A Review on Microstrip Filter for the Application in Communication System

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Abstract - *RF and Microwave filters can be implemented with transmission lines. Filters are significant RF and Microwave components. Transmission line filters can be easy to implement, depending on the type of transmission line used. The aim of this project is to develop a set of transmission line filters for students to do practical work with.*

Key Words: Microstrip, Filter, Cut off frequency, VSWR, Group Delay, Resonance etc.

1. INTRODUCTION

Filters are one of the most widely used components for radio frequency as well as for microwave communications. The function of a filter is to allow a certain range of frequencies to pass while to attenuate the others. Thus clearly there is a pass-band and a stop-band. Ideally in the pass-band there should be no attenuation while in the stop-band there should be maximum attenuation.

Filters are essentially frequency selective elements. The filtering behavior results frequency dependent reactance's provided by inductors and capacitors. At lower frequencies lumped element inductors and capacitors can be used to design filters while at microwave frequencies lumped element inductors and capacitors cannot be used and thus transmission line sections are used which behave as inductors and capacitors. Minimizing the losses in the pass-band of a filter is extremely important since it not only reduces the overall losses for a transmitter but also improves the noise figure when used with a receiver.

Recently, there has been an increasing interest in studying microstrip lines within various periodic structures that prohibit wave propagation in certain frequency bands, including photonic band gap (PBG), electromagnetic band gap (EBG) and defected ground structures (DGS). Each periodic structure has its own properties and advantages. For example, DGS can be simply realized by etching only a few areas on the ground plane under the microstrip line. The frequency behavior of the EBG is better than the DGS, but the manufacturing process of EBG is very complex. Some applications of DGS are planar resonators, high characteristic impedance transmission lines, filters, couplers, dividers/combiners, oscillators, antennas, power amplifiers, branch line couplers, phase shifters and dual band transmitters.

Tunable low pass filters are useful in application that requires suppression of out-of-band interference signals. The paper proposes the integration of short wire in etched ground plane to create tunable low pass filter. The advantages are convincing: the ease of integration and low loss performance.

A dielectric resonator (also dielectricresonatoroscillator, DRO) is an electronic component that exhibits resonance for a narrow range of frequencies, generally in the microwave band. The resonance is similar to that of a circular hollow metallic waveguide, except that the boundary is defined by large change in permittivity rather than by a conductor. Dielectric resonators generally consist of a "puck" of ceramic that has a large dielectric constant and a low dissipation factor. The resonance frequency is determined by the overall physical dimensions of the puck and the dielectric constant of the material. With such a high dielectric constant, it will confine more electromagnetic energy. Various filters are designed using dielectric resonators which has better power handling capacity. This paper intended to use this DR's to improve power handling capacity.

1.1 FILTER FUNCTION

Four general filters function are desirable:-

1. Band-pass filter: select only a desired band of frequencies.

2. Band-stop filter: eliminate an undesired band of frequencies.

3. Low-pass filter: allow only frequencies below a cut-off frequency to pass.

4. High-pass filter: allow only frequencies above a cut-off frequency to pass.

2. MICROWAVE FILTER

Microwave filters are one of the most important components in receivers. A microwave filter is a two port network used to control the frequency response at a certain point in a microwave system by providing transmission at frequencies within the pass band of the filter and attenuation in the stop band of the filter. In microwave frequencies lumped element inductors and capacitors cannot be used and thus transmission line sections are used which behave as inductors and capacitors.

Minimizing the losses in the pass band of a filter is extremely important since it is not only reduces the overall losses for a transistor but also improves the noise figure when used with a receiver.

The main functions of the filters are:

(1) To reject undesirable signals outside the filter pass band and

(2) To separate or combine signals according to their frequency.

A good example for the latter application is the canalized receiver in which banks of filters are used to separate input signals. Sometimes filters are also used for impedance matching. Filters are almost always used before and after a mixer to reduce spurious signals due to image frequencies, local oscillator feed through, and out-of- frequency band noise and signals

2.1 Characteristic of Microwave Filters

There are many kinds of filters used in microwave receivers, so it is impossible to cover all of them. If a filter is needed on the output of a jammer, it is desirable to place it approximately half way between the jammer and antenna vs. adjacent to either. The transmission line attenuation improves the VSWR of the filter at the transmitter. This may allow use of a less expensive filter or use of reflective filter vs. an absorptive filter.

1. IRIS Filter

Based on active irises. In iris waveguide filters the coupling elements are realised by inductive "curtins" extending from each side of the waveguide. The irises are often soldered in slits which are cut or milled in the waveguide. Compared to metal insert filters and finline filters the iris filter is smaller in size since the lengths of the coupling elements are only equal to the thickness of the irises.

