INTEGRATED ANTENNAS USING A THREE-PORT 180° ANTENNA HYBRID

Young-Huang CHOU and Shyh-Jong CHUNG
Dept. of Communication Engg., National Chiao Tung University
1001 Ta Hsueh Rd., Hsinchu
Taiwan, R.O.C.
E-mail: sjchung@cm.nctu.edu.tw

1. Introduction

Integrated antennas, which combine antennas with solid-state circuits, were constructed to fulfill the necessity of low cost, small size and low transmission power loss [1]. In the front end of a communication link or a radar system, the circuits, such as mixers, LNA's, and modulators, can be realized by directly mounting the diodes or FETs on the antennas. The results showed obvious contributions to the circuit's size reduction and cost down. Moreover, the transmission loss was reduced by the elimination of the transmission paths between the antenna and the circuit devices, especially for higher frequency applications.

Except for the circuits mentioned above, the hybrids and dividers are also important components in the transceiver design. Due to the isolation characteristic, the Wilkinson power divider has been used in many applications. In order to reuse the power absorbed by the isolation lumped resistor, Tseng and Chung built a modified Wilkinson power divider [2], which used the radiation resistance of an offset-fed slot antenna to replace the lumped resistor. With this arrangement, the power absorbed by the isolation resistance is radiated by the antenna.

In this paper, a compact three-port antenna structure, named 180° antenna hybrid, is introduced and demonstrated. Instead of using the slot antenna, this study uses the aperture-coupled patch antenna to replace the lumped resistor in the Wilkinson power divider. By means of the feasible configuration of this three-port 180° antenna hybrid, a balanced mixer integrated with the patch antenna and an active transmitting antenna are designed and realized.

2. Design and Measurement of the Three-Port 180° Antenna Hybrid

The configuration of the proposed three-port 180° antenna hybrid is shown in Fig.1. A standard microstrip-line Wilkinson power divider is fabricated on the circuit substrate of the two-layer structure, with the lumped resistor replaced by a two-port aperture-coupled patch antenna on the antenna substrate. The circuit substrate is chosen with $\varepsilon_{rc} = 2.2$ (dielectric constant) and $h_c = 20\,mil$ (thickness), and the antenna substrate is with $\varepsilon_{ra} = 2.33$ and $h_a = 31\,mil$. The aperture-coupled patch antenna is equivalent to a series load of impedance $Z_a = R_a + jX_a$ (or normalized impedance $z_a = Z_a / Z_0 = r_a + jx_a$) [3]. To satisfy the isolation requirement between ports 2 and 3, the normalized impedance should be designed as $z_a = 2$, which is accomplished by suitably varying the patch width W and aperture length L_s. With the operating frequency chosen as 5.8 GHz, the designed antenna has patch sizes of $W \times L$ (width$\times$length) = 18.96$mm$$\times$15.14$mm$ and aperture sizes of $W_s \times L_s$ (width$\times$length) = 0.5$mm$$\times$7.58$mm$. After finishing the two-port antenna design, the 180° antenna hybrid is finally constructed by attaching the two quarter-wavelength microstrip lines (of impedance $\sqrt{2}Z_0$) to the two ports of the antenna (Fig.1). The quarter-wavelength lines should be placed as close as possible to the two sides of the coupling aperture to reduce the influence of the phase shifts due to extra microstrip-line lengths.

The designed three-port 180° antenna hybrid was fabricated and measured using a HP

8720C network analyzer. Fig.2 illustrates the measured scattering parameters. The center frequency is 5.9 GHz, which is slightly different from the design one. As can be seen in the figure, this antenna hybrid possesses good performances. When a signal is fed to port 1, the power is equally split to port 2 and port 3 ($S_{21} = S_{31} \approx$ -3 dB). From the conservation of energy, no power is radiated out from the antenna. The return loss (S_{11}) is under –20 dB over a large frequency range. Also, the isolation (S_{32}) between ports 2 and 3 was measured to be –40 dB at the center frequency, with a –20 dB bandwidth of 1.5 %. The return losses (S_{22} and S_{33}) of these two ports exhibited a –10 dB bandwidth of 8.1 % with a minimum value of –27 dB at the center frequency.

3. Balanced Mixer Integrated with Antenna

The basic configuration of a balanced mixer includes two or more single-ended mixers connected by 90° or 180° hybrid circuits. By means of the characteristics of the hybrid circuits, this type of mixers contains the advantages of good input return loss and/or RF/LO isolation. A single-balanced mixer, using the three-port 180° antenna hybrid, is proposed as shown in Fig.3. Two Schottky diodes (HP HSMS-2860) are mounted on ports 2 and 3 of the antenna hybrid and terminated by two fan stub virtual grounds. The received RF signal from the antenna is directly transmitted to the diodes and mixed with the LO signal from port 1. The resultant IF signal is then extracted from the high impedance RF chocks at the short terminals of the fan stubs.

