Circulators

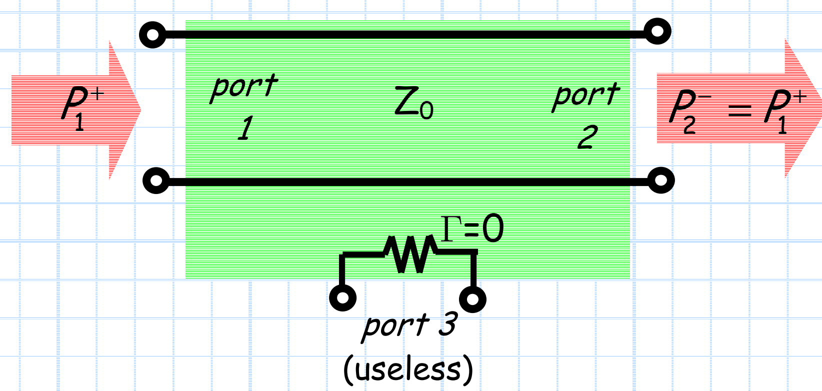
A circulator is a matched, lossless but **non-reciprocal** 3-port device, whose scattering matrix is ideally:

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

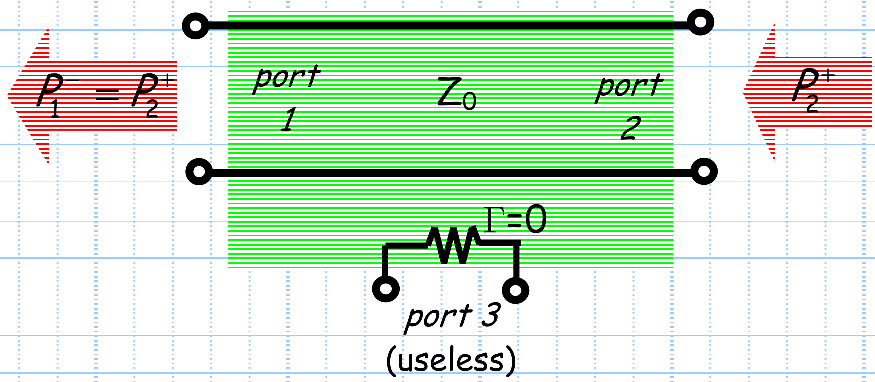
Circulators use anisotropic **ferrite** materials, which are often "biased" by a permanent magnet! The result is a **non-reciprocal** device!

Note that for a circulator, power incident on port 1 will exit **completely** from port 2:

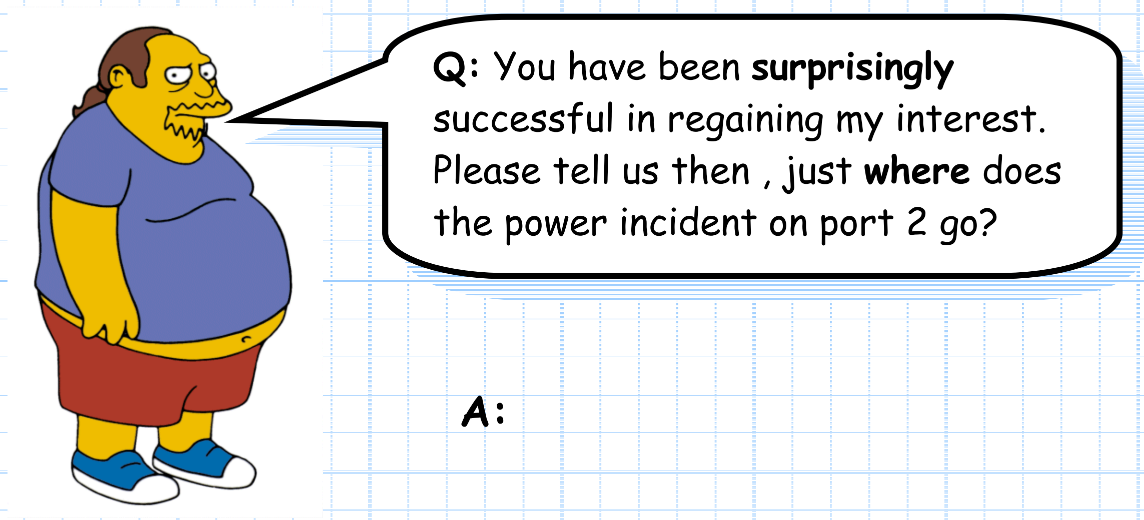
$$P_2^- = P_1^+$$



True! But a transmission line, being a **reciprocal** device, will likewise have the property that power **incident** on **port 2** will completely **exit 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 !



