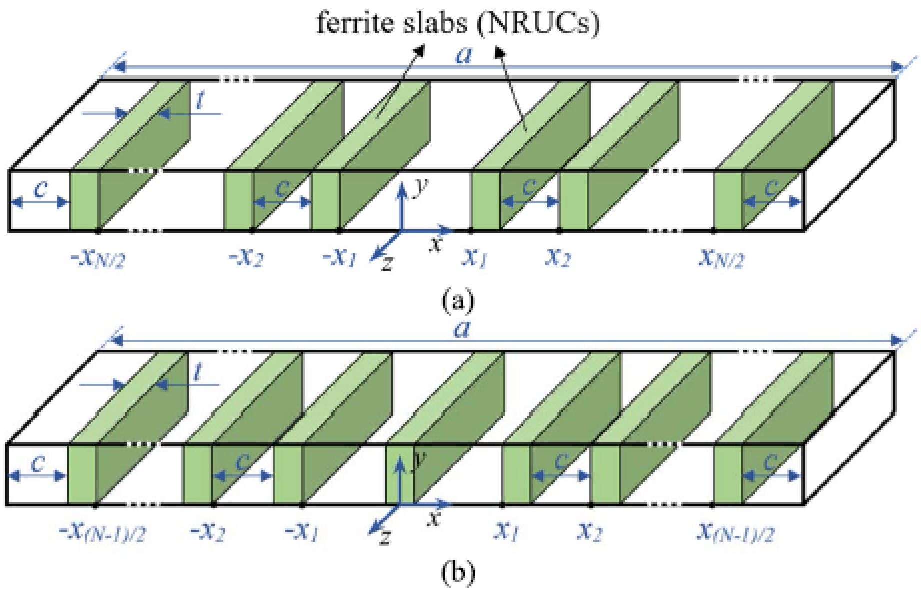


Figure 6: General topology of multiferrite slab loaded SIW for (a) even and (c) odd numbers of ferrite slabs. All ferrite slabs are biased in the (positive or negative) y-direction.

For even number of ferrite slab supporting N mode within the SIW . To reduce the number of unknown parameters position of each ferrite slab can be written as a function of two variable a and C where a is the SIW width and C is the distance of each NRUC

$$X_{p-}1 = X_p - C - t, 1, p, N/2 \tag{15}$$

where$X_N/2 = a/2 - C - tThecorrespondingmagneticfieldsintheferriteregioncanbefollowingequation$

$$H_x = \frac{1}{\omega\mu\mu_e}(-\mu_y - K\frac{dE_y}{dx}) \tag{16}$$

$$H_z = \frac{j}{\omega\mu\mu_e}(K_y + \mu\frac{dE_Y}{dx}) \tag{17}$$

above these two equation derived from maxwell equation references DM pozar in section 9.3

1.6 Dual mode SIW twin ferrite Loaded SIW kernel configration

The S parameters of twin ferrite Loaded SIW with ferrites biased in the same direction are reciprocal consider SIW width a=47.5mm,$\epsilon_r = 2.94$

applying Boundary condition for N=2 the structure solved for different value of C field pattern observed two dominant mode first field pattern in both mode are not symmetrically due to stucture itself

second both mode have maxima at each ferrite slab interfare which are in phase or out phase 3rd for small and large value C first and second mode propagate dominantly along different ferrite slab Two different mode exist simultaneously so excitation is a linear combination of these two mode TE10 and TE20 are symmetrically in phase and out phase will be resulting excited mode semi common and semi differential for small value of C first mode dominantly propagates along the ferrite left interface at the right side loosely disturbed by the SIW boundary condition so it is quickly adopt behaviour of NRUC on the other hand second mode dominantly propagate along the ferrite slab it is significantly disturbed so it is slowly adopt NRUC behaviour.

1.7 concurrent dual mode circulator Design

first position of ferrite determined by maximum propagation constant for all mode according figure 7(b)nonreciprocal dual channel channelized waveguide (NDW) creating two distinct channels forward and reverse propagating wave. Additon side create a non reciprocal junction at each side of SIWwhere theory of junction circulator may be adopted design the junction. the key point is to create standing wave mechanism nonreciprocal circulation among three ports of wave nonrecciprocal reasonator can be create magnetic field null situated in front of one of the port depending upon excitation of the port if port one is excited the magnetic null resulted from the reasonance must be placed in front of port2 to transmit the whole wave into the port 3

