A Miniaturized Lumped-element In-phase Power Divider with a Simple Layout

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Abstract—This paper describes a miniaturized lumped-element in-phase power divider with a simple layout. We first propose a miniaturized lumped-element in-phase power divider composed of two inductors, a resistor, and three capacitors. The simulation and experimental results reveal that the proposed power divider will be effective in maintaining isolation between output ports.

Keywords—in-phase; lumped-element; miniaturized; passive circuit; power divider

I. INTRODUCTION

Currently, owing to the emergence of monolithic microwave integrated circuit (MMIC) technology, wireless sensor networks connected with wireless communications of sensor nodes have been attracting attention [1]. For constructing a wireless sensor network in the future by placing many sensor nodes, it is important to suppress the power consumption of the sensor nodes that are placed at several locations.

Similar to remote meter reading of the wattmeter, a sensor node can be placed in locations where electricity can be supplied. However, to improve user convenience by allowing easier placement of the sensor nodes, they are usually placed in locations where no electricity can be supplied. Thus, it is necessary to develop a battery that is functional for several years. The power consumption of the transmitting power amplifier circuit, which is a particularly large power consumer, needs to be reduced.

As an example, Wilkinson power divider circuits are often used for high-output power amplifiers and are applied to MMIC technology [2]. Because the conventional circuit uses two λ/4 distributed transmission lines, the size of the Wilkinson power divider is proportional to the wavelength at the center frequency of f_0. Although there have been many efforts to miniaturize the Wilkinson power divider using three-dimensional (3-D) technologies [3] and capacitive loading [4], the fabrication of a power divider with a chip area suitable for MMIC is still a challenge.

Reducing circuit size by replacing the transmission line sections with lumped-element components has also been attempted [5]. Typical lumped-element Wilkinson power dividers using a lumped-element equivalent π-network and T-network use a resistor, four capacitors, and two inductors [6], [7].

For example, the physical length of a λ/4 coplanar waveguide transmission line on a GaAs substrate (relative dielectric constant: 12.6) at a frequency of 1 GHz is more than 25 mm, whereas the size of the spiral inductor necessary for the lumped-element equivalent π-network or T-network is approximately 0.5 mm × 0.5 mm [8]. Although these lumped-element power dividers can reduce circuit size, their operating frequency ranges are narrower than that of the conventional power divider using two λ/4 distributed transmission lines.

To attain broadband operating frequency characteristics, J. S. Staudinger proposed a bandpass circuit topology based on establishing an impedance transformer network with cascades of low-pass and high-pass lumped elements [9]. A three-way divider operating between 4 and 10 GHz using nine capacitors, seven inductors, and three resistors was fabricated.

In an earlier paper, we proposed miniaturized broadband lumped-element in-phase power dividers with a minimum number of lumped elements [10]. Figure 1 shows the previously proposed miniaturized broadband lumped-element in-phase power divider composed of two inductors, a resistor, and two capacitors. The simulation results revealed that the proposed lumped-element in-phase power divider can help to miniaturize circuits (by decreasing inductances by approximately 30%, reducing the number of necessary capacitors to half, and decreasing necessary capacitances by approximately 30% as compared to conventional lumped-element dividers) and attain broadband frequency characteristics (by increasing the normalized operating frequency bandwidths (f)/f_0 by approximately 80% as compared to conventional lumped-element dividers).

![Figure 1. Previously proposed lumped-element in-phase power divider.](image)

However, for the circuit configuration, if we attempt to miniaturize the circuit by placing L_1 and L_2 in proximity, as shown in Fig. 2 (closer to each other than they are to the...
ground plane), undesired electromagnetic coupling between the two inductors occurs, and isolation characteristics between output ports deteriorate. We have to consider these effects when we design the layout of an MMIC.

This paper describes a miniaturized lumped-element in-phase power divider with a simple layout. First, we propose a miniaturized lumped-element in-phase power divider composed of two inductors, a resistor, and three capacitors. Next, we discuss the simulation performed and the experiment conducted using chip components to confirm the feasibility of the proposed circuit.

\[ R = \frac{2Z_0}{1 + (2\pi f_0)^2 C_2 Z_0} \]  
\[ L_2 = \frac{2C_1 Z_0}{1 + (2\pi f_0)^2 C_2 Z_0} \]

By setting the design parameters \( f_0, Z_0, L_1, L_2, C_1, C_2, \) and \( R \) to satisfy these equations, we can obtain the best performance of the power divider.

If we design the layout of the proposed power divider as shown in Fig. 4, electromagnetic coupling between inductors will be reduced, and the additional transmission lines will be eliminated as compared to the previously proposed power divider.

One common approach to building an N-way power divider is a tree structure. This structure consists of individual two-way dividers connected in a tree-type topology, as shown in Fig. 5. For RF interconnects, these connected transmission lines or inductors are as short as possible to minimize parasitics. The proposed power divider shown in Fig. 3 is preferable to the previously proposed power divider shown in Fig. 1.
III. SIMULATION RESULTS OF THE PROPOSED IN-PHASE POWER DIVIDER

In order to confirm the validity of the proposed circuit configuration described above, the frequency characteristics of the proposed in-phase power dividers were simulated using RF and microwave design software (AWR Microwave Office [13] and Agilent ADS [14]).

Figure 6 shows the simulation results for the proposed lumped-element in-phase power divider shown in Fig. 3. $f_0$, $Z_0$, $L_1$, $L_2$, $C_1$, $C_2$, and $R$ were assumed to be 590 MHz, 50 Ω, 12 nH, 12 nH, 5 pF, 5 pF, and 50 Ω, respectively. The measured S parameters of the chip inductors and chip capacitors were used in the simulation.

For the frequency range of 600 to 660 MHz, the divider exhibits power splits of $-3.2 \pm 0.1$ dB and return losses of greater than 20 dB. Furthermore, isolation between output ports is greater than 20 dB for the frequency range of 580 to 680 MHz.

IV. EXPERIMENTAL RESULTS OF THE PROPOSED IN-PHASE POWER DIVIDER

Next, we fabricated the proposed power divider on an FR4 substrate (3 cm × 3 cm). The dielectric constant and thickness of the substrate were 4.4 and 1.6 mm, respectively. Figure 7 shows the photograph of the fabricated power divider.

Although the amplitude difference between output ports is slightly increased because of the asymmetric layout of capacitor $C_1$, the experimental results are roughly in accordance with the simulation results.

Figure 7. Photograph of the proposed in-phase power divider shown in Fig. 3.
V. CONCLUSION

This paper describes a miniaturized lumped-element in-phase power divider with a simple layout. We proposed a miniaturized lumped-element in-phase power divider composed of two inductors, a resistor, and three capacitors. The simulation and experimental results reveal that the proposed power divider will be effective in maintaining isolation between output ports.

Our next goal is to verify and evaluate the new method in a practical application of the MMIC.

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