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SPACE DIVERSITY

Space diversity has been used for over ten years by industrial microwave users, and as a result of recent FCC rulings, space diversity will be finding increased application by the common carriers.

Point-to-point microwave paths, except when quite short or when located in extremely favorable areas, are subject to fading, or fluctuations in the intensity of a received signal caused by changes in the characteristics of the propagation path or transmission medium. Appropriate measures must be taken to sufficiently minimize the effects of fading and to provide the required system reliability.

Fading can be minimized by using diversity techniques where two paths are available for transmitting the same information. These paths are chosen such that simultaneous fading is unlikely. There are two distinct diversity techniques for point-to-point, line-of-sight microwave systems – frequency diversity and space diversity. Frequency diversity uses two different frequencies to transmit the same information. With space diversity, the same frequency is used, but two antennas, separated vertically, transmit or receive the information over two different paths through space (see Figure 1).

Compared to space diversity, frequency diversity is less expensive, uses simpler equipment arrangements, and has some operational and maintenance advantages. But, new FCC (Federal Communications Commission) rules prohibit frequency diversity for common carriers unless sufficient evidence can be shown that frequency diversity is the only way to obtain the required system reliability. This new ruling was established to preserve microwave frequencies for working radio channels, since there is a high demand for microwave frequencies and only a limited supply.

The use of frequency diversity is now limited by the FCC to only one protection channel for the 4-GHz band and one for the 6-GHz band, and frequency diversity will not be authorized unless the user applying for a license has at least three working channels. An exception to the three working channels provision can be made if the user can show that a total of three working channels will be required within three years.

