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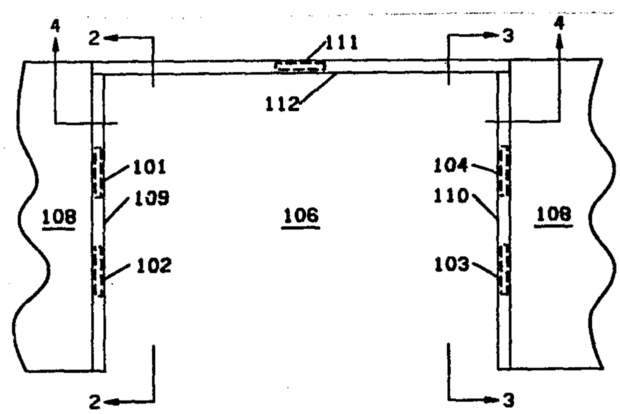
(54) Electronic article surveillance system.

(57) An electronic article surveillance system for microwave frequencies (500 MHz and higher) has microstrip antenna arrays each array comprising a dielectric substrate having a plurality of metal patches, spaced apart in the normal direction of travel through a surveillance zone, on one side and a metal ground plane on the other side. Each metal patch and the adjacent portion of the ground plane together form a cavity resonator which resonates at a desired transmitter or return signal frequency and thereby form a signal radiating or receiving structure. The patch size, patch to ground plane spacing, and spacing between patches are determined by the desired resonant frequency.



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ELECTRONIC ARTICLE SURVEILLANCE SYSTEM

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to electronic article surveillance systems and more particularly to electronic article surveillance systems employing microwave transmitter frequencies.

Description of the Prior Art

Systems for deterring or detecting theft of articles, commonly known as electronic article surveillance (or EAS) systems, have come into increasingly widespread use, especially in retail stores. Such systems generally include one or more tags which are attached to articles to be protected against theft, one or more transmitters and associated antennas which radiate signals into a protected area or surveillance zone, and a receiver and associated antenna which will detect the presence of a tag in the surveillance zone and cause an alarm to be actuated. The surveillance zone is usually located near an exit from the protected premises. The desired surveillance zone may be an exit doorway, for example.

Electronic article surveillance systems in commercial use may be classified into two groups on the basis of transmitter frequency or frequencies employed. The first group consists of systems employing one or more microwave frequencies. A "microwave frequency" as used herein is a radio frequency higher than 500 megahertz (MHz). The second group consists of systems utilizing lower frequencies. The present system belongs to the first group, i.e., those employing microwave frequencies.

References illustrating microwave EAS systems include U.S. Patent 3,895,368 to Gordon et al., and U.S. Patent 4,063,229 to Welsh et al. The Gordon et al. system includes both a microwave transmitter and a low frequency signal generator. An especially desirable microwave system is the dual frequency system described in the copending commonly assigned application of Harold B. Williams, Serial No. 373,251, filed April 29, 1982 (hereinafter the "Williams application").

Minasy U.S. Patent 3,493,955 is illustrative of systems using frequencies below the microwave range.

Microwave systems constitute a large majority of the electronic article surveillance systems currently in use. An advantage of microwave systems over systems employing lower frequencies is that microwave systems have a longer range than lower frequency systems and can therefore be used to protect wider doorways. This is a major advantage, particularly for protecting stores in shopping malls.

Presently known microwave EAS systems have certain limitations. One is that antennas now used for such systems require appreciable depth. As a consequence, the antennas are generally housed in free standing pedestals of considerable thickness, which are ordinarily placed near an exit doorway of a protected premises. Such installations use valuable floor space and are conspicuous. Unobtrusive installations are not possible.

Another drawback of microwave EAS systems is that all such systems known to date have a problem of "over-ranging" to a greater or lesser extent. "Over-ranging" arises because a transmitter signal or signals are radiated beyond the intended surveillance zone and are picked up, either by tags in the interior of the store or by spurious metal objects, such as strollers or baby carriages either inside or outside the store. The remote tag or spurious metal object may reradiate a signal back to the receiver, possibly triggering a false alarm. "Over-ranging" continues to be somewhat of a problem despite the use of transmitter antenna arrangements designed to confine the transmitter signals to the desired surveillance zone and despite the use of means within the receiver for discriminating between valid and spurious return signals.

