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An Introduction to Defected Ground Structures in Microstrip Circuits

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Here is an overview of a recent development in distributed circuit design that offers improved performance in many filter and antenna applications

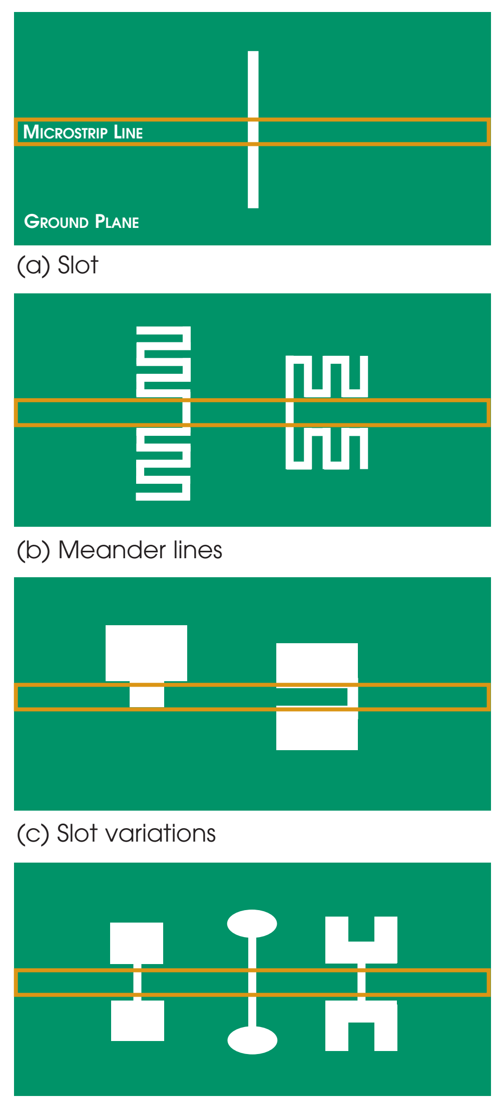
In recent years, there have been several new concepts applied to distributed microwave circuits. One such technique is *defected ground structure* or DGS, where the ground plane metal of a microstrip (or stripline, or coplanar waveguide) circuit is intentionally modified to enhance performance.

The name for this technique simply means that a "defect" has been placed in the ground plane, which is typically considered to be an approximation of an infinite, perfectly-conducting current sink. Of course, a ground plane at microwave frequencies is far removed from the idealized behavior of perfect ground. Although the additional perturbations of DGS alter the uniformity of the ground plane, they do not render it defective.

DGS Element Characteristics

The basic element of DGS is a resonant gap or slot in the ground metal, placed directly under a transmission line and aligned for efficient coupling to the line. Figure 1 shows several resonant structures that may be used. Each one differs in occupied area, equivalent L-C ratio, coupling coefficient, higher-order responses, and other electrical parameters. A user will select the structure that works best for the particular application.

The equivalent circuit for a DGS is a parallel-tuned circuit in series with the transmission line to which it is coupled [1] (see Figure 2). The input and output impedances are that of the line section, while the equivalent values of L, C and R are determined by the dimensions of the



(a) Slot

(b) Meander lines

(c) Slot variations

(d) Various dumbbell shapes

Figure 1 · Some common configurations for DGS resonant structures.

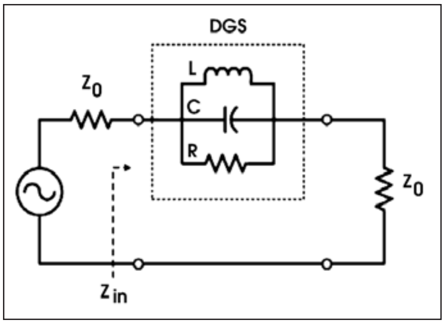


Figure 2 · Equivalent circuit of a DGS element. The values of L, C and R are determined by the dimensions and location relative to the "through" transmission line.

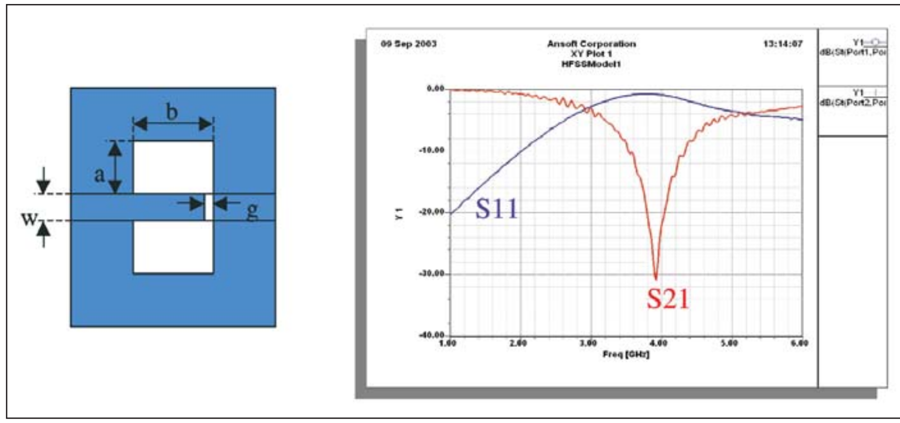


Figure 3 · Structure of a specific DGS type and its frequency response, obtained by electromagnetic simulation (2).

