MICROSTRIP FILTER DESIGN TECHNIQUES: AN OVERVIEW

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ABSTRACT

In this paper, two common techniques indesigning microstrip microwave filterwere reviewed which areperiodic and non-periodic microstrip line perturbation techniques and matched filter. This technique are widely used in RF microstrip designs such asPhotonic Band Gap (PBG), Defected Ground Structure (DGS), Defected Microstrip Structure (DMS), Ground Plane Aperture (GPA), Electromagnetic Band Gap (EBG), high-impedance surface (HIPs), and uniplanar compact photonic bandgap (UC-PBG), distorted UC-PBG (DUC-PBG), dual-mode ring resonator, and Multi-Band Matched Bandstop Filter Design.

Keywords: periodic or non-periodic microstrip line perturbation, defected ground structure (DGS), photonic band Gap (PBG), defected microstrip structure (DMS), matched filter, reflection-mode filter.

INTRODUCTION

New technologies for designing filter are being research all over the world to meet the growing demand for advance filter design with greater frequencies response and characteristic. Filter design often grapple with the trade-off among electrical and physical parameters such as physical size, insertion loss, loss variation, isolation, group delay, and production cost. Different techniques in designing filters have some advantage and disadvantages that need to be considered.

In all RF application, filters play significant role as a key component for combining, separating, selecting, and rejecting frequencies within assigned spectral limits. RF filter can be generalized as four type; lowpass, highpass, bandpass, and bandstop filter. Filters can be realized in various structure types. Most of the common filter are LC filters, helical filters, coaxial filters, microstrip and stripline filters, transmission line filters, interdigital filters, and acoustic filters; ceramic filters, crystal filters, surface acoustic wave (SAW) filter.

Most of the microstrip filters often share a same concept and theories in designing it. Some of the common filters concept is unloaded quality factors of lossy Reactive Elements and periodic or non-periodic microstrip line perturbation techniques.

The main objective of this paper is to give the viewers a wide perspective about the concepts used in most common microstrip filters with cases from the researchers.

PERIODIC OR NON-PERIODIC MICROSTRIP LINE PERTURBATION

Yablonovitch and John proposed PBG in 1987 [1, 2] which utilizes metallic ground plane that breaks traditional microwave circuit design which only concentrate on surface components and distributions of the substrate. Since then, many design and technique developed such as Photonic Band Gap (PBG), Defected Ground Structure (DGS), Defected Microstrip Structure (DMS), Ground Plane Aperture (GPA), and Electromagnetic Band Gap (EBG). Each technique has different advantages and disadvantages.

Photonic Band Gap (PBG) or Electromagnetic Band Gap (EBG) materials are one of the periodic structures which yield a wide band pass and band rejection response. The structure can be developed by implementing periodic perturbation such as dielectric patterns, holes, and rods in substrates and waveguides. It will disturb photon propagation in a photonic crystal, so the electromagnetic waves in the material are perturbed due to the periodic discontinuity, hence making a slow wave effect occurrence [3, 4].

Nevertheless, it is difficult to use EBG structure in microwave components due to its modelling difficulties. Thus, realizing small size for EBG structure is one of the most important issues to be solved. Due to that problems, some design of the EBG configuration has been propose , high-impedance surface (HIPs), and uniplanar compact photonic bandgap (UC-PBG), distorted UC-PBG (DUC-PBG) [3, 5].

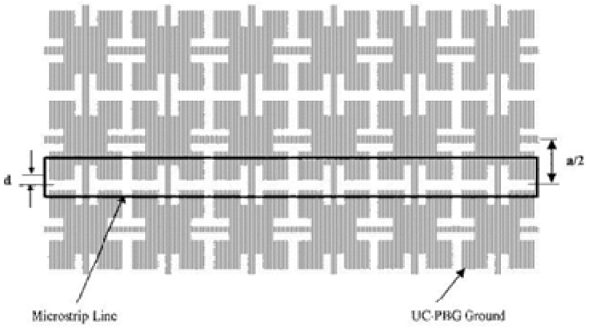


Figure-1. Schematics of microstrip line on the UC-PBG ground plane [5].

