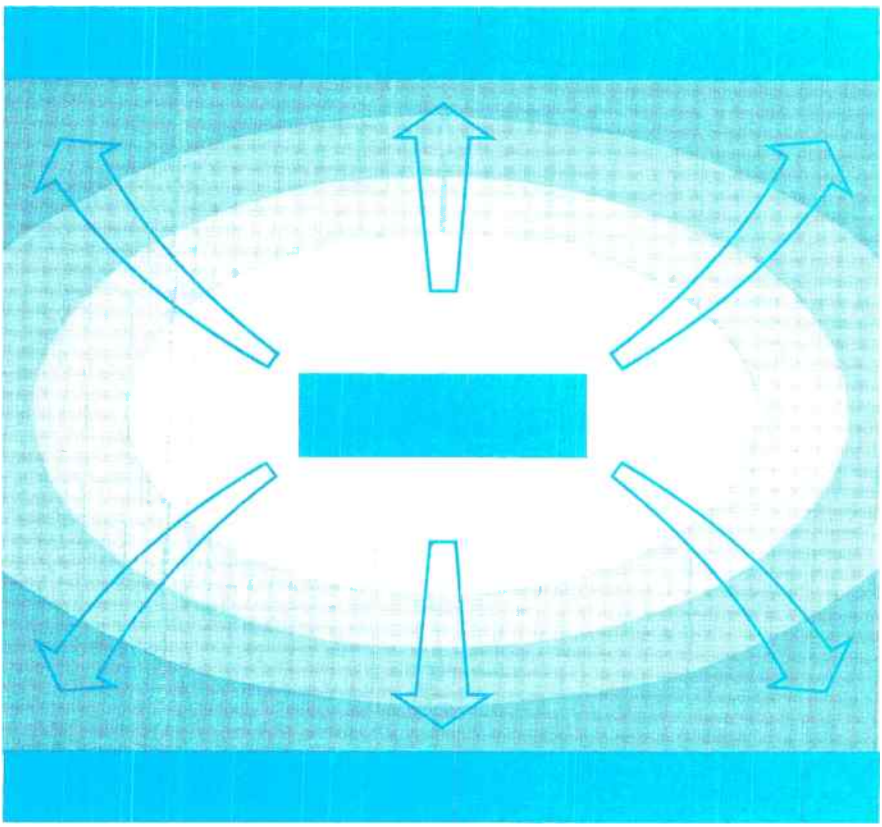
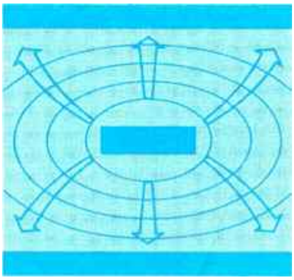
GTE LENKURT

DEMODULATOR

SEPTEMBER 1972

STRIP TRANSMISSION LINES





The transmission line is an important component of any microwave transmission equipment. Within a certain frequency spectrum, strip transmission line provides an efficient and compact conveyance for microwave signals.

A transmission line conducts electromagnetic energy at any frequency from one point or circuit element to another. At low frequencies, transmission of energy is a simple matter, but where microwave frequencies are involved (above 1000 MHz), the problem of transmission becomes much more complex.

The simplest transmission line consists of two parallel wires which are used to transmit low radio frequencies with little electrical loss. At frequencies above two or three hundred megahertz, the losses by radiation of a two-wire line become too high, and coaxial line must be used as the transmission medium. For frequencies above 1000 megahertz, the losses of coaxial line become significant, and waveguide must be used. In recent years, strip transmission line, also known as strip line, and/or flat transmission line, has been developed as a transmission medium for directing electromagnetic energy at microwave frequencies.

Electromagnetic Energy

Electromagnetic energy can be manifested in many forms of radiant energy. Some of these include radio waves, visible light waves, heat waves, gamma rays, X-rays, and cosmic rays. In telecommunications, radio waves are regarded as the main form of radiant energy. When electromagnetic energy in the form of radio waves is propagated along a transmission line, electric and magnetic fields – traveling in a specific direction – are set up around the conductor. This excitation of electric and magnetic fields produces an electromagnetic wave, and it is the energy contained in this wave which the transmission line must convey from one point to another with as little loss as possible. In a two-conductor transmission line, low-frequency electromagnetic energy is propagated along two parallel conductors. Figure 1 shows such a line with its respective electric and magnetic fields.

