The Lenkurt® Demodulator

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FERRITE DEVICES FOR MICROWAVE

Until recently it had been considered impossible to construct electrical transmission circuits which would not transmit energy in both directions. The discovery of the "one-way" properties of ferrites at microwave frequencies made possible for the first time passive non-reciprocal circuits. Ferrite devices are being used increasingly to perform important system functions in the microwave field.

This article describes ferrites, their unique non-reciprocal properties, and their application in two devices used in Lenkurt's Type 74A Microtel equipment.

Problems encountered in microwave carrier systems occasionally have been solved by methods which introduce losses or installation and maintenance complexities to the system. Two such problems are: (1) frequency changing of the radio-frequency carrier oscillator caused by reflection of energy from the transmitting antenna, and (2) interference between circuits when one antenna is used to transmit and receive signals from several microwave transmitters and receivers.

Resistive attenuators have been used in microwave systems to isolate the oscillator from the antenna and minimize reflections. However, attenuators cause losses in the transmitted signals as well as the desired loss in the reflected signal. Recently, ferrite devices have been developed which prevent antenna reflections from re-entering the transmitter and changing its frequency.

Using one antenna for several microwave transmitters and receivers (multiplexing) has been accomplished by several methods. In one method the transmitters and receivers are connected to a common line through parallel filters. Because these filters are in parallel, adjustment of one filter usually affects the adjacent filters. Optimum tuning is difficult and becomes more so as frequencies increase. Further, waveguide dimensional stability is required between adjacent filters.

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Another multiplexing method uses microwave hybrids combined with filters. However, separate antennas are required for transmitting and receiving, and a loss in signal strength of about 3 db occurs. Transmission line spacing between the hybrids and filters is also critical.

The non-reciprocal, or one-way, properties of ferrites makes possible the manufacture of simple electrically passive devices which will separate transmitters and receivers with little signal loss and few critical waveguide lengths.

Ferrites

Ferrites are compounds of iron, oxygen and any one of several other metals. Their chemical formula is MFe_2O_4, with M representing the metal other than iron. If the other metal is zinc, for example, the substance is termed "zinc ferrite." Metals such as cadmium, cobalt, copper, magnesium and nickel also may be used.

Ferrites used in microwave are made by combining the oxides of two or more of these metals with an oxide of iron (ferric oxide). The resulting material is a solid solution of two or more ferrites and is identified by the names of the non-ferric metal atoms. An example is manganese-zinc ferrite.

The properties of ferrite crystals depend upon the kinds of metal atoms combining with the ferric oxide, and their geometric arrangement in the total molecular structure. In general, they possess the permeability of magnetic metals but show a resistivity running up to 10^{16} (10,000,000,000,000,000) times that of iron. This characteristic allows them to handle microwaves with negligible eddy current losses.

Non-Reciprocal Properties of Ferrites

The non-reciprocal properties exhibited by ferrites at microwave frequencies make possible circuit devices with performance characteristics previously unobtainable. The two properties are called ferromagnetic resonance absorption and Faraday rotation.

Ferromagnetic resonance absorption in ferrites results from their unique permeability characteristic in the presence of a steady magnetic field. The commonly held theory to explain this characteristic is that some ferrite electrons behave as small gyroscopes in a manner similar to that of spinning tops in a gravitational field.

When a top is started spinning and is released, it will align its axis of rotation with the direction of the gravitational field. If a force is applied momentarily to the top at right angles to its axis of rotation, the top will lean over and move around, or precess about, its original axis of rotation at a frequency determined by gravitational force and the top's mass and velocity of spin. If the frequency of application of the force in the direction of precession is equal to the frequency of precession, the top will lean further and further from the vertical as it absorbs energy.

An electron is characterized by a negative electrical charge and a magnetic moment similar to that which would result from the charge spinning in a small circle. These properties may be represented by a spinning magnetic top (Fig. 1 a). With the application of a steady magnetic field to a ferrite, the axes of these assumed electron spins are aligned with the field. If the spin axis

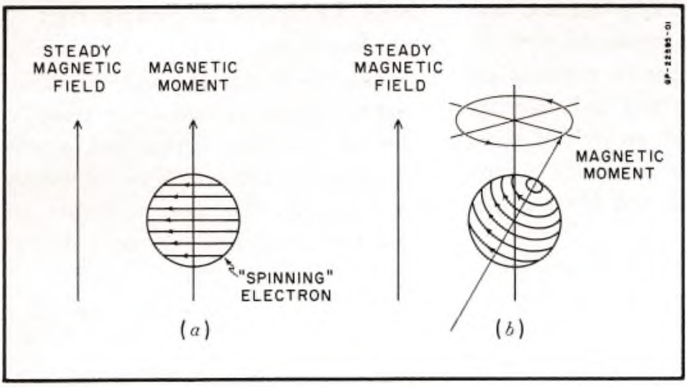


Fig. 1. (a) Electron represented as a spinning magnetic top. (b) Precession of a spinning electron about an axis parallel to the steady magnetic field.

is momentarily deflected, the spinning electrons will begin to precess as gyroscopes about the steady magnetic field at a frequency which depends upon the magnitude of the field (Fig. 1b). This frequency is the ferromagnetic resonance frequency.