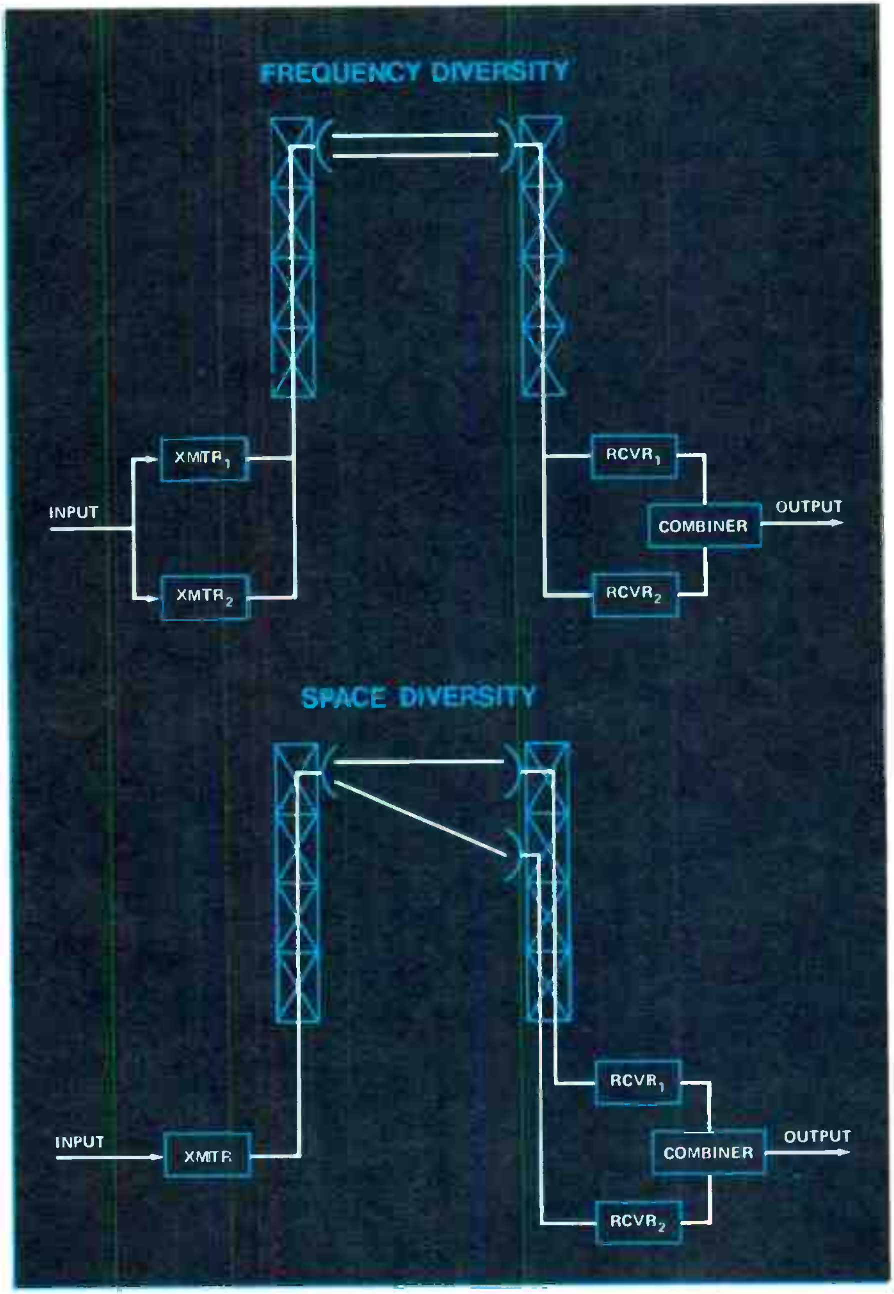

Figure 1. Frequency diversity and space diversity accomplish similar ends but they use different equipment configurations.

In effect, the FCC rules ban any form of frequency diversity for new systems in the 4- and 6-GHz bands except for routes which have at least three parallel working channels. So, except where waivers can be obtained, frequency diversity cannot be used for hops carrying only one or two working channels, and the only good alternative is to use space diversity. But, because of unfamiliarity with it, and to some extent because of some past misconceptions about it, many engineers are still skeptical about the capabilities of space diversity.

Fortunately, successful applications of space diversity do exist. Since frequency diversity has never been allowed in the industrial bands, these private microwave users turned to space diversity more than ten years ago to give them the degree of reliability needed. There are now hundreds of microwave paths operating with space diversity, mostly in the 6.575- to 6.875-MHz industrial band.

The initial decision by industrial microwave users to employ space diversity was accepted with some misgivings, since literature at that time was somewhat dubious about the protection provided by space diversity. But once the decisions were made, and the first space-diversity systems implemented, all doubts were quickly dispelled. The results obtained using vertical space diversity have generally been outstanding and have offered a superb degree of protection against fading.

The kind of diversity spacing that has been used in line-of-sight microwave systems should really be called height diversity, or vertical space diversity, since the spacing used is invariably vertical. It is generally accepted that horizontal spacings would have to be much greater than vertical spacings to provide equivalent diversity action. Although there is no direct proof, neither are there any positive tests to determine the relative effectiveness of horizontal spacings.

Published material seems to indicate that vertical space diversity is at least as good as frequency diversity, and in many cases considerably better when comparing propagation protection. Bell Laboratories' work shows space diversity substantially better than frequency diversity, particularly at 6 GHz and higher. At 4 GHz the difference is less significant, but the Bell Labs' data indicates that space diversity is still favorable. Space diversity appears to be effective in all microwave bands, even down to 2 GHz. Published Japanese experiments indicate that space diversity has an even greater protection advantage over frequency diversity than the Bell Labs' work indicates. But, because of the economic and operational advantages of frequency diversity, space diversity has only been used in a few isolated multiline cases where frequency diversity was not adequate.