As an electromagnetic wave propagates along a transmission line, it is attenuated as a function of distance due to resistive losses in the conductors and dielectric losses in the dielectric material. The magnitude of this loss must be low if the transmission line is to function efficiently.

Modes

Closely associated with an electromagnetic wave is its mode of transmission. The electric and magnetic field-configuration in which energy at a given frequency propagates along a transmission line is referred to as a mode. Theoretically, in any transmission line, there is an infinite number of modes which can be excited or established along the line. Each is charac-

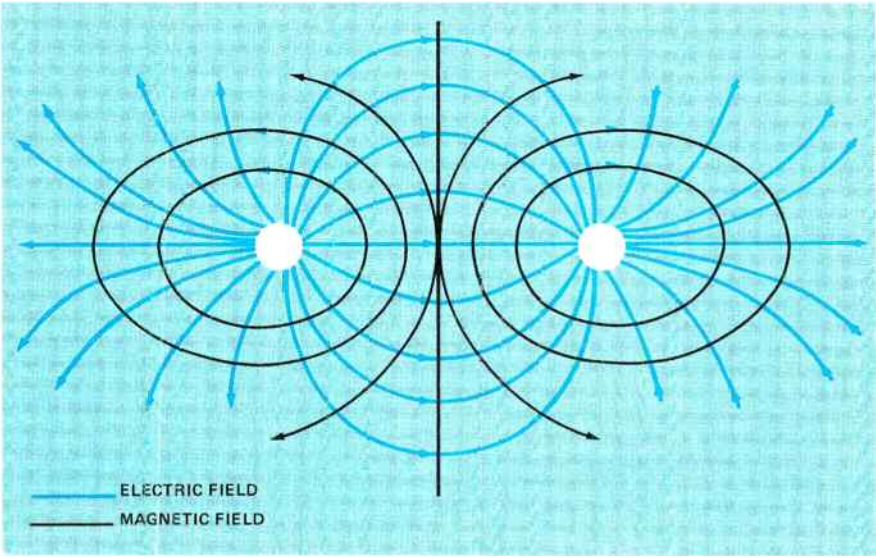


Figure 1. Two-conductor transmission line and its electric and magnetic fields. Here, current enters one line and comes out of the other.

terized by a particular configuration of electric and magnetic fields. In most applications, the line is physically designed so that its operating frequency is capable of efficient energy transmission in only one mode. The appearance of other modes causes an attenuation of the signal, in such a line.

The principal or TEM (transverse electromagnetic) mode is most commonly used with coaxial transmission line. The most outstanding characteristic of this mode is that it consists only of electric and magnetic fields that are transverse to the direction of energy flow. Or, more simply, both electric and magnetic fields are everywhere perpendicular to the direction of propagation. In contrast, higher-order modes have electric or magnetic field components either of which may lie in the direction of energy flow. TEM waves can transmit energy at frequencies down to dc, while the higher-order modes have cutoff frequencies below which energy cannot be transmitted along the line. A transmission line must have two separate conductors to support a TEM wave. (Such as in open two-wire or coaxial transmission line.) Waveguide has only one path of transmission and therefore cannot operate in the principal mode of transmission. It must operate in the transverse electric or transverse magnetic modes. This difference is the essential reason behind the unique modal configurations of coaxial and waveguide transmission mediums.

