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Electromagnetic Stop-Band Network Improves Class F Amplifier Performance

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This article describes an electromagnetic stop-band (ESB) network for high-efficiency class F power amplifiers, providing improved performance in both the pass band and stop band

In a class F power amplifier, producing the required short circuit at even harmonics and the open circuit at the odd harmonics at the active device output can substantially increase efficiency of the power amplifier [1, 2]. With such harmonic tuning, the voltage across the active device output and current through it do not contain harmonics of the same order simultaneously. In practice, it is very difficult to control impedances for an infinite number of harmonics, and the so-called Third-Harmonic Peaking tuning is typically used. In this case, the input impedance of the output network is controlled up to third harmonic. A noticeable increase in efficiency can be achieved if a higher harmonics are also taken into account [3].

Recently, photonic bandgap (PBG) and defected-ground microstrip structures have been proposed as a novel way to accomplish filtering that provides a broad rejection band [4-11]. Such structures can be successfully used as the output networks of high-efficiency power amplifiers. As was suggested in [12], the terminology "electromagnetic stop-band" (ESB) is probably more appropriate than "photonic bandgap." ESB seems to be more commonly used for microwaves, so it is used in this paper.

To achieve high amplifier efficiency, an output network should also provide acceptable matching at the fundamental frequency. So, insertion loss in the pass band should be as small as possible. The weakness of the mentioned PBG (or ESB) structures, when used as amplifier output networks, is their imperfect characteristics in the pass band. This article presents an approach to improve the matching within the pass band.

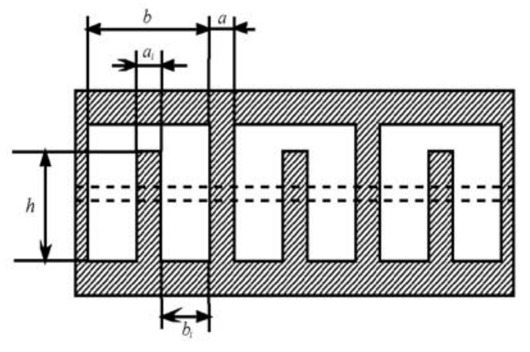

Figure 1 · Proposed double-period ESB structure with improved pass band matching.

Double-Period ESB Structure Design

The top view of the proposed microstrip ESB structure is shown in Figure 1. The ground plane of this ESB contains periodically located Π-shaped holes. The holes sizes are chosen so that structure has one period from one side of strip ($T = a + b$) and two times lower period from another side ($T_i = T/2 = a_i + b_i$). Thus, for given T and b, other sizes can be calculated as:

$$a = a_i = T - b$$

$$b_i = \frac{b - a_i}{2} = b - \frac{T}{2}$$

Simulated scattering parameters of the

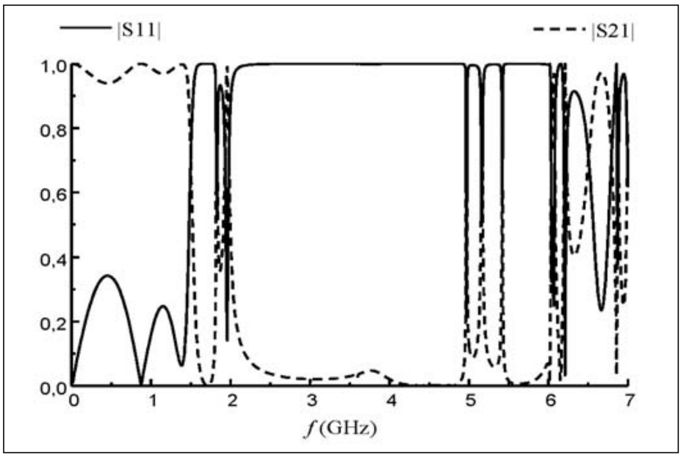

Figure 2 · Scattering parameters of ESB structure under consideration.

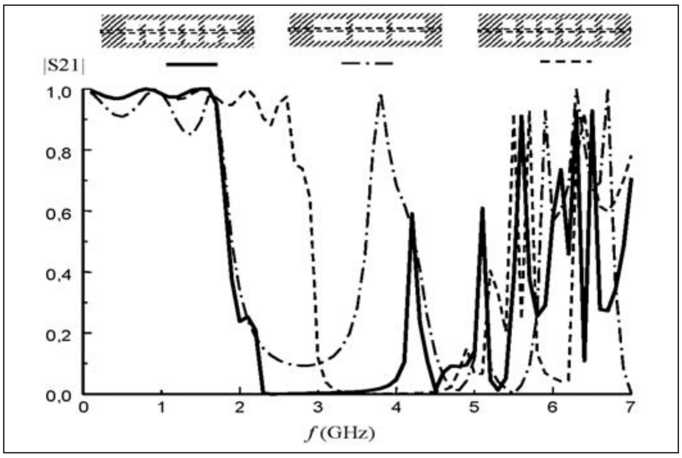

Figure 3 · Insertion loss of ESB structures with b = 16 mm.

