Chapter 4

PBG STRUCTURE AS AMPLIFIER OUTPUT NETWORK

1. DESIGN CONCEPT

Producing the short circuit at even and the open circuit at the odd harmonics to the active device output (class F operation) can substantially increase efficiency of power amplifier[29,30]. With such a harmonic tuning, the voltage across active device output and current through it do not contain harmonics of the same order simultaneously. Practically, it is very difficult to control impedances for infinite number of harmonics, so usually the so-called Third-harmonic Peaking tuning is used. In this case the input impedance of output network is controlled up to the third harmonic. Increase in the number of higher harmonics taken into account leads to noticeable efficiency increase.

Recently, photonic band-gap (PBG) and defected ground microstrip structures have been proposed as a novel way to accomplish the filtering providing a broad rejection band. Such structures can be successfully used as the output networks of high-efficiency power amplifiers. As it was suggested[31], terminology "photonic band-gap" should be avoided and more appropriate one should be used: electromagnetic stop-band (ESB). The new proposed terminology seems to be more common for microwaves, so it is used for novel structures.

The two main types of PBG microstrip structures were considered in the publications[32-43]: with holes in a ground plane, and with holes in a dielectric substrate. The shapes of holes vary from simple round and rectangular[32-34] to the different special forms[35-42].

While utilizing as the filters, such structures provide wider and dipper stop band than the original microstrip ones. The above properties can be explained by the photonic band-gaps[43] due to the periodical shape locations.

The known Bragg equation can be used for the structure period definition[43]:

$$2d\sin\theta = k\lambda\,,\ d = k\frac{\lambda}{2}\,, \tag{4-1}$$

where d is the period of structure, k is the integer number, λ is the wavelength in the media, $\theta = 90°$ is the grazing angle. Equation 4-1 presents the equality between the longitudinal period of structure and the integer number of half-wavelength. Using Eq. 4-1, the period of structure with the photonic band-gap close to certain central frequency can be calculated. However, the stop-band width and deepness as well as pass-band characteristics depend not only on the structure period, but also on the hole shape and size, and number of holes.

The idea of using the PBG-structures as the output networks of power amplifiers was presented by Radisic et al.[32,33]. The proposed structure[32,33] is shown in Fig. 4-1.

The structure was formed by the lattice of round holes in the ground plane of microstrip line. It was noted, that the optimal output network characteristics could be obtained for the relation of a hole radius to structure period from 0.15 to 0.25. Smaller relation gives reduced perturbation, but also reduced stop-band dip, while greater relation produces unsatisfactory big ripples in the pass band[33].

Karmakar et al.[34] present another variant of round-hole PBG microstrip structure (Fig. 4-2). In this case, the radius of holes varies longitudinally proportionally to the binomial or Chebyshev coefficients.

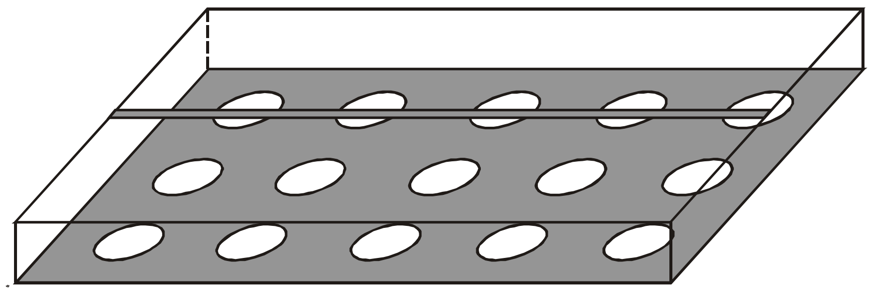

Figure 4-1. PBG structure[32,33].