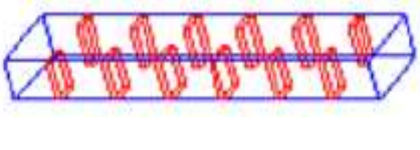


Fig -1: Iris Band pass Filter

2. PURE METAL Filter

In E-plane pure metal insert filters the insert bridges the broad walls of a rectangular wave guide. These filters are low-loss components suitable for high power applications. The ladder shaped inserts can be accurately manufactured with low cost photolithographic techniques or by precision milling.

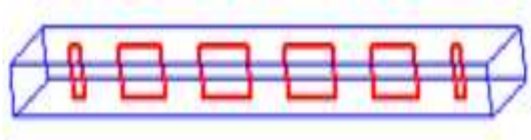


Fig -2: Pure metal filter

3. FINELINE Filter

In fineline filters, metal "fins" are printed on each side of a dielectric substrate which bridges the broad walls of a rectangular waveguide. The ladder shaped inserts can be accurately manufactured with low cost photolithographic techniques. If the dielectric constant of the substrate is set to 1 (one) the fineline filter becomes a "double metal insert" waveguide filter. A filter type with improved out-of-band characteristics.

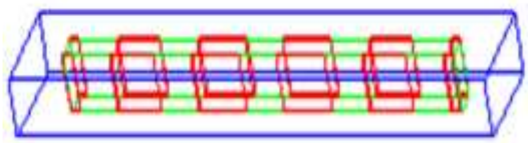


Fig -3: Fineline Filter

2.2 Specifications of microwave filters

1. Insertion Loss

Insertion loss is equal to the difference in dB power measured at the filter input and at the filter output. The power measured at the filter input is equal to the measured power when the filter is replaced by a properly matched power meter or network analyzer. The input impedance of the measuring instrument should be equal to the characteristic impedance of the filter or system. Unless otherwise specified, Mini-Circuits' filters are designed for 50 ohm systems. Similarly, the power measured at the filter output is equal to the measured power when the filter is terminated by the same measuring instrument as discussed. The insertion loss will be equal to the sum of three loss factors. One is the loss due to the impedance mismatch at the filter input, the second is due to the mismatch at the filter output, and the third is due to the dissipative loss associated with each reactive element within the filter. Insertion loss is a figure of merit for an electronic filter and this data is generally specified with a filter. Insertion loss is defined as a ratio of the signal level in a test configuration without the filter installed ($|V_1|$) to the signal level with the filter installed ($|V_2|$).

2. Return Loss

Return loss or reflection loss is the loss of signal power resulting from the reflection caused at a discontinuity in a transmission line or optical fiber. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line.

3. Pass Band

Pass band is equal to the frequency range for which the filter insertion loss is less than a specified value. For example, most of the Mini-Circuits' low-pass filter (LPF) models are specified to have a maximum insertion loss value of 1 dB within the pass band.

4. Stop Band

Stop band is equal to the frequency range at which the filter insertion loss is greater than a specified value. For example, most of the Mini- Circuits' low-pass filter (LPF) models are characterized by the frequency range where the insertion loss is greater than 20 dB and 40 dB in the stop band. These two values are arbitrary; they could easily have been chosen for some other values. The purpose of selecting 20 dB and 44 dB is twofold. One is to provide the design engineer with a simple means to calculate the frequency selectivity of the filter. The second is to allow a quick calculation of the suitability of the filter in a particular situation. Since 20 dB or 40 dB represent sufficient loss requirements in many systems, these values were chosen.

5. Cut of Frequency

Cut-off frequency, fco is the frequency at which the filter insertion loss is equal to 3 dB. It is a very convenient point for expressing the pass band and stop band boundary points. In addition, it allows a convenient means to normalize the frequency response of a filter. For example, if the frequency of a low-pass filter (LPF) response were divided by fco then the resulting response would be "normalized" to . The normalized response allows the design engineer to quickly specify the filter needed to meet his system requirements.

6. VSWR

Voltage and current on the transmission line are a superposition of an incident and reflected wave. If the system is static, i.e. if and are not changing in time, the superposition of waves will also be static. This static superposition of waves on the line is called a standing wave. Because of the complicated shape of this standing wave, the voltage will vary with position along the line, from some minimum value to some maximum value. The ratio of two is one way to quantify the mismatch of the line.

7. Group Delay

Group Delay is the time delay within the pass band of a filter and is the derivative of the phase response with respect to frequency, in radians. Typically the group delay deviation is specified as a peak to peak maximum allowable in the pass band. It is of interest since it can limit the minimum symbol width of a digital signal for a given BER (Bit Error Rate).

3. Basic Structure and Transmission Characteristics

DGS is an etched periodic or non-periodic cascaded configuration defect in ground of a planar transmission line (e.g., microstrip, coplanar and conductor backed coplanar wave guide) which disturbs the shield current distribution in the ground plane cause of the defect in the ground. This disturbance will change characteristics of a transmission line such as line capacitance and inductance. In a word, any defect etched in the ground plane of the microstrip can give rise to increasing effective capacitance and inductance.