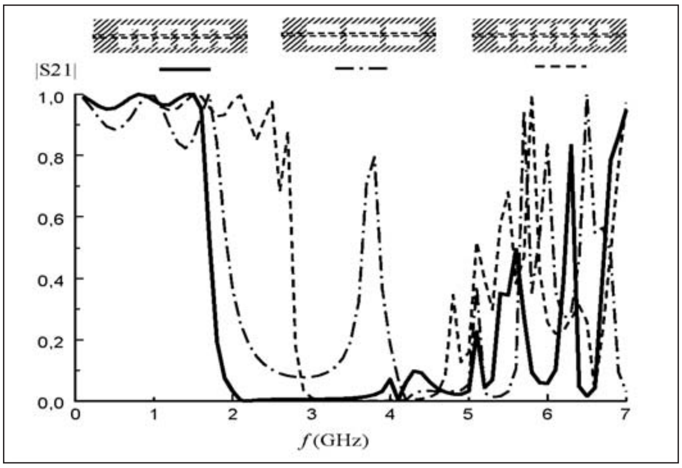

Figure 4 · Insertion loss of ESB structures with b = 18 mm.

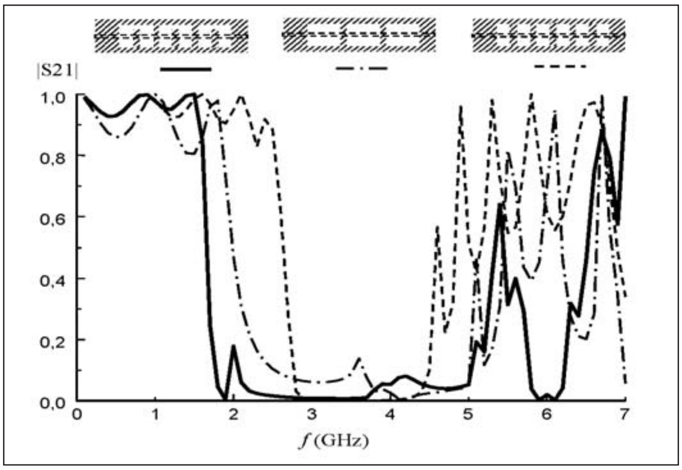

Figure 5 · Insertion loss of ESB structures with b = 20 mm.

proposed ESB structure are shown in Figure 2. It can be seen that the three-stage structure has a good match at the fundamental frequency (~850 MHz) and rejects the higher harmonics, up to five.

In order to show the benefits of the proposed double-period ESB, several simulations were conducted for different hole shapes and sizes. The period of structure was the same (T = 24 mm) in all simulations, but with differences in the relationships between the "filled" and "unfilled" regions' sizes.

The simulation results are shown in Figures 3 to 5. For all figures, the solid line means double-period configuration with Π-shaped holes, while dashed and dash-and-dot lines mean rectangular holes in single-period configurations with the periods T_i and T, respectively. Figure 3 relates to the b = 16 mm, and Figures 4 and 5 to the b = 18 mm and b = 20 mm, correspondingly. The figures show that use of Π-shaped holes instead of simple rectangular ones lets us achieve better characteristics for both the pass band and the rejection band.

In the pass band, insertion loss of double-period structure is almost the same as insertion loss of the single-period structure with lower period T_i. It is known that number of ripples in the pass band is one unit less than the number of sections in the finite periodic structure. So, for a six-section structure there are five ripples in the pass band. The amplitude of ripples usually decreases with an increase of their number, that is, with increasing of sections in a structure. But, simply increasing the number of sections leads to a simultaneous increase of the size and height of overall construction. However, as can be seen from Figures 3 to 5, using the proposed double-period structure allows us to obtain low amplitude ripples in the pass band without increasing the number of sections.

In the rejection band, the characteristics of double-period structure become even better than the single-period structure with period T.

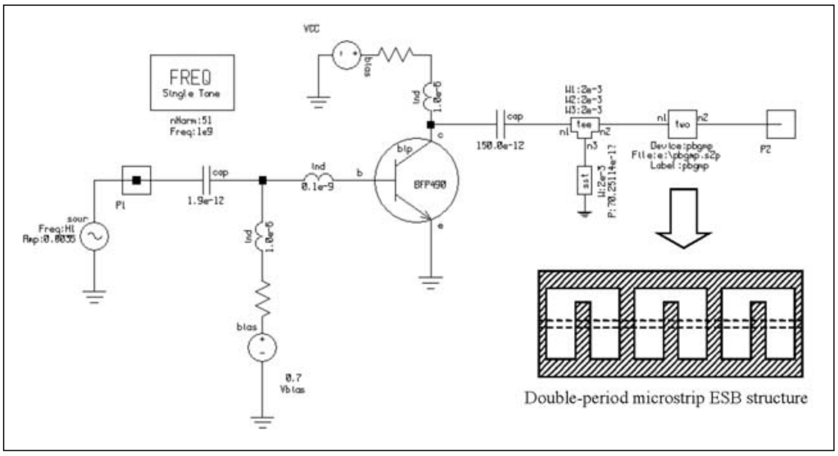

Figure 6 · Equivalent circuit of polyharmonic power amplifier with double-period microstrip structure.