Coaxial Transmission Line

In coaxial transmission line, electromagnetic waves propagate through the dielectric material which is bounded by the inner and outer conductors. Because of "skin effect" – the tendency of RF current to travel near the surface of a conductor – most of the

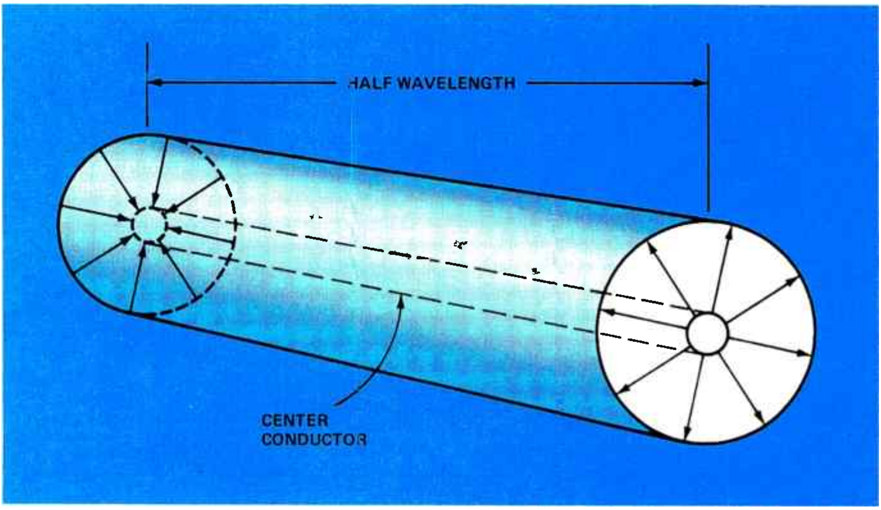


Figure 2. In coaxial transmission line, the electric fields are in opposite directions at each half-wavelength.

electromagnetic current is concentrated on the surfaces of the conductors. The electric fields of coaxial line are all radial in that they are directed toward or away from the conductor at any given time. For each half wavelength along a coaxial line, the electric fields will be in opposite directions as shown in Figure 2.

For the transmission of electromagnetic energy in a single mode, the mean circumference of the coaxial line must be restricted to less than one wavelength. Because of the shorter wavelengths of higher frequencies, the maximum permissible dimensions of coaxial line are small and the losses are increasingly high. The magnitude of those losses may require the use of waveguide or strip transmission lines.

Waveguide

Any transmission line may be referred to as a waveguide since it guides electromagnetic waves from one point to another. More commonly, however, waveguide refers to hollow metal pipes used as microwave transmission lines. They may be rectangular, circular, or elliptical in cross section; but, by far, the most commonly used is rectangular waveguide. In waveguide, electromagnetic waves are propagated through the hollow interior of the metal structure causing electric current to flow along the inner surfaces.

The mode at which electromagnetic energy propagates along a waveguide has a specific cutoff frequency. This is the lowest frequency that will propagate through that transmission line while operating in that mode. The "dominant mode" is the mode which has the lowest frequency of propagation for a set of given waveguide dimensions. It is the mode most often used and appears as shown in Figure 3, at one instant in time. Energy at frequencies below the cutoff frequency is greatly attenuated, while energy above the cutoff frequency is transmitted with very little attenuation.

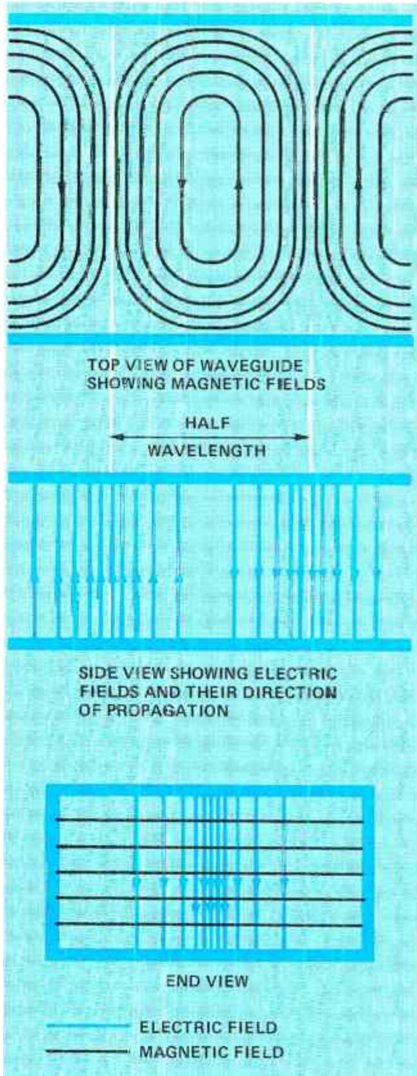


Figure 3. Field configuration of the dominant mode in rectangular waveguide.