Antenna Spacings

In the 6-GHz band, a non-critical vertical spacing on the order of 30 to 40 feet will provide more than adequate, indeed extremely good, diversity. In the past. controversy has developed over the proper way to select spacings. Advocates and users of space diversity developed theories and methods for calculating "optimum" spacings, based on the assumption that the only significant contributor to multipath fading is a single discrete reflection from a path point determined by calculation from path parameters. Another view was that most overland microwave paths are subject to many atmospheric and geographic factors that cause fading, so there probably is not a way to calculate an optimum spacing.

Most users today share the view that the spacings are non-critical and need not be calculated, at least on conventional overland paths. Diversity action tends to improve as spacings increase, so from this point of view, the larger the better. However, increasing the spacing may mean increasing tower heights and costs, and the 30- to 40-foot range seems to be a good compromise in the 6-GHz band.

For many years the rule of thumb was that 40-foot spacings on a 6-GHz path with a 40-dB fade margin would give a diversity improvement, or reliability improvement, against multipath fading, of at least 100 to 1. Based on present experience this was an extremely conservative rule of thumb. Published experimental and theoretical data from Bell Labs on various aspects of microwave propagation, including both frequency and space diversity effects, indicates something like a 250 to 1 improvement for a 6-GHz path with a 40-dB fade margin. Published Japanese data indicates an even greater improvement – on the order of 5,000 to 1. Calculation methods based on Bell's work can therefore be used with considerable confidence that the results will be at least realistic, if not conservative.

Methods are now available to calculate expected, non-diversity outages, as a function of path and climate parameters, and also as a function of the improvements to be obtained by diversity. A relaxed view has been taken on antenna spacings – generally, 30 to 40 feet at 6 GHz, 45 to 50 at 4 GHz, and 60 to 80 at 2 GHz will provide enough diversity to essentially eliminate multipath fading. At 11 GHz, spacings of 25 to 30 feet would be adequate. Occasionally, on a path where water reflection or severe ground reflection is likely to predominate, a discrete calculation method can be used, but this is rare. Experience indicates that even if small spacings (15 to 20 feet) are used, there is still good diversity action, at least in the 6-GHz bands. Even 10-foot spacings have been found to provide significant reliability improvements.

Towers and Antennas

An ultraconservative method of determining tower heights for space diversity would be to increase each non-diversity height by the required amount of diversity spacing. In effect, this would mean applying the path clearance criteria for the bottom antenna to the bottom transmission path. A more reasonable approach, though still quite conservative, would be to increase tower heights by half the diversity spacing. This is equivalent to applying the clearance criteria to the path from the top antenna to the bottom antenna. The most commonly used approach however, is to apply the basic path criteria to the top-to-top path, and a slightly more relaxed criterion to the top-to-bottom paths. Figure 2 shows three common antenna arrangements that result in three different tower heights. It is necessary under any conditions to check for problems due to near-in obstacles close to one end of the path which might block the lower antenna.

Disadvantages

There are several disadvantages to space diversity. One of these, at least in systems involving message circuits, is the impossibility of performing end-to-end testing without taking the system out of service, and is perhaps the major disadvantage of using space diversity compared to frequency diversity. Greater cost, mainly because of the extra antennas and waveguide, plus the effect on tower loading and sometimes height, is an obvious disadvantage. Space-diversity systems also require switching and sensing equipment that adds to the system's complexity.

Space diversity can be applied only on a per-hop basis, and each RF channel must have its own individual space diversity protection. This is not critical with industrial applications, where systems typically involve only a single working channel over a microwave route. But it is important to common carriers, where systems with multiple RF channels are quite common.

The "second channel" in a space diversity system is not separable, so it cannot be used on an occasional basis for other services, as is often done with a frequency-diversity protection channel. Two hot-standby, space-diversity channels are not easily converted into a 1-for-3 multiline diversity arrangement, which might occur under the present FCC rules.

