# A Dual CP Slot Antenna Using a Modified Wilkinson Power Divider Configuration

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*Abstract*—**A dual circularly polarized (CP) slot antenna based on a proposed equal-split Wilkinson power divider is presented. An offset-fed slot antenna, which was analyzed using the method of moments together with a mixed potential integral equation, was used to replace the lumped resistor in the divider. A dual CP slot antenna operating at $S$-band was designed and demonstrated experimentally. The antenna possessed a return loss bandwidth of 39.3%, an isolation bandwidth of 10% for VSWR <2, and 3-dB axial ratio bandwidth of 28%.**

*Index Terms*—**Dual CP slot antenna, moment method, Wilkinson power divider.**

## I. Introduction

IN AN equal-split Wilkinson power divider, a balance port is connected to two unbalance ones through two quarter-wave transformers, and a lumped resistor with a normalized impedance of 2 is placed between the two unbalanced ports to fulfill the matching and isolation requirements. When a wave is coming from one of the unbalance ports to the divider, half of the power is transmitted to the balance port with a phase delay of 90°, and the rest of the power is absorbed by the lumped resistor. This absorbed power is transferred to heat and thus cannot be used again. It is the motivation of this letter to design a Wilkinson divider without any resistor so that no power is wasted in the structure. To accomplish this, an offset-fed slot antenna, which is equivalent to a series impedance [1], [2], is used to replace the lumped resistor (see the inset in Fig. 3). As will be shown later, by changing the feeding position of the antenna, the equivalent impedance can be adjusted to the required one.

Using this modified configuration of the Wilkinson power divider, a dual circularly polarized (CP) slot antenna, as shown in Fig. 1, is designed and measured. The geometry contains the modified divider (with a vertical slot antenna) and another (horizontal) slot antenna fed by the balance port. When a wave is incident to port 1, half of the power is immediately passed to the vertical antenna, and the rest is transmitted, through a quarter-wave transformer (90° line), to the horizontal antenna. Since the fields radiated from the two linear antennas are with orthogonal polarizations, equal amplitudes, and 90° phase difference, the total radiation field is thus a circularly polarized wave. Similarly, for a wave incident to port 2, the total radiation field is also a CP wave. But due to the opposite alignment of the field fed to the vertical slot, this CP wave is orthogonal to that for an incident wave at port 1. The analysis of the offset-fed slot antenna is presented in Section II. With the analyzed results, the modified Wilkinson divider and the dual CP slot antenna were designed and are shown in the following two sections. Finally, conclusions are made in Section V.

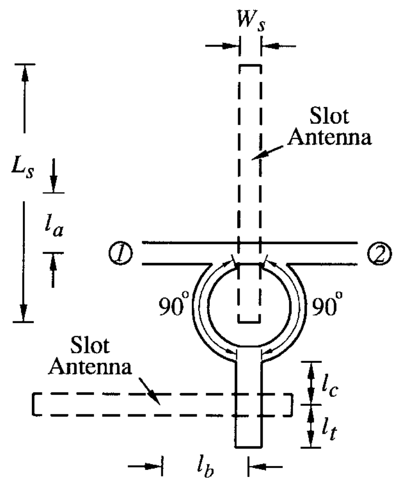


Fig. 1. Geometry of a dual circularly polarized (CP) slot antenna using a modified equal-split Wilkinson power divider.

## II. Offset-Fed Slot Antenna

The equivalent circuit for a narrow slot antenna offset-fed by a microstrip line comprises a series combination of a resistive and a reactive components [1]. To obtain the equivalent impedance, the method of moments coupled with a mixed potential integral equation is used to analyze this offset-fed slot antenna. Applying the equivalence principle, the slot is closed off and replaced by equivalent magnetic surface currents above and below the ground plane. To ensure the continuity of the tangential electric fields across the slot, the magnetic current below the ground plane should be equal to the negative of that above. To avoid treating the nonuniform current distribution on the microstrip line, the line is modeled as a rectangular waveguide with a top and a bottom electric walls and two magnetic sidewalls [3], [4]. Using the reciprocity theorem, the excited forward and backward quasi-TEM waves in the waveguide can be expressed as functions of the magnetic surface current [5]. After incorporating the continuity of the

