Circulators and Isolators

Why are circulators and isolators relatively expensive in the world of cheap microelectronics? Because for the most part they are hand assembled, tuned and tested. Tolerances on material properties of the ferrite and magnet as well as mechanical tolerances mean that invariably someone must make at least minimum wage tweaking the product. Tuning methods are different at different manufacturers. One method is to design the part so that the ports are all greater than 50 ohms, then tweak the impedance down by squeezing RTV over the traces to increase their capacitance while watching the result in real time on a network analyzer.

Circulators

A circulator is a ferrite device (ferrite is a class of materials with strange magnetic properties) with usually three ports. The beautiful thing about circulators is that they are non-reciprocal. That is, energy into port 1 predominantly exits port 2, energy into port 2 exits port 3, and energy into port 3 exits port 1. In a reciprocal device the same fraction of energy that flows from port 1 to port 2 would occur to energy flowing the opposite direction, from port 2 to port 1.
The selection of ports is arbitrary, and circulators can be made to "circulate" either clockwise (CW) or counterclockwise (CCW).
A circulator is sometimes called a "**duplexer**", meaning that is duplexes two signals into one channel (e.g. transmit and receive into an antenna). This is not to be confused with the term **"diplexer"** which is refers to a filter arrangement where two frequency bands are separated into two channels from a single three-terminal device. A lot of people mix up these terms. You can remember the correct definitions because "filter" and "diplexer" both have an "i" in them, and "circulator" and "duplexer" both have a "u".
What are circulators good for? The make a great antenna interface for a transmit/receive system. Energy can be made to flow from the transmitter (port 1) to the antenna (port 2) during transmit, and from the antenna (port 2) to the receiver (port 3) during receive. Circulators have low electrical losses and can be made to handle huge powers, well into kilowatts. They usually operate over no more than an octave bandwidth, and are purely an RF component (they don't work at DC).

Circulator rule of thumb!

A circulator's isolation is roughly equal to its return loss, and should always be specified to the same requirement. A circulator with 20 dB isolation will need to have a return loss of 20 dB. In essence, if you terminate the third arm in a perfect 50 ohms, the clockwise isolation you will measure in a CCW circulator won't be better than the stray signal that is bouncing off the loaded port due to the reflected signal due to its mismatch to 50 ohms.

Isolators

By terminating one port, a circulator becomes an isolator, which has the property that energy flows on one direction only. This is an extremely useful device for "isolating" components in a chain, so that bad VSWRs don't contribute to gain ripple.
Circulators and isolators can be made from 100's of MHz to through W-band (110 GHz). They can be packaged as planar microstrip components, coaxial components or as waveguide components. Waveguide circulators and isolators have by far the best electrical characteristics. You can specify insertion loss down to less than 0.2 dB in some cases. Microstrip and coax circulators and isolators might have losses between 0.5 and 1.0 dB. Note that the more bandwidth you ask for, the worse the insertion loss and isolation will be.