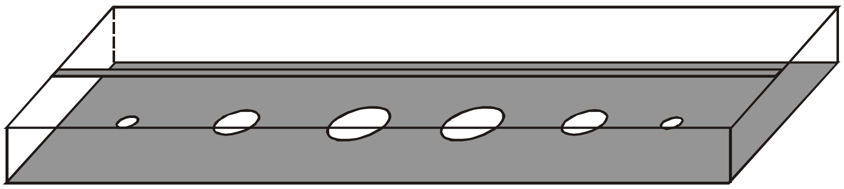

Figure 4-2. PBG structure with longitudinally varying round holes[34].

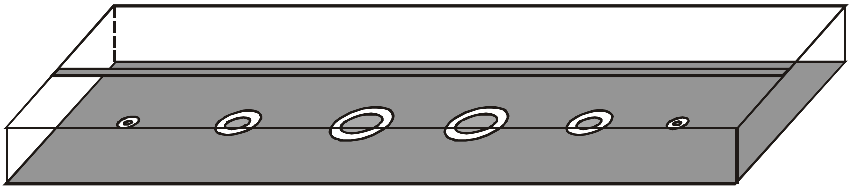

Figure 4-3. PBG structure with longitudinally varying ring holes[34].

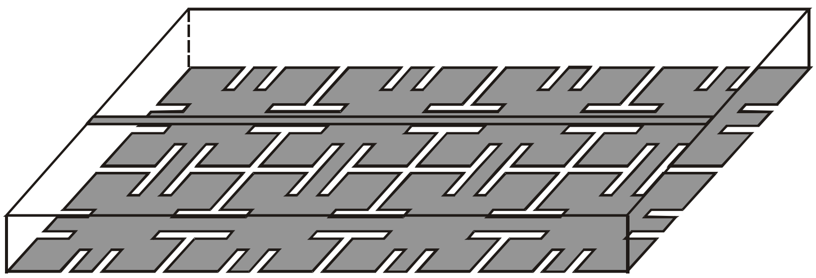

Figure 4-4. Compact PBG structure[35-37].

As it was shown[34], such choice of holes' sizes provides the lower ripples' values in the pass-band, as well as wider stop-band; and further characteristics' improvement could be achieved by implementing the ring shape of holes (Fig. 4-3).

The next issue under consideration was the size of PBG structures. Yang et al.[35-37] proposed compact variant with ground plane consisted of metal pads connected by narrow lines as shown in Fig. 4-4. Thus, this structure presents distributed LC-network properties and has much smaller size compared with the above ones (Figs. 4-1 - 4-3).

The so-called Defected Ground Structure (DGS) proposed by Ahn et al.[38] is shown in Fig. 4-5. In distinction from ESB variant, that is theoretically infinite, DGS has the limited number of sections a priory. This assumption can be used to obtain a simple equivalent circuit of DGS.

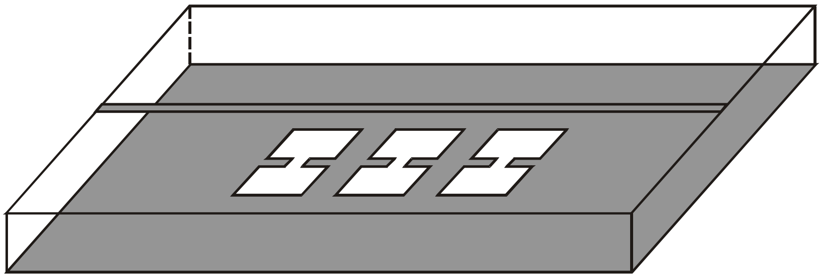

Figure 4-5. Defected Ground Structure[38].

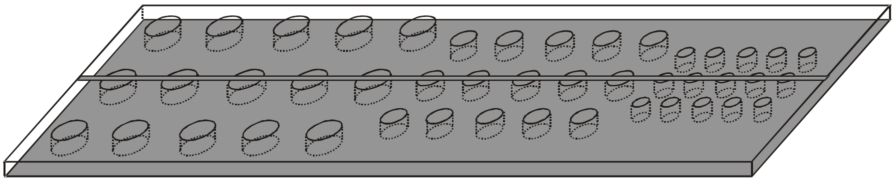

Figure 4-6. Series combination of several PBG sections[41].

