Harmonic suppressed and shrunken Gysel power divider with plain structure

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Abstract

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Utilizing several stubs at the input and output ports of the conventional Gysel power divider, this paper presents a novel scheme of a shrunken Gysel power divider featuring plain structure and harmonic suppression. One other significant feature is precise closed-form equations attained by the principles of matching and isolation. To demonstrate the functionality and soundness of design, a microstrip implementation of this design operating at 1 GHz with the second and third harmonic suppression is developed. Simulation and measurement results for the proposed scheme, which are highly consistent with one another, indicate good insertion loss, return loss, isolation, while sustaining high-power handling capability over the Wilkinson power divider.

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1. Introduction

As microwave systems and components, such as feeding networks for antenna arrays, power amplifiers, and mixers have advanced in several aspects, so have power dividers and combiners as integral parts microwave systems. During past several years, researchers have taken heed to the development of the Wilkinson power divider [1] in various aspects. However, the Gysel power divider [2], playing a crucial role in high-power microwave systems, is partially overlooked owing to its relatively enormous size and more complex structure than the Wilkinson power divider. Either type of these dividers suffers from the presence of odd harmonic responses because of exploiting quarter wavelength transmission lines. Hence, studies to ameliorate the functionality and performance of these two types in terms of miniaturization and harmonic suppression are still underway.
Among the most prevalent methods of miniaturization and harmonic suppression, Electromagnetic Band Gap (EBG) [3-7], additional stubs [8-9], Defected Ground Structure (DGS) [10-11], and lumped elements [12] are outstanding ones. On the other hand, the power-handling capability is substantially restricted inasmuch as all of these means are conducted on the Wilkinson power divider. Recently, an unequal Gysel power divider with harmonic suppression and simple design was proposed in [13]. This structure is still bulky with restricted ratio of power division.

In this paper, a plain topology of a miniaturized Gysel power divider featuring harmonic rejection and equal-split power division is expounded. Three additional stubs, incorporated into the conventional layout, contribute to the realization of compact size, harmonic suppression, the capability of handling high power, and accurate closed-form formulas.
2. Design prototype and its analysis

The proposed design is illustrated in Figure 1 in which the two open-circuit ($z_0, \pi/4$) and one short-circuit ($z_s, \pi/3$) stubs are used. The role of these stubs is adding transmission zeros to the response of the conventional power divider in conjunction with miniaturization. Note that all the impedances used in this paper are in the normalized form regarding port 1 impedance as the reference. The method of even and odd-mode analysis can lead to obtaining all the unknown parameters as rendered below.

The equivalent circuit of the presented design in the case of even-mode is depicted in Figure 2(a). Under this condition, thanks to the exploitation of the quarter wavelength transmission line ($z_3, \pi/2$), any power dissipation can be avoided on isolation resistors. Figure 2(b), on the other hand, provides an illustration of the odd-mode case in which the mid-plane is short-circuit. Note that the value of $z_3$ only have an impact on the bandwidth and can arbitrarily be selected such that the lower the value of $z_3$, the higher the bandwidth. Evidently, $z_3=0.4$ can provide higher bandwidth [2]. Even-mode case can produce the following equation

\[
jy_b - jy_y \cot \psi + \frac{y_1 (\frac{1}{2} - j \frac{y_A}{2} + jy_y \tan \varphi)}{y_1 + j(\frac{1}{2} - j \frac{y_A}{2} \tan \varphi)} = 1. \tag{1}
\]

Moreover, odd-mode case matching condition leads to obtaining the following equation

\[
jy_b - jy_y \cot \varphi + \frac{y_2 (1 + jy_y \tan \psi)}{y_2 + j \tan \psi} = 1. \tag{2}
\]

If we divide equation (1) into real and imaginary parts and solve the real part, the following equation is obtained

\[
y_2 = (y_a + y_b + y_1 \cot \varphi) \tan \psi. \tag{3}
\]

