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Power Divider Based on Stepped-Impedance Slotline

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Abstract—A novel 180° out-of-phase power divider based on stepped-impedance slotline is presented in this article. This power divider employs one T-junction formed by microstrip line and slotline to obtain two out-of-phase dividing signals. Stepped-impedance slotline and lumped resistor are introduced to improve the isolation between output ports. The experimental data show that the proposed power divider has good performance on insertion loss, return losses, isolation, phase balance, as well as group delay over the wide band 5 GHz–10 GHz.

1. INTRODUCTION

Power divider is one of the most crucial passive components in modern wireless communication systems. As all know, Wilkinson power divider is the most classical power divider. Up to now, there have been number of improved Wilkinson power dividers being proposed [1–5]. With the research on slotline techniques, various power dividers based on slotline techniques have been designed [6–8]. By utilizing microstrip-to-slotline coupling structure [9–13], some UWB multilayer power dividers have been proposed in [14–19]. According to the phase difference between output ports, the slotline power dividers can be classified in-phase power dividers and out-of-phase power dividers. Due to the opposite directions of output ports towards, the phase difference of two dividing signals is 180° for the power dividers based on slotline techniques in [6–8, 14–16]. In-phase dividing signals can be obtained as long as the two output branches are placed in the same direction like the ones in [17–19]. In [6], an out-of-phase power divider based on slotline techniques was designed. This slotline power divider consisted of one microstrip-slotline transition and one T-junction that formed by microstrip line and slotline. The input signal was fed from one microstrip-slotline transition, and was divided into two signals by the T-junction. Because of the symmetric structure, the amplitude and phase balances of the power divider were almost perfect in the UWB frequency band (3.1 GHz–10.6 GHz). What's more, due to the impedance matching, the return loss at input port is excellent. The slotline power dividers proposed in [7, 8], which were similar to the one in [6], can be regarded as the improved structures of the one in [6]. In order to improve the performance, slotline power divider designed in [14] employed multilayer structure. The two output branches that terminated with circular microstrip stubs which acted as compensatory circuits were split and placed in top layer and bottom layer, respectively. Comparing with the power divider in [6], the performance of this power divider, such as return losses at all ports, has been improved. However, the isolation between output ports and return losses at output ports were greatly poor because of the inherent property that a reciprocal and lossless three-port network cannot acquire good return losses at all ports.

In order to improve the isolation and return loss at output ports, some properties must be sacrificed. In order to simplify the design, the lossless property is usually sacrificed by introducing one lumped resistor. According to this principle, another three novel in-phase slotline power dividers with isolation

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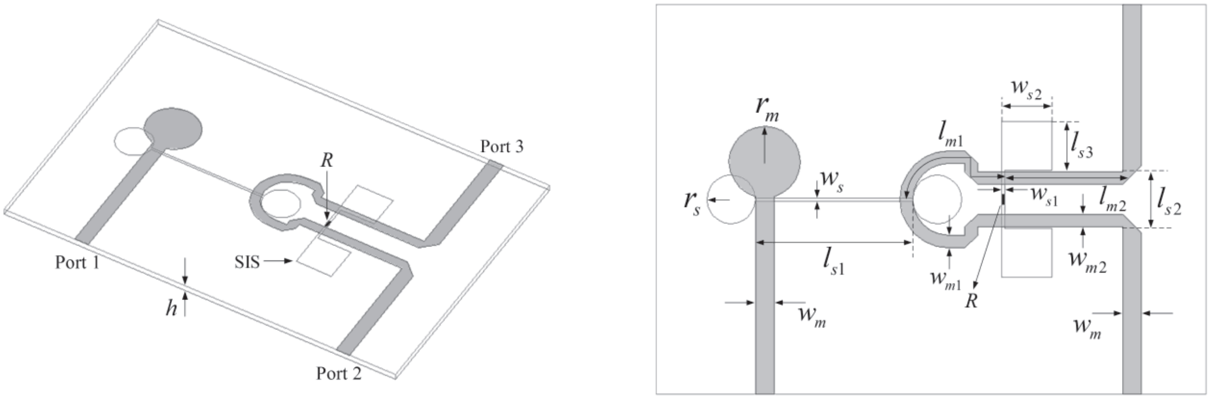
resistors have been presented [17–19]. The lumped resistors introduced in these power dividers all were embedded in the holes that were drilled in the substrates. As to the isolation of out-of-phase power divider, it is almost difficult to improve by using simple structure. Because if one lumped resistor is installed on output microstrip branches directly like the Wilkinson power divider or the in-phase slotline power dividers proposed in [17–19], there will be a current flowing through the lumped resistor when the out-of-phase power divider works, which will result in a large insertion loss. In [20, 21], A two-way out-of-phase power divider and a three-way out-of-phase power divider based on double-sided parallel striplines (DSPSL) were designed. Their isolations were improved by bridging the isolation resistors across the slots that divided the ground plane into two parts. However, these out-of-phase power dividers were not slotline power dividers. What's worse, the lumped resistors were difficult to embed in the ground plane which locating in the middle layer.