The very basic shape of DGS is dumbbell shape. The dumbbell DGS are composed of two $a \times b$ rectangular defected areas, $g \times w$ gaps and a narrow connecting slot wide etched areas in backside metallic ground plane as shown in Fig. 8. This is the first DGS [11]. DGSs have the characteristics of stop band, slow-wave effect and high impedance.

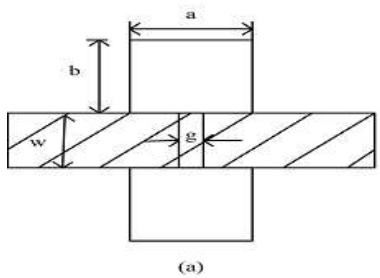


Fig -4: DSG Geometry

DGS has more advantages than PBG as follows:

(1) The circuit area becomes relatively small without periodic structures because only a few DGS elements have the similar typical properties as the periodic structure like the stop-band characteristic.

(2) The simulated *S*-parameters for dumbbell DGS unit can be matched to the one-pole Butterworth-type low-pass response. For the DGS unit, DGS pattern is simply fabricated and its equivalent circuit is easily extracted.

(3) DGS needs less circuit sizes for only a unit or a few periodic structures showing slow-wave effect. Compared with PBG (Photonic band gap), DGS is more easily to be designed and implemented and has higher precision with regular defect structures. Therefore, it is very extensive to extend its practical application to microwave circuits.

1. DSC Unit

There have been two research aspects for adequately utilizing the unique performance of DGS: DGS unit and periodic DGS. A variety of slot geometries etched in the microstrip line ground plane have been reported in the literature [12–16]. In Fig. 8.a, it is shown that a variety of attached area shapes including spiral head, arrowhead-slot and "H" shape slots and so on. There also have been more complex DGSs so as to improve the circuit performance such as: a square open-loop with a slot in middle section, open-loop dumbbell and interdigital DGS. The new DGS unit could control the two transmission zeros near the pass band edges and easily control the frequency of the slot by changing the length of the metal fingers.

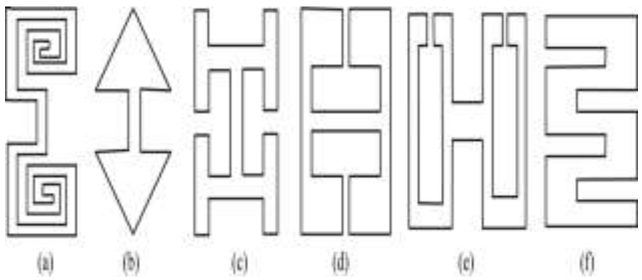


Fig -5: Differrent cell geometries

The use of a bent microstrip line does not significantly change the frequency behavior that remains as for the straight DGS microstrip line. The bending technique leads to a 2D configuration, in which the microstrip line presents multiple bends, following a similar structure as that of a meander line. This configuration has a broad stopband and allows a large number of periods in a reasonable circuit area. New proposed DGS unit has some advantages than dumbbell DGS:

(1) A higher slow wave factor and more compact circuit. The circuit area of filter using "H" shape slots is much smaller about 26.3% than using dumbbell DGS.

(2) A narrow width stopband and deeper rejection.

(3) A slightly larger external Q. To compare the transfer characteristics of the U-slot DGS with that of the conventional DGS, the spiral-shaped DGS and U-slot DGS are designed to provide the same resonance frequency. Q factor of the spiral DGS is 7.478 (3 dB bandwidth of 0.39 GHz), while the U-slot DGS provides a high-Q factor of 36.05 (3 dB bandwidth is 0.081 GHz) .

In a word, more and more new DGSs are proposed which bring a great convenience to the design of microwave circuit to realize various passive and active device compact structures and to suppress the harmonics.

2. Periodic DSC

Periodic structures such as PBG and DGS for planar transmission lines have drawn a wide interest for their extensive applicability in antennas and microwave circuits. Transmission lines with a periodic structure have a finite pass and rejection band as low-pass filters.

The increased slow-wave effect and the additional equivalent components are important properties of periodic structure that can be realized and the circuit sizes can be reduced using these properties. Periodic means repetition of the physics structure. By cascading DGS resonant cells in the ground plane the depth and bandwidth of the stop band for the proposed DGS circuit are inclined to depend on the number of period. Period DGSs care about parameters including the shape of unit DGS, distance between two DGS units and the distribution of the different DGSs. As shown in Fig. 8.3, by now there are two types of periodic DGS: one is (a) horizontally periodic DGS (HPDGS), the other is (b) vertically periodic DGS (VPDGS).

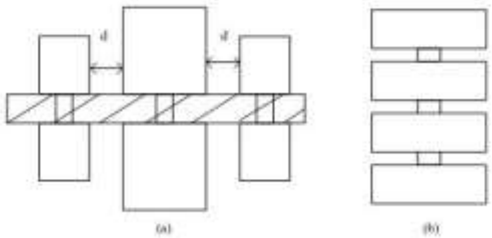


Fig -6: Periodic DGS: (a) HPDGS, (b) VPDGS.