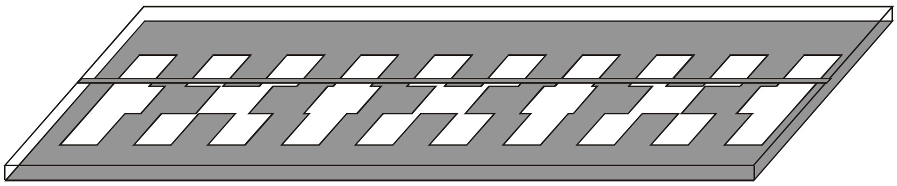

Figure 4-7. Parallel combination of several PBG sections[42].

The DGSs as it is shown in Fig. 4-5 were utilized by Lim et al.[39,40] for reducing the size of high-efficiency power amplifiers.

The attempts to further extension of stop-band were made by Rumsey et al.[41] (Fig. 4-6) and Kim et al.[42] (Fig. 4-7). Their structures are combined by several PBG-sections with different periods. The variant[41] presented in Fig. 4-6 reflects the series combination, while the Fig. 4-7 shows the parallel case[42]. Providing almost the same stop-band properties, the second structure has obvious advantage of smaller overall size.

Except a few publications[35-37], no special attention was given to the pass-band characteristic. However, it plays a significant role in a power amplifier design. In order to achieve high amplifier efficiency, an output network should provide acceptable matching at the fundamental frequency. Therefore, insertion loss in the pass-band should be as small as possible.

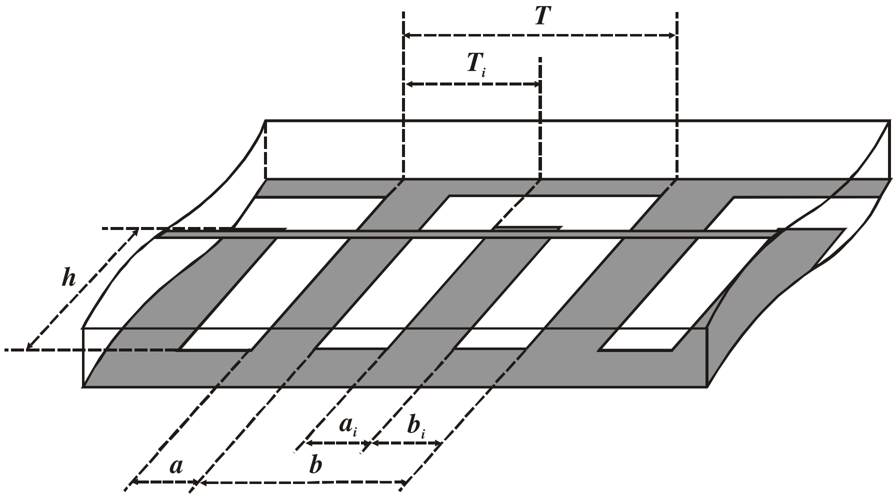

Figure 4-8. Proposed double-period ESB structure.

The ESB structure shown in Fig. 4-8[44] was designed taking into account the pass-band requirements. The main idea is that it has several divisible periods. The simplest variant of the proposed approach (Fig. 4-8) consists of two periods, one of which is twice as much as the other. So the shape of holes in the ground plane looks like Π.

The holes sizes are chosen so that the structure has one period on one side of the strip:

$$T = a + b \tag{4-2}$$

and twice lower period on the other side:

$$T_i = \frac{T}{2} = a_i + b_i\,. \tag{4-3}$$

Thus, for given *T* and *b*, other sizes can be calculated as:

$$a = a_i = T - b\,, \tag{4-4}$$

$$b_i = \frac{b - a_i}{2} = b - \frac{T}{2}\,. \tag{4-5}$$

2. DOUBLE-PERIOD FIFTH-HARMONIC PEAKING ESB NETWORK.

Simulated scattering parameters of the proposed three-section double-period ESB are shown in Fig. 4-9. It can be seen, that three-stage structure presents the matching at the fundamental frequency (~850 MHz) and rejects the higher harmonics up to five. Therefore, Fifth-Harmonic Peaking[21] for power amplifier can be realized.