In this article, a wideband 180° out-of-phase power divider is proposed by using microstrip-to-slotline transition and simple designing rules. Stepped-impedance slotline (SIS) [22–25] and one lumped resistor are introduced to improve the isolation between out-of-phase output ports. Simulated and measured results, which exhibit a good agreement, show that the proposed power divider has good return loss, high isolation, excellent phase balance, as well as flat group delay over the band 5 GHz–10 GHz.

2. POWER DIVIDER DESIGN AND DISCUSSION

The proposed novel 180° out-of-phase slotline power divider with high isolation is exhibited in Figure 1. A basic T-junction, which is a microstrip-to-slotline transition in essence, formed by microstrip line and slotline, is utilized to realize out-of-phase power dividing. Another microstrip-to-slotline transition is designed to convert the input port from slotline type to microstrip type. The input microstrip branch is terminated with one circular microstrip stub and the slotline is terminated with two circular slotline stubs. No matter the capacitive microstrip circular stub or the inductive slotline circular stubs, they all act as compensatory circuits to improve the performance of microstrip-to-slotline transition.

SIS has been studied and utilized in some designs, such as the resonators in [22, 23, 25] and the diplexers in [24]. However, study about applying SIS on power divider has not been done up to now. In this design, a SIS is introduced and etched under the output branches. Besides, one lumped resistor is introduced and bridged across the sides of SIS to improve the isolation of the out-of-phase slotline power divider proposed in this paper. In order to understand the working process detailedly, odd-mode and even-mode analysis method can be applied to this power divider. When odd-mode signals are fed to the output ports, the phase difference between two output branches is 180° and there is no current flowing through the resistor. Whereas there is a current flowing through the resistor when even-mode signals fed to the output ports. These features are opposite to the in-phase power dividers with lumped



(a) (b)

Figure 1. Configuration of presented out-of-phase power divider. (a) 3D view. (b) Top view.

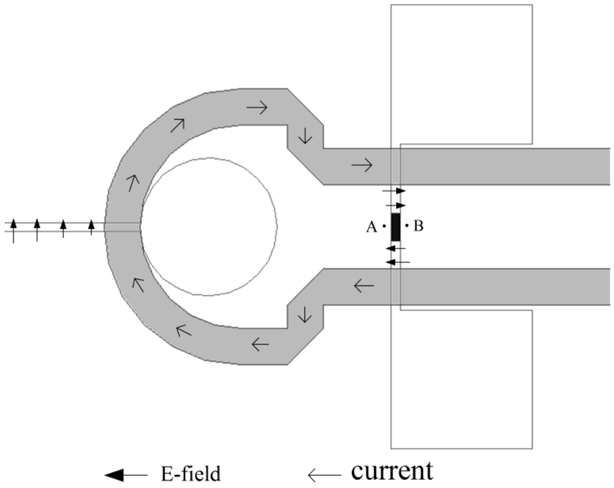


Figure 2. Rough distribution of E-field and current when the power divider works.

resistors like Wilkinson power dividers. Figure 2 shows the rough schematic diagram with E-field and current when the power divider works. It is obvious that the voltages at point A and point B are equal. Therefore, there is no current flowing through the resistor the power divider works. In addition, Quarter-wavelength transitional output branches are employed to convert the impedance so that good return losses can be obtained at all ports. What's more, to simplify the design procedure, the width of transitional microstrip lines w_{m1} and w_{m2} are selected as the same value.