Redundancy

Frequency-diversity systems have the feature that a complete end-to-end protection channel can be automatically switched-in to replace a failed channel. Regardless of whether the failure was caused by fading or equipment trouble, 100% equipment redundancy is automatically available with frequency diversity. In 1-for-N or 2-for-N multiline protection systems, switching is not required on every hop, but can be implemented over a switching section comprising a number of hops in tandem. Neither of these things is true about space diversity.

Space diversity, depending on how it is applied, may provide partial equipment redundancy or no equipment redundancy. As commonly used in industrial space diversity applications, two complete receivers are normally provided at the receive end of each microwave hop, one connected to the upper antenna and one to the lower antenna. The output of each receiver contains the full information band and in the absence of fading, loss of one receiver does not affect the output to the load, since an automatic switch or combiner is provided to leave both signals on line or to select the good receiver when fading or equipment failure causes the other receiver to lose its signal output.

Figure 3 shows a single, one-way RF channel, transmitting from A-to-B

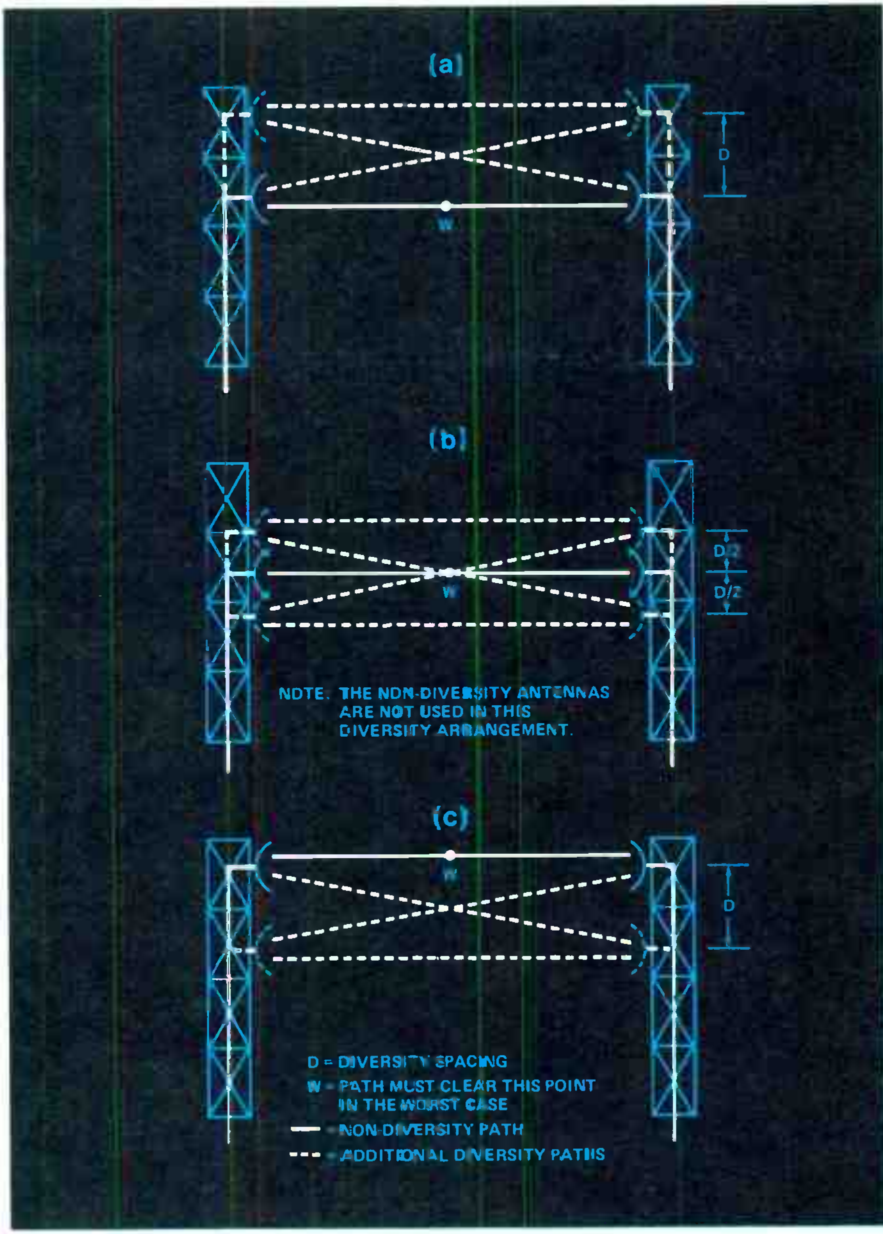