DGS structure and its position relative to the transmission line. The range of structures—of which Figure 1 is only a small sample—arises from different requirements for bandwidth (Q) and center frequency, as well as practical concerns such as a size/shape that does not overlap other portions of the circuit, or a structure that can be easily trimmed to the desired center frequency.

Figure 3 shows the frequency response of a single resonator [2]. This one-pole "notch" in frequency response can be used to provide additional rejection at the edges of a filter passband, or at an out-of-band frequency such as a harmonic, mixer image, or any frequency where the filter structure has poor rejection due to re-entry or moding effects. Similarly, DGS resonators can also be used to remove higher-order responses in directional couplers and power combiner/dividers.

Being a physical structure, analysis of DGS circuits is best accomplished using electromagnetic simulation with multi-layer 2-D or 3-D tools. It is also important to construct and measure circuits that are intended for production. Common microstrip considerations, such as variations in dielectric constant or etched line dimensional tolerance, tend to have greater effect with narrow bandwidth circuits such as DGS.

Example: A DGS-Enhanced Filter

DGS allows the designer to place a notch (zero in the transfer function) almost anywhere. When placed just outside a bandpass filter's passband, the steepness of the rolloff and the close-in stopband are both improved. Simple microstrip filters have asymmetrical stopbands, and the need for a more complex design can be avoided if DGS elements are used to improve stopband performance.

This can be seen in the filter example of Figure 4 [2]. This filter has two DGS elements, placed the input and output of a simple coupled line bandpass filter. The filter's center frequency is 3.0 GHz, while the DGS resonators are designed for a notch at 3.92 GHz. The plot of Fig. 4 shows a fast rolloff on the high frequency side of the passband, which is much greater than that of the basic coupled line filter.

A classic characteristic of distributed filters is higher order responses, with the most trouble some being at twice the center frequency. This can be seen clearly at the upper frequency edge of the plot in Fig. 4. If the application requires elimination of this "second passband," additional filter elements are required. This can be accomplished

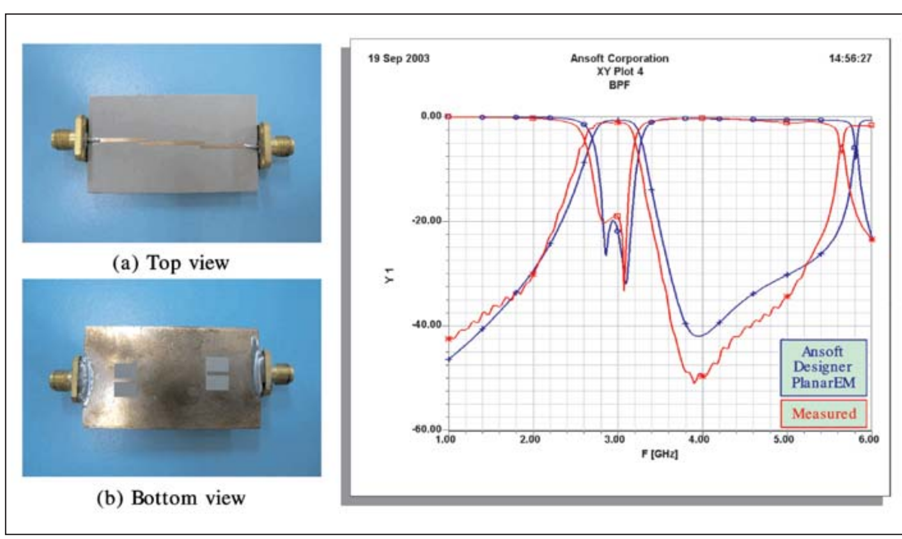


Figure 4 · Layout, simulation and measurements of a coupled-line bandpass filter centered at 3.0 GHz (2). The filter includes two 3.92 GHz DGS elements, located adjacent to the input and output.