In order to show the benefits of double-period configuration, several simulations were conducted for different holes' shapes and sizes (Figs. 4-10 - 4-12).

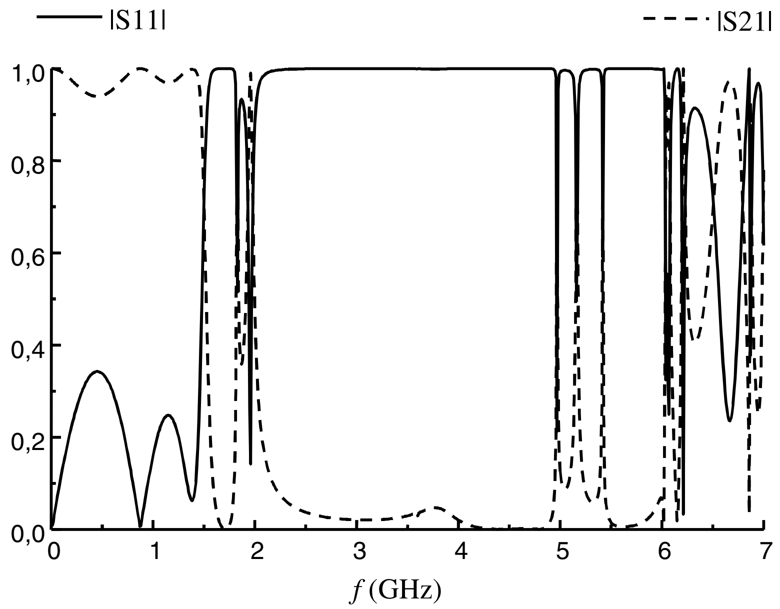

Figure 4-9. Scattering parameters of considered structure.

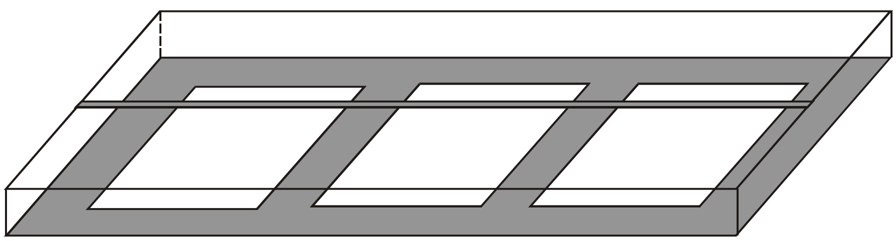

Figure 4-10. Square-shape structure.

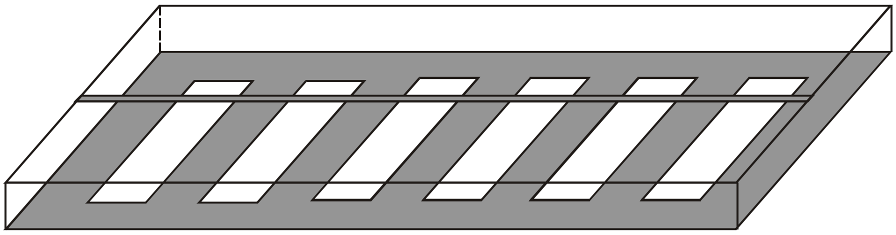

Figure 4-11. Rectangular-shape structure.

