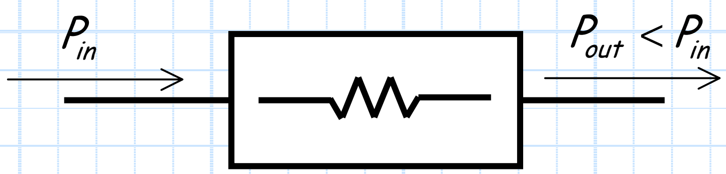
Attenuators

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

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



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

$$\bar{\bar{\mathbf{S}}} = \begin{bmatrix} 0 & \alpha \\ \alpha & 0 \end{bmatrix}$$

where $|\alpha| < 1$.

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

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

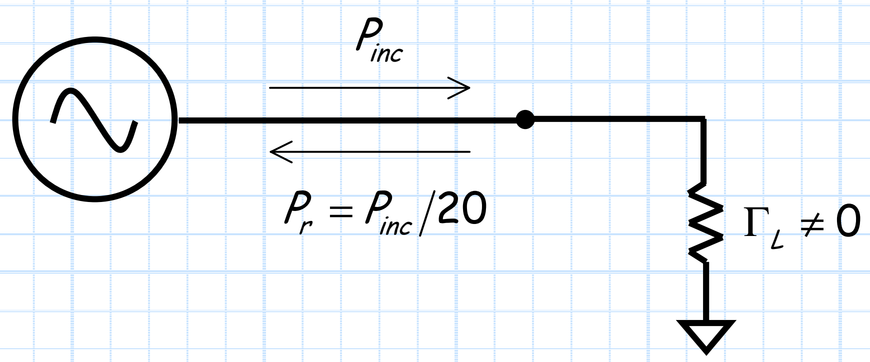
$$\boxed{\textit{Attenuation} = -10 \log_{10} |\alpha|^2}$$

Typical values of **fixed** attenuators (sometimes called "pads") are 3 dB, 6 dB, 10 dB, 20 dB and 30 dB.

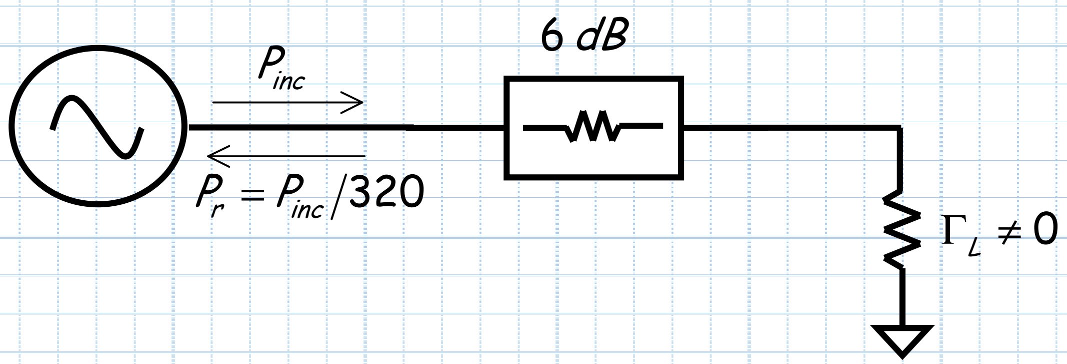
For example, a 6 dB pad will attenuate as signal by 6 dB—the output power will be **one forth** of the input power.

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).

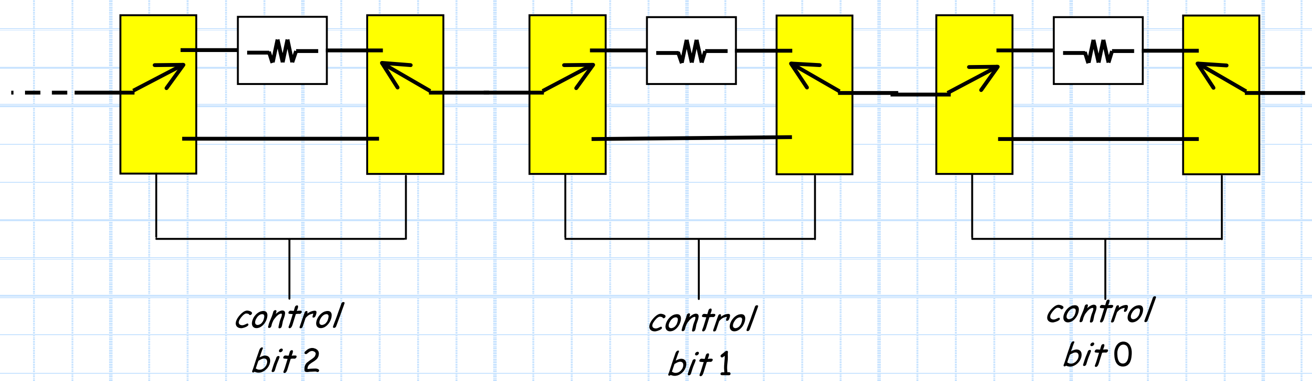
There are two types of (electronically) adjustable attenuators: **digital** and **voltage controlled**.

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.

