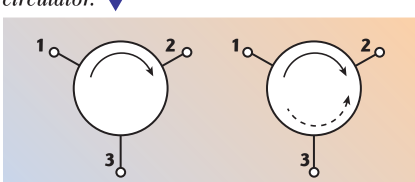
FERRITE CIRCULATOR SWITCHES AND THEIR APPLICATIONS

When looking for a coaxial microwave switch that can handle moderate power levels, the options considered are likely to be a PIN diode switch or an electromechanical switch. Both of these switch types have been well engineered over the years, but still suffer from inherent disadvantages. The PIN diode switch introduces significant levels of distortion products, while the electromechanical switch is relatively slow, and has lower life expectancy and reliability. In contrast, coaxial circulator switches, which have not received much attention, are capable of significant improvement over the PIN diode and electromechanical switches in distortion products and mechanical reliability, respectively.

A coaxial circulator is a three-port device utilizing a transversely magnetized ferrite junction to circulate incoming microwave energy from port 1 to port 2, port 2 to port 3 and port 3 to port 1.[1,2] It can be made to function as a SPDT switch by reversing the direction of the transverse magnetic field, thus changing the sense of circulation (1-3, 3-2, 2-1). This is shown schematically in ***Figure 1***. Field reversal is effected within a closed-loop magnetic circuit that includes the microwave ferrite(s).

Fig. 1 Ferrite junction circulator.



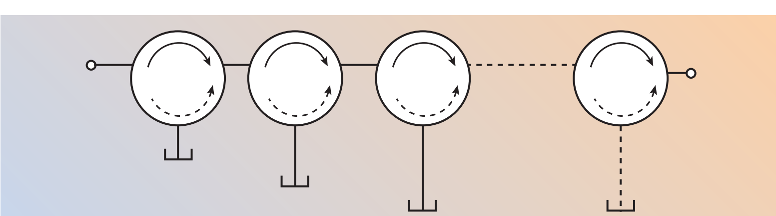


Fig. 2 Digital phase shifter using ferrite junctions.

Fast, compact switching circulators were first reported in stripline, waveguide and microstrip geometries in the mid-1960s.[3-5] One of the more unusual applications was and still is for Dicke Radiometers,[6] where the ferrite switch introduces very little thermal noise. The common application for coaxial interface (stripline) units was switched phase bits for medium power phased-array radars (see ***Figure 2***).[3] Waveguide switches became commercially available as stand-alone units for frequencies above 8 GHz. Microstrip units, having power limitations, are typically integrated into larger MMIC assemblies. As higher power microwave PIN diodes and improved frequency performance mechanical switches became available, the demand for coaxial ferrite switches diminished.

Diode and mechanical switches have some disadvantages relative to ferrite switches. Diode switches, although faster switching than ferrite junctions, have non-linearities that produce intermodulation products if more than one frequency is present, and do not latch (thus requiring holding current). While elec-

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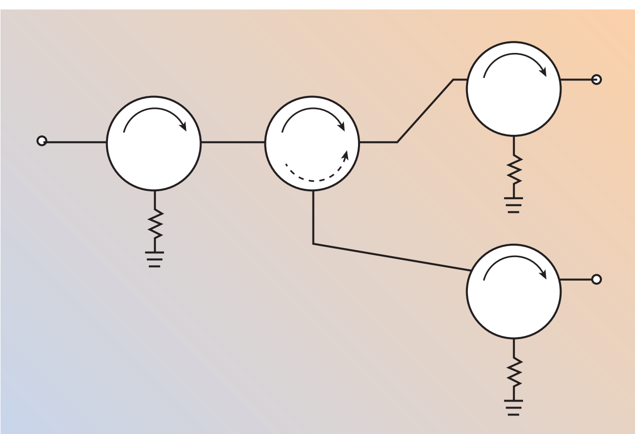
trically linear, mechanical switches are unreliable when left in a latched state for a long period of time, switch more slowly than ferrite junctions and do not allow hot switching (switching with RF power applied).

Various topologies are possible depending on the arrangement of switched paths, reciprocity requirements (same through phase for forward and reverse path), the importance of isolation between un-switched ports, or the need for good SWR during the switching interval.[7] Isolation between switched ports and hot switching SWR can be enhanced by adding non-switching junctions (see ***Figure 3***).

The magnetic circuit return path can be contained entirely within the RF region or be external to it. Internal path versions switch faster and require less switching energy than external path versions at the expense of somewhat reduced microwave performance, increased construction complexity and difficulty in keeping RF energy off the switching current wire.[8–10] External path units retain full microwave performance compared to non-switching units, and RF and switching control lines are separate. Switching circuitry can be included on the unit or be external to it. Operation is possible as either full- or half-latched (latched in one state only). In fully latching operation, the flux remanence B_r, of the overall magnetic circuit, produces an internal magnetic field in the microwave ferrite sufficient for below-resonance operation at or below saturation. The magnetic field and the switch state is reversed by a current pulse on the control line.[10] This imposes a practical low frequency limit of approximately 2 GHz for a latchable unit. Half-latched operation uses a



▲ *Fig. 3 Non-switching junctions add isolation.*

TABLE I SWITCH TYPE COMPARISON			
Switch Type	**Ferrite**	**Electromechanical**	**PIN Diode**
Power level	medium	highest	medium
Switching speed	medium	slowest	fastest
Hot switching	yes	low power only	yes
Distortion products	medium	best	worst
SWR	best	medium	worst
Life	medium	worst	best
Isolation	medium	best	worst

permanent magnet to bias the microwave ferrite in the latched state; this field is overcome and reversed by a bucking coil in the unlatched state. For the magnetic circuit flux remanence to provide sufficient field to the microwave ferrite, air gaps must be minimized.[10,11] Materials used for the magnetic return path must be chosen for temperature stability considerations and magnetic flux level required by the microwave ferrite.[12] Switching time and energy depend on ferrite volume, magnetization level ($4\pi M_s$) and eddy currents generated during switching. These are functions of center frequency, ferrite junction and return path design, and eddy current suppression. Conducting layers of the stripline geometry must appear thick (a few skin depths) to the microwave energy but thin to the frequency components produced by the switching current pulse. This is best achieved by silver plating a magnetically permeable material that has radial slots to disrupt the eddy currents.[10]

Any below-resonance ferrite junction can be fitted with a latchable external return path. For applications where IM performance, switching time, latchability, reliability and cost are critical (that is, remote switching between transmitters), a coaxial ferrite switching circulator may be the preferred solution. ***Table 1*** outlines the trade-off between the three types of switches for some significant device parameters. ■

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