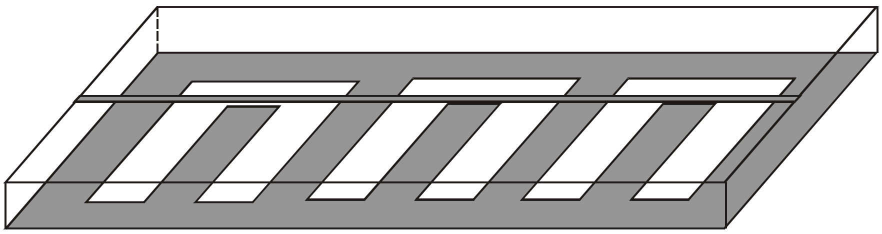

Figure 4-12. Double-period structure.

The simulation results are shown in figures 4-13 - 4-15. For all figures, solid line means double-period configuration with Π-shaped holes, while dashed and dash-and-dot ones mean rectangular holes single-period configurations with the periods T_i and T, respectively. The Fig. 4-13 relates to the h = 16 mm, and Fig. 4-14 and 4-15 – to the h = 18 mm and h = 20 mm, correspondingly. The figures show, that using Π-shaped holes instead of simple rectangular ones let achieve better characteristics both for pass band and for 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 number of sections in the finite periodic structure. Therefore, for six-sections structure there are five ripples in the pass band. The amplitude of ripples usually decreases with the increase of their number, i.e. with increase of sections in a structure. Nevertheless, simple increasing of sections' number leads to simultaneous increase of the size and height of overall construction. However, as it can be seen in Figs. 4-13 - 4-15, using the proposed double-period structure allows to obtain low amplitude of ripples in the pass band without the number of sections increased.

In the rejection band, the characteristics of the double-period structure become similar to ones of the single-period structure with period T, and even better.

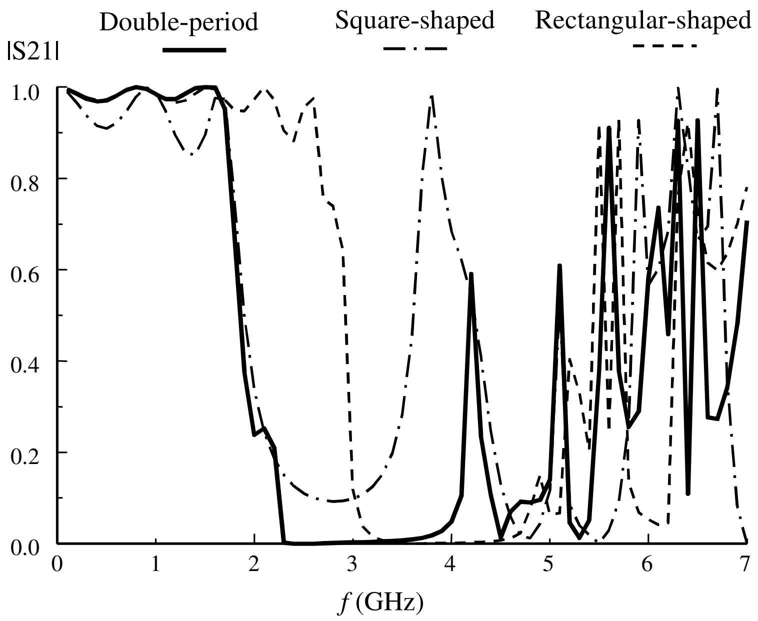

Figure 4-13. Insertion loss of ESB structures with h = 16 mm.