Having studied the principle of operation of the slotline power divider, a simple designing procedure can be utilized to its design. For the sake of cascading with other devices or systems, the width of input and output branches w_m is selected as $50\,\Omega$. The length of slotline l_{s1} is chosen as about a quarter wavelength at center frequency. While the length of transitional output branches l_{m1} and l_{m2} are selected to be about a quarter wavelength at center frequency. The radius of r_m and r_s usually are chosen to be approximately $\lambda_m/12$ and $\lambda_s/24$, respectively. λ_m and λ_s are the guided wavelength of microstrip line and slotline respectively. In order to obtain good impedance matching between microstrip line and slotline, their characteristic impedances (Z_m, Z_s) should satisfy the following expression [6].

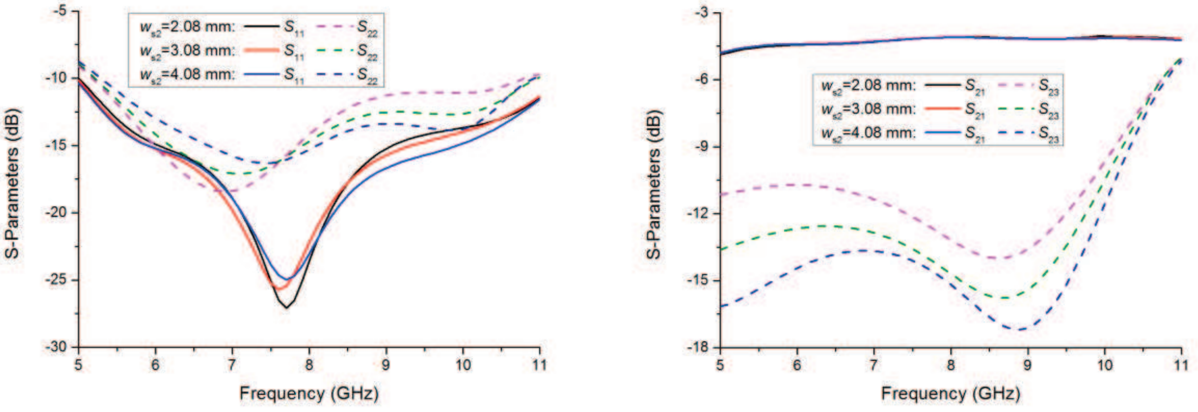
$$Z_m = Z_s \times n^2 \tag{1}$$

where n is coupling coefficient between slotline and microstrip line, which can be derived from [10]

$$\begin{cases} n = \cos\left(\dfrac{2\pi h u}{\lambda_0}\right) - (\cot q)\cdot\sin\left(\dfrac{2\pi h u}{\lambda_0}\right) \\ q = \dfrac{2\pi h u}{\lambda_0} + \arctan\left(\dfrac{u}{v}\right) \\ u = \sqrt{\varepsilon_r - \left(\dfrac{\lambda_0}{\lambda_s}\right)^2} \\ v = \sqrt{\left(\dfrac{\lambda_0}{\lambda_s}\right)^2 - 1} \end{cases} \tag{2}$$

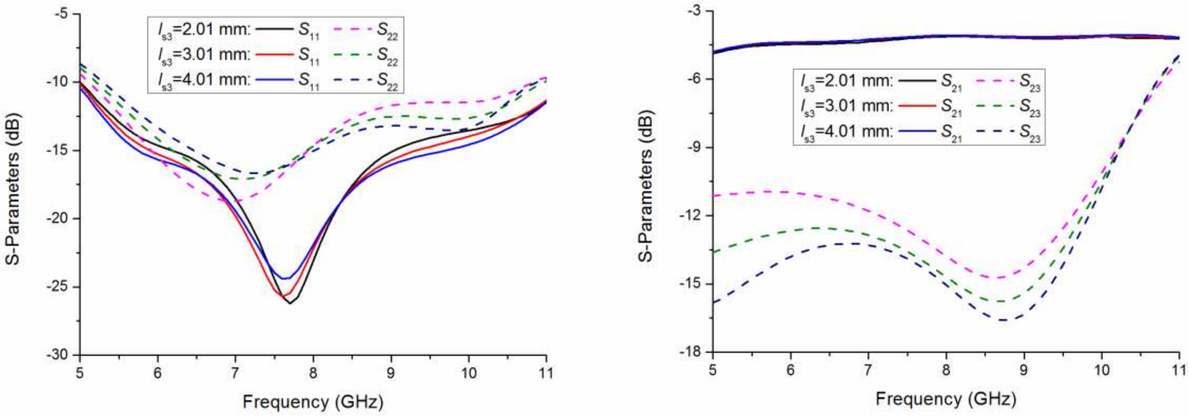
where h is the thickness of substrate. λ_0 the guided wavelength at center frequency in air, and λ_s the effective wavelength of slotline at center frequency point.

