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

\[
\mathbf{S} = \begin{bmatrix}
0 & 0 & 1 \\
1 & 0 & 0 \\
0 & 1 & 0 \\
\end{bmatrix}
\]

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:

\[ P_2^- = P_1^+ \]

Pardon me while I sarcastically **yawn**. This behavior is likewise true for a **transmission line**. Oh please, continue to waste my valuable time.
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!

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:

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:

Likewise, power flowing into port 3 will exit—port 1!
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., $|S_{21}|^2 = |S_{32}|^2 = |S_{13}|^2 \approx 0.75$).