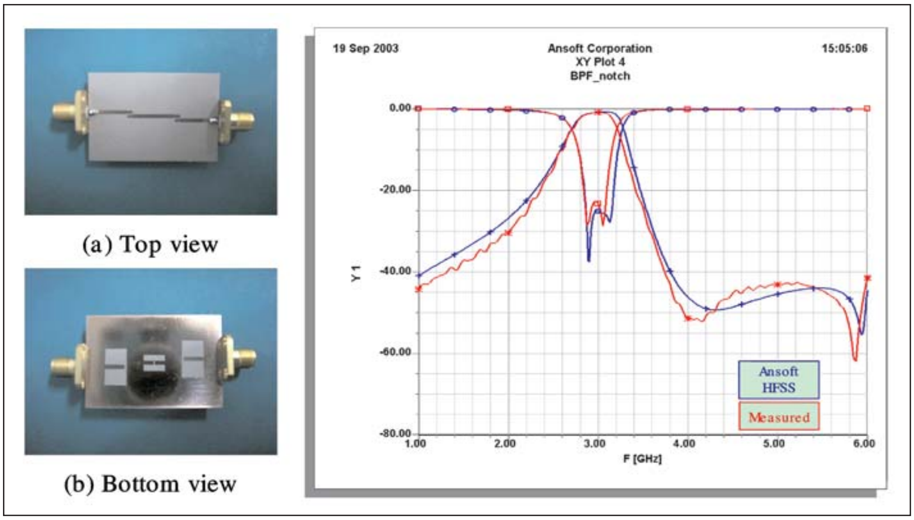


Figure 5 · Layout and performance of the example bandpass filter, which is now further enhanced with a DGS element that reduces the unwanted second harmonic response.

simply by adding another DGS element resonant at the second harmonic frequency. The rejection of this resonant notch will greatly reduce the filter's unwanted response.

The example in [2] includes this scenario, adding a DGS at the center of the filter. Its design frequency of 5.9 GHz places it in the offending region. The filter layout and performance plots for this further enhancement are shown in Figure 5. When compared with the response of the simpler filter in Fig. 4, it is easy to see the improvement near 6 GHz.

Disadvantages of DGS

The main disadvantage of the defected ground technique is that it radiates. The top illustration of Fig.1 is not only a DGS element, it is a slot antenna—a highly efficient radiator. Although much of the incident energy at the resonant frequency is reflected back down the transmission line, there will be significant radiation.

Radiation within enclosed microwave circuits can be difficult to include in simulation. Boundary conditions are usually set to be absorbing (no reflections), which simplifies calculations, but excludes the structures around the circuit being examined. In some cases, the size of the enclosure will make the problem too large to achieve a solution in a reasonable time, and the details of the physical structure may take a very long to determine and enter into the software.

EM simulation is certainly accurate for the circuit itself, but with uncertainty of radiation effects, the construction and careful evaluation of a prototype is strongly recommended. An experienced designer may be able to create a simplified model of the enclosure for more accurate simulation, but measurement remains essential for verification.

A lesser disadvantage is that DGS structures increase the area of the circuit. However, the additional area will usually be less than that of alternative solutions for achieving similarly improved performance.

Additional Applications of DGS

Delay lines—Placement of DGS resonators along a transmission line introduce changes in the propagation of the wave along the line. The DGS elements do not affect the odd mode transmission, but slows the even mode, which must propagate around the edges of the DGS "slot." With this change in the phase velocity of the wave, the effective dielectric constant is effectively altered, creating a type of slow-wave structure.

Delay lines and phase shifters can be simplified in many cases. Also, the common capacitive-loaded microstrip line sometimes used for these type of slow-wave applications can be enhanced with the addition of DGS resonators.

Antennas—The filtering characteristics of DGS can be applied to antennas, reducing mutual coupling between antenna array elements, or reducing unwanted responses (similar to filters). This is the most common application of DGS for antennas, as it can reduce sidelobes in phased arrays, improve the performance of couplers and power dividers, and reduce the response to out-of-band signals for both transmit and receive.

An interesting application combines the slot antenna and phase shift behaviors of DGS. An array of DGS elements can be arranged on a flat surface and illuminated by a feed antenna, much like a parabolic reflector antenna. Each element re-radiates the exciting signal, but a phase shift can be built into the structure to correct for the distance of each element from the feed. The re-radiating elements introduce additional loss, but the convenience of a flat form factor is extremely attractive for transportable equipment or applications where a low-profile is essential.

References

1. I. Chang, B. Lee, "Design of Defected Ground Structures for Harmonic Control of Active Microstrip Antennas," *IEEE AP-S International Symposium*, Vol. 2, 852-855, 2002.

2. J. Yun, P. Shin, "Design Applications of Defected Ground Structures," Ansoft Corporation, 2003 Global Seminars. Available at www.ansoft.com. *Figures 3, 4 and 5 are reproduced from this reference, courtesy Ansoft, LLC.*