Designing Resistive Unequal Power Dividers

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The resistive power splitter of Figure 1 has long been a favorite of RF and microwave engineers. It divides an RF input signal equally between its two output ports. This splitter is a natural choice when flat frequency response is required over a very broad frequency range. Its simplicity makes it an attractive option for many designs.

When unequal output amplitudes are desired, a similar splitter can be constructed. Figure 2 illustrates a power splitter with unequal outputs. The power loss at the primary output port can be any value between 0 dB and 6.02 dB. The power loss at the secondary output port will be some value greater than 6.02 dB. For example, a splitter that has 1.72 dB loss at its primary output will have 20 dB loss at its secondary output. All ports are matched to some characteristic impedance, $Z_0$.

Since the unequal splitter consists of only four resistors, its size and cost are negligible in most applications.

Design Procedure

In order to design the unequal splitter, first consider the Tee pad of Figure 3. This pad can be designed to have some value of loss, less than 6.02 dB. To get the second output, we’ll replace the parallel resistor $R_p$ with a voltage divider, as shown in Figure 2. The resistor values $R_t$ and $R_u$ will be chosen so that when output 2 is terminated in $Z_0$, the resulting network has the same resistance as $R_p$, and so that port 2 presents an impedance of $Z_0$ to its load when the other ports are terminated in $Z_0$. The attenuation at output 2 will depend on the attenuation value that we choose for output 1. The lower the attenuation at output 1,
the higher the attenuation at output 2. Some typical values are shown in Table 1 and plotted in Figure 4.

First, choose a value of attenuation for output 1, and design the Tee pad of Figure 3 for that attenuation value. Given the value of $dB_1$, and normalizing $Z_0$ to unity, we can solve for the resistor values $R_s$ and $R_p$.

Now, let $R_p$ from the network above be broken up into a network consisting of $R_t$, $R_u$, and the port 2 load impedance $Z_0$. We require that the resistance of this network, from the top of $R_t$ to ground, be equal to $R_p$ above. We also require that the output impedance at port 2 be equal to $Z_0$. With these two conditions, we can solve for the values of $R_t$, and $R_u$.

Table 1 · Component values for resistive dividers with various common attenuation values.

<table>
<thead>
<tr>
<th>$dB_1$</th>
<th>$dB_2$</th>
<th>$R_s$ (ohms)</th>
<th>$R_t$ (ohms)</th>
<th>$R_u$ (ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>44.80</td>
<td>0.287</td>
<td>4317.704</td>
<td>50.582</td>
</tr>
<tr>
<td>0.5</td>
<td>30.81</td>
<td>1.438</td>
<td>842.368</td>
<td>53.055</td>
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<tr>
<td>0.55</td>
<td>30.00</td>
<td>1.582</td>
<td>763.280</td>
<td>53.382</td>
</tr>
<tr>
<td>1.00</td>
<td>24.78</td>
<td>2.875</td>
<td>406.805</td>
<td>56.523</td>
</tr>
<tr>
<td>1.72</td>
<td>20.00</td>
<td>4.94505</td>
<td>222.527</td>
<td>62.499</td>
</tr>
<tr>
<td>2.00</td>
<td>18.68</td>
<td>5.731</td>
<td>186.947</td>
<td>65.168</td>
</tr>
<tr>
<td>3.00</td>
<td>15.01</td>
<td>8.549</td>
<td>111.529</td>
<td>77.531</td>
</tr>
<tr>
<td>4.00</td>
<td>12.25</td>
<td>11.313</td>
<td>71.755</td>
<td>97.698</td>
</tr>
<tr>
<td>4.92</td>
<td>10.00</td>
<td>13.794</td>
<td>47.159</td>
<td>136.037</td>
</tr>
<tr>
<td>5.00</td>
<td>9.80</td>
<td>14.006</td>
<td>45.288</td>
<td>141.601</td>
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<tr>
<td>6.00</td>
<td>6.45</td>
<td>16.613</td>
<td>19.254</td>
<td>1026.093</td>
</tr>
<tr>
<td>6.02</td>
<td>6.02</td>
<td>16.666</td>
<td>16.666</td>
<td>OPEN CKT</td>
</tr>
</tbody>
</table>

$Z_0 = 1$

$\alpha = ALOG \left( -\frac{dB_1}{20} \right)$

$Rs = \frac{1 - \alpha}{1 + \alpha}$

$R_p = \frac{1 - Rs^2}{2 \cdot Rs}$

$Ru = \sqrt{\frac{1}{1 - \frac{1}{4 \cdot R_p + Rs + 1}}}$

$R_t = R_p - \left( \frac{R_u}{Ru + 1} \right)$

At this point, we have chosen values, which satisfy the conditions for a desired attenuation value at port 1, and for all ports to be matched to $Z_0$.

There are no more degrees of freedom, since all of our resistor values...
have been assigned. We now solve for the attenuation at port 2.

In order to simplify the notation, we introduce the intermediate variable \( Q \).

\[
Q = \frac{R_p + R_p \cdot R_s}{R_p + R_s + 1}
\]

\[
\beta = \frac{Q^2 + Q \cdot R_s}{1 + \frac{1}{R_u}} \cdot R_p
\]

where \( \beta \) is loss at port 2, as a voltage ratio, that is: \( dB_2 = 20 \log(\beta) \)

The design equations will now be restated in cookbook form:

Variables \( S, P, \) and \( T \) are the normalized values of \( R_s, R_p, \) and \( R_t, \) respectively.

Given: \( Z_0 \) is the system characteristic impedance and \( dB_1 \) is Loss at port 1

\[
S = \frac{1 - \alpha}{1 + \alpha}
\]

\[
P = \frac{1 - S^2}{2 \cdot S}
\]

\[
U = \frac{1}{\sqrt{1 - \frac{4}{2 \cdot P + S + 1}}}
\]

\[
T = P \left( \frac{U}{U + 1} \right)
\]

\[
Q = \frac{P + P \cdot S}{P + S + 1}
\]

\[
\beta = \frac{Q^2 + Q \cdot S}{1 + \frac{1}{P}} \cdot \frac{P}{R_u}
\]

Loss at port 2, as a voltage ratio is: \( dB_2 = 20 \cdot \log(\beta) \)

\[
Rs = Zo \cdot S
\]

\[
Rt = Zo \cdot T
\]

\[
Ru = Zo \cdot U
\]

All logarithms are to the base 10.

A calculator program is available to conveniently evaluate the design equations for any attenuation value and any characteristic impedance. Interested readers can find this program at the author’s Web site: www.rfcascade.com.

**Author Information**

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