Figure 2. In the most conservative space diversity arrangement (a) with all the spacing above the existing antenna, all paths give adequate clearance: when the spacing is split above and below the existing antenna (b), three out of four paths are good: and when all the spacing is below (c), only the top-to-top path is good.

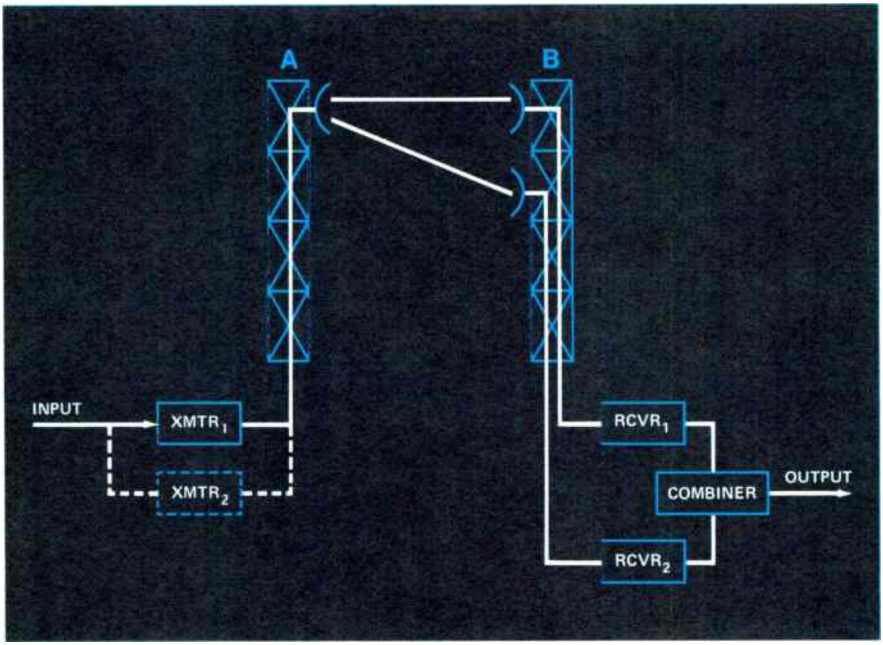

Figure 3. A one-way space-diversity systems uses diversity at the receiver end.

on a single frequency. Most systems will be duplex, and the opposite direction of transmission would require a reversed duplicate of the arrangement shown in Figure 3, transmitting from B-to-A on a separate single frequency. The space diversity in the direction of B-to-A will require two spaced antennas at the A end, in the normal configuration. In this configuration, full receiver equipment redundancy is provided, but the transmitter will not have equipment redundancy per se, since normal operation involves only one transmitter.

To provide transmitter equipment redundancy, the normal practice is to equip a complete spare transmitter, in a hot-standby arrangement, as shown in Figure 3 by the dashed lines at A. The two transmitters are identical, and typically both are modulated by the input signal and both are generating output power. But, in general, only one is "on line" at a given time. Fast-acting waveguide switches are used to keep one transmitter "on line" and the other "off line" at a given time.