For energy to propagate along a waveguide of given dimensions, the operating frequency must be higher than that of the cutoff frequency. For this reason, waveguide becomes too large to be practical at lower frequencies, and its use is therefore limited to the microwave frequency range. In most waveguide applications, the dimensions of the guide are designed so that only one mode of operation will be present at the operating frequency of the system. The greatest advantages of waveguide over coaxial line are higher frequency capacity, lower signal attenuation, and simple structural design.

Strip Transmission Line

A strip transmission line is very similar in electromagnetic properties to coaxial transmission line. It propagates the same kind of wave (TEM) between two conductors as does coaxial line.

The general configuration of a strip transmission line is shown in Figure 4. The strip conductor is bounded by a dielectric material, which, in turn, is confined by two ground planes. The dielectric has the capacity to reduce the physical dimensions of the line for any operating frequency. For example, if a half-wave transmission line is needed in a circuit, strip line will reduce the length of the line by the square root of the dielectric constant. This reduction in length varies with the dielectric material. By selecting the proper material, an efficient and compact circuit may be designed. Compactness, however, is not the main advantage of strip transmission line, its greatest value is in greater ease of manufacture. Once a line has been properly designed to perform a certain function, it can be manufactured in great quantities using standard photoetching techniques. Strip line manufacturing techniques provide precisely-controlled circuitry of lower cost, reduced size and weight, and greater ruggedness and reliability.

The strip transmission line evolved from the coaxial line. Figure 5 shows

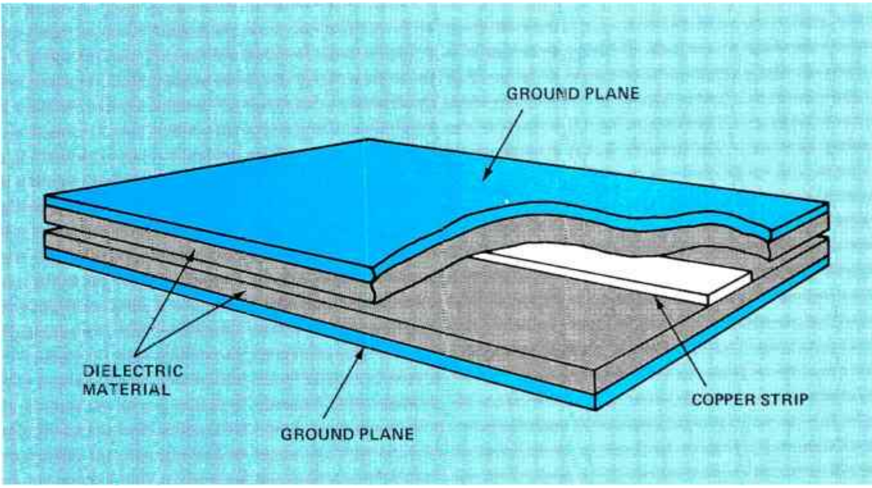


Figure 4. General configuration of a strip transmission line.

