STACKED CIRCULATORS AND METHOD FOR STACKING CIRCULATORS

FIELD OF THE DISCLOSURE

This disclosure relates to microwave technology, and more particularly to microwave circulators. This disclosure further concerns the relative orientation of circulators when they are placed next to each other.

BACKGROUND OF THE DISCLOSURE

Circulators are nonreciprocal devices that route microwave signals in a preferential direction. The essential element of a circulator is a magnet which maintains a preferred direction of propagation in the circulator due to Faraday rotation.

Figure 1a illustrates schematically a circulator with three conductors 11, 12 and 13 and a magnet 8. The magnet 8 induces a magnetic bias field which affect a ferrimagnetic material (not shown) located at the junction. The conductors extend beyond the illustrated figure and transmit microwave signals from one component to another. A microwave signal 1 which enters the circulator through conductor 11 exits through conductor 12 due to Faraday rotation in the ferrimagnetic material. It does not exit through conductor 13. Conversely, signal 2, which enters through conductor 12, exits through conductor 13 and signal 3, which enters through 13, exits at 11.

Figure 1b illustrates a configuration where conductor 13 terminates in a microwave-absorbing element 7. In this case the circulator functions as an isolator which allows signal 1 to pass from conductor 11 to conductor 12 but prevents microwave signal 2 from entering conductor 11. This feature is particularly useful in applications where signal 1 is a weak signal and the microwave-generating element at the other end (the end which is not illustrated) of conductor 11 is sensitive to external interference.

For example, a qubit or sensor operating at cryogenic temperatures may generate an output signal 1 which comprises just a few microwave photons. The output line has to be connected to preamplifiers when the output signal is read out. These preamplifiers may be located at higher temperatures than the qubit or sensor. The qubit or sensor can be

In any embodiment presented in this disclosure, each first circulator and each second circulator may comprise a microwave-absorbing element 47, similar to element 7 in figure 1b, which minimizes microwave transfer in the undesired direction (from port 32 toward port 31 in assembly 21, for example). The microwave absorbing element 47 may be a microwave terminator, i.e. a resistive load whose resistance is matched to the characteristic impedance of the circulator output port (e.g. 50 or 75 ohms).

In any embodiment presented in this disclosure, the circulator assemblies may be attached to a mechanical support structure that is rigid enough to overcome the repulsive magnetic force between adjacent circulator assemblies. The mechanical support then holds together the circulator stack.

In addition to organizing adjacent first circulator assemblies in one row as the preceding figures illustrate, additional circulators can be organized in additional rows in the same arrangement. If a second row is implemented, these additional circulators may be called second circulators.

In other words, the arrangement may comprise two or more second circulator assemblies in a second stack where the second circulator assemblies are stacked adjacent to each other. The first and second stacks may be adjacent to each other so that each second circulator assembly is adjacent to one of the two or more first circulator assemblies. Furthermore, each second circulator assembly comprises one or more second circulators. Each of the one or more second circulators may be a microwave circulator. Each of the one or more second circulators may comprise a second magnet with a north-seeking pole and a south-seeking pole. Each of the one or more second magnets may comprise a ferrimagnetic element.

Each second circulator assembly may be oriented so that the south-seeking poles of all second magnets in the second circulator assembly face the north-seeking poles of the first magnets in the adjacent first circulator assembly, and the north-seeking poles of all second magnets in the second circulator assembly face the south-seeking poles of the first magnets in the adjacent first circulator assembly.

This option is illustrated in figure 5, where reference numbers 51 – 53 and 59 correspond to reference numbers 21 – 23 and 29, respectively, in the preceding figures. Unlike figures 2a – 3c, figure 5 illustrate an xy cross-section. That is, if the perspective in figures 2a – 3c is called a “side view” of the arrangement, then the perspective in figure 5 may be called a “top view”.