The measured conversion loss as a function of the LO frequency is shown in Fig.4. The RF frequency was fixed at 5.85 GHz and the LO power was 4.5 dBm. The received RF power from the antenna was estimated to be –30 dBm. It is seen that the conversion loss had an average level of 3.5 dB, with a peak-to-peak variation below 1.5 dB.

4. Active Transmitting Antenna

In the design of active transmitting antennas, the antenna can be directly loaded to an oscillator [4] or be placed at the feedback path of a feedback oscillator [5]. An injection-locking signal may be added to the circuit for stabilizing the oscillation frequency or modulating the transmitted signal. For these purposes, a separate coupler is usually needed to tap the oscillator signal to the loading antenna or to couple the injection signal to the oscillator circuit, which increases the design complexity and the circuit size.

Using the three-port antenna hybrid, a compact active antenna was constructed as shown in Fig.5. A feedback oscillator was used in the design, which contains an amplifier and a feedback network implemented by the antenna hybrid. The amplifier was designed using NEC NE32484A HEMT with about 8dB small-signal gain around 5.9 GHz (V_{ds} = 1 V and V_{gs} = -0.2 V). To isolate the biases of the gate and the drain, a DC block using the coupled-line configuration was inserted in the feedback path. When a signal enters port 2 of the antenna hybrid, half of the power is radiated out by the antenna. The rest is transmitted to port 1 and then enlarged by the amplifier. To satisfy the oscillation phase requirement, the electrical length of the feedback loop C was adjusted to be a multiple of 360° at 5.9 GHz. It is noticed that, the active antenna may oscillate at lower frequencies where the phase and gain requirements for oscillation are met. To eliminate these spurious oscillations, the amplifier should be designed with lower gains at low frequencies so that the required gain condition can be destroyed. An injection signal can be fed to port 3 of the antenna hybrid. Half of this signal's power goes to port 1 and can be used to lock the oscillation frequency of the active antenna.

Fig.6 presents the frequency spectrum of the finished active antenna. A clean spectrum was measured near 5.88 GHz, which is very close to the design one. The received power by a standard horn antenna at a distance of 375 *cm* was –30.5 dBm, corresponding to an EIRP of 15.1 mW. Good radiation patterns have also been measured. The crosspolarization field is at least 20 dB lower than the co-polarization field in both E-plane and H-plane.

5. Conclusions

In this study, a novel three-port 180° antenna hybrid has been proposed and demonstrated. The scattering characteristics of the finished 5.9 GHz antenna hybrid had been shown to be as good as those of an ordinary Wilkinson power divider. By means of the feasible configuration of this three-port 180° antenna hybrid, a balanced mixer integrated with the patch antenna and an active transmitting antenna were designed and realized. The measured results for the balanced mixer showed that the average conversion loss for an LO input power of 4.5 dBm was 3.5 dB in the frequency range of 5.56 GHz to 5.82 GHz, with a peak-to-peak variation below 1.5 dB. The active transmitting antenna oscillated at a frequency very close to the design one. The corresponding EIRP was 15.1 mW and the cross-polarized radiation field was at least 20 dB lower than the co-polarized one. It is seen that, by using the 180° antenna hybrid, circuits can be conveniently integrated with the antennas, which is useful in reducing the size and the cost of the transceivers in communication systems.

6. Acknowledgment

This work was supported by the Academic Advancement Program of Ministry of Education, Taiwan, ROC.

7. References

[1] J. A. Navarro and K. Chang, *Integrated Active Antennas and Spatial Power Combining*. MA: John Wiley and Sons Inc., 1996.

[2] W.-J. Tseng and S.-J. Chung, “A dual CP slot antenna using a modified Wilkinson power divider configuration,” *IEEE Microwave and Guided Wave Lett.*, vol. 8, pp.205-207, May 1998.

[3] D. M. Pozar, “A reciprocity method of analysis for slot and slot-coupled microstrip antennas,” *IEEE Trans. Microwave Theory Tech.*, vol. 34, pp.1439-1446, Dec. 1986.

[4] X. D. Wu and K. Chang, “Novel active FET circular patch antenna arrays for quasi-optical power combining,” *IEEE Trans. Microwave Theory Tech.*, vol. 42, no. 5, pp.766-771, May 1994.

[5] W.-J. Tseng and S.-J. Chung, “Analysis and application of a two-port aperture-coupled microstrip antenna,” *IEEE Trans. Microwave Theory Tech.*, vol. 46, pp.530-535, May 1998.