The dimensions of SIS are associated with the characteristic impedance of transitional output branches and value of lumped resistor. In this design, the value of lumped resistor is chosen as $100\,\Omega$, which is motivated by the similar reasoning as in Wilkinson power divider. In order to understand the influence of SIS on the performance of the proposed slotline power divider in detail, some simulation analyses with different dimensions are finished. Figures 3–6 exhibit the influence on frequency response



(a) (b)

Figure 3. The influence of w_{s2} on frequency response. (a) Influence on return losses at input and output ports. (b) Influence on insertion loss and isolation.



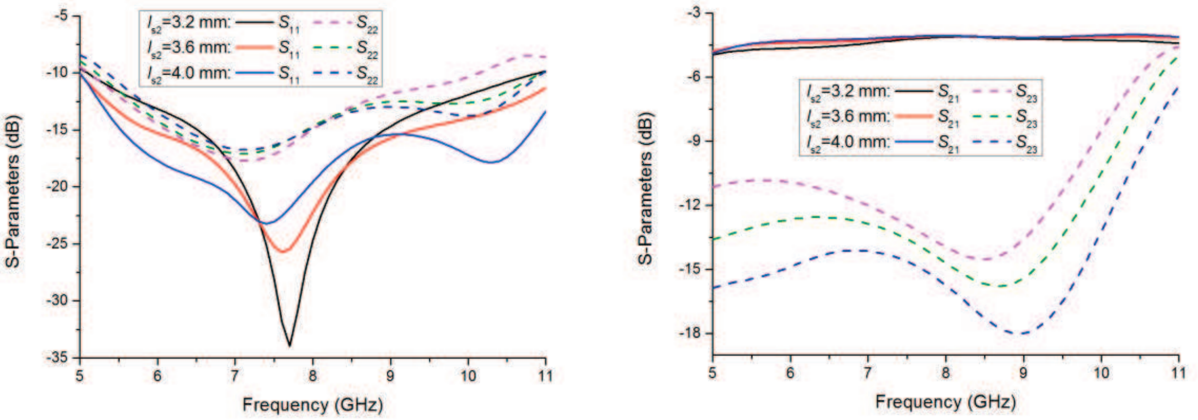
(a) (b)

Figure 4. The influence of l_{s3} on frequency response. (a) Influence on return losses at input and output ports. (b) Influence on insertion loss and isolation.

with different dimensions. The influence of the width of SIS w_{s2} on frequency response is studied in Figure 3. It is obvious to find that the influence on return loss at input port and insertion loss is negligible. Nevertheless, with the increase of w_{s2}, the frequency response of return loss at output port (S_{22}) will move towards high frequency. And with the decrease of w_{s2}, the frequency response of isolation (S_{23}) will be worsen. The length of SIS l_{s3} is also studied in Figure 4. Its frequency response on different dimensions is similar to w_{s2}. With different length, the return loss at output port and isolation are different.

