A Highly Miniaturized Active 90° Power Combiner MMIC Employing CE and CC Circuits
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In this work, a highly miniaturized active 90° power combiner, employing InGaP/GaAs heterojunction bipolar transistors (HBT), was fabricated on a GaAs substrate for MMIC applications. A novel composite structure employing common-emitter (CE) and common-collector (CC) circuits is proposed for 90° power combining. The size of the active 90° power combiner is approximately 2.2 percent of a conventional passive combiner. The active 90° power combiner showed good RF performance, comparable to a passive combiner at S-band. This work is the first 90° power combiner reported employing active devices.

A 90° power combiner has been used for signal mixing at the intermediate frequency (IF) output port of an image rejection mixer.1,2 Until now, a passive branch-line coupler was mainly employed for 90° power combining.1,3 However, the passive branch-line coupler occupies a very large circuit area.

For example, if the branch-line coupler is fabricated on a GaAs substrate with a thickness of 100 µm, for a signal mixing with an IF of 2.4 GHz, the size will be approximately 10.92 × 10.54 mm. Therefore, passive power combiners cannot be integrated on MMICs due to their very large size.4 To reduce the size of the 90° power combiner,6 it has to be fabricated using an active device. However, no study of a 90° power combiner employing an active device has been reported yet. In this work, for integration of the 90° power combiner on a MMIC, a highly miniaturized active 90° power combiner employing CE and CC circuits with InGaP/GaAs heterojunction bipolar transistors (HBT) is proposed.

Design of An Active 90° Power Combiner Employing CE and CC with InGaP/GaAs HBT
Figure 1 shows the schematic circuit of an active 90° power combiner employing CE and CC circuits. As shown, a novel composite structure employing common-emitter (CE) and common-collector (CC) circuits was used, with the output ports of the CE and CC circuits connected to each other. To compensate for the insertion loss of the active 90° power combiner, an amplifier was added at the output port.

The output voltage gain and output phase of the CE circuit are given by:

\[
A_{v1} = \frac{V_{\text{out}}}{V_{\text{in1}}} = \frac{-jX_C}{r'_e}, \quad (X_C = \omega L_C) \quad (1.1)
\]

\[
\angle A_{v1} = -90^\circ \quad (1.2)
\]

where \(r'_e\) is the emitter resistor of the transistor.

The output voltage gain and output phase of the CC circuit are given by:

\[
\text{ OPCP}\]
where $\omega$ is the operating frequency.

Ideal characteristics of the 90° power combiner employing CE and CC circuits require that the output signal from the incoming port 1 ($S_{31}$) and the incoming port 2 ($S_{32}$) should have a 90° phase difference and equal power. Thus, the circuit elements were determined to obtain the required relationship. In other words, for a 90° phase difference between output signal $S_{31}$ and $S_{32}$, the following equation should be satisfied using Equations 1.2 and 2.2

$$\angle A_{v2} = \tan^{-1}\left(\frac{r_e}{X_E}\right)$$

(2.2)

In the above equation, $X_E$ must be infinite ($X_E = \infty$) in order that the phase difference be -90°. Thus, from Equation (2.1), the following relationship must be satisfied

$$\angle A_{v1} - \angle A_{v2} = -90° - \tan^{-1}\left(\frac{r_e}{X_E}\right)$$

(3)

If $X_E = \infty$, from Equation 2.1, $A_{v2} = 1$. Therefore, from Equations 1.1 and 2.1, for an equal power of the output signals $S_{31}$ and $S_{32}$, the following equation should be satisfied

$$\omega = \frac{1}{\sqrt{L_E C_E}}$$

(4)
\[ |A_{v1}| - |A_{v2}|, \left| \frac{-jX_C}{r'_e} \right| = \]

\[ \left| \frac{jX_E}{r'_e + jX_e} \right| \approx 1 \]  \hspace{1cm} (5)

From the above equation, the following relation is given

\[ X_C = \omega L_C = r'_e \]  \hspace{1cm} (6)

Finally, the circuit elements \( L_E, C_E \) and \( L_C \) were determined from Equations 4, 5 and 6.