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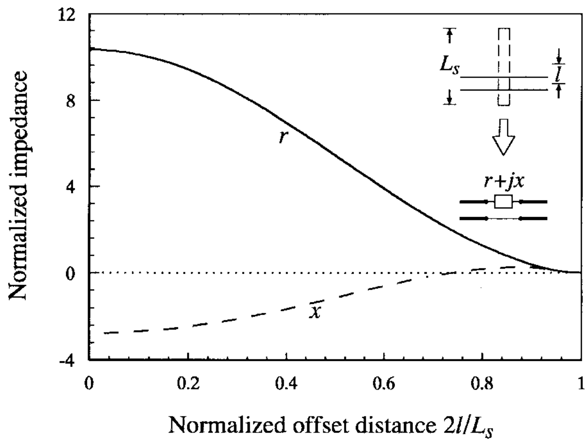


Fig. 2. Normalized equivalent series impedance of a slot antenna fed by an infinitely long microstrip line, as functions of the normalized offset distance ($2l/L_s$). $f = 3.02$ GHz.

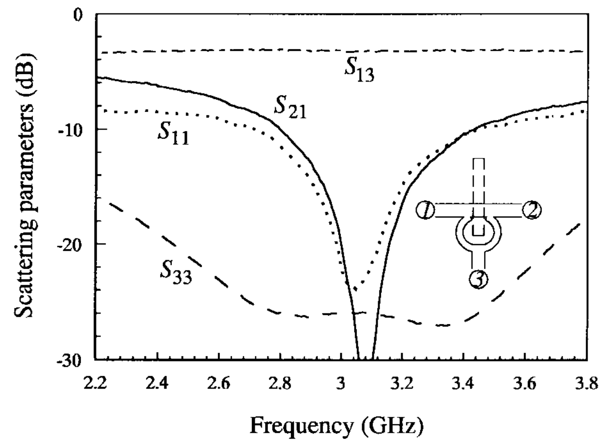


Fig. 3. Frequency response of a modified equal-split Wilkinson power divider with an offset-fed slot antenna in place of the lumped resistor.

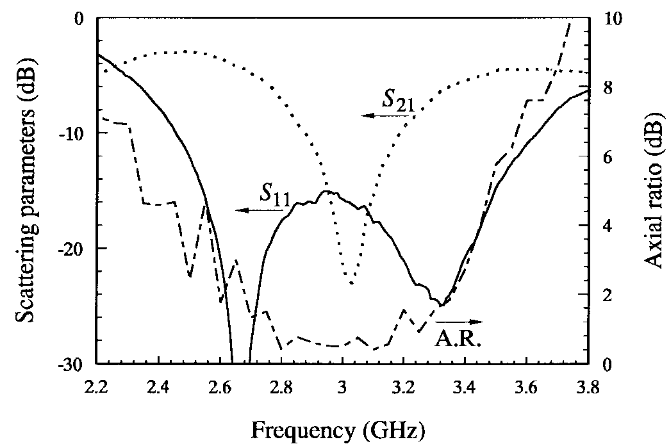


Fig. 4. Measured results of the scattering parameters and axial ratio at broadside for the CP slot antenna.

tangential magnetic fields over the slot, a mixed potential integral equation is obtained. The unknown magnetic current on the slot is then solved using the Galerkin's method of moments, from which the equivalent series impedance is accessible.