Precessional motion is highly damped in ferromagnetic solids. If no further energy is imparted to the spinning electrons, they will re-align themselves with the magnetic field, giving up energy to the ferrite molecules to be dissipated as heat.

Now suppose a microwave signal with the same frequency as the frequency of precession is applied to a ferrite in a plane perpendicular to the aligning magnetic field. If the signal is propagated in the direction such that its magnetic field has the same sense of rotation as the precession of the electrons, the condition of resonance exists. Rf energy is imparted to the electrons, which go into violent oscillation. The energy they receive is dissipated in the ferrite material as heat, and the microwave signal is effectively absorbed.

If the rf signal travels in the opposite direction through the ferrite, the sense of rotation of its magnetic field will be opposite to that of the precessing electrons, and no net transfer of energy will occur. The signal will pass through the ferrite with very little attenuation.

Thus a ferrite device constitutes a one-way transmission system for microwaves when the applied steady magnetic field has the proper value to cause the precession frequency of the spinning electrons to be the same as the applied microwave frequency.

Another useful property of ferrites is known as Faraday rotation. In 1845 Michael Faraday demonstrated that the plane of vibration of a light wave was rotated when it was passed through certain materials in a direction parallel to an applied steady magnetic field. If the light wave is then sent back through the material, it will be rotated an equal amount in the same direction as before. The total rotation will be twice the original rotation. Thus, the Faraday rotation of the plane of polarization in optics is non-reciprocal. Fig. 2 shows Faraday rotation in a ferrite device.

If microwaves are propagated through a ferrite which has an applied steady magnetic field in the direction of the propagation, they will experience Faraday rotation of their plane of polar-

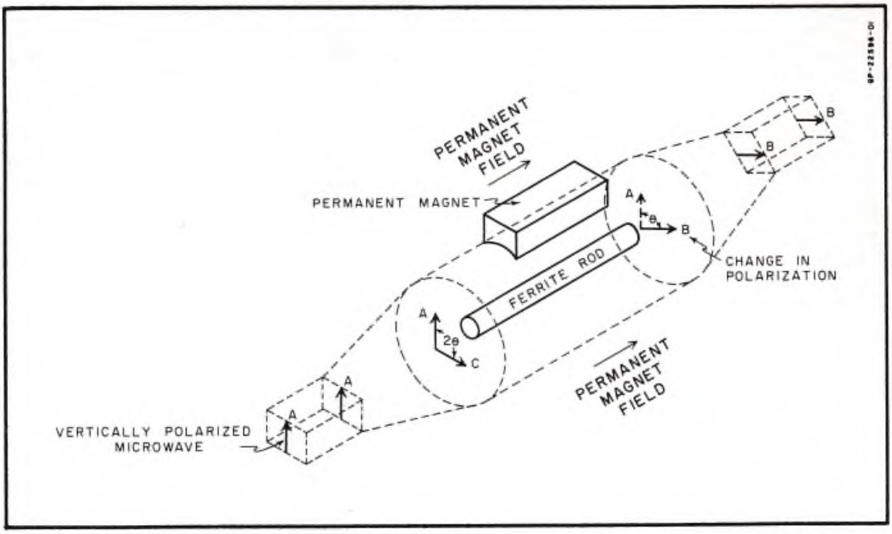


Fig. 2. A ferrite gyrator using Faraday rotation. Signal A passes through ferrite rod, is rotated θ degrees, and emerges as signal B. If B is reflected, it will be rotated another θ degrees for a total rotation of 2θ.

ization. This requires that the steady field be of such value that ferromagnetic resonance would occur at a frequency as far as possible from the microwave. Under this condition, the spinning electrons in the ferrite couple with the microwave field and cause its plane of polarization to rotate in a direction in space that is the same for forward and reverse propagation.

Practical Ferrite Devices

Many ferrite devices are available commercially. Those used for microwave applications generally depend on resonance absorption or Faraday rotation.