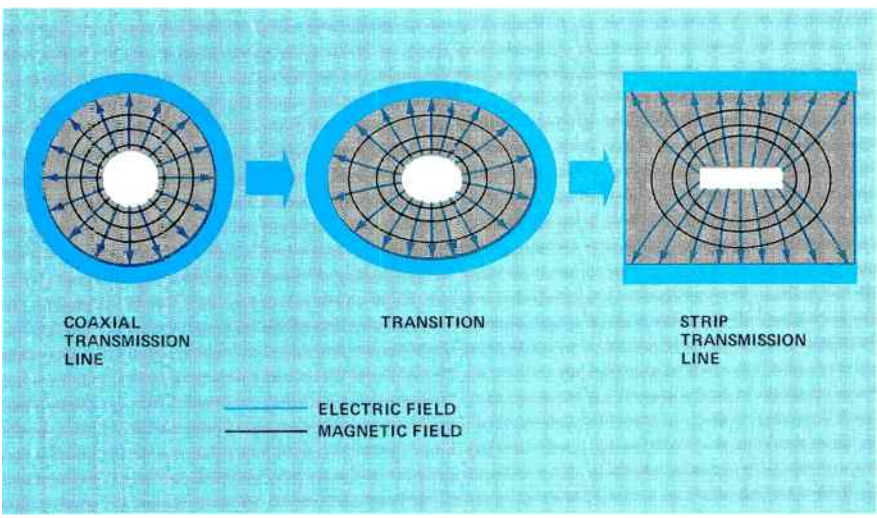


Figure 5. Strip transmission line evolved from the coaxial transmission line.

the evolution from coaxial to strip line with respect to electric and magnetic fields. In coaxial line the magnetic lines of force surround the center conductor while the electric field extends from the inner to the outer conductor. In strip line, the outer conductor divides into two parallel ground planes.

As with coaxial transmission line, the principal mode (TEM) is generally used. The ground planes of the strip line are at the same potential. The field is mainly confined to the area

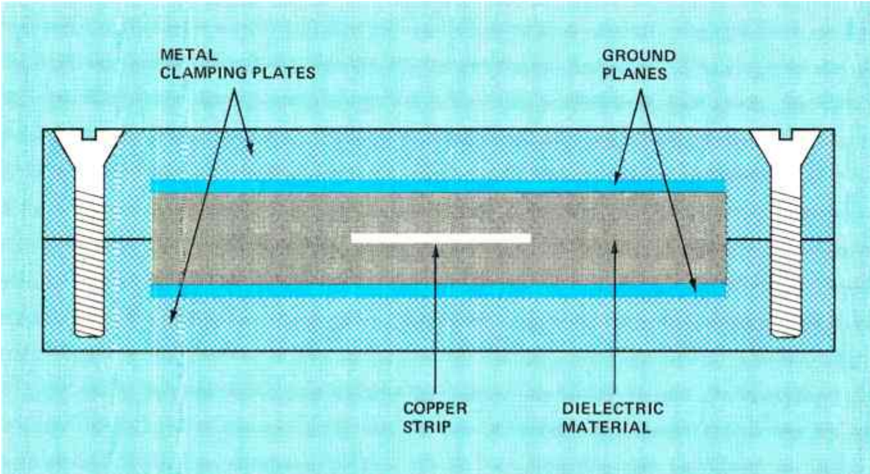


Figure 6. General appearance of a complete strip transmission line. (End view)

between the strip and the ground planes, with the field intensity falling off rapidly with distance from the conducting strip. If the distance from the edge of the strip to the edge of the ground-plane area is as much as two times the spacing between the ground planes, the intensity of the field at the edge is very low.

A wide variety of microwave circuits can be constructed using strip line. Some of these include hybrid Tee's, filters, mixers, circulators, directional couplers, power dividers, antennas, attenuators, and transformers. Such components may be designed and constructed with greater facility than corresponding structures in coaxial transmission line or rectangular waveguide.

Dielectric Material

The dielectric material is an important part of the strip line. It stores the electromagnetic energy which propagates along the conducting strip. The higher the dielectric constant of the material, the greater the concentration of the electric lines of force within the dielectric material.

The energy stored in the dielectric as it travels along is similar to the energy stored in an ocean wave as it moves along the surface of the sea. The energy in the wave is not released until it makes contact with some obstruction such as a ship or a shore. In the case of strip line, the stored energy is not released until it reaches the desired circuit element.

The dielectric constant of a material is a fixed value and is determined by the nature of the material. In recent years it has been possible to effect a desired dielectric constant by mixing materials of different dielectric constant. Such a process is called "dielectric loading" and may, for example, involve the combination of Teflon® (dielectric constant, 2.1) and fiber glass (dielectric constant, 3.88) to give a material with a dielectric constant of 2.37. It is now possible to achieve dielectric constants upwards of 50 by proper mixture of existing materials.