Antennas used in microwave EAS systems include dipole antenna arrays such as those disclosed in the Williams application, and circularly polarized helical antennas such as those disclosed in the copending commonly assigned application of Philip Daniel Fancher, Serial No. 367,715, filed April 12, 1982 (hereinafter the "Fancher application" equilavent to European Patent Application 83102895.6). The transmitter antenna arrays of both the Williams and Fancher applications may include a reflector consisting of a conductive metal panel or mesh grid, and the receiver antennas of the Williams application (like both the transmitter and receiver antennas of Fancher) are circularly polarized. Antenna strips of the Williams application may be supported on a dielectric backing. Dipole or turnstile antennas such as those shown in the Williams application radiate or receive signals over a wide angle, so that signals are radiated into or received from both the interior and the exterior of the protected premises as well as the desired surveillance zone. False alarms from tags or spurious metal objects may result, as previously explained. Helical antennas such as those illustrated in the Fancher application also have a wide beam width (typically about 60°). Although this is narrower than the typical beam width achieved with dipole antennas, it is still wide enough to result in false alarms. In addition, helical antennas require considerable axial length in order to achieve a 60° beam width at a typical EAS transmitter frequency of 915 MHz.

Welsh et al. U.S. Patent 4,063,229, cited supra, also discloses (at column 6, line 54 to column 7, line 4) various forms of antennas and associated accessories (including reflectors) which may be used in microwave EAS systems.

Microstrip antennas have been the subject of a number of patents and other publications in the last decade or so, use of microstrip antennas to date has been confined largely to aircraft, missiles, and other military applications. Patch antennas having an air dielectric have also been developed in recent years, but have not achieved either widespread usage or the prominence in the literature that microstrip antennas have achieved.

U.S. Patent No. 4,366,484 to Weiss et al. describes a temperature compensated radio frequency antenna having two metallic members and a resonant cavity therebetween which is partially filled with air and partially filled with a dielectric material.

U.S. Patent No. 4,291,312 to Kaloi discloses various forms of dual ground plane microstrip antennas, including arrays having a plurality of radiating elements and a feed network on one side of a dielectric substrate, and a ground planes on both sides of the substrate.

Other U.S. patents illustrating microstrip antennas include the following: 3,803,623 to Charlot; 3,811,128 to Munson; 3,921,177 to Munson, and 3,987,455 to Olyphant.

SUMMARY OF THE INVENTION

According to this invention, a microwave frequency electronic article surveillance system is provided with at least one antenna means comprising an antenna having a dielectric substrate, at least one metallic patch on one side of the substrate, and a metallic ground plane on the opposite side of the substrate. The patch and the ground plane together form a signal radiating or receiving structure. Either the transmitter antenna means, or the receiver antenna means, or (preferably) both, are in accordance with this invention.

To minimize "over-ranging", it is preferred to use a plurality of antenna elements spaced apart along the normal direction of travel of an article through the surveillance zone.

In preferred embodiments of this invention, the transmitter antenna means includes at least one antenna array for each transmitter frequency, and the receiver antenna means includes at least one antenna array. Each antenna array includes a dielectric substrate, at least two thin metallic patches arranged in spaced apart side-by-side relationship along the normal direction of travel on one side of the substrate, and a metallic ground plane on the opposite side of the substrate. Each patch and the portion of the ground plane behind the patch form a cavity resonator. All patches on an array have the same resonant frequency. The patches are preferably circularly polarized.

An EAS system according to this invention also includes transmitter means for generating at least one microwave signal, tag means comprising at least one tag adapted to be attached to a protected article and operable to receive said at least one microwave signal and to reradiate a return signal, and receiver means for detecting said return signal and actuating an alarm when a tag is present in the surveillance zone. The transmitter, tag and receiver may all be conventional components of an EAS system.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a front elevational view showing a preferred arrangement of transmitter antenna and receiver antenna arrays in accordance with this invention.

FIG. 2 is a side view, taken along line 2-2 of FIG. 1.

FIG. 3 is a side view, taken along line 3-3 of FIG. 1.

FIG. 4 is a view looking upward, taken along line 4-4 of FIG. 1.