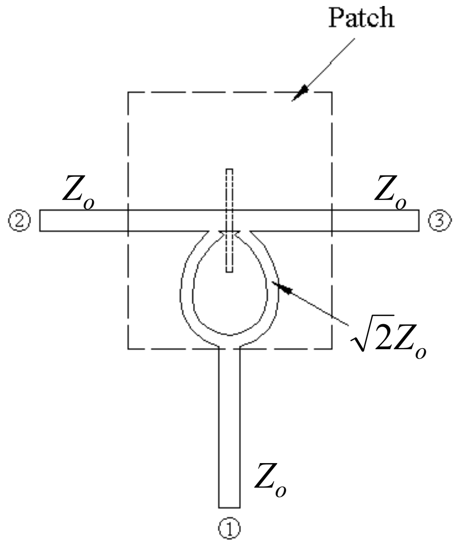

Fig.1 Geometry of a three-port 180° antenna hybrid.

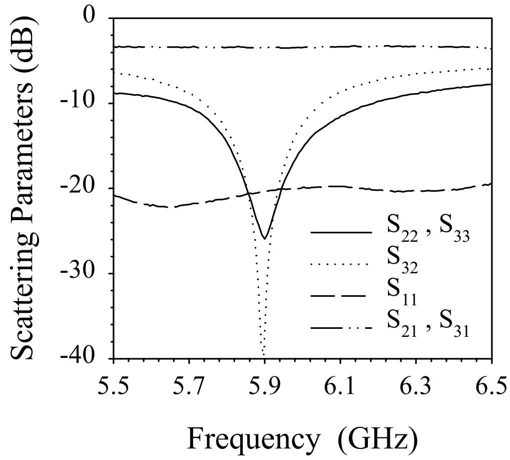

Fig.2 Measured scattering parameters of the three-port 180° antenna hybrid.

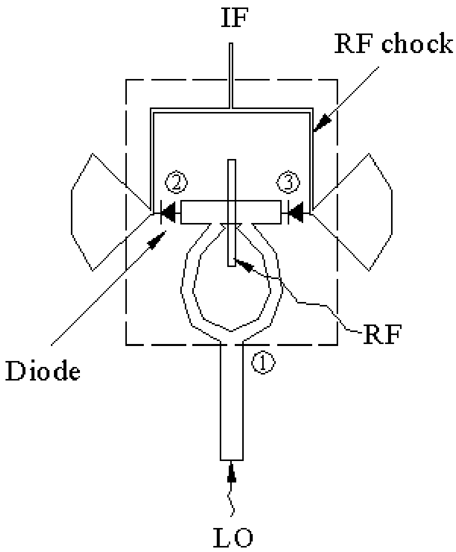

Fig.3 Geometry of a balanced mixer using the three-port 180° antenna hybrid.

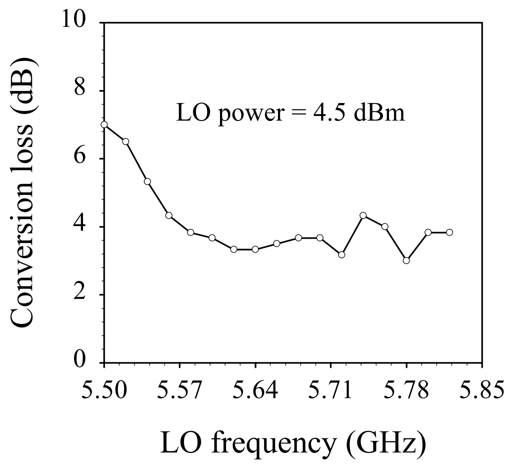

Fig.4 Measured conversion loss of the balanced mixer as a function of the LO frequency.

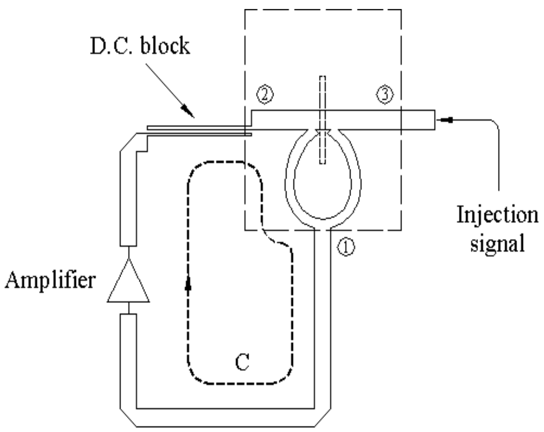

Fig.5 Geometry of an active transmitting antenna.

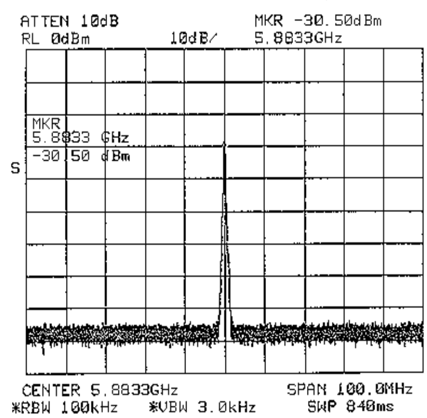

Fig.6 Measured power spectrum of the active transmitting antenna.