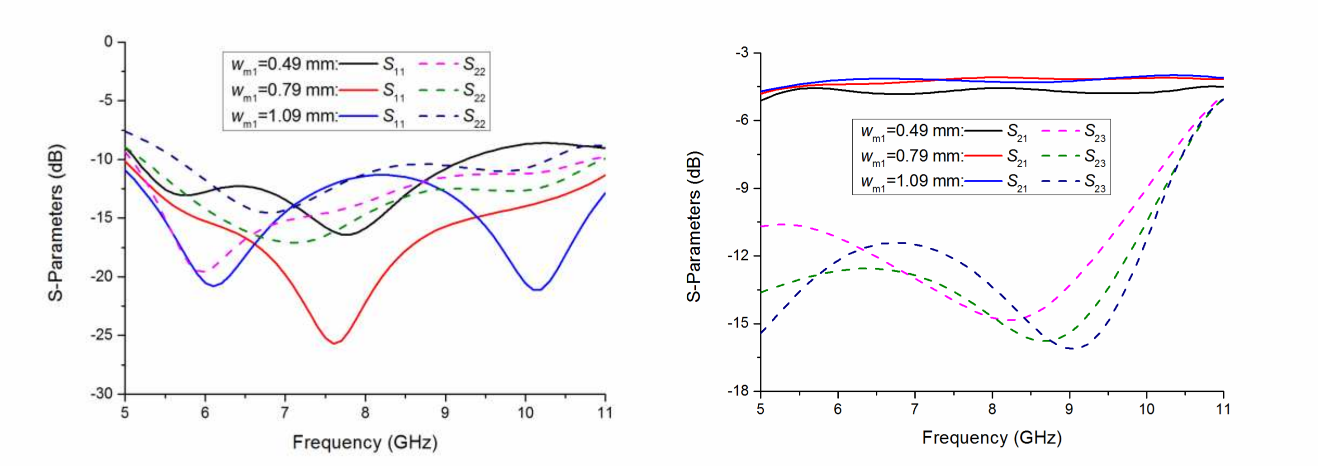
In Figure 5, another parameter of SIS l_{s2} is researched. Different from parameters w_{s2} and l_{s2}, the change of l_{s2} will not only affect the isolation and return loss at output port, but also influence the insertion loss and return loss at input port, because the change of l_{s2} will give rise to impedance mismatching.

In Figure 6, the influence of the width of transitional output branches w_{m1} on the performance of the proposed power divider is also studied. As we all know, for the same substrate, the wider the width is, the greater the impedance is. Thus, the change of w_{m1}, even though the change is slight, will result in impedance matching. Comparing with the simulation results shown in Figures 3–5, we can find that the impact from the change of w_{m1} is far more than the ones from the change of w_{s2}, l_{s3} or l_{s2}.



(a) (b)

Figure 5. The influence of l_{s2} on frequency response. (a) Influence on return losses at input and output ports. (b) Influence on insertion loss and isolation.



(a) (b)

Figure 6. The influence of w_{m1} on frequency response. (a) Influence on return losses at input and output ports. (b) Influence on insertion loss and isolation.

3. EXPERIMENTAL RESULTS

This novel power divider is fabricated on Rogers 4350B with relative dielectric constant of 3.48, thickness of 0.508 mm, and loss tangent of 0.004. Its photographs are shown in Figure 7. The dimensions of the power divider are listed as (unit: mm): $r_m = 2.2$, $r_s = 1.5$, $w_m = 1.15$, $w_s = 0.19$, $l_{s1} = 9.73$, $w_{m1} = 0.79$, $l_{m1} = 7.47$, $w_{s1} = 0.2$, $w_{s2} = 3.08$, $l_{s2} = 3.6$, $l_{s3} = 3.01$, $w_{m2} = 0.79$, $l_{m2} = 7.26$. What's more, the lumped resistor R is selected to be $100\,\Omega$.

Figures 8(a) and (b) exhibit the simulated and measured results of the novel out-of-phase slotline power divider, respectively. Comparing Figures 8(a) with 8(b), we can find that the measured results show a good agreement with the simulated ones. The errors between them result from machining error and soldering error. For the band from 5 GHz to 10 GHz, the simulated and measured return losses both are better than 11 dB at input port, while the simulated and measured ones at output ports are approximately 10 dB and 15 dB, respectively. The simulated isolation between out-of-phase output ports is more than 12 dB for the same band, which is better than the measured one about 1 dB. Besides, the measured insertion loss is about 1 dB ± 0.5 dB over the wide band 5 GHz–10 GHz, while the simulated

