A REVIEW OF MICROWAVE FERRITE DEVICES

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Ferrites are used at frequencies between 100 Mc and 300,000 Mc in non-reciprocal attenuators (isolators), circulators, nonreciprocal phase shifters, power limiters, microwave switches, modulators, frequency multipliers, parametric amplifiers, sideband generators and variable attenuators and phase shifters. These applications fall into two categories: (1) unique functions such as those performed by the ferrite isolator and circulator where other types of devices are clearly inferior; (2) marginal functions such as the ferrite limiter or switch where a gas or semiconductor device would ordinarily provide superior performance. Ferrite devices of both categories have been improved recently. Those that perform the unique functions have been made to operate in new kinds of microwave systems or at higher power levels or at ultra-high frequencies or at millimeter wavelengths. Those that perform marginal functions have been adapted to work in specialized systems where they have provided higher power-handling capacity or longer lifetime or lower cost or smaller size or shorter recovery time or smaller insertion loss, but rarely more than one of these in each case.

An example of the competitive situation existing between marginal ferrite devices and semiconductor devices arises in the case of components for the phased-array antenna systems. Here the phase shifters and switches that are needed must be supplied in great quantities. Either cost, size or insertion

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loss (or all of these) may dictate a decision between the semiconductor or ferrite device. In another type of application, switching time or power handling capacity may have greater significance. An improved model of either device or novel idea for cutting costs may suddenly cause the decision to be reversed. Occasionally, the only safe way to proceed with a system design is to develop both types of device simultaneously to see which one will eventually do the better job. Indeed, the marginal devices exhibit an on-again, off-again existence of this kind. Several examples will be given of systems using marginal devices along with a discussion of the ferrite limiters, switches, multipliers or amplifiers involved.

An outstanding example of the extension of the unique function of ferrite devices to new systems is the adaptation of circulators and one-way transmission lines (isolators) to millimeter wavelengths. As a result, a whole line of microwave components are now available throughout the EHF range. A variety of new schemes have been developed to accomplish this. The difficulty of building tiny ferrite devices in millimeter-size waveguide was overcome by using less structure-sensitive devices such as the Y-circulator or the dielectric-guide Faraday rotator perfected by Barnes. The need to bias ferrite devices at resonance with extremely large magnetic fields for operation at millimeter wavelengths was overcome by the development and use of magnetic oxide materials having large built-in internal magnetic fields. These internal fields can be as large as 50,000 gauss in the oxides of the magnetoplumbite class which have hexagonal crystal structure similar to Ferroxdure. The internal field intensity and the saturation magnetization can be adjusted by the selective substitution of metal ions such as strontium, aluminum, nickel or cobalt so as to render the properties of the material nearly temperature independent up to the Neel temperature which usually lies between 450 and 550° C. By this process, the appropriate internal field intensity can be selected for the required operating frequency and only the small fields of trimmer magnets need to be applied externally. In addition to the improvement of the basic magnetic materials, the millimeter-wave adaption of off-resonance devices such as the circulators, field-displacement isolators, and Faraday rotators to perform the isolator function have solved the high-magnetic field problem completely. These require only 20 to 30 gauss to be applied externally to magnetize the ferrite and their operation is independent of the ferromagnetic resonance condition.

An essential function which could hardly be performed by another type of device is the protection of a magnetron (or any rf power source) from load fluctuations, particularly when the magnetron is followed by one or more stages of power amplification. If a travelling-wave or backward-wave amplifier such as an amplitron is used, a slight reflection at the load can propagate back through the amplifier, unattenuated, and enter the magnetron at a power level comparable to the magnetron's output. Ferrite isolators have found wider use during the past few years in preventing this difficulty because the high power-handling capabilities of the isolators have been improved and models have been designed for operation at low microwave frequencies and in the UHF range.

This paper will summarize the wider recent applications of the classical, unique ferrite devices as a result of the improvements in performance. A summary will also be given of the marginal ferrite devices along with their operating characteristics. Several examples will be given of the use of ferrite devices in microwave systems where particular properties of each device were selected on the basis of an important system requirement. A brief historical sketch will be included to indicate the rate of progress.

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