Isolators. The principle of ferromagnetic resonance absorption is applied in resonance isolators. They are so called because they operate in ferromagnetic resonance with the transmitted microwave signal to isolate one transmission stage from reflections arising from succeeding stages. Fig. 3a is the symbol for an isolator indicating attenuation of a signal flowing in the direction of the arrow.

When an isolator is located next to a klystron oscillator feeding a long waveguide connecting it to the antenna, the frequency pulling of the oscillator by the long line effect can virtually be eliminated. This greatly improves the linearity of frequency modulation which can be obtained with klystrons. The isolator also reduces phase distortion caused by multiple reflections between the oscillator and antenna. These functions are performed by the isolator with very small losses to the transmitted signal and very large losses to reflected signals.

Circulators. Faraday rotation of microwave is used in the operation of circulators which are so named because

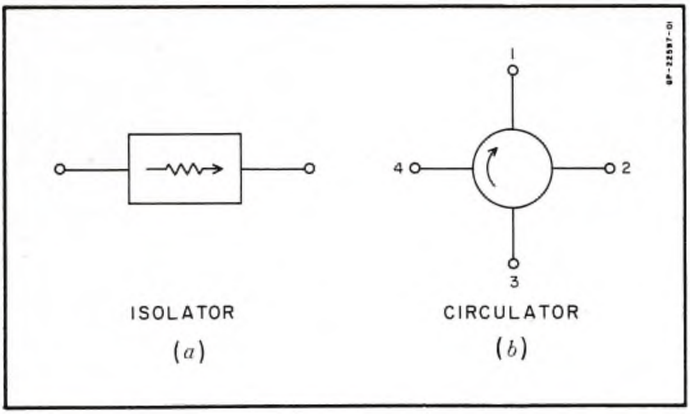


Fig. 3. Graphical symbols used to represent isolators and circulators in block diagrams.

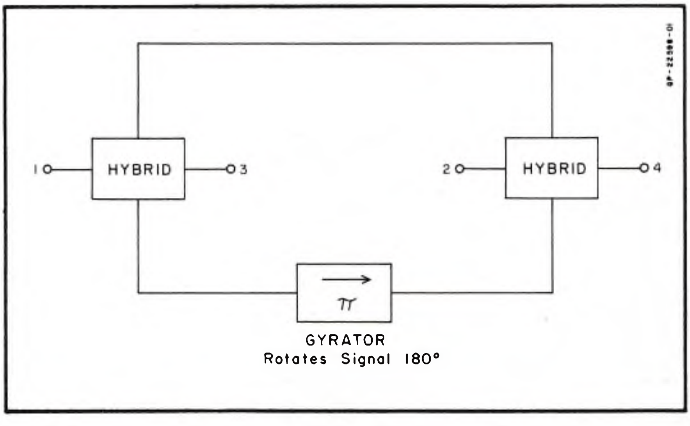
they will pass power from one terminal of this device to the others in sequence until the power is absorbed in a termination.

Fig. 3b is the symbol for a four port circulator. The arrow indicates the direction of circulation of a signal entering the device. If entry is at 1, the signal is routed to 2 where it may be either terminated or reflected and routed to 3. It proceeds from 3 to 4 to 1 in the same manner.

Fig. 4 is a schematic of the circulator. A ferrite gyrator, using Faraday rotation of 90° and a 90° twist in the waveguide, introduces a one-direction phase shift of 180° in half of the signal passing between the hybrids. This causes the two halves of the signal to add vectorially at the hybrids in such a way that flow of the signal is from 1 to 2, 2 to 3, 3 to 4, and 4 to 1. Fig. 5 shows the application of a circulator to multiplex two transmitters and two receivers to an common antenna.

A signal at the frequency of filter F_1 is received by the antenna, enters at 1, and is routed to 2. F_3 and F_4 are tuned to different frequencies so the signal is reflected to 3. This port is shorted and

Fig. 4. A typical circulator with four ports. Signal paths are from 1 to 2, 2 to 3, 3 to 4, and 4 to 1.



the signal is again reflected and is routed to 4. There it finds F_1 tuned to its frequency and passes through to R_1.

A signal from transmitter T_2 passes into the circulator at port 2, moves past the short, 3, and the filters not tuned to its frequency at 4, and terminates at the antenna, 1.

In this multiplexing system each filter is in parallel with only one other. Tuning becomes simple and dimensional stability in the waveguide connecting filters is not critical. Attenuation is about 0.5 db between adjacent ports.

Other Ferrite Devices

Ferrite devices perform many functions other than isolation and circulation. Their operation usually depends on variation of the magnetic control field applied to the ferrite.

