Comparative Study of a Micro-strip Line with DGS and without DGS

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ABSTRACT — The low pass filter is used in many application of microwave communication. Therefore it is necessary to design a good low pass filter for the faithful reproduction of wanted signals. Previously used methods to design the low pass filter using insertion loss method don’t give a very good flat response. So, a new method has been proposed for the filter design which gives a good response as compared to the conventional designs. A new DGS (Defected Ground Structure) technique to design a low pass filter is proposed here, ground is defected or cut in a desired shape which improves its performance. The size of filter is also reduced with the help of DGS.

INDEX TERMS—LPF, DGS, MICROSTRIP

INTRODUCTION

Microwave system often requires means for suppressing unwanted signals and/or separating signals having different frequencies. These functions are performed by electric filters. Filters are usually categorised by their frequency characteristics, namely low-pass, high-pass, bandpass and bandstop. The first objective is to study about the conventional microwave Low Pass Filter (LPF). The second objective is to study about Low Pass Filter using Defected Ground Structure (DGS).

When a conventional low pass filter (using capacitor, inductor etc.) is used for suppressing unwanted signals or separating signals having different frequencies, it shows discontinuity elements and has repeated high impedance. A defective ground structure (DGS) is an internally designed defect on a ground plane that creates additional effective inductance and capacitance. The technique can be used to design microstrip line with desired characteristics, thus significantly reducing the footprint of the microstrip structure.

Microstrip Filter

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 passband of the filter and attenuation in stopband of the filter.

The general structure of a microstrip is illustrated in figure 1. A conducting strip (microstrip line) with a width $W$ and a thickness $t$ is on the top of a dielectric substrate that has a relative dielectric constant $\varepsilon_r$ and a thickness $h$, and the bottom of the substrate is a ground (conducting) plane.

Guided Wavelength, Propagation Constant, Phase Velocity, and Electrical Length

The guided wavelength of microstrip is given by

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_{re}}}$$

where $\lambda_o$ is the free space wavelength at operation frequency $f$. The associated propagation constant $\beta$ and phase velocity $V_p$ can be determined by

$$\beta = \frac{2\pi}{\lambda_{se}}$$

$$V_p = \frac{\omega}{\beta} = \frac{c}{\sqrt{\varepsilon_{re}}}$$

where $c$ is the velocity of light ($c = 3.0 \times 10^8$ m/s) in free space.

The electrical length for a given physical length $l$ of the microstrip is defined by

$$\Theta = \beta \ell$$

THEORETICAL ANALYSIS OF DISPERSION CHARACTERISTICS OF DEFECT
2.1 Introduction
Defected ground structure (DGS) is usually realized by etching a specific pattern on the ground plane of a microstrip structure. The most frequently used DGS is the dumbbell shaped one proposed by Dahaln. With an additional Inductance due to the magnetic flux flow in the etched out apertures and gap capacitance on the ground plane (DGS), a certain band of frequencies are prohibited. The DGS is used to improve the power efficiency of power amplifiers, for enhancing the performance of filters. More recently slow wave effects are utilized to reduce the size of planar passive circuit.

Basically, when transmission line is incorporated with DGS, it yields low pass performance due to change in its surface impedance. Surface impedance is changed due to an etched defect of the ground plane, which in turn disturbs the shielded current distribution in the plane. The change in surface impedance changes the phase velocity of the current. The change in phase velocity leads to change in the apparent effective permittivity.

2.2 Basic Theory
A simple schematic view of DGS shown in Figure 2.2

- **Due to Discontinuities on Gm:** Change in its L and C
- **Change in its Impedance:** Change in its Resonant Frequency
- **Change in its resonant Frequency:** Change in its electrical length or z

**Figure 2.1 Flow chart of effect of DGS**

Thus we create DGS in various planar passive structures to reduce the size of the filter and enhancing the bandwidth, which is our main aim.

Slow wave factor (SWF).
The slow wave factor is the relation between the wave number in free space $k_0$ and the propagation constant $\beta$ of the transmission line. For lossless microstrip line,

$$SWF = \sqrt{\varepsilon_{eff}}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(1 + \frac{12h}{w}\right)^{-0.55}$$

$$\beta = \sqrt{\varepsilon_{eff}} \cdot k_0 = \frac{\omega}{\nu_p} = \frac{\omega}{c} \sqrt{\varepsilon_{eff}}$$

**Figure 2.2: Discontinuities in ground and microstrip surfaces; (a) DGS**

Here DGS is designed by connecting two rectangular electromagnetic band gap cells with a slot. As can be seen in Figure 2.2(a), h is the height of the substrate, W is the width of the microstrip line, a and b are the arm lengths and g is gap of the slot under the microstrip line on the ground plane. The frequency of operation can be changed with DGS dimension.