The prominent feature of the proposed structure is possible to organize the periodicity along the vertical direction as well as the horizontal direction. It is named as VPDGS. On the other hand, the conventional DGS for planar transmission lines have the only HPDGS with serially cascading structure along the transmission direction. HPDGS initially is produced for enlarging the stopband of frequency response curve. Few uniform square-patterned defects form a periodic DGS for planar circuit, which provides excellent stop band and slow wave characteristics. They have been reported and used in oscillators and amplifiers [23–26]. Nonuniform circular-patterned DGSs using the function distribution compared with the previous periodic DGSs are proposed. They have a compensated microstrip line and the dimensions of the square defects are varied proportionally to relative amplitudes distribution of the exponential function *distribution* (*n* denotes the positive integer), or Chebyshev, distribution, distribution and so on. VPDGS produces much higher slow wave factor than HPDGS. The increased slow-wave factor means the longer electrical length for the same physical length. As an application example, a size-reduced amplifier was designed by inserting VPDGS into the matching network. Two series microstrip lines in input and output matching networks of the amplifier were reduced to 38.5% and 44.4% of the original lengths, respectively.

3. DSC Resonator’s

Bandstop circuits are one of the most important parts of many passive and active microwave and millimeter-wave devices employed to suppress the harmonics. In signal processing, a band-stop filter or band-rejection filter is a filter that passes most frequencies unaltered, but attenuates those in a specific range to very low levels. It is the opposite of a bandpass filter. Bandstop filters are also known as band-elimination, band-reject, or notch filters, this kind of filter passes all frequencies above and below a particular range set by the component values. Not surprisingly, it can be made out of a low-pass and a highpass filter, just like the bandpass design, except that this time we connect the two filter sections in parallel with each other instead of in series.

DGS, which is realized by etching off a defected pattern or periodic structures from the backside metallic ground plane, has been known as providing rejection of certain frequency band, namely, band-gap effects. The stop-band is useful to suppress the unwanted surface waves, spurious and leakage transmission. Therefore, a direct application of such frequency selective characteristics in microwave filters is becoming a hotspot research recently.

DGS combined with microstrip line causes a resonant character of the structure transmission with a resonant frequency controlled by changing the shape and size of the slot. The shape of the slot is modified from a simple hole to a more complicated shape. Many novel types of microstrip filters have been proposed and designed. Periodic or non-periodic DGS are realized by etching a slot in the backside metallic ground plane. The etched slot disturbs effectively the current distribution in the ground plane of microstrip line and the results in resonant characteristics.

4. Equivalent circuit of DSC

Design and analysis are two challenges for DGS. The commercially available EM solver is the main resource to design and analyze DGS. To apply the proposed DGS section to a practical circuit design example, it is necessary to extract the equivalent circuit parameters.

In order to derive the equivalent circuit parameters of DGS unit at the reference plane, the S-parameters vs. frequency should be calculated by full-wave electromagnetic (EM)-simulation to explain the cut-off and attenuation pole characteristics of the DGS section. The circuit parameters for the derived equivalent circuit can be extracted from the simulation result which can be fit for the one-pole Butterworth-type low-pass response.

At present, DGS can be equivalent by three types of equivalent circuits:

(1) LC and RLC equivalent circuits,

(2) π shaped equivalent circuit,

(3) quasi-static equivalent circuit.

1) LC and RLC Equivalent Circuits

The equivalent circuit of the DGS and one-pole Butterworth prototype of the LPF are given in Fig. 5. The rectangular parts of dumbbell DGS increase route length of current and the effective inductance. The slot part accumulates charge and increases the effective capacitor of the microstrip line. Two rectangular defected areas and one connecting slot correspond to the equivalently added inductance (L) and capacitance (C), respectively. Accordingly, a resonance occurs at a certain frequency because of the parallel L-C circuit. Inversely, it is intuitively known that the equivalent circuit includes a pair of parallel inductor-capacitor form the resonant phenomenon in the S-parameter.

As the etched area of the unit lattice increases, the effective series inductance increase and increasing the series inductance gives rise to a lower cutoff frequency. When the etched gap distance increases, the effective capacitance decreases so that the attenuation pole location moves up to higher frequency.

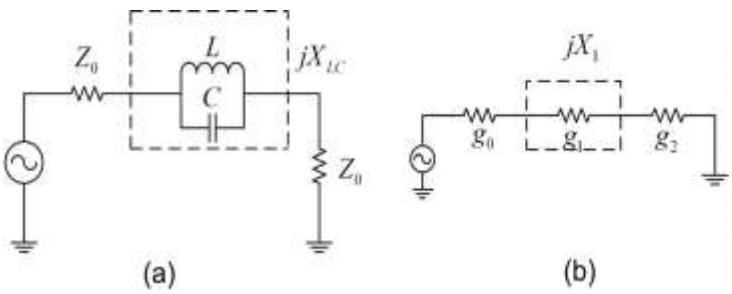


Fig -7: LC equivalent circuit: (a) equivalent circuit of the dumbbell DGS circuit,

(b) Butterworth-type one-pole prototype low-pass filter circuit.