When the system is of the remodulating (baseband) type, the outputs at baseband can be combined or selectively switched in such a way that a completely hitless transfer operation takes place. It is desirable to equalize the electrical lengths of the two paths to within ±5 nanoseconds to insure that the information arriving at the combiner is in precise phase and time synchronization. Since a differential of 5 nanoseconds represents only a small part of even a high-speed digital bit, a change from one receiver to another will not cause an information change due to displacement. Equalization of path lengths is a simple process at baseband and need be done only at the time of initial lineup.

If the receivers are of the heterodyne type, with an output of 70 MHz instead of baseband, things are different. Unless synchronization techniques are used, the 70-MHz outputs of the two receivers generally will not be in phase, and may even be of opposite phase. This dictates the use of selective switching instead of combining. Near-hitless transfer is assured by using solid-state switching devices with extremely fast transfer times. A space-diversity system switched at IF frequency provides equipment protection and redundancy for the IF and RF portions of the receiver, but separate protection is needed for any demodulator and baseband equipment following the switch.

Combining and Switching

RF combining and switching have been used for problem paths on multiline systems where the frequency diversity protection has been inadequate and additional propagation protection in the form of space diversity is needed over a particular path. One way of doing this is to combine the RF signals from the two vertically spaced antennas in a "magic Tee" before applying them to the input of the receiver (see Figure 4). This scheme requires careful control of the relative positioning of the two antennas and very precise equalization of the electrical length of the two waveguides connecting the two antennas to the "magic Tee", since for proper operation the two signals have to be closely "in phase" at the microwave frequency.

At 6 GHz, a path length difference of about an inch would put the two signals out of phase by 180°, and could conceivably cause a complete loss of received signal. For this reason, systems using this method generally introduce some method of automatically sensing the degree of phase difference, and automatically controlling a variable phase shifter in one receiver branch so as to bring the phases into close alignment, even if path variations cause a considerable differential in electrical lengths. The arrangement shown in Figure 4 is a complex and expensive system to implement, and its very complexity may introduce more difficulties than those it is designed to prevent.

A considerably simpler arrangement, using RF switching instead of combining has been used to provide space diversity protection on paths with excessive fading (see Figure 5). In this arrangement, the waveguide from the two spaced antennas is fed into ports of a latching circulator which connects one of these inputs to the receiver and the other to a termination. In normal operation the receiver is connected to the main antenna. When there is a loss of signal at the receiver, as shown by the AGC (automatic gain control) voltage dropping

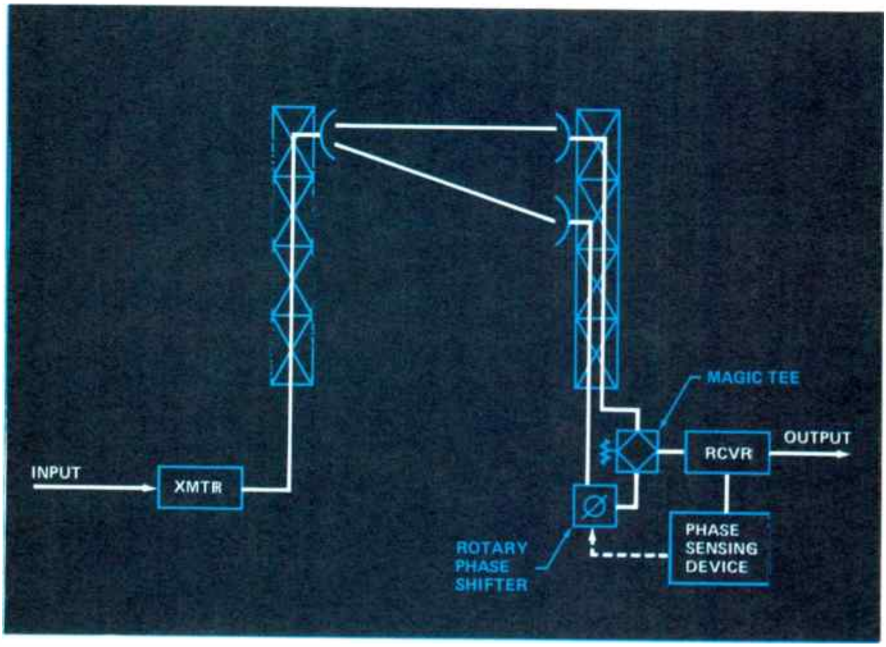

Figure 4. Space diversity without equipment redundancy uses a "magic Tee" for combining and a rotary phase shifter for automatic phase control.

to a preset level, logic circuitry switches the circulator to the other position, connecting the auxiliary antenna to the receiver.