Several EBG structure in the ground plane have been researched in [6-14]. Some of the disadvantage of EBG structure is packaging problem and realization of MMIC. A multilayer structure of PBG was proposed in

[15] to avoid the packaging problem, but still realization in MMIC is problematic.

Meanwhile, Nesic [16] proposed a novel PBG microstrip structure without etching in the ground plane for filter. In 2007 [17], a new comb-type microstrip line PBG was introduced based on [16] research. Resulting wider, deeper and steeper stopband characteristics and 14% size reduced from conventional band stop filter [18]. Some of the microwave application of EBG is antenna, microwave filter, resonator and as a waveguide which was discussed in [19].

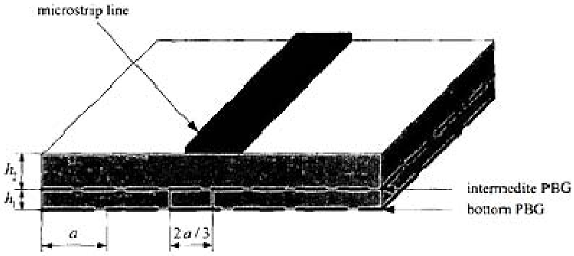
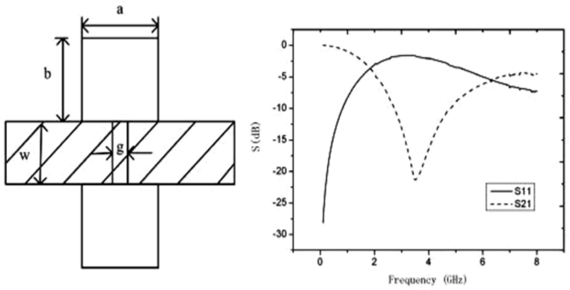


Figure-2. Schematic view of the two-layer PBG structure.

Defective Ground Structure (DGS) is etched periodic or non-periodic cascaded configuration defect on the ground plane to create a slow-wave effect. The DGS give rise to effective inductance and capacitance reaction on the structure by disturbing the shield current distribution on the ground plane [20]. This technique contributes for high impedance and band rejection characteristics of slow-wave, while significantly reduce the structure size.

The basic lattice shape of DGS was dumbbell shaped [21], compose of two *a* X *b* rectangular defected areas, *g* X *w* gaps and a narrow connecting slot wide etched areas in backside metallic ground plane as shown in Figure-3 (a). The first dumbbell DGS researched was [22].



(a) (b)

Figure-3. The first DGS unit: (a) Dumbbell DGS unit, (b) Simulated S-parameters of dumbbell DGS unit.

DGS characteristics are more practical than PBG. (1) Smaller circuit area due to less DGS structure needed to have similar properties like the stop-band characteristic compared to PBG. (2) Designing and implementing DGS structure is easier compared with PBG. (3) DGS lattice shape is simple to fabricate and it is easy to extract the equivalent circuit of DGS like simulated dumbbell shape DGS S-parameters can be matched to the Butterworth lowpass filter response [20].

There are many varieties that can be design using DGS in either microstrip, coplanar waveguide (CPW), or as resonator [23]. Some of it is the ability to control the separation of the first two resonant modes by simply add floating metal inside the dumbbell shape DGS shown in Figure-4 (b) and (d). It also can facilitate dc bias for electronic tuning [24].

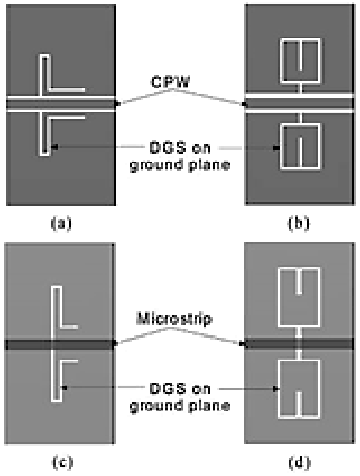


Figure-4. Various defected ground structures: (a) CPW L-shaped DGS, (b) CPW metal-loaded dumbbell-shaped DGS, (c) microstrip L-shaped DGS, and (d) microstrip metal-loaded dumbbell-shaped DGS.