FIG. 5 is a view looking upward, along line 4-4 of FIG. 1, of a modified antenna arrangement according to this invention.

FIG. 6 is a schematic diagram of an electronic article surveillance system which includes the transmitter and receiver antennas of this invention.

FIG. 7 is an isometric view of a tag or passive transponder used in the system shown in FIG. 6.

FIG. 8 is a front elevational view of a transmitter antenna array according to this invention.

FIG. 9 is a vertical sectional view taken along line 9-9 of FIG. 8.

FIG. 10 is a front elevational view of a receiver antenna array according to this invention.

FIG. 11 is an end view of the receiver antenna array shown in FIG. 10.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described with particular reference to an electronic article surveillance system having two transmitters which radiate signals on two frequencies in the microwave range. The two frequencies used herein for illustration are 905 MHz and 925 MHz. Such a system is described in detail in the Williams application.

Referring now to FIGS. 1 to 4, the transmitter antenna means of the present invention comprises four microstrip patch type transmitter antenna arrays 101, 102, 103, 104. The arrays are mounted on either side of doorway 106, which is an exit doorway in wall 108 of a protected premises. Two of these arrays, 101 and 102, are concealed in cabinet 109 on one side of doorway 106. The other two arrays, 103 and 104, are concealed in cabinet 110 on the opposite side of doorway 106. Cabinets 109, 110 are non-metallic so as not to interfere with signal propagation.

Each array comprises a dielectric substrate having a plurality of square metallic patches on one side and a metallic ground plane on the other side, as will be described in detail with reference to FIGS. 8 and 9. The patches on each array are spaced apart along the normal direction of travel of an article through the surveillance zone, as may be seen in FIGS. 2 and 3. The ground planes of arrays 101, 102 preferably lie in a common vertical plane. Likewise, the ground planes of arrays 103, 104 also preferably lie in a common vertical plane. Both vertical planes are parallel to the normal direction of travel through the surveillance zone.

Arrays 101, 102, 103, 104 are shallow, typically no more than 2 inches (5.1 cm) thick. Consequently, cabinets 109, 110 need not be more than about 3 inches (7.6 cm) thick. Cabinets 109, 110 can therefore be installed unobtrusively at the sides of doorway 106, and they do not materially decrease the width of the doorway.

Alternatively, the arrays 101, 102, 103, 104 may be placed in free standing pedestals on either side of the doorway. Pedestals are preferred when a conspicuous installation is desired, while the illustrated arrangement affords an unobtrusive installation.

Arrays 101 and 103 (one on each side of doorway 106) radiate one transmitter frequency signal f_1, say 905 MHz. The other two arrays 102 and 104 (one on each side of doorway 106) radiate the other transmitter frequency signal f_2, say 925 MHz. A pair of arrays which radiate the same transmitter frequency signal (e.g., arrays 101 and 103) are preferably placed at different elevations as shown. Both transmitter frequency signals are radiated from both walls to minimize the effect of "shadows" due to the presence of persons or objects within the surveillance zone (since persons and objects act as shields for signals in the microwave range) and thereby to assure that both signals are radiated throughout the surveillance zone.

The receiver antenna means of the present invention comprises a single microstrip patch type receiver antenna array 111 which is concealed in cabinet 112 in the ceiling of doorway 106, or suspended close to the doorway. The patches on the receiver antenna array 111 are spaced apart along the normal direction of travel of an article through the surveillance zone, as may be seen in FIG. 4. The ground plane of array 111 lies in a horizontal plane. Cabinet 112 is ordinarily not more than 3 inches thick.

Location of a pair of transmitter antennas on each side of a doorway and a receiver antenna in the ceiling, as described above, is not a novel feature of this invention. Such an arrangement is described in the Fancher application.

The normal direction of travel of a protected article through the surveillance zone (i.e., doorway 106) is from the interior of the protected premises through doorway 106 to the outside. This direction is essentially horizontal. If a protected article having a tag attached thereto passes through doorway 106, the tag will pick up transmitter signals from transmitter antenna arrays 101, 102, 103, 104 and reradiate a return signal to receiver antenna array 111, causing an alarm to sound as will be described later.