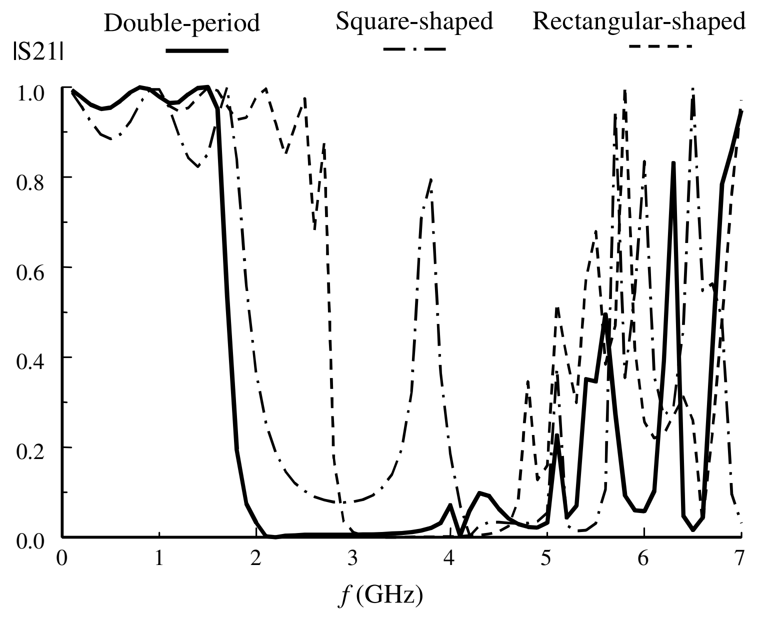

Figure 4-14. Insertion loss of ESB structures with h = 18 mm.

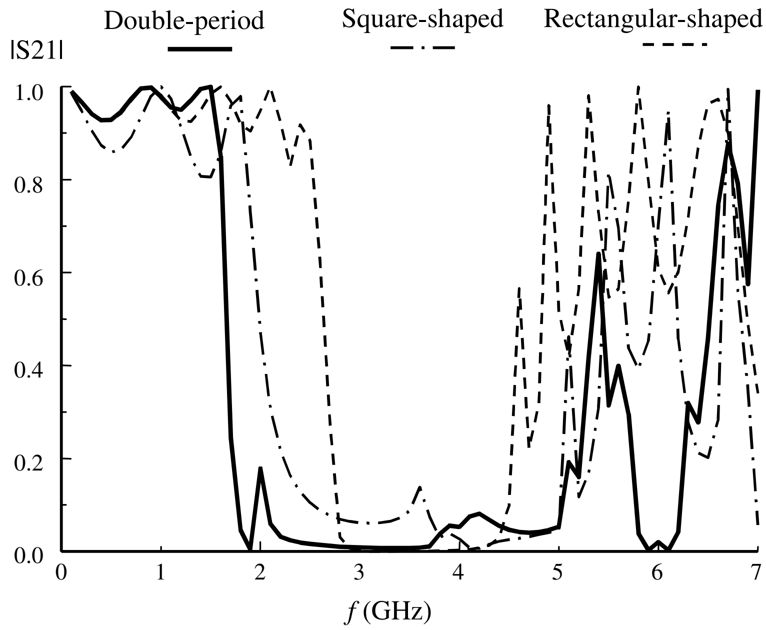

Figure 4-15. Insertion loss of ESB structures with h = 20 mm.

3. EXPERIMENTAL VERIFICATION RESULTS

In order to verify simulation results, three different ESB structures (Figs. 4-16 - 4-18) were fabricated and measured.

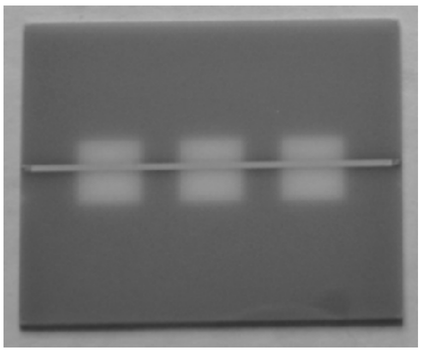

Figure 4-16. Fabricated square-shape ESB structure.

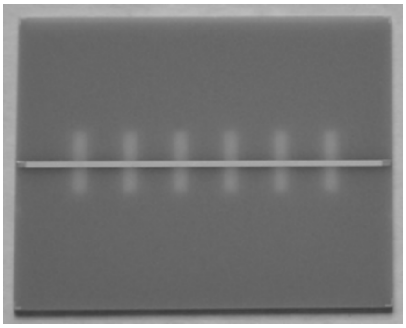

Figure 4-17. Fabricated rectangular-shape ESB structure.