DGS can also be coupled to achieve wider stopband, and sharper attenuation response. In paper [25], a coupled gap ring DGS (CGRDGS) was proposed. CGRDGS was compared with circle and square dumbbell DGS, shown in Figure-5 and 6 with centred frequency 6.53GHz, 4.44GHz, and 4.24GHz respectively. A better filter response is obtained using CGRDGS.

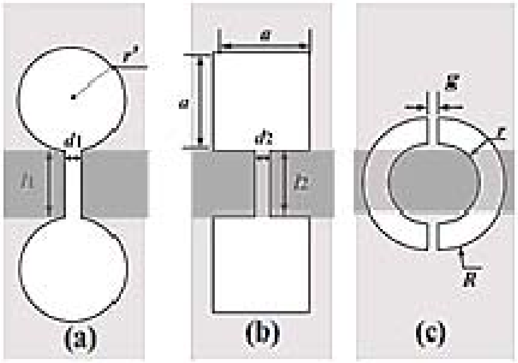


Figure-5. (a) Circle dumbbell DGS (b) Square dumbbell DGS (c) Coupled gap-ring DGS.

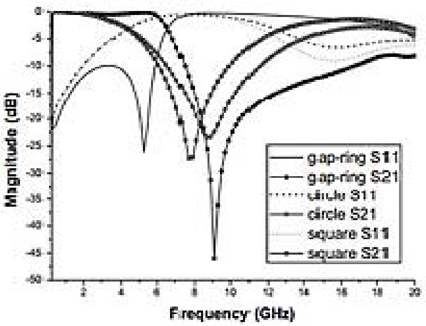
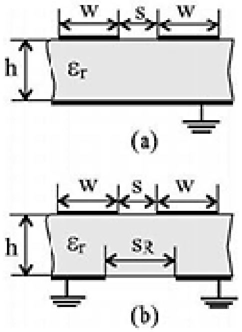


Figure-6. The S-parameters for three types of DGS.

A Ground Plane Aperture (GPA) technique is used for improving the effectiveness of the capacitive coupling factor in parallel-coupled microstrip line (PCML). Strong coupling required by some filter specifications leads to very small values of strip width and strips spacing, which sometimes cannot be accurately achieved in practice [26].

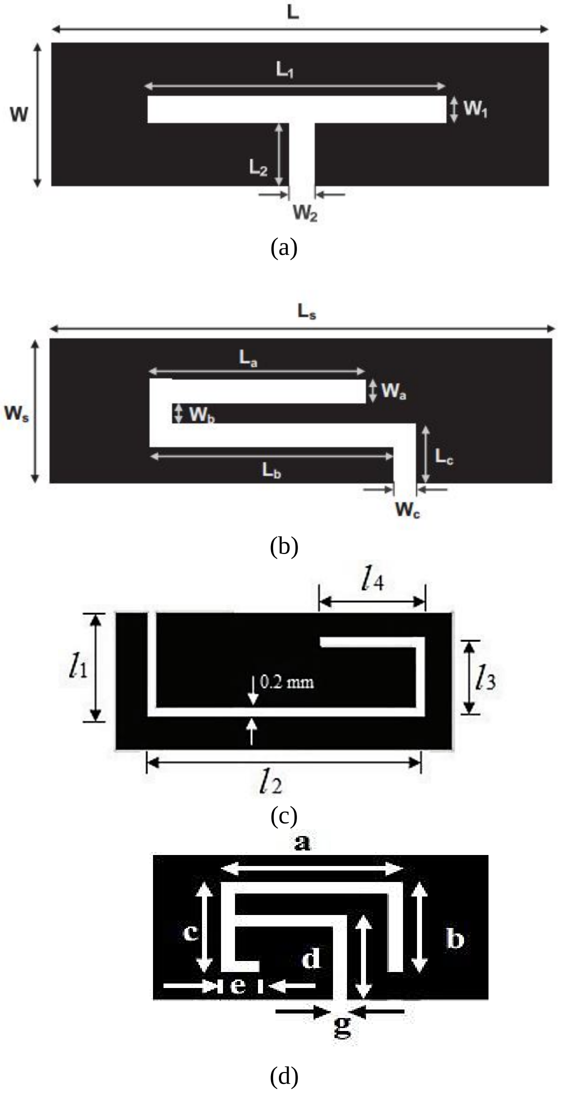


(a)
(b)

Figure-7. Cross sections of basic building blocks of microstrip coupled lines for filter design. (a) Conventional. (b) Modified with ground-plane aperture.

