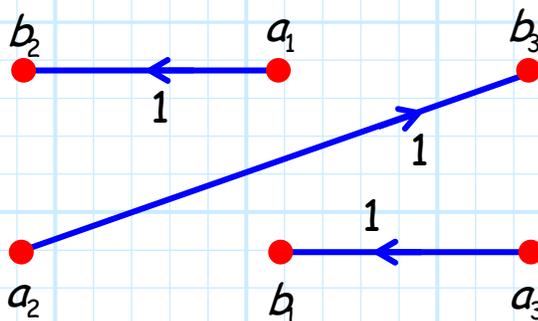


# Circulators

A circulator is a matched, lossless but **non-reciprocal** 3-port device, whose scattering matrix is **ideally**:

$$S = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

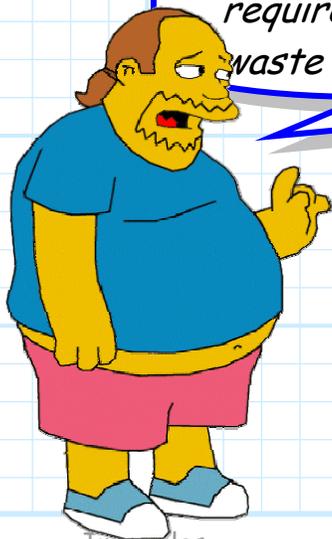


Circulators use anisotropic **ferrite** materials, which are often "biased" by a permanent magnet! → The result is a **non-reciprocal** device!

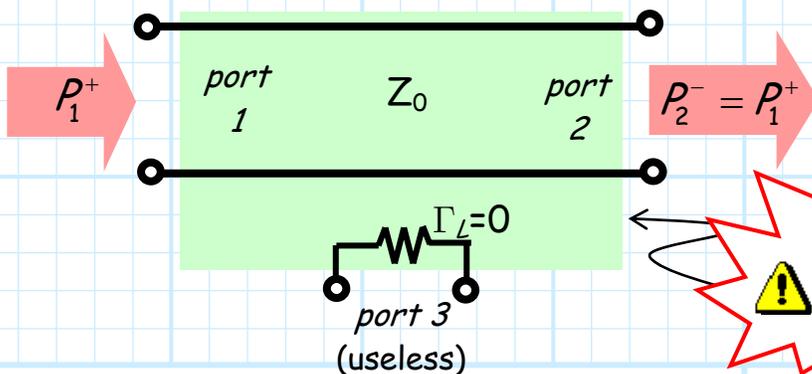
First, we note that for a circulator, the power incident on port 1 will exit **completely** from port 2:

$$P_2^- = P_1^+$$

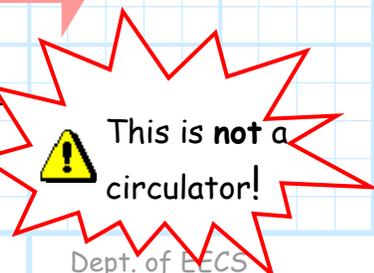
*Pardon me while I sarcastically yawn. This unremarkable behavior is likewise true for the simple circuit below, which requires just a length of transmission line. Oh please, continue to waste our valuable time.*



Jim Stiles

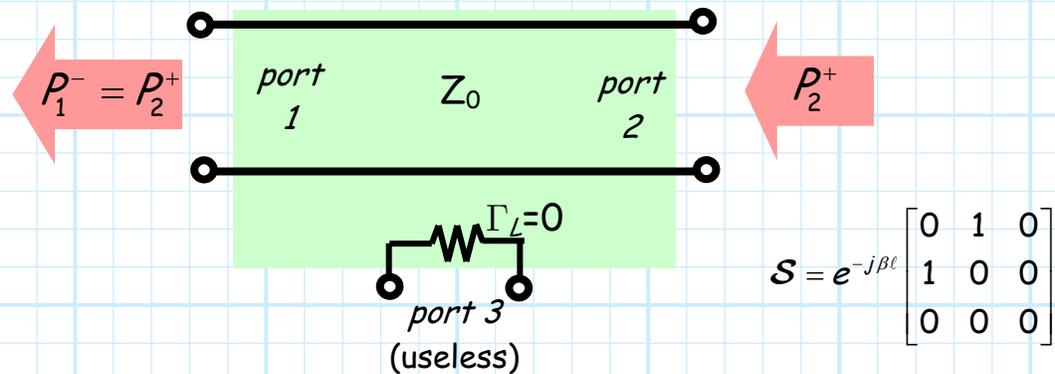


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True! But a transmission line, being a **reciprocal** device, will likewise result in the power incident on **port 2** of your simple circuit to **exit completely from port 1** ( $P_1^- = P_2^+$ ):



But, this is **not** true for a circulator! If power is incident on port 2, then **no power** will exit port 1!