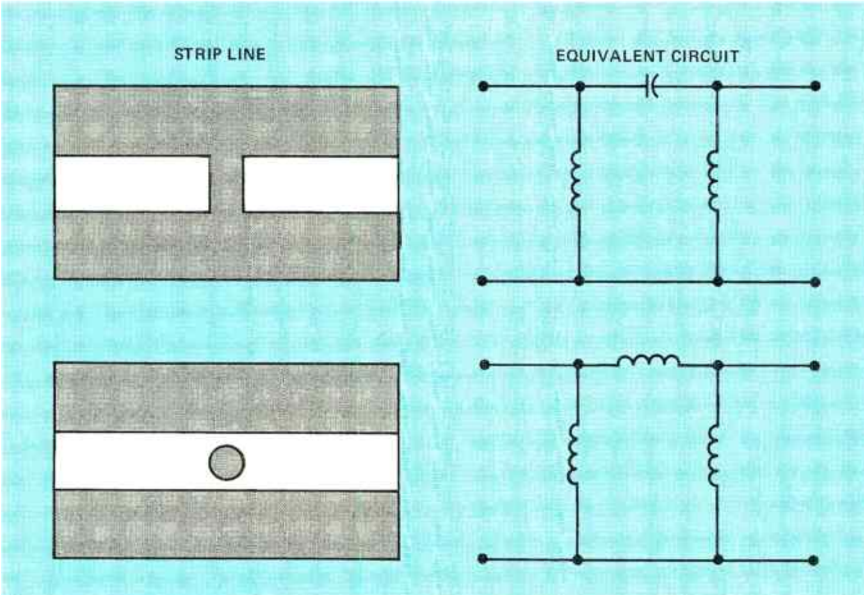


Figure 7. A space or circle positioned along a strip line gives the equivalent circuit of networks made up of discrete components.

Construction

The strip transmission lines designed by GTE Lenkurt are made from two sheets of copper laminates, each of which is copper-clad on both sides, and with the desired dielectric material in the center. On the surface of one sheet, the desired strip is etched to precise dimensions using standard photoetching techniques similar to those used in printed circuit board construction. The second sheet is completely stripped of copper on one side. The two boards are then clamped together to form the complete transmission line as shown in Figure 6. It is also possible to design the strip line with discrete components physically connected to the line and located within a hollow region of the metal clamping structure. This gives an extremely compact device, but it has disadvantages in that additional machining requires extra labor and may also introduce new loss elements.

Unique Properties

Quite often, discussions on strip lines tend to be surrounded by an esoteric aura because of the unique properties and complex physical and mathematical implications involved. In fact, strip transmission lines are still to a large degree under development, but have found many practical uses in the newer microwave equipment.

Although strip lines follow the same electrical laws as does standard electronic circuitry, their physical appearance is markedly different than conventional circuits because of the high frequencies at which they operate. Components such as resistors, capacitors, and coils which are normal-