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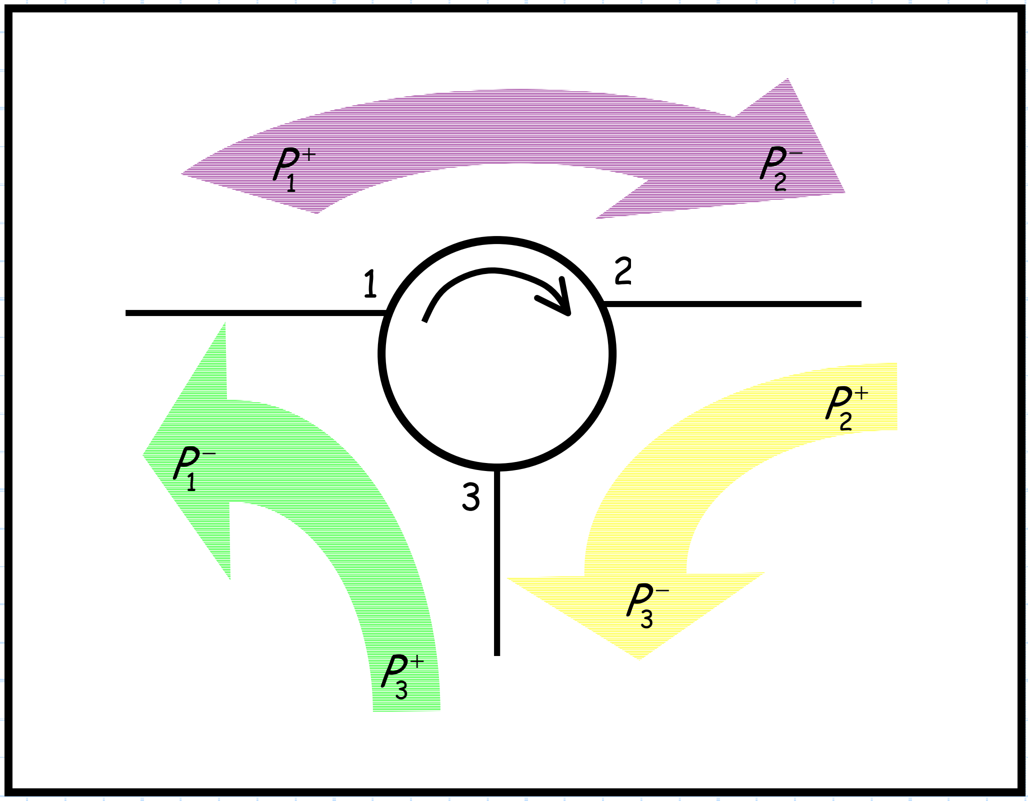
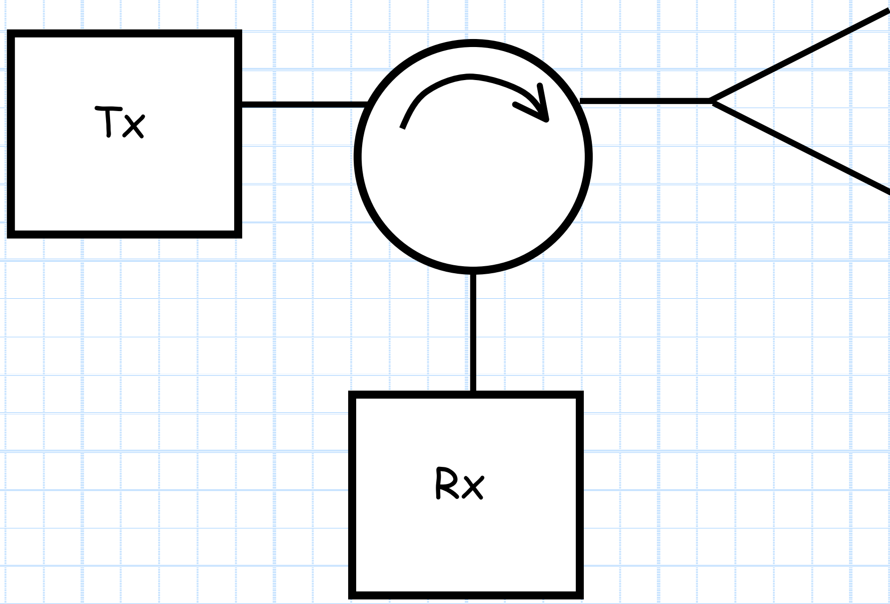
Likewise, power flowing into **port 3** will exit—**port 1**!

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. The generally produce a large, static **magnetic field**.

4. They typically exhibit a large **insertion loss** (e.g., $|S_{21}|^2 = |S_{32}|^2 = |S_{13}|^2 \approx 0.75$).