In order to match DGS to Butterworth low-pass filter reactance values of both circuits are equal at the cutoff frequency. So L and C are derived.

Resonance (attenuation pole) and cut-off frequency which can be obtained from EM simulation results. The characteristics of most of DGS are similar to dumbbell DGS, so they could be discussed by one-pole Butterworth low-pass filter too. Furthermore, radiation effects are more or less neglected. DGS unit can be modeled most efficiently by a parallel R, L, and C resonant circuit connected to transmission lines at its both sides as shown in Fig. 6. This resistance corresponds to the radiation, conductor and dielectric losses in the defect. From EM simulations or measurements for a given DGS, the equivalent R, L, and C values are obtained from the expression (23). The size of DGS is determined by accurate curve-fitting results for equivalent-circuit elements to correspond exactly to the required inductance.

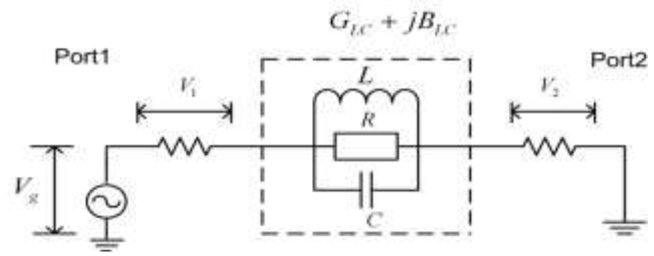


Fig -8: RLC equivalent circuit

2) LC and RLC Equivalent Circuits

However, it is very difficult to implement the DGS circuits for the purposed of the harmonic termination to satisfy simultaneously the excellent pass band and stop band characteristics. More accurate equivalent circuit models than the *LC* and *RLC* equivalent circuit were proposed, such as π shaped equivalent circuit shown in Fig. 2.13.

Considered the phase influence of DGS, Park proposed π shaped equivalent which simulates both amplitude vs. frequency and phase vs. frequency characteristics. The *S*-parameters vs. frequency curve of π shaped equivalent is more anatomized than *LC* and *RLC* equivalents, but its circuit is more complex and the parameters is so many that the equivalent is difficult to extract.

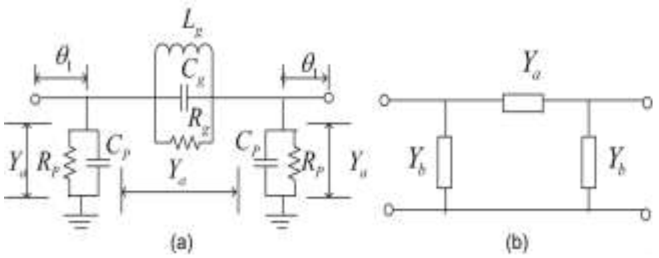


Fig -9: π shaped equivalent circuit for unit DGS: (a) equivalent circuit, (b) π shaped circuit.

*2)*quasi-static equivalent circuit.

Different from the two types of equivalent circuits mentioned above, a quasi-static equivalent circuit model of a dumbbell DGS is developed which is directly derived from the physical dimensions of dumbbell DGS is depicted in Fig. 8. This overcomes the limitation of report full-wave analysis by developing the equivalent circuit model. This approach gives a comprehensive understanding of the physical principle of DGS including how the DGS creates band stop and band pass responses and which dimensions play the most vital role to create the distinct performance. At present, the equivalent circuits are mostly concerned about influences of the addition of DGS such as radiation, or an equivalent circuit corresponded to a new DGS. Because different DGS has different characteristic, different equivalent circuits are not formed uniform circuit model and mathematics theory for the moment.

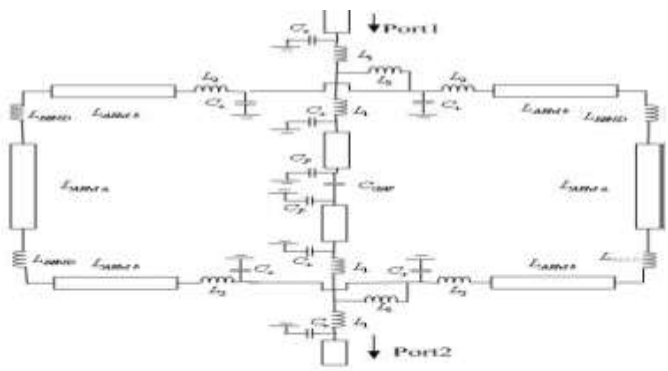


Fig -10:Equivalent-circuit model of unit cell DGS

Thus, the optimization based on an equivalent circuit network is highly desirable to design and evolve this kind of circuit configuration.