By implementing the centered slot at the ground plane which the width SR can be adjusted to tune the even/odd phase velocities in order to suppress the spurious band, it show an improvement on the coupling [27] and making the dimension of the *w* and *s* is larger and become less problematic to fabricate. This structure was analysed in [28] and [29].

Defected Microstrip Structure (DMS) was proposed on the basis of DGS which also disturbs current distribution on strip line. This results in the modification of the line properties and increase of the effective inductance and capacitance and gives stopband characteristics in the frequency response. DMS can be realized by etching a slot on the microstrip line [30]. It also applied to improve performances of microwave circuit like DGS. Some of the structure pattern of DMS is T-shaped [31, 32], G-Shaped [31], L-shaped [33], and spiral shaped [34].



(a)
(b)
(c)
(d)

Figure-8. Structure of defected microstrip structure (a) conventional T-shaped, (b) G-shaped, (c) L-shaped, and (d) Spiral shaped.

DMS has no drawbacks as DGS which suffers from leakage through ground plane and radiation through the etched slot that can cause distortions in measurements [32].

MATCHED FILTER

Filters employing this concept are referred to as “non-reflective filters” [35], “reflection filters” [36], “reflection-mode filters” [37], “absorptive filters” [38, 39, 40], and “perfectly matched filters” [41].

It has been well known, since at least the reflection-type phase shifter [42] work of the early 1960’s, that the reflection characteristic of a one-port network can be realized into the transmission characteristic of a two-port by using either a circulator or a 3-dB hybrid or directional coupler, as shown in Figure-9. [43].

The lossy nature of microstrip makes it difficult to achieve a high Q factor. The perfect-notched concept [40, 43] is applied to improve the Q factor of bandstop limiter in [44]. This technique achieves low insertion loss, flexible channel bandwidth and centre frequency, low spike leakage, and a high level of power limiting.

Based on a reflection mode filter, this concept makes use of two identical lossy resonators coupled to a 3-dB 90° hybrid coupler with correct coupling factors. At the centre frequency, the incident signals are critically coupled to the resonators and absorbed in the resistive part of the resonators leaving no reflected signals at the output. This theoretically gives infinite attenuation [45].

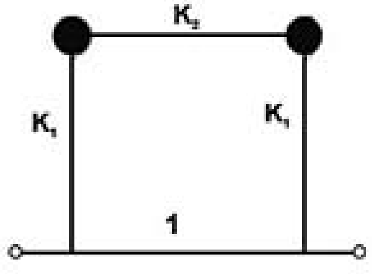


Figure-9. Generalized coupled-resonator model of a matched notch filter.

In [44], Hamzah *et al* has proved that perfectly matched bandstop concept allows the construction of multiband matched bandstop filter design by simply cascading two single band matched bandstop filter shown in Figure-10. In [46], it has been prove that dual-mode ring resonator matched bandstop filter allows the construction of reconfigurable design by adding PIN diode as switching elements. The simulation and measurement result have shown that the circuit can be reconfigured between allpass and bandstop using two PIN diodes at K2 coupling in the dual-mode ring resonator.

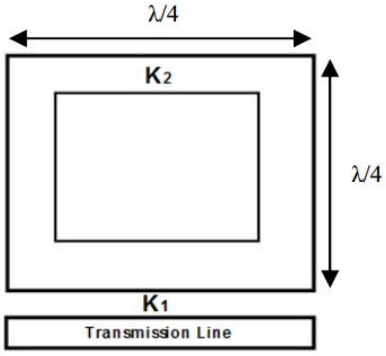


Figure-10. Notch topology dual-mode ring resonator [46].

Beside the effect of the different coupling gap of K1 to the attenuation level of bandstop filter is very sensitive. The smallest changes of coupling gap will change the attenuation level. Hence, any fabrication process must be a tight tolerance for this kind of design.

