II-4. A Symmetrical, Distributed Constant Circulator

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Ferrite circulators that have been built in the past fall into two categories: non-symmetrical, distributed-parameter type, such as the Faraday rotation and differential phase shift circulators; and the symmetrical, abrupt discontinuity type, such as the "Wye" junction circulator. This paper describes a third type, which has both the properties of symmetry and a distributed interaction region. As such, it is believed that this type of circulator has potential for quite large bandwidths.

The circulator consists of a ferrite rod, longitudinally magnetized, with three conductors arranged symmetrically about the rod, as shown in Fig. 1. A common ground shield surrounds the entire circulator. The three conductors are terminated with coaxial connectors on the left-hand or input side. In one version, the other ends of the conductor are likewise terminated in connectors to form a six-port circulator. In a simple version, the conductors are shorted to a ground plane on the right-hand side, thus forming a three-port circulator.

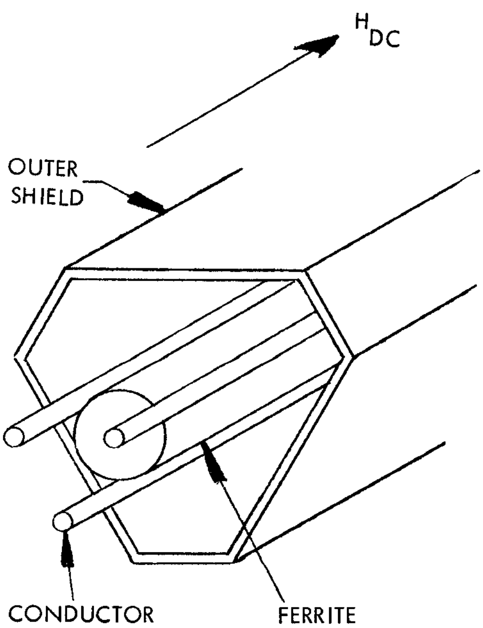

Fig. 1 Symmetrical, distributed-constant circulator

Analysis of the circulator is most conveniently handled by the use of symmetrical components. Referring to Fig. 1, we will represent the voltages on the three conductors as:

$$v_0 = V_E \varepsilon^{j\beta^E z} + V_+ \varepsilon^{j\beta^+ z} + V_- \varepsilon^{j\beta^- z},$$
$$v_1 = V_E \varepsilon^{j\beta^E z} + aV_+ \varepsilon^{j\beta^+ z} + a^2 V_- \varepsilon^{j\beta^- z},$$
$$v_2 = V_E \varepsilon^{j\beta^E z} + a^2 V_+ E^{j\beta^+ z} + aV_- E^{j\beta^- z},$$

where $a = \varepsilon^{j2\pi/3}$. With this definition, the three modes are: an even mode, a plus circularly polarized mode, and a minus circularly polarized mode, and we can use a scalar rather than tensor permeability for the ferrite medium. This allows the definition of three propagation constants, β^+, β^-, β^E:

$$\beta^+ = \omega\sqrt{\mu_0 \varepsilon_0 \varepsilon}\ \sqrt{1 + X^+},$$
$$\beta^- = \omega\sqrt{\mu_0 \varepsilon_0 \varepsilon}\ \sqrt{1 + X^-},$$
$$\beta^E = \omega\sqrt{\mu_0 \varepsilon_0 \varepsilon}\ \sqrt{1 + X^E}.$$

Furthermore, we can assume that:

$$(\beta^+ - \beta^E) \approx -(\beta^- - \beta^E).$$

An input of amplitude 3A is assumed on the 0th conductor by setting $V_+ = V_- = V_E = A$, at a distance $Z = L$, where L is given by

$$L = \frac{2\pi}{3(\beta^+ - \beta^E)},$$

it is seen that the voltage on the 1 wire is equal to 3A and the voltage on wires 0 and 2 is equal to zero. Thus, the energy has circulated from the 0th wire to the 1 wire. Likewise, an input on 1 will circulate to 2, etc. It can also be shown that if a shorting plane is placed at $Z = L/2$, a three-port circulator will result.

To examine the frequency dependence of this circulator, we need only to look at the frequency dependence of L.

$$L = \frac{2\pi}{3(\beta^+ - \beta^E)},$$
$$= \frac{4\pi}{3\omega\sqrt{\mu_0 \varepsilon_0 \varepsilon}\left[\dfrac{\omega\,\omega_m}{\omega_H{}^2 - \omega^2}\right]},$$
$$\approx \frac{4\pi}{3\gamma 4\pi M\sqrt{\mu_0 \varepsilon_0 \varepsilon}}.$$

Thus, it is seen that L is almost frequency independent for $\omega >> \omega_H$.

For a practical device, it is necessary to know how to calculate the input impedance in terms of the physical parameters. It is desirable to have a 50 ohm input impedance to avoid the use of transformers which would limit the useful bandwidth.

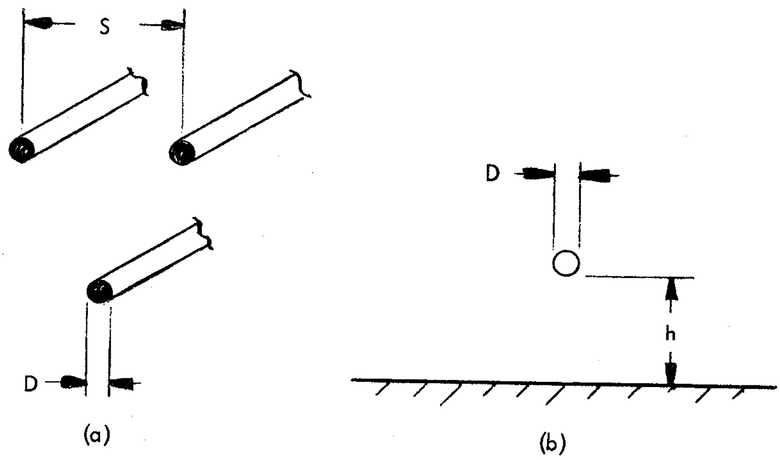

Fig. 2 (a) Three-wire, three-phase circuit used to calculate plus and minus mode impedances. (b) Equivalent circuit used to calculate even mode impedance.

The input admittance is given by:

$$Y = 1/3\,(Y^{+} + Y^{-} + Y^{E}).$$

The equivalent circuit for Y^{+} and Y^{-} is shown in Figure 2 (a) and that for Y^{E} in 2 (b). The equations are given below:

$$Z_{\pm} = \frac{60}{\sqrt{\varepsilon}} \ln \frac{2S}{D}$$

$$Z_{E} = \frac{60}{\sqrt{\varepsilon}} \ln \frac{4h}{D}$$

where D = wire diameter, S = wire spacing, and h = wire-to-shield spacing.

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