4. LITERATURE REVIEW

1. In 2017 **Sen Chen ; Ling-Feng Shi ; Gong-Xu Liu ; Jian-Hui Xun, "An alternate circuit for narrow-bandpass elliptic microstrip filter design"** They propose demonstrates the dual transmission zeros (TZs) of band pass elliptic prototype filters that can be directly implemented with two resonators in microstrip. An experimental filter based on the proposed alternate circuits is designed and fabricated. In order to improve the rejection of stop band, two additional TZs are introduced to the proposed filter.

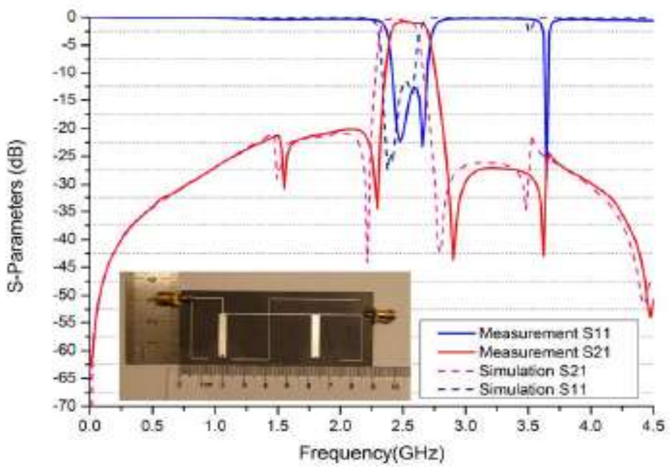


Fig -11: Frequency vs S parameter graph

2. In 1999 **Jia-Sheng Hong ; M.J. Lancaster ; D. Jedamzik ; R.B. Greed**, "**On the development of superconducting microstrip filters for mobile communications applications**" They propose recent developments of an eight-pole planar high-temperature superconducting (HTS) bandpass filter with a quasi-elliptic function response. A novel planar filter configuration that allows a pair of transmission zeros to be placed at the band edges is described. The miniature HTS filter has a fraction bandwidth less than 1% and is designed for mobile

communication base-station applications to increase sensitivity and selectivity. Design considerations including filter characteristics, design approach, sensitivity analysis and unloaded quality factor of resonators are addressed.

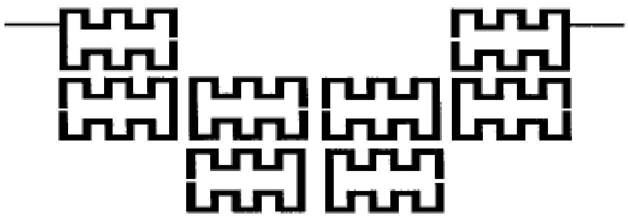


Fig -12: Structure geometry

3. In 2017 **Baoping Ren ; Zhewang Ma ; Haiwen Liu ; Masataka Ohira ; Pin Wen ; Xiaolong Wang ; Xuehui Guan, "Design of a compact diplexer using microstrip and slotline dual-mode resonators"** They propose a novel compact diplexer with hybrid resonant structure is proposed in this paper. The hybrid structure includes one microstrip stub-loaded dual-mode resonator and one slot line stub-loaded dual-mode resonator. These two dual-mode resonators both with two controllable resonant modes and one transmission zero are used to construct the desired passbands of the proposed diplexer. Meanwhile, the inherent transmissions zeros are designed to locate in the stopbands and thereby improve the isolation between the two passbands.

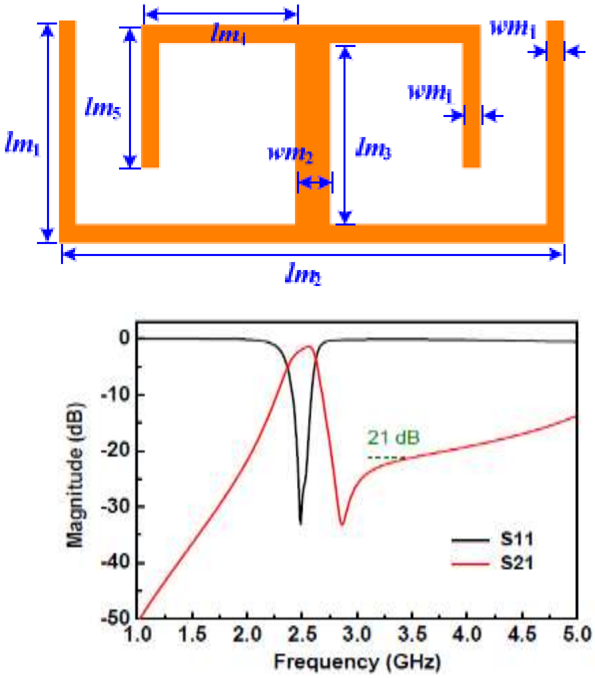


Fig -13 Defined structure and its result obtained

4. In 2017 **Mohammed Fadhel Hasan ; Ali Sadeq Abdulhadi Jalal ; Emad Shehab Ahmed, "Compact dual-band microstrip band pass filter design based on stub loaded resonator for wireless applications"** They propose a simple, compact design of dual-band bandpass filter is introduced in this paper. The proposed filter is based on stub loaded resonator (SLR). It is composed of two stub loaded half wavelength open ring resonators. The design is performed in two steps to obtain the required dual-band response. The first band is produced by using two half wave open ring resonators while the other band is obtained by loading a stub to the half wave open ring resonator.