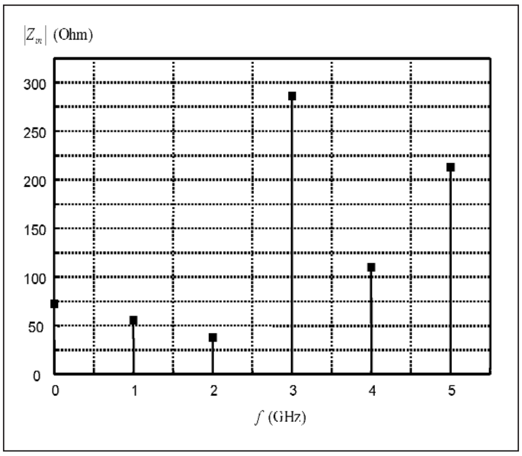

Figure 7 · Magnitude of the output network's impedance versus frequency.

Class-F Power Amplifier Design

Using the proposed double-period microstrip ESB structure, a polyharmonic class-F power amplifier operated at 1 GHz was designed and the three-section ESB was used as the output network. Equivalent circuit of this amplifier is shown in Figure 6.

The microstrip double-period structure was incorporated into the amplifier circuit as a two-port with known S-parameters. The shorted section of original microstrip line was used for tuning of output network's input impedance.

The magnitude of output network's input impedance versus frequency, accounting for the shorted section is shown in Figure 7. Its value at the fundamental frequency is equal to a critical resistance, with respect to maximum power output capability without saturation.

The input impedance magnitudes for the third and fifth harmonics exceed, at some times, the fundamental frequency value (Figure 7). These are mandatory conditions to emphasize the third and fifth harmonics in the output voltage and to achieve target signals' waveforms.

The simulated collector current and collector-emitter voltage waveforms are shown in Figure 8. As can be seen, the collector-emitter voltage has a smoothed bottom, which corresponds to decreased dissipated power and increased efficiency.

The collector efficiency was as high as 78.6% along with PAE equal 78.2%. This achieved result is less—by 4.7%—than the maximally possible 83.3% for the case of fifth-harmonic peaking [3]. This can be explained by a non-zero minimum collector-emitter voltage, which is needed to avoid saturation. The 83.3% value was obtained for the zero minimum voltage case.

The amplifier output power and efficiency versus frequency are shown in Figure 9. One can see that collector efficiency is above 60% within more than 300 MHz frequency band. Over the measured range, the output power varies from 180 mW to a maximum of 280 mW at 960 MHz and exceeds 240 mW over a 200 MHz frequency band.

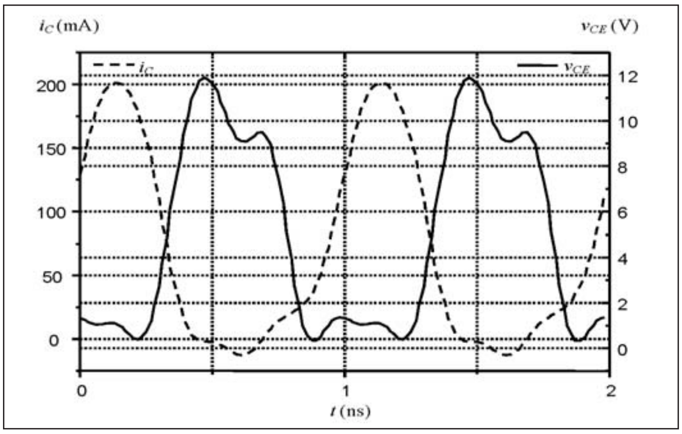

Figure 8 · The simulated collector current and collector-emitter voltage waveforms.

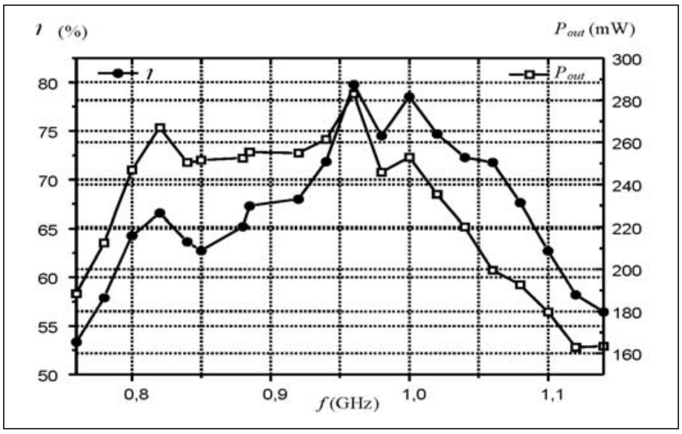

Figure 9 · The simulated amplifier output power and collector efficiency versus frequency.

Conclusion

This paper shows the advantages of using the double-period structures as output networks for polyharmonic power amplifiers. With acceptable characteristics in both the pass band and in the rejection band, the ESB network allows amplifier design with high efficiency over a wide frequency band.

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