For a conventional microstrip line, a quasi TEM mode propagates under the microstrip filament and infinite ground plane. The electric and magnetic fields are mostly confined under the microstrip line. The return current on the ground plane is the negative image of the current on the microstrip line. The return path of the current is fully disturbed and this current is confined to the periphery of perturbation along DGS side arm. Hence we can analyze delay occurs due to increased path and also due to perturbation the phase velocity is reduced.

Here ↓ shows decreasing nature, ↑ shows increasing nature.
Applying these basic observations, we can use it in the reduction in size. The DGS slot is modeled by a parallel LC resonant circuit.

$$C = \frac{f_c}{2Z_0 \cdot 2\pi(f_0^2 - f_c^2)}$$

$$L = \frac{1}{4\pi^2 f_0^2 C}$$

Microstrip Line without DGS

Microstrip Line with DGS

Fig.2.3 Schematic view of microstrip line with DGS and its equivalent circuit

Fig.2.4 Simple Microstrip line of 50 ohm

Fig.2.5 model of microstrip line without DGS of 50 ohm simulated on HFSS

Microstrip line with DGS

Fig.2.6 DGS unit cell

Fig.2.7 Response of line with DGS Unit cell in $S_{21}$ (dB)
Observation:

Figure 2.6 shows that microstrip line with DGS unit cell is a good guiding structure with small distortion due to the linear phase variation of $S_{21}$ with frequency. Note that a jumping phenomenon occurs at the resonant frequency. Compared to the microstrip line without DGS unit, the microstrip with DGS unit exhibits a faster phase variation which exhibits slow-wave behaviors below $\omega_0$ and a slower phase variation which exhibits fast-wave behaviors beyond $\omega_0$, where $\omega_0$ is angle frequency and equal to $2\pi f_0$. This phenomenon can be explained as follows.

Case A: $\omega < \omega_0$.

$\omega \cdot L < 1/(\omega \cdot C)$ and the inductive microstrip line are obtained.

Case B: $\omega > \omega_0$.

$\omega \cdot L > 1/(\omega \cdot C)$ and the capacitive microstrip line are obtained.

Case C: $\omega = \omega_0$.

$\omega \cdot L = 1/(\omega \cdot C)$ and jumping phenomenon occurs.

Generally, the slow-wave factor is defined by $\lambda_0/\lambda_g$, where $\lambda_g$ is the guided wavelength and $\lambda_0$ is the free space wavelength.

The comparison reveals that:
1) The SWF of the microstrip line with DGS unit are improved while frequency increases.
2) A jumping phenomenon occurs at $f_0$.
3) DGS unit provides slow-wave behaviors below $f_0$ and fast-wave behavior beyond $f_0$.
4) Because of the constant coefficient $\sqrt{\varepsilon_{eff}}$ the total effect of dispersion characteristics of microstrip lines with DGS unit still exhibits slow-wave behaviors compared to free space propagation.

From expression, we conclude there is change in electrical length, means change in phase.

$$\Delta \theta = \theta_d - \theta_0$$  \hspace{1cm} (1)

Here $\theta_d = \beta_d L$, $\theta_0 = \beta_0 L_o$

$$\Delta \theta = \frac{360}{\lambda_{gd}} - \frac{1}{\Lambda_o}$$  \hspace{1cm} (2)

$$\lambda_{gd} = \frac{360}{\Delta \theta + \frac{360L_o}{\lambda_{g0}}}$$

$$\varepsilon_{eff} = \left(\frac{\lambda_o}{\lambda_{gd}}\right)^2$$ and $$\varepsilon_{eff} = \left(\frac{\lambda_0}{\lambda_{g0}}\right)^2$$

$$\sqrt{\varepsilon_{eff}} = SWF_d = \frac{\lambda_0}{360L} (\Delta \theta) + \sqrt{\varepsilon_{eff}}$$  \hspace{1cm} (3)

Now for determination of slow wave factor of microstrip line with DGS unit and its equivalent LC resonator, we take the substrate FR4 $\varepsilon_r=4.4$, $h=0.7874$. $W=2.413$ of 50 ohm microstrip line at frequency (7GHz), the DGS unit has Dimension $a=b=3$mm and the gap $=0.2$mm. The DGS circuit was simulated by HFSS. The magnitude and phase characteristics of the microstrip line with DGS unit as shown in figure (2.7) & (28).

After inserting DGS on ground plane of microstrip line the phase and magnitude of $S_{21}$ is changed due to slow wave factor. The
CONCLUSION:
Thus we see that
1) The SWF of the microstrip line with DGS unit are improved while frequency increases.
2) A jumping phenomenon occurs at $f_0$.
3) DGS unit provides slow-wave behaviors below $f_0$ and fast-wave behavior beyond $f_0$.
4) Because of the constant coefficient $\sqrt{\varepsilon_{\text{eff}}}$, the total effect of dispersion characteristics of microstrip lines with DGS unit still exhibits slow-wave behaviors compared to free space propagation.

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