Fig. 2 illustrates the variations of the normalized equivalent series impedance ($r+jx$), as functions of the normalized offset distance $2l/L_s$ (with $l$ being the distance from the feed point to the center of the slot). The frequency is set at 3.02 GHz. The slot of sizes $L_s \times W_s$ ($= 43.3 \times 0.7$ mm$^2$) is fabricated on the ground plane of a substrate of $\varepsilon_r = 2.2$ and $h = 0.508$ mm and is fed by a microstrip line of width 1.57 mm (50 Ω). It is seen that both the resistance ($r$) and reactance ($x$) of the impedance are maximum when the feeding microstrip line is placed at the slot center, and approach zeros while the microstrip line moves toward the slot edges. The resistance drops to 100 Ω ($r = 2$) as the offset $2l/L_s$ equals 0.739, where the reactance happens to be zero. Also note that, as $2l/L_s = 0.827$, the resistance is equal to 50 Ω ($r = 1$) and the reactance equal to 11.1 Ω ($x = 0.222$). Several slots with different feed positions have been measured. The results showed that a series impedance of $100 + j0$ Ω occurred at 3.04 GHz with $2l/L_s = 0.752$. At the same frequency, a resistance of 50 Ω was obtained as $2l/L_s = 0.807$, with a corresponding reactance of 27.5 Ω.

## III. Modified Wilkinson Power Divider

Before designing the dual CP slot antenna, the modified Wilkinson power divider was first constructed and measured. The 100-Ω lumped resistor in the traditional Wilkinson divider was replaced by the off-fed slot antenna of sizes 43.3 × 0.7 mm$^2$ fed at $2l_a/L_s = 0.752$. The quarter-wave microstrip lines were with a width of 0.894 mm, corresponding to a characteristic impedance of 70.7 Ω. Fig. 3 illustrates the measured scattering parameters of the modified Wilkinson power divider. It is seen that, while a wave is incident to port 3, both ports 1 and 2 receive half of the power ($S_{13} = S_{23} = -3.3$ dB). The return loss ($S_{33}$) keeps at a quite low value (−26 dB) over a large frequency band. Also, for a wave incident to port 1, both the return loss ($S_{11}$) and the isolation ($S_{21}$) have a 10-dB fractional bandwidth of about 22%. ($S_{11} \approx S_{21} \approx -24$ dB at the frequency of 3.04 GHz.)

## IV. Dual CP Slot Antenna

To accomplish a dual CP slot antenna using the modified Wilkinson power divider, a second slot antenna perpendicular to the first one was loaded in port 3, as shown in Fig. 1. This antenna has the same sizes as the first one but is fed at $2l_b/L_s = 0.807$, corresponding to a series resistance of 50 Ω at 3.04 GHz. A tuning stub of length $l_t = 12.1$ mm is used to eliminate the series reactance of the slot. Also, due to the different feed offset, the calculated linearly polarized field excited by the second slot at broadside has an about 10° phase advance than that of the first slot. Hence, a phase compensation line of length $l_c = 2$ mm (10° phase delay) was placed before the feed point of the second slot (see Fig. 1). Fig. 4 depicts the measured scattering parameters and axial ratio at broadside for the designed dual CP slot antenna. The return loss has a 10-dB bandwidth of as large as 39.3%. The 3-dB axial ratio bandwidth is about 28%. Furthermore, the 10-dB isolation bandwidth is 10.3%, with a maximum isolation of 23 dB at 3.04 GHz. Due to the offsets of the two slot antenna centers (38 mm in the vertical plane and 17 mm in the horizontal plane), the phase difference of the radiation fields from the slots may change with the deviation of the observation angle from the broadside direction. Particularly, when an extra 90° phase delay due to the path length difference between the slot radiation fields occurs, the total field would turn from a CP one to a linearly polarized one. This has been measured at the observation angles of ±30° in the vertical plane, which are smaller than the estimated values of ±41°.

## V. Conclusions

In this letter, we have designed and demonstrated a dual CP slot antenna, basing it on a proposed modified Wilkinson power divider formed by replacing the lumped resistor with an offset-fed slot antenna. The method of moments together with a mixed potential integral equation was used to analyze the slot antenna. Good agreement has been achieved between the calculations and measurements. The fabricated dual CP slot antenna had a 10-dB return loss bandwidth of as large as 39.3%, a 3-dB axial ratio bandwidth of 28%, and a 10-dB isolation bandwidth of 10.3%.

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