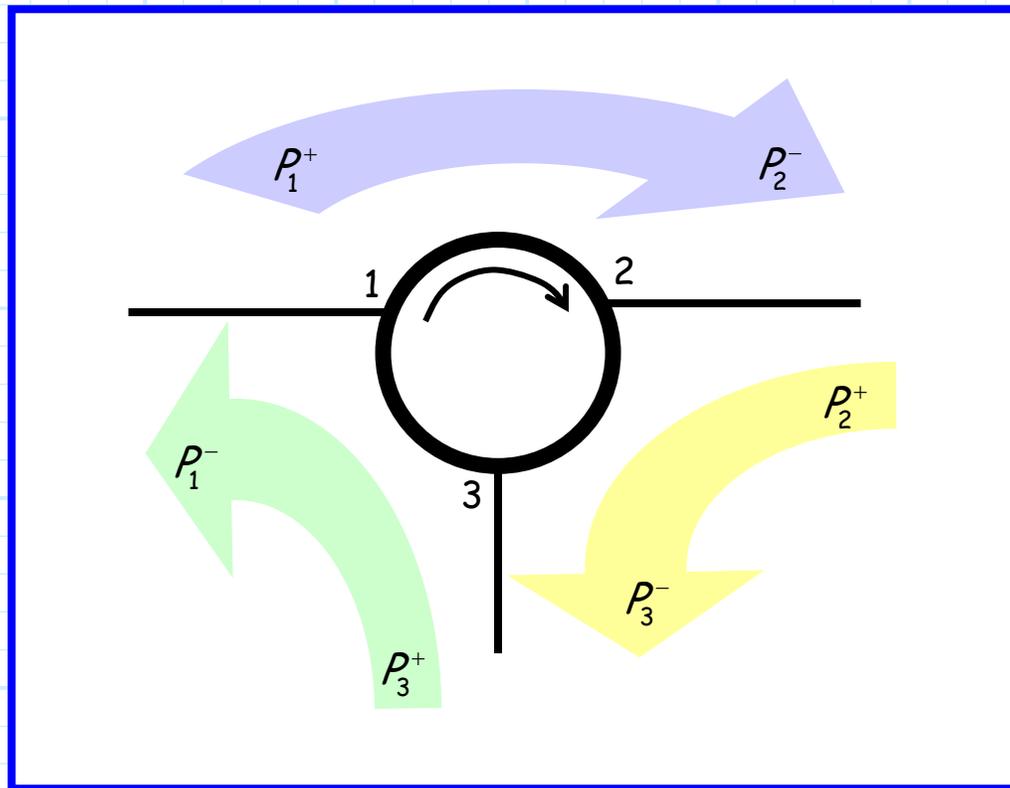


**Q:** You have been *surprisingly* successful in regaining my interest. Please tell us then, just *where* does the power incident on port 2 go?

**A:** It will exit from port 3!

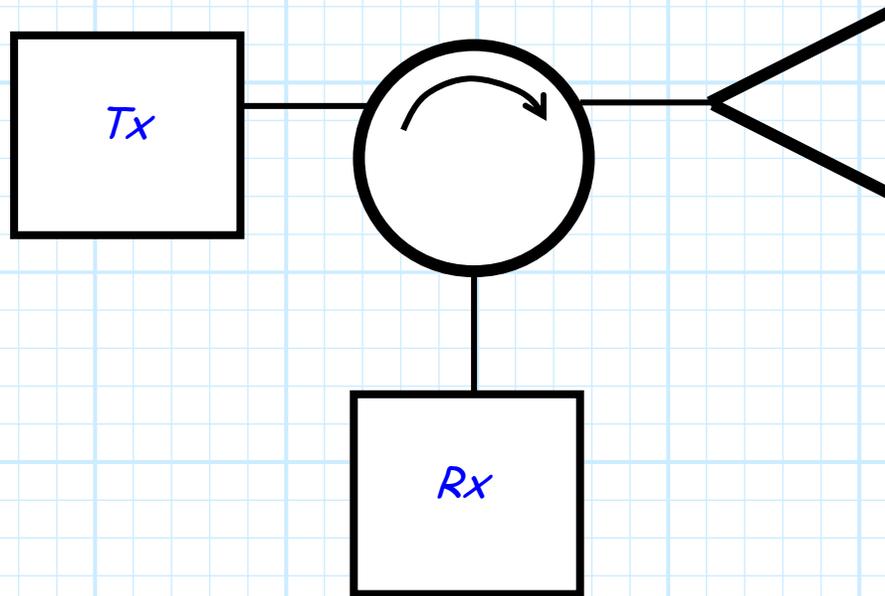
Likewise, power flowing into **port 3** will exit—**port 1**!

It is evident, then how the circulator gets its **name**: power appears to **circulate** around the device, a behavior that is emphasized by its device **symbol**:



We can see that, for example, a **source** at port 2 “thinks” it is attached to a **load** at port 3, while a **load** at port 2 “thinks” it is attached to a **source** at port 1!

This behavior is useful when we want to use **one** antenna as **both** the transmitter and receiver antenna. The transmit antenna (i.e., the load) at port 2 **gets** its power from the transmitter at **port 1**. However, the receive antenna (i.e., the source) at port 2 **delivers** its power to the receiver at **port 3**!



It is **particularly** important to keep the transmitter power from getting to the receiver. To accomplish this, the **antenna** must be **matched** to the transmission line. Do you see why?

Finally, we should note some major **drawbacks** with a circulator:

1. They're **expensive**.
2. They're **heavy**.
3. They generally produce a large, static **magnetic field**.
4. They typically exhibit a large **insertion loss** (e.g.,  $|S_{21}|^2 = |S_{32}|^2 = |S_{13}|^2 \approx 0.75$ ).