**Measurement of An Active 90° Power Combiner Employing CE and CC with InGaP/GaAs HBT**

**Figure 2** Photograph of the fabricated active 90° power combiner.

*Figure 2* shows a photograph of the active 90° power combiner MMIC employing CE and CC InGaP/GaAs HBTs, which was fabricated on a GaAs substrate. The size of the fabricated chip, including the active 90° power combiner and amplifier, is \( 2.42 \times 1.05 \) mm, which is 2.2 percent of the size of a conventional branch-line coupler fabricated on a GaAs MMIC (as mentioned previously, the size of a passive coupler is \( 10.54 \times 10.92 \) mm).
Figure 3 Measured $S_{31}$ and $S_{32}$ characteristics.

Figure 4 Measured phase difference between $S_{31}$ and $S_{32}$.

Figure 5 Measured isolation characteristics.
Figure 6 shows the output power characteristic of the active 90° power combiner. As shown, P1dB is approximately -3 dBm. The active 90° power combiner shows a power saturation level higher than -3 dBm due to the nonlinear characteristic of the InGaP/GaAs HBT. Therefore, the proposed active 90° power combiner can be used for a receiver or medium power transmitter of a wireless communication system. The characteristics of the active 90° power combiner are summarized in Table 1 for a comparison with the characteristics of a conventional 90° passive coupler.
Conclusion

In this work, a highly miniaturized active 90° power combiner employing CE and CC with InGaP/GaAs HBT was fabricated on a GaAs substrate for MMIC applications. For a 90° phase difference and equal power coupling, a novel composite structure is proposed, employing CE and CC circuits. The size of the active 90° power combiner including amplifier is 2.42 x 1.05 mm, which is 2.2 percent of the size of a conventional passive coupler. The active 90° power combiner showed good RF performances, comparable to those of a conventional passive coupler at S-band, and also showed a gain, due to the amplifier integrated on a MMIC. This work is the first report known of a 90° power combiner employing active devices.

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**TABLE I**

**COMPARISON OF THE CHARACTERISTICS OF A CONVENTIONAL, PASSIVE AND ACTIVE COMBINER**

<table>
<thead>
<tr>
<th></th>
<th>Passive Branch-line Coupler</th>
<th>Active 90° Power Combiner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit size</td>
<td>10.56 x 10.92 mm</td>
<td>2.42 x 1.05 mm</td>
</tr>
<tr>
<td>Size comparison</td>
<td>100%</td>
<td>2.2%</td>
</tr>
<tr>
<td>Power loss</td>
<td>-3.65 dB</td>
<td>×</td>
</tr>
<tr>
<td>Linearity</td>
<td>∞</td>
<td>-3 dBm</td>
</tr>
<tr>
<td>Isolation</td>
<td>-30.2 dB</td>
<td>-26.6 dB</td>
</tr>
<tr>
<td>Amplitude balance</td>
<td>-3.65 dB/-3.6 dB</td>
<td>10.5 dB/10.3 dB</td>
</tr>
<tr>
<td>Power consumption</td>
<td>×</td>
<td>187 mW</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>640 MHz</td>
<td>330 MHz</td>
</tr>
</tbody>
</table>

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Conclusion

In this work, a highly miniaturized active 90° power combiner employing CE and CC with InGaP/GaAs HBT was fabricated on a GaAs substrate for MMIC applications. For a 90° phase difference and equal power coupling, a novel composite structure is proposed, employing CE and CC circuits. The size of the active 90° power combiner including amplifier is 2.42 x 1.05 mm, which is 2.2 percent of the size of a conventional passive coupler. The active 90° power combiner showed good RF performances, comparable to those of a conventional passive coupler at S-band, and also showed a gain, due to the amplifier integrated on a MMIC. This work is the first report known of a 90° power combiner employing active devices.

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