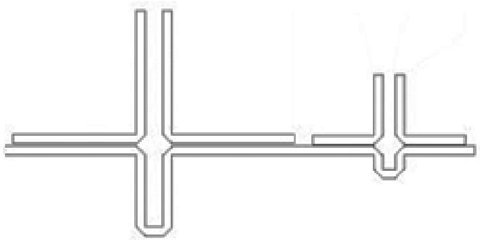
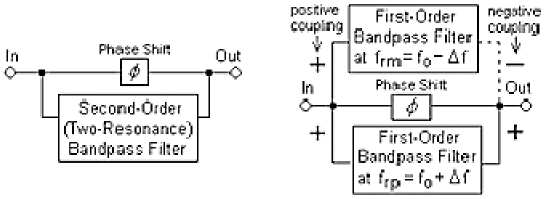


Figure-11. Shape of multi-band matched bandstop filter design.

Bandstop filters that substantially absorb stopband signals, although still limited in performance by resonator Qu, can be orders of magnitude more selective than reflective bandstop filters with identical resonator Qu [40]. Absorptive bandstop filters function by matching the source resistance into the resonator resistances (resonator impedances at resonance) at stopband frequencies, so that signal power is dissipated in, rather than reflected from, the lossy resonators. Microwave absorptive bandstop filters have traditionally been comprised of lossy reflection-mode networks coupled to 3dB hybrid couplers [47] or circulators [39].



(a) (b)

Figure-12. Conceptual diagrams of first-order absorptive bandstop filters based on (a) a single second-order bandpass filter and (b) two first-order bandpass filters.

In [41], two additional, more compact, absorptive bandstop filter topologies were proposed. Jachowski *et al* claim that the new absorptive bandstop filter topologies are ideally suited to electronic frequency control, with the unique ability to partially compensate for frequency dependent losses, couplings, and phase shifts by adjustments to resonant frequencies alone.

Conventional electronically tunable bandstop filters suffer performance degradation due to the finite unloaded Q of the resonators and also the loss associated with the tuning elements [48]. Recently a new filter topology using lossy resonators has been introduced where the topology can be used to partially compensate for the loss [40, 41, 43].

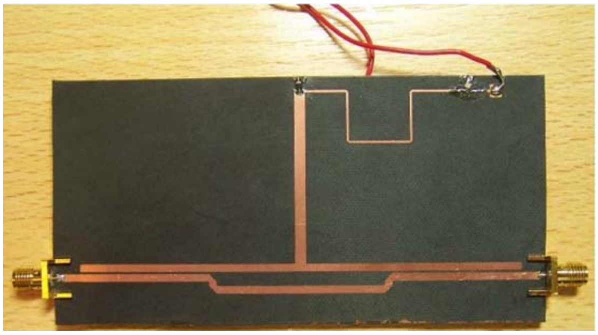


Figure-13. Microstrip circuit prototype of matched notch filter with tunable impedance inverter [49].

A frequency agile bandstop filter based on this topology was presented [41], but such filters as well as conventional tunable bandstop filters encounter performance degradation in terms of tuning bandwidth and stopband bandwidth due to the frequency- dependant losses and couplings. In this paper, theory describing a microstrip T-shunt stub impedance inverter is presented that validates the suitability of the inverter for narrowband filter design. Such an impedance inverter is made tunable to provide the optimum inter-resonator coupling using a varactor diode.

The tunability of the inverter properties can be used to compensate for the frequency dependant couplings in the conventional tunable bandstop filters to retain the optimum stopband bandwidth or loaded Q while tuning the center frequencies, thus maximizing the available tuning bandwidth. The bandwidth tuning is accomplished by changing the coupling among filter resonators. The filters were realized with some additional transmission line segments with the attached varactor diodes or switch elements, in order to achieve the inter-resonator coupling tuning as shown in Figure-12 [49].

CONCLUSIONS

In this article, common techniques to design microstrip microwave filter were discussed. There are many other techniques to design microstrip filter. Some of them arelowpass prototype filter, transfer function, elliptic function, microstrip waveguide, stepped-impedance, Butterworth Response, Chebyshev Response, Richards' Transformation, and Kuroda Identities. Each of the techniques has its own advantages and disadvantages. It is also depending on the design parameter and specification needed for suitable configuration.

Microstrip filter design technique has a large room for improvement in term of the efficiency, quality, compatibility, durability, size, and cost of production. It was vastly been research all around the world.

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