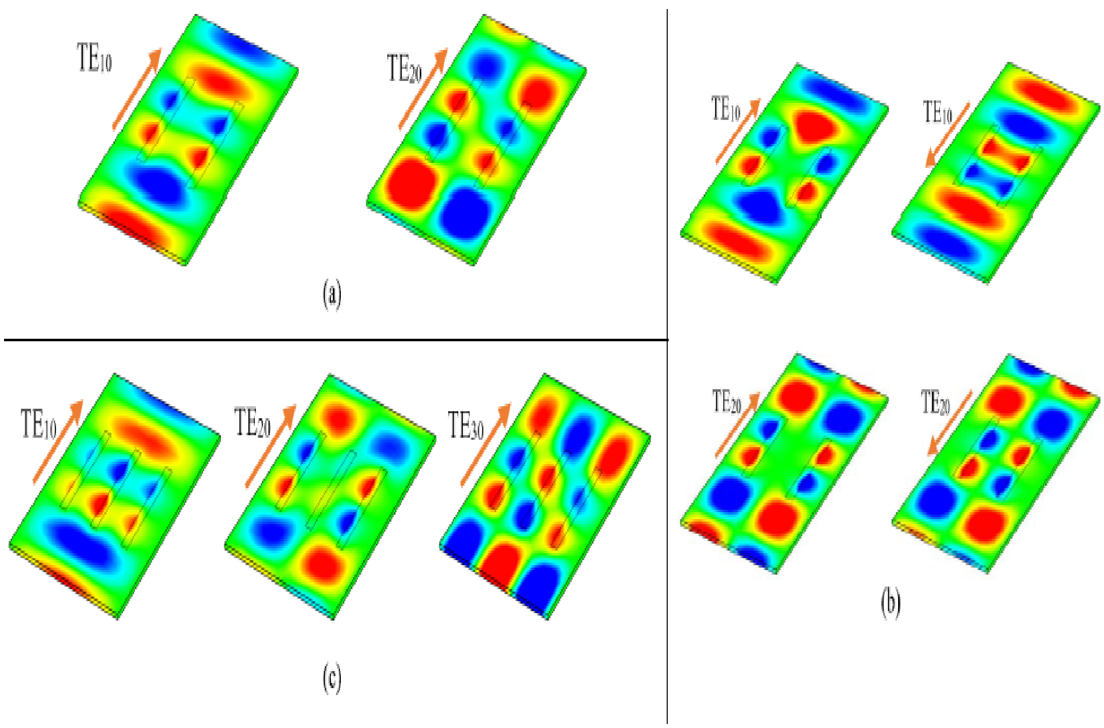


Figure 7: Simulated E-field pattern in CST for a multiferrite loaded SIW. (a) Dual-mode twin-ferrite loaded SIW with the same direction biasing. (b) Dual-mode twin-ferrite loaded SIW with antisymmetrical biasing. (c) Triple-mode triple-ferrite loaded SIW with the same direction biasing.

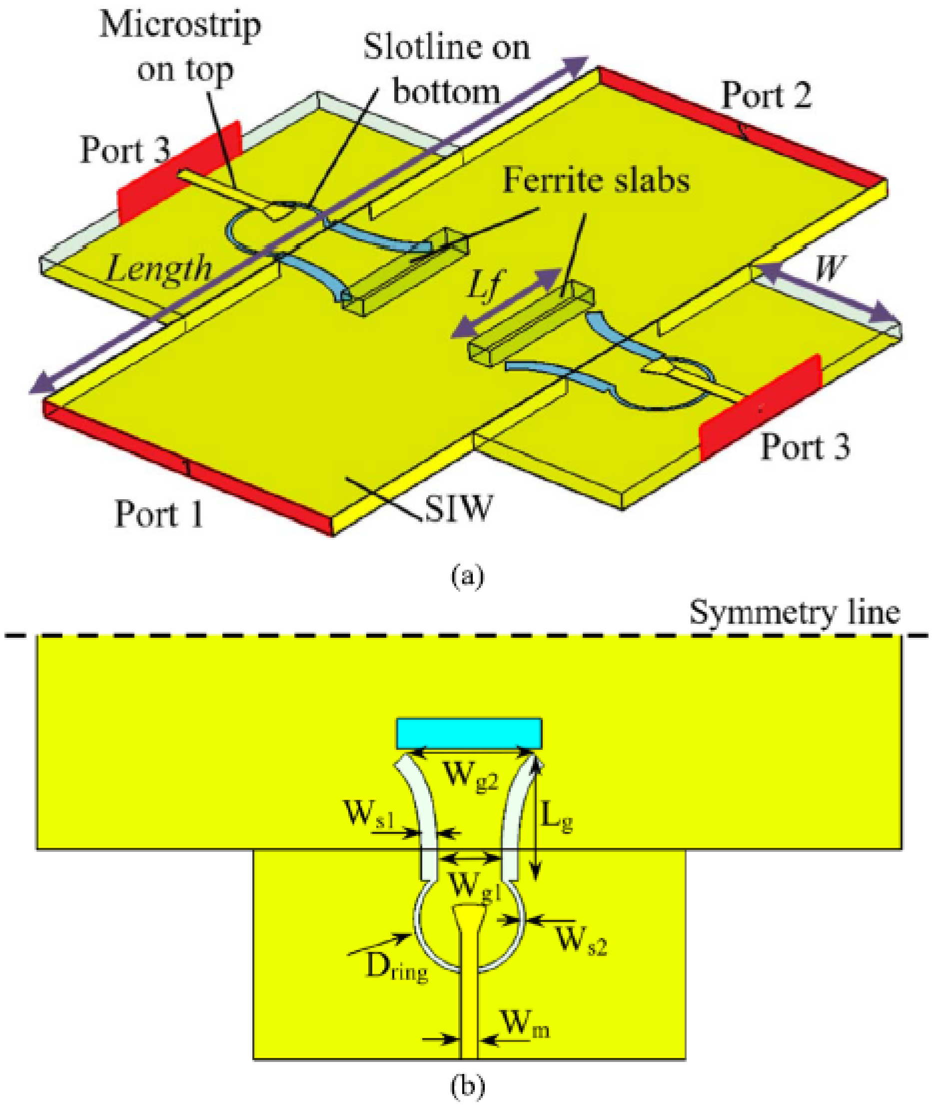


Figure 8: schematic proposed of dual mode circuator

1.8 Observation

- increasing ferrite thickness is unnecessary
- propagation constant should be the function of ferrite thickness

1.9 Plan for next Week

- Understanding theory of waveguide and mode of propagation
- installing CST software and spending time on it

1.10 Rfrence

- D. M. Pozar, Microwave Engineering. Fourth Edition, Wiley, 2012.
- B. Lax and K. J. Button, Microwave Ferrites and Ferrimagnetics. New York: McGraw-Hill, 1962.