**Attenuators**

Under certain situations, we may actually want to **reduce** signal power!

Thus, we need an inverse amplifier—an **attenuator**.

\[ P_{\text{in}} \rightarrow \text{Attenuator} \rightarrow P_{\text{out}} < P_{\text{in}} \]

An **ideal** attenuator has a scattering matrix of the form:

\[
\begin{bmatrix}
0 & \alpha \\
\alpha & 0
\end{bmatrix}
\]

where \(|\alpha| < 1\).

Thus, an attenuator is **matched** and **reciprocal**, but it is certainly **not** lossless.

The **attenuation** of an attenuator is defined as:

\[
\text{Attenuation} = -10 \log_{10} |\alpha|^2
\]

Typical values of **fixed** attenuators (sometimes called “pads”) are 3 dB, 6 dB, 10 dB, 20 dB and 30 dB.
For example, a 6 dB pad will attenuate the signal by 6 dB—the output power will be one forth of the input power.

One application of fixed attenuators is to improve return loss.

For example, consider the case where the return loss of a mismatched load is 13 dB:

Say we now add a 6 dB pad between the source and the load—we find that the return loss has improved to 25 dB!

The reason that the return loss improves by 12 dB (as opposed to 6 dB) is that reflected power is attenuated twice—once as it travels toward the load, and again after it is reflected from it.
Note from the standpoint of the source, the load is much better matched. As a result, the effect of pulling is reduced.

However, there is a definite downside to “matching” with a fixed attenuator—the power delivered to the load is also reduced by 6 dB!

Q: Why do you keep referring to these devices as fixed attenuators? Do you really think we would use a broken one?

A: In addition to fixed attenuators, engineers often used variable attenuators in radio system designs. A variable attenuator is a device whose attenuation can be adjusted (i.e., varied).

There are two types of (electronically) adjustable attenuators: digital and voltage controlled.

**Digital Attenuators**

As the name implies, digital attenuators are controlled with a set of digital (i.e., binary) control lines. As a result, the attenuator can be set to a specific number of discrete values.

For example, a 6-bit attenuator can be set to one of $2^6 = 64$ different attenuation values!
Digital attenuators are typically made from switches and fixed attenuators, arranged in the following form:

Theoretically, we can construct a digital attenuator with as many sections as we wish. However, because of switch insertion loss, digital attenuators typically use no more than 8 to 10 bits (i.e., 8 to 10 sections).

It is apparent from the schematic above that each section allows us to switch in its attenuator into the signal path (maximum attenuation):
Or we can **bypass** the attenuators, thus providing no attenuation (except for switch insertion loss!):

![Diagram of bypassing attenuators]

Or we can select **some** attenuators and bypass **others**, thus setting the attenuation to be somewhere in between max and min!

![Diagram of selecting and bypassing attenuators]

For most digital attenuators, the attenuation of each section has a **different** value, and almost always are selected such that the values in dB are **binary**.

For example, consider a 6-bit digital attenuator. A typical design might use **these** attenuator values:

<table>
<thead>
<tr>
<th>bit 5</th>
<th>bit 4</th>
<th>bit 3</th>
<th>bit 2</th>
<th>bit 1</th>
<th>bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 dB</td>
<td>16 dB</td>
<td>8 dB</td>
<td>4 dB</td>
<td>2 dB</td>
<td>1 dB</td>
</tr>
</tbody>
</table>
We note therefore, that by selecting the proper switches, we can select any attenuation between 0 dB and 63 dB, in steps of 1 dB.

For example, the 6-bit binary word 101101 would result in attenuation of:

\[32 + 8 + 4 + 1 = 45 \text{ dB}\]

Note also that 101101 is the binary representation of the decimal number 45—the binary control word equals the attenuation in dB!!

**Voltage Controlled Attenuators**

Another adjustable attenuator is the voltage-controlled attenuator. This device uses a single control line, with the voltage at that control determining the attenuation of the device (an “analog” attenuator!):

\[\text{Attenuation} = f(V_c)\]

Typical voltage control attenuators can provide attenuation from a minimum of a few dB to a maximum of as much as 50 dB.
Unlike the digital attenuator, this attenuation range is a **continuous** function of $V_c$, so that any and every attenuation between the minimum and maximum values can be selected.

Voltage controlled attenuators are typically **smaller**, simpler, and **cheaper** than their digital counterparts.

**Q:** So why did you waste our time with digital attenuators? It sounds like voltage controlled attenuators are **always** the way to go!

**A:** We have yet to discuss the **bad stuff** about voltage controlled attenuators!

* Voltage controlled attenuators are generally speaking **poorly matched**, with a return loss that varies with the control voltage $V_c$.

* Likewise, the phase delay, bandwidth, and just about every other device parameter also **changes** with $V_c$!

* Moreover, voltage controlled attenuators are notoriously **sensitive** to temperature, power supply variations, and load impedance.
Digital attenuators, on the other hand, generally exhibit none of the problems!

In addition, digital attenuators are ready made for integration with digital controllers or processors (i.e., computers).

However, digital attenuators do have a downside—they can be large and expensive.