If we substitute $y_2$ obtained from Equation (3) for $y_2$ in Equation (2) and solve the real part of Equation (2), $y_b$ is as follows

\[
y_b = y_1 \cot \varphi \tag{4}
\]

Also, $y_a$ is simplified from solving the imaginary part of Equation (2) providing that Equations (3) and (4) are used in it.

\[
y_a = -2y_1 \cot \varphi + \frac{\sqrt{2} \cos \psi}{\sqrt{(1-\cos(2\psi))}} \tag{5}
\]

If we substitute parameters obtained from Equations (3)-(5) for such parameters in Equation (1) and solve the real part of Equation (1), $y_1$ is as follows

\[
y_1 = \frac{\sin^2 \varphi}{\sqrt{(1-\cos(2\psi))}} \tag{6}
\]
Ultimately, all the impedance values are obtained as follows:

\[ z_2 = \frac{1}{y_2}, \quad z_1 = \frac{1}{y_1} \]  
\[ z_o = \frac{1}{y_b} \]  
\[ z_s = \frac{1}{\sqrt{3}y_a} \]

(7)  
(8)  
(9)

In (1)-(9), \( \phi \) and \( \psi \) are the two free variables in this design. Intense investigation shows that their electrical lengths can easily be chosen under 90 degrees. This, in turn, leads to inadvertent miniaturization which is highly demandable for Gysel power divider design.

A for high-power handling capability, extra heat can be conducted to the surrounding environment through two external isolation resistors with a direct route for heat sinking. However, the Wilkinson power divider employs just one isolation resistor between its internal lines, thereby impeding the heat transfer. After all, the new structure maintains high-power handling capability advantage over the Wilkinson divider.

### 3. Experimental results

For verification, an equal split power divider with \( \phi = 60^\circ, \psi = 30^\circ \) is developed. The remainder of parameters can be attained as \( z_1 = 0.81, z_2 = 1, z_3 = 0.4, z_o = 1.41, \) and \( z_s = 1.81 \) from Equations (1)-(9). Two SMD 0805 resistors with the values of \( r_1 = 51 \, \Omega \) were used for manufacturing. Fabrication was carried out on the dielectric substrate (Rogers RO4003C) featuring dielectric constant of 3.38, thickness of 0.813 mm, and loss tangent of 0.0021. To investigate the correctness and accuracy of the equations and the prototype, simulation was conducted by ADS Simulation software. Figure 3 shows the layout of the prototype and the fabricated power divider. If the port and resistor extensions are to be neglected, the occupied area is about \( 0.189 \lambda g \times 0.345 \lambda g \), where \( \lambda g \) is the guided wavelength at 1 GHz. Agilent E8361C vector network analyzer was used to perform the measurements of scattering parameters over the frequency range of 500 MHz to 3.5 GHz. The measured and simulated results illustrated in Figure 4 are commensurate with one another. 10% fractional bandwidth was observed from measurement results that return loss and isolation at the fundamental frequency are better than \(-15 \, \text{dB} \) over the frequency range from 980 to 1080 MHz. Within this frequency band, the minimal to maximal amplitude variation of \( S_{21} \) is \(-3.1 \) to \(-3.2 \, \text{dB} \). Measurement results show that the attenuation levels for the second and third harmonics (2 and 3 GHz) are \(-37 \) and \(-23 \, \text{dB} \), respectively. The infinitesimal discrepancies between the measured and simulated results are mainly due to the precision of fabrication and the parasitic effects of isolation resistors.
4. Conclusions

A compact Gysel power divider with harmonic rejection band plain structure was presented here in. This design maintained its matching and isolation condition, whereas it added several striking features to the conventional circuit using three extra stubs. A simple equal split Gysel power divider operating at 1 GHz has been fabricated with a standard fabrication process and not including rigorous processes, such as ground etching, multilayer metals, and lumped elements. This, in turn, contributes to the low-cost and easy fabrication process. The simulation and measurement outcomes indicate that this
structure is appropriate for applying in small-sized and high-power handling circuits with harmonic rejection.

References