The switch is "blind" in that there is no guarantee that a satisfactory signal will exist on the auxiliary antenna. Hence, other logic circuitry is used to tell the receiver what to do if no signal or an inadequate signal appears on the auxiliary antenna. Although some problems exist with a blind switching arrangement, it has been found to provide a substantial degree of improvement and a consequent reduction in outage time on some paths. Blind switching is also simple and easy to implement. In this arrangement, each RF channel receiver has its own individual switching and control mechanism.

There are many systems where spaced antennas are only used at one end of the path. This is particularly true when adding space diversity to existing systems whose towers have not been designed to handle extra antenna loads and in situations where one end of the path, perhaps in a built-up urban area, does not permit enough height for a second vertically spaced antenna.

To have conventional space diversity in one direction, the spaced antennas are associated with the receivers. To achieve space diversity in the oppo-

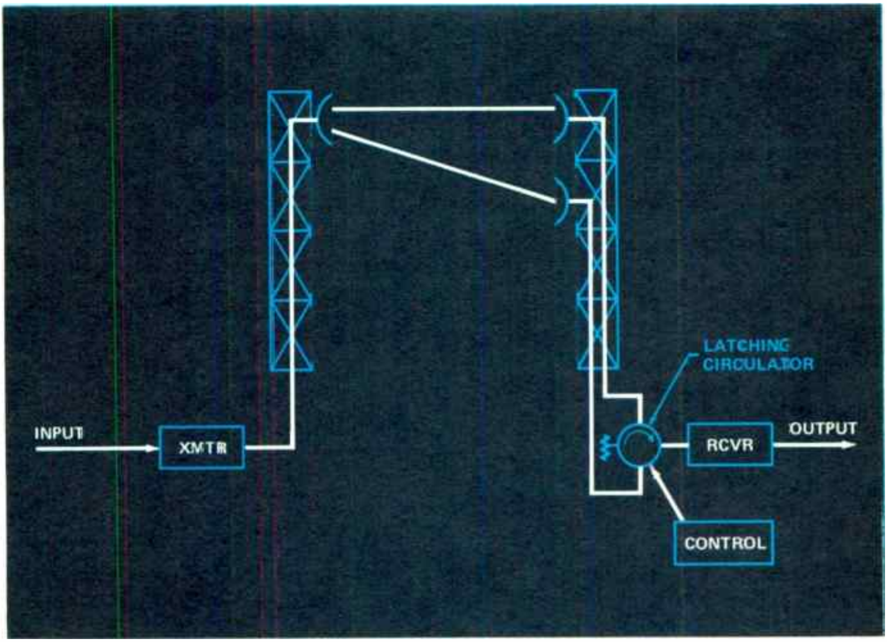

Figure 5. Space diversity without equipment redundancy can also be done using a latching circulator for "blind" RF switching at the receiver.

site direction, the spaced antennas must be associated with the transmitters.

General Use

Vertical space diversity, using relatively modest spacings, can provide extremely effective propagation protection against selective (multipath) fading. In addition to its added cost, space diversity has some operational and maintenance disadvantages when compared to frequency diversity, and these should be recognized and understood by those considering its use. Space diversity can be applied in a number of different ways, and using the experience of the industrial microwave users, several ingenious applications have already been worked out for common carriers. Other common carrier applications no doubt will develop as space diversity comes into more general use.

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