One type of device provides amplitude modulation of a transmitted signal by varying its attenuation. It can also be used as an on-off switch.

Another device acts as an automatic gain control by using a sample of the transmitted power to control the attenuation introduced into a waveguide.

Many other devices can be constructed utilizing the principles of resonance absorption and Faraday rotation.

Applications to Lenkurt's Microtel

Lenkurt's Type 74A *Microtel* radio system uses an isolator following the transmitting klystron and offers a circulator panel as an option. One circulator permits up to three transmitter-receiver combinations to use the same antenna. If four or five transmitter-receiver com-

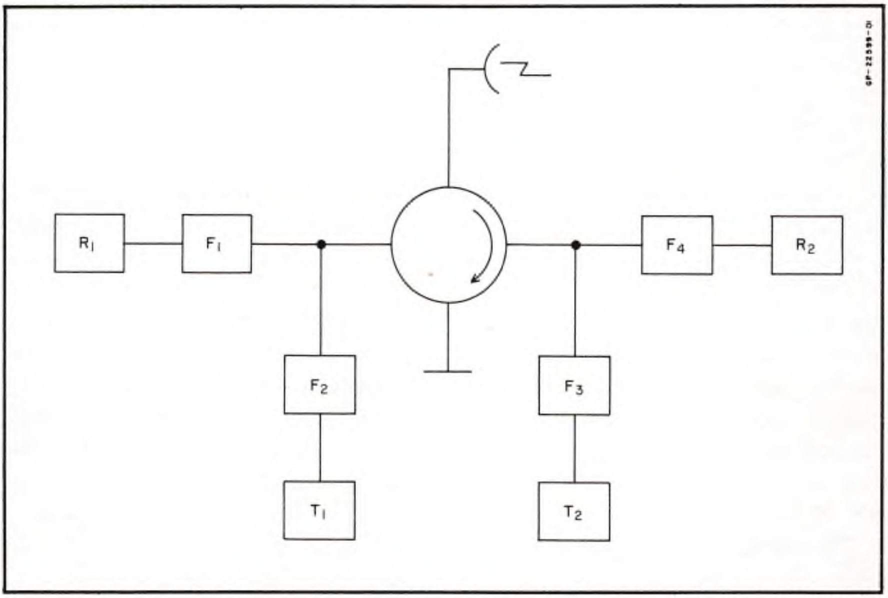


Fig. 5. Two transmitters and two receivers connected to a common antenna by a circulator. F_1, F_2, F_3, F_4 are filters tuned to the frequencies of their respective transmitters or receivers.

binations are to be coupled to one antenna, two circulator panels must be used.

The resonance isolator which follows the klystron is essential for a high channel density system when it must operate into a long length of waveguide. Without the isolator, the "long line" effect would force the use of less satisfactory antenna systems.

DO-IT-YOURSELF TRAINING COURSES

New additions to Lenkurt's Customer Training Program are do-it-yourself courses for training departments. An increasing number of requests have been received from customers for training material to set up installation and maintenance courses similar to those offered at Lenkurt's Training School in San Carlos. As a result of these requests, complete training packages covering 45-class equipment have been prepared.

A general course covering all Lenkurt 45-class equipment is available, as are individual courses for each equipment type. Included in each course are an instructor's manual with master outline, reference publications, student reference manuals, visual training aids, quizzes and final examinations.

All training material is keyed to standard equipment instruction manuals. Use of instruction manuals in class to review detailed information on individual units, panels and assemblies familiarizes the students with the various bulletins and associated drawings they will later use to install and maintain 45-class equipment.

The instructor's master outline makes it possible for the courses to be given with maximum effectiveness. It was prepared on the basis of several years of experience in Lenkurt's Training School and follows the program used there. It contains a listing of all material required for conducting a class, a suggested classroom layout, and an index listing in sequence the material to be covered.

Each item on an index has suggestions for presentation, points to be emphasized, and explains the use of training aids and reference material. Time estimates are shown for each phase of the course. To stimulate class participation in discussions, typical questions are included in the master outline to assist the instructor in promoting class interest.

The quizzes and final examination serve a two-fold purpose. They indicate how well each student has absorbed the material and how effectively the instructor has presented it to the class as a whole.

Classroom lectures should be supplemented by applying lecture material to an operating system. For this purpose, an operating system—two terminals equipped with a minimum of four channels—should be available to the students. Adequate test equipment, patch cords and plugs also should be provided at each terminal location.

Information on training material is available from Lenkurt and Automatic Electric.

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