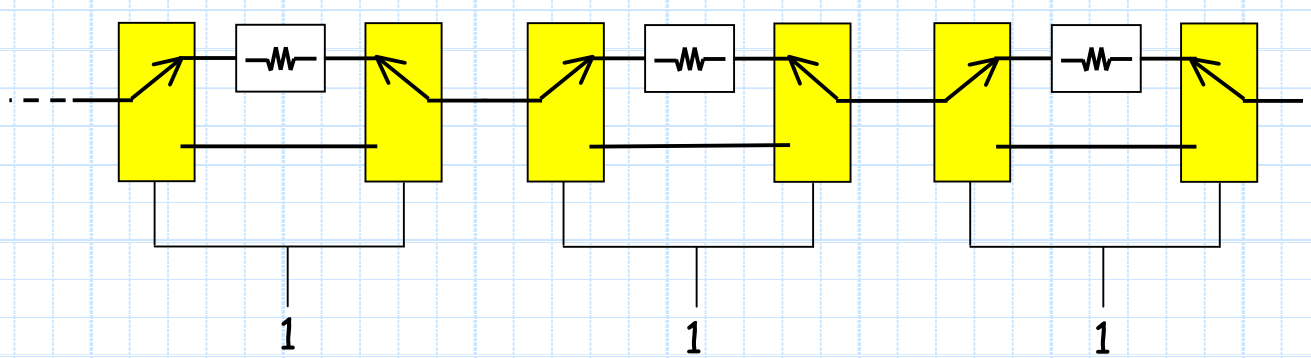
For example, a 6-bit attenuator can be set to one of $2^6 = 64$ **different** attenuation values!

Digital atennuators are typically made from **switches** and **fixed** attenuators, arranged in the following form:

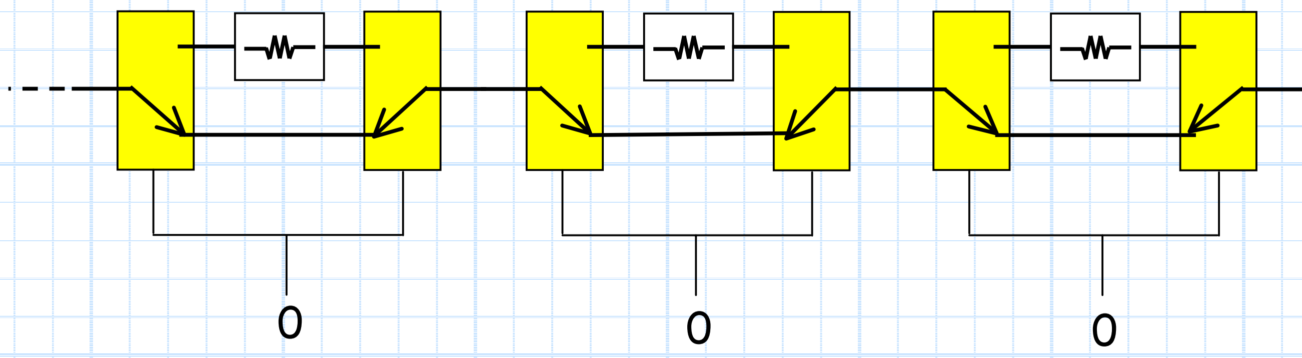


Theoretically, we can construct a digital attenuator with as **many** sections as we wish. However, because of switch **insertion loss**, digital attenuators typically use no more than 8 to 10 bits (i.e., 8 to 10 sections).

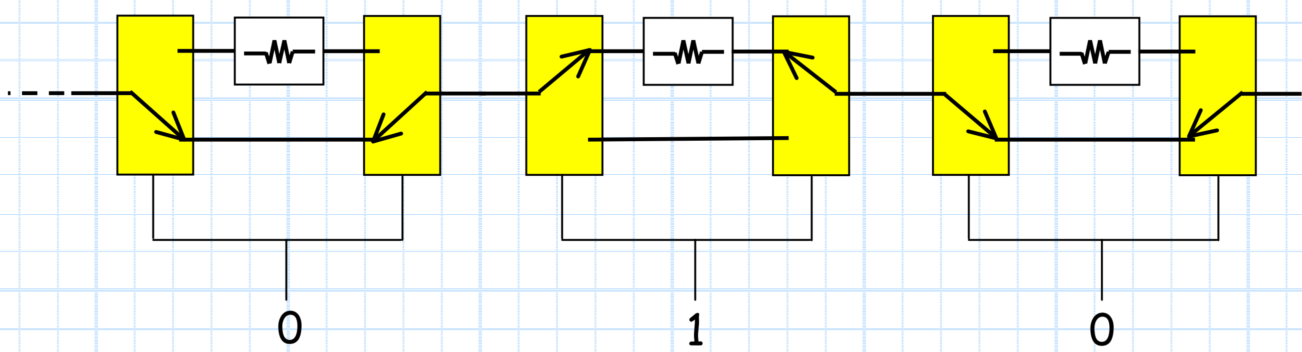
It is apparent from the schematic above that each section allows us to switch in its attenuator into the signal path (maximum attenuation):



Or we can **bypass** the attenuators, thus providing no attenuation (except for switch insertion loss!):



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



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 an 6-bit digital attenuator. A typical design might use **these** attenuator values:

	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
attenuator	32 dB	16 dB	8 dB	4 dB	2 dB	1 dB

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:

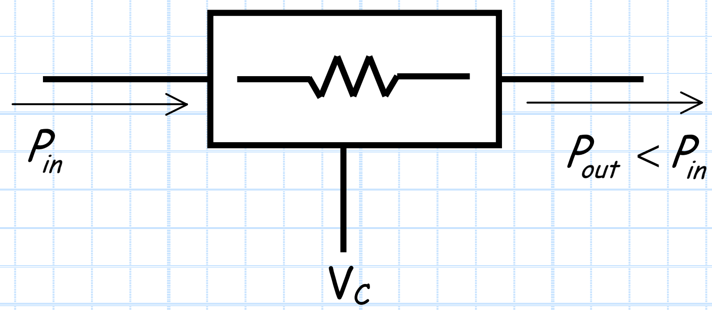
$$32 + 8 + 4 + 1 = 45 \text{ dB}$$

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!):

$$Attenuation = f\left(V_C\right)$$



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).

Howerever, digital attenuators do have a downside—they are typically large and **very expensive**.