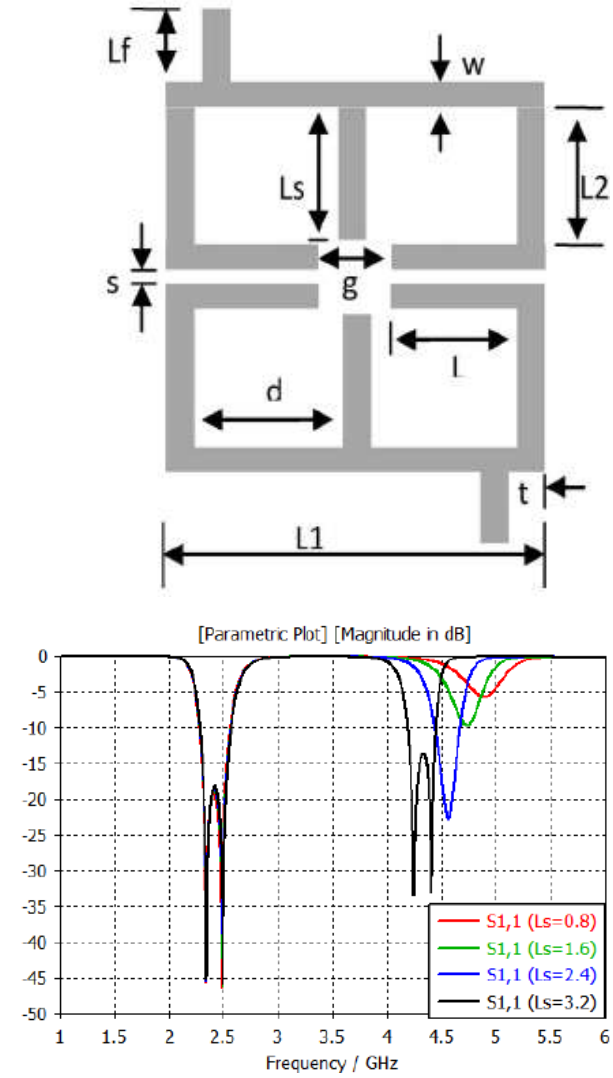


Fig -14 Defined structure and results obtained

5. In 2018 **Hongliang Guo ; Jia Ni ; Jiasheng Hong ; Petronilo Martin Iglesias,** They presents a recent investigation of dual-mode microstrip filter with non-resonating nodes and nonuniform Q lossy technique. By utilizing the dual-path and dual-mode property of dual-mode open-loop resonator, non-uniform Q distribution is deployed for passband flatness improvement. As there is no coupling between even-mode and odd-mode, the odd-mode Q-factor can be properly reduced by loading resistors over the symmetric plane of each resonators.

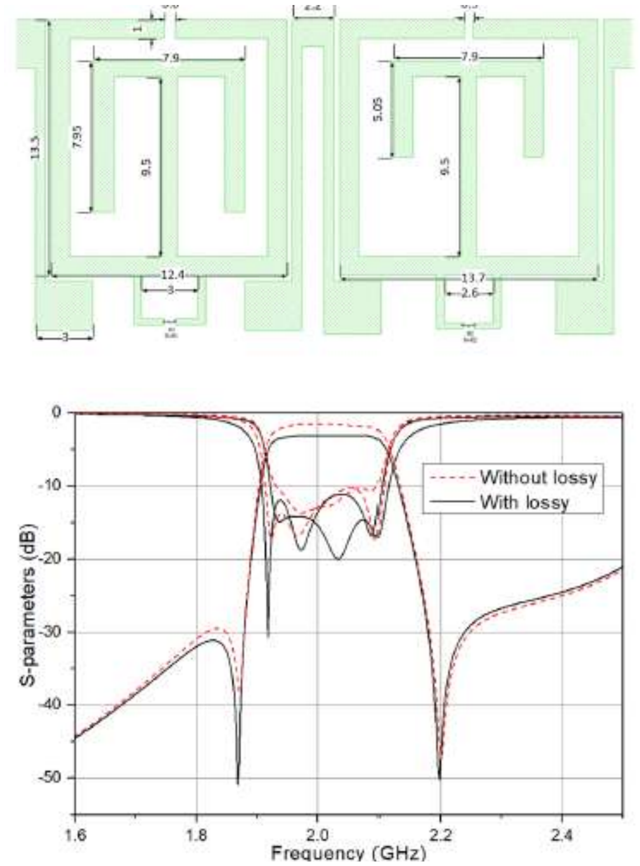
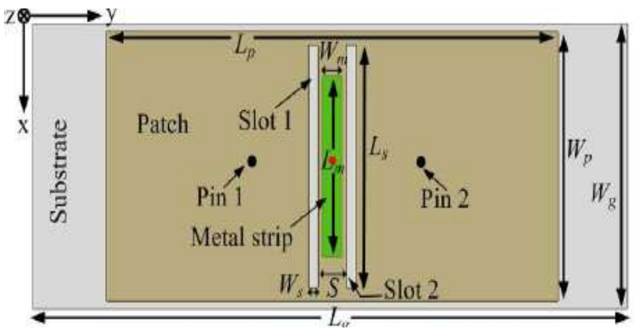