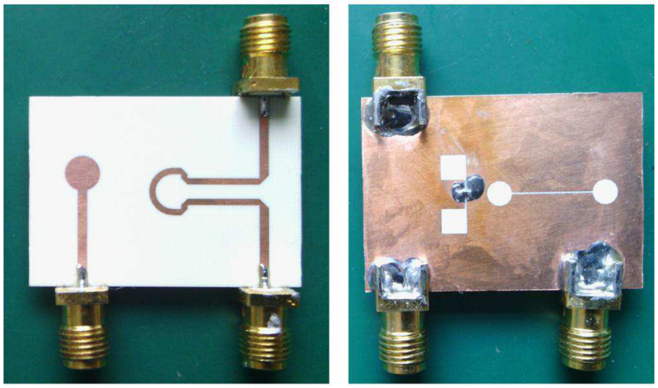
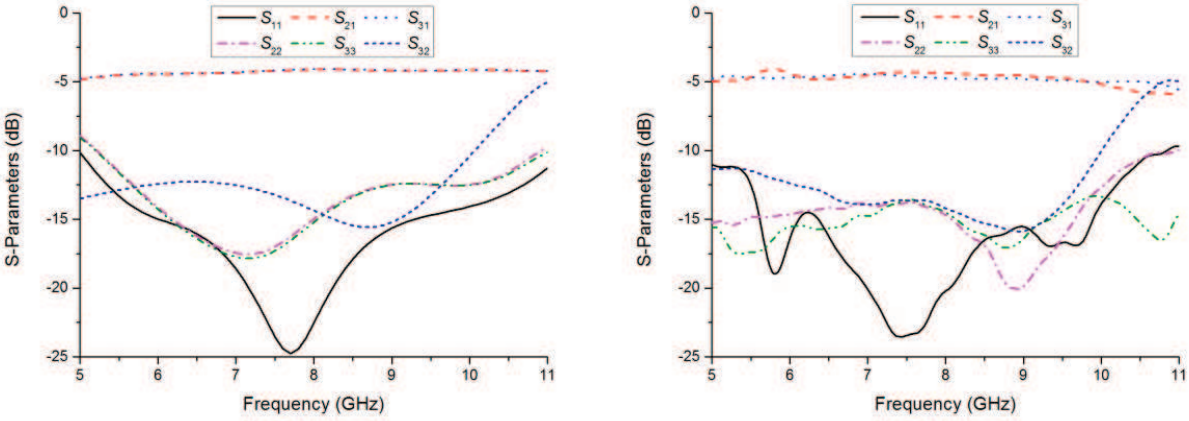

(a) (b)

Figure 7. Photograph of designed power divider. (a) Top view. (b) Bottom view.



(a) (b)

Figure 8. Experimental results of return loss, isolation and insertion loss. (a) Simulated results. (b) Measured results.

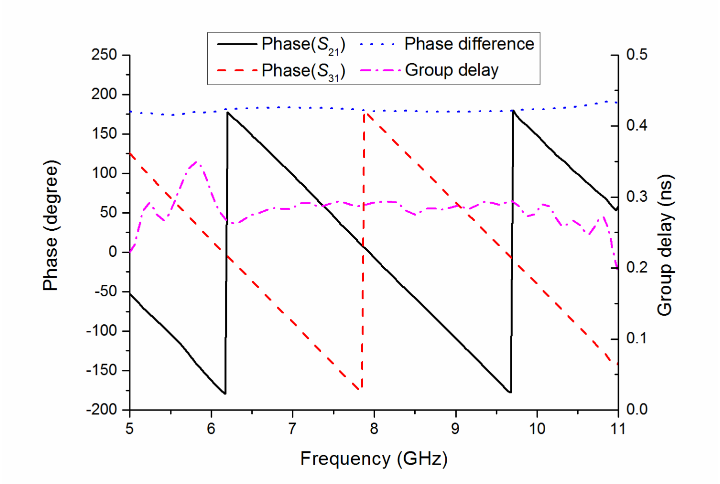


Figure 9. Measured phase difference and group delay.

one is approximately 1 dB ± 0.3 dB. In addition, The measured phase difference and group delay are shown in Figure 9, which shows that the phase difference is about 180° ± 3° and exhibits that the group delay is greatly flat with maximum peak-to-peak value of 0.15 ns for range from 5 GHz to 10 GHz.

4. CONCLUSION

A novel out-of-phase slotline power divider based on SIS is studied and designed. The simulated and measured results, which exhibit a good agreement, indicate that the proposed out-of-phase power divider has good return loss at all ports, high isolation and excellent phase balance between output ports, as well as flat group delay over the range 5 GHz–10 GHz.

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