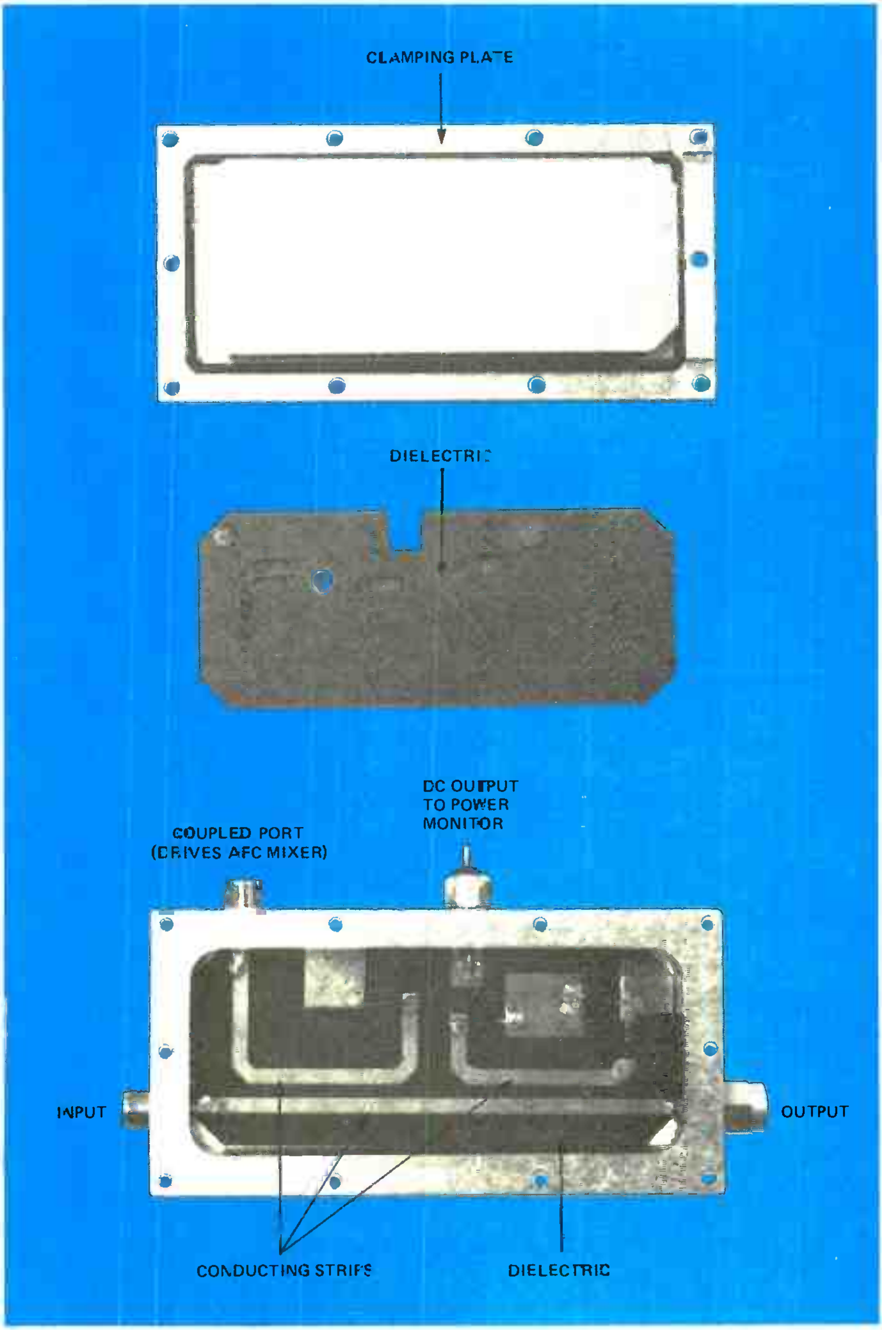


Figure 8. The principal of the strip line is used in construction of directional couplers.

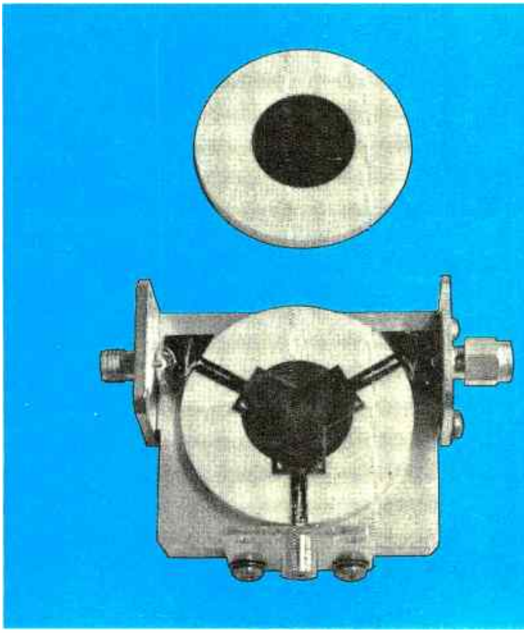


Figure 9. Strip-line circulators constructed by GTE Lenkurt find many applications in microwave radio.

ly used at lower radio frequencies become extremely small and inefficient at microwave frequencies. Microwave circuitry is therefore often manifested in lengths of transmission line rather than discrete components. By designing strip lines of various lengths and patterns, it is possible to achieve results which are equivalent to those obtained by conventional components at lower frequencies.