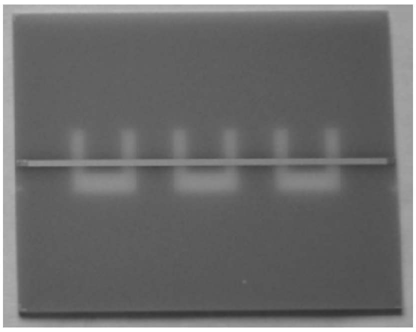

Figure 4-18. Fabricated double-period ESB structure.

Insertion losses of these structures are shown in Figs. 4.19, 4.20.

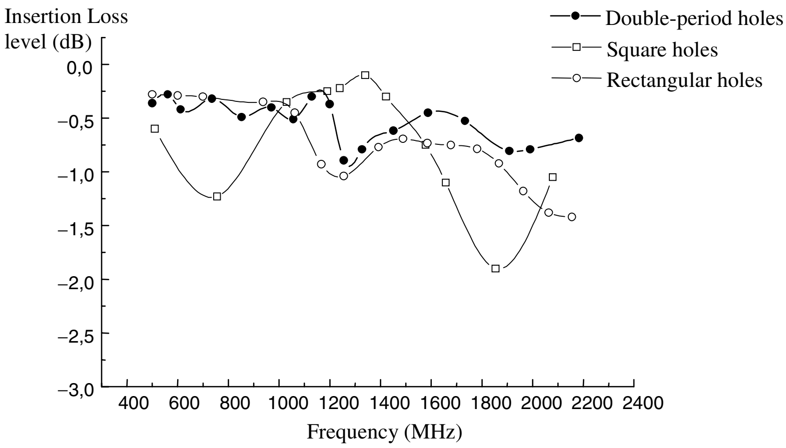

Figure 4-19. Insertion Loss in the pass-band.

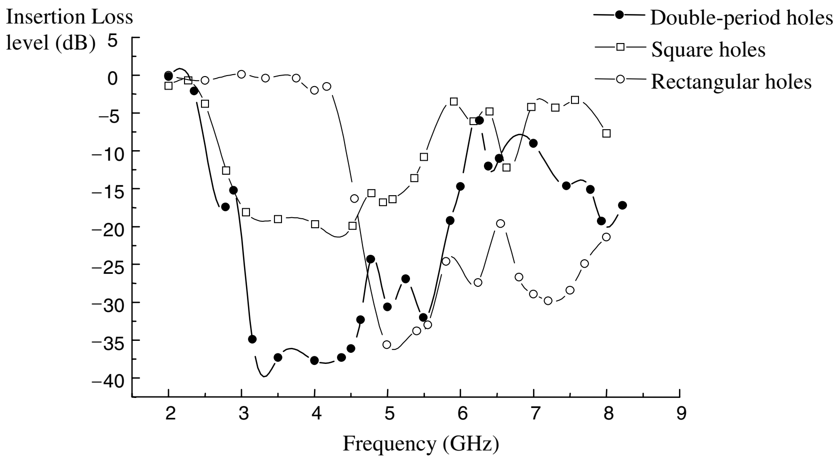

Figure 4-20. Insertion Loss in the rejection band.

One can note, as were predicted by simulations, that the stop-band of the double-period structure is defined by bigger period, while ripples in the pass band are almost the same as for the structure with lower period. Therefore, the proposed structure has the improved characteristics both in stop band and in pass-band, and can be successfully utilized as output network of high-efficiency power amplifier.

4. SUMMARY

The current methods of microwave power amplifiers output networks design utilizing the photonic band-gap structures are considered. Application of such networks is useful and promising due its unique stop-band properties and fabrication simplicity.

The simulation and experimental investigation results of novel two-periods microstrip PBG-structure are presented. The three-section structure prototype has the satisfactory characteristics in the pass-band (see Fig. 4-19), and wide and deep stop-band (see Fig. 4-20).