Fig -15: Defined structure and results obtained

6. In 2018 **Jian-Feng Li ; Zhi Ning Chen ; Duo-Long Wu ; Gary Zhang ; Yan-Jie Wu, "Dual-Beam Filtering Patch Antennas for Wireless Communication Application"** A dual-beam filtering patch antenna consisting of a slotted patch, a metal strip underneath the patch, two pins, and a ground plane is proposed for wireless communication application. A wide operation band with stable symmetrical dual-beam far-held radiation pattern is obtained, and two radiation nulls at the lower and the upper band edges, respectively, are controlled to ensure a sharp rolloff rate at the band edges for both reflection coefficient and realize gain.



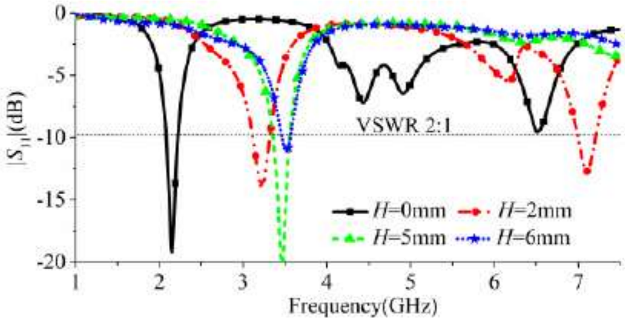


Fig -16: Defined structure and results obtained

7. In 2018 **Divya ; K. Muthumeenakshi ; S. Radha, "Design of Wideband Micro strip Band pass Filter for Ultra Low Power Wireless Applications"** Nowadays, RF Energy harvesting plays an important role in scavenging energy from the ambient sources. The RF energy harvester consist of antenna and filter to improve the performance of the output voltage. The RF circuit also receives the interference signal which reduces the overall performance of the circuit. To reduce the ripples and harmonics at the output voltage of the RF energy harvester a filter is needed.

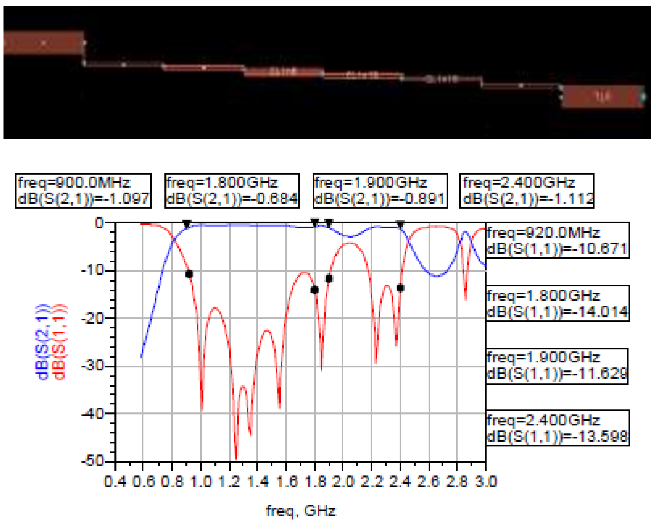


Fig -17 Defined structure and results obtained

5. CONCLUSIONS

Filters are one of the most widely used components for radio frequency as well as for microwave communications. The function of a filter is to allow a certain range of frequencies to pass while to attenuate the others. Thus clearly there is a pass-band and a stop-band. Ideally in the pass-band there should be no attenuation while in the stop-band there should be maximum attenuation.

Filters are essentially frequency selective elements. The filtering behavior results frequency dependent reactance's provided by inductors and capacitors. At lower frequencies lumped element inductors and capacitors can be used to design filters while at microwave frequencies lumped element inductors and capacitors cannot be used and thus transmission line sections are used which behave as inductors and capacitors. Minimizing the losses in the pass-band of a filter is extremely important since it not only reduces the overall losses for a transmitter but also improves the noise figure when used with a receiver.

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