Microwave Filters

Strip transmission line may be used to provide some of the resonant or reactive elements that make up microwave filters. For example, precise positioning of spaces or holes along the line will give the equivalent result as conventional coil and capacitor networks made of discrete components. (See Figure 7) The inductive and capacitive values of these networks are mainly determined by the length of the space, the diameter of the hole, and the width of the conducting strip.

Strip-Line Directional Couplers

The directional couplers built by GTE Lenkurt in strip-line form utilize more than one conductor on a single dielectric substrate. The physical layout of these couplers adheres to design equations which enable the calculation of the amount of coupling between two conducting strips. The length, width and distance of separation of two strips are crucial factors in determining the amount of energy which can be transferred from one strip to the other. The general layout of a strip line directional coupler with two couplers in tandem appears as shown in Figure 8.

Circulators

A circulator is a microwave coupling device which has a number of

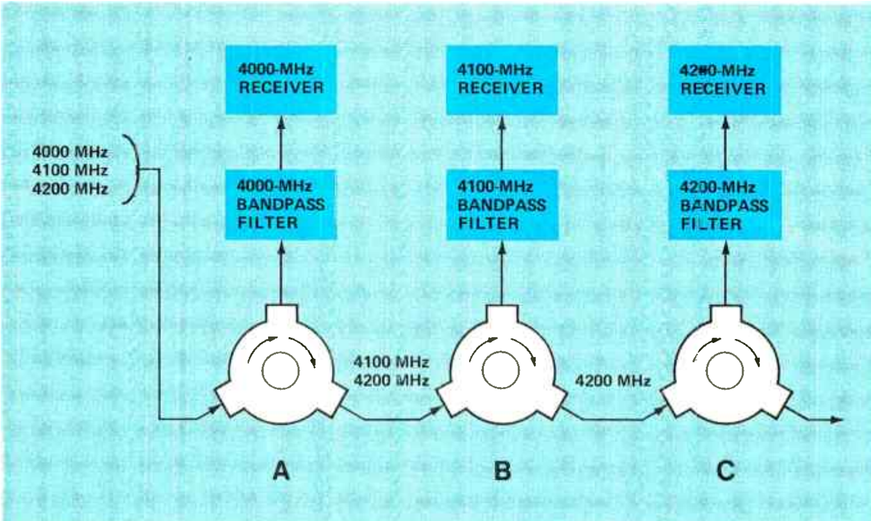


Figure 10. Strip-line circulators may be used as frequency separators for incoming microwave frequencies.

terminals arranged in such a way that energy entering at one terminal is transmitted to the next adjacent terminal in the desired direction. Strip-line circulators such as those built by GTE Lenkurt appear as shown in Figure 9. The circulator uses ferrite magnetic materials in such a configuration that the fields traveling in one direction do not affect the fields traveling in other directions. Circulators find many uses in microwave equipment design. One of their most common uses is in the separation of frequencies of incoming microwave signals as shown in Figure 10. The bandpass filter connected to circulator A may, for example, only accept the 4000-MHz signal. The remaining frequencies will then be transferred via circulator A to circulator B. The bandpass filter connected to circulator B will accept only the 4100-MHz signal, and pass the rest to circulator C. In this way, a whole band of incoming frequencies can be separated and directed to their respective receivers.

The use of strip transmission line has frequency limitations just as coax or waveguide. Some manufacturers utilize strip line at frequencies as high as 8 or 9 GHz, but it is more commonly used at 2 to 4 GHz.

Later Developments

The ease of manufacture and the compactness of the strip line are highly desirable traits, conducive to todays modern microwave components. The strip line principle has brought about other developments in the field of microelectronics. Microstrip circuitry evolved from the strip line, and although some aspects of both techniques are still in the developmental stage, each is finding practical applications and widespread acceptance in the microwave industry.

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