FIG. 5 shows an alternative arrangement of antenna arrays. In this arrangement, two transmitter antenna arrays 101, 102, one for each transmitter frequency, and a receiver antenna array 111, are all placed in cabinet 112, which is located in the ceiling above doorway 106 as shown in FIG. 1. The ground planes of all three arrays preferably lie in a common horizontal plane. The patches of all three arrays are spaced apart along the normal direction of travel of an article through the surveillance zone.

FIG. 6 illustrates a preferred electronic article surveillance system in which the antennas of the present invention may be utilized. This system may be like that of the Williams application except for antenna structures and placement.

Referring to FIG. 6, the present system has transmitter means comprising transmitters 121, 122 which generate microwave signals. The frequencies of the signals generated by transmitters 121, 122 are preferably close together, that is, they preferably differ from each other by no more than about three percent. For purposes of illustration herein, transmitters 121, 122 generate signals having frequencies of 905 MHz and 925 MHz, respectively. One of these signals, say the 925 MHz signal, may be modulated by a low frequency audio tone (2 kilohertz, for example). The other signal is preferably an unmodulated continuous wave signal.

The signal generated by transmitters 121, 122 (also designated as TR-1 and TR-2, respectively) are fed through cables 123, 124 to antenna arrays 101, 102, and through cables 125, 126 to antenna arrays 103, 104. The cables may be conventional low loss coaxial cables. Antenna arrays 101, 102 are located on one side of the surveillance zone (i.e., doorway 106) and antenna arrays 103, 104 are located on the opposite side of the surveillance zone. The signals fed to antenna arrays 101, 102 (which are on the side of doorway 106 more remote from the transmitters 121, 122) may be amplified by linear amplifiers 127, 128. The linear amplifiers 127, 128 compensate for the losses in cables 123, 124 and include filtering to eliminate noise and reduce undesired intermodulation products.

Transmitters 121, 122 and amplifiers 127, 128 have appropriate power supplies (typically providing a low D.C. voltage, e.g., 18 volts derived conventionally from 110 volt or 220 volt AC power lines) not shown.

Transmitter antenna arrays 101, 102, 103, 104 (which collectively constitute transmitter antenna means) radiate their respective microwave signals into the surveillance zone, i.e., doorway 106.

The system of this invention also includes one or more tags 130, which may be attached to protected articles. A tag 130, when in the surveillance zone, receives microwave signals from antennas 101, 102, 103 and 104 and reradiates one or more return signals in response thereto. The return signals are received by receiver antenna array 111. The preferred tag is a passive transponder.

FIG. 7 illustrates the preferred tag 130 in detail. Tag 130 comprises a flat metal antenna loop 132 with a gap on one side, and a non-linear impedance element 134 which may be a semiconductor diode, supported on or embedded in a non-conductive (e.g., plastic) substrate 136. Antenna loop 132 provides a folded dipole configuration. The overall length and shape of antenna loop 132 are preferably chosen to make it resonant at a mean center frequency, which is the arithmetic mean between the two microwave frequencies generated by transmitters 121, 122. The mean center frequency in the illustrated embodiment is 915 MHz (transmitter frequencies in the illustrated embodiment are 905 MHz and 925 MHz as previously noted). While the details of tag 130 do not form part of the present invention and are essentially the same as the details of the tag or transponder of the Williams application, they have been repeated here for convenience.

Because of its non-linear nature, tag 130 responds to the transmitter signals (905 MHz and 925 MHz in the illustrated embodiment) by reradiating a small return signal at the sum frequency signal of 1830 MHz, in addition to other return signals (including the second harmonic frequencies of 1810 MHz and 1850 MHz) of lesser amplitude. The sum frequency signal (and other signals) reradiated by tag 130 will include any modulation which is present in either of the transmitter signals.

Returning now to FIG. 6, receiver 140 is coupled through cable 142 to receiver antenna array 111. Receiver 140 is also coupled to alarm 144.

One may use compact transmitters 121, 122 located inside cabinets 109, 110, and a compact receiver 140 located inside cabinet 112, instead of remotely located transmitters and receiver as shown in FIG. 6, if desired. (In the embodiment of FIG. 5, compact transmitters and a compact receiver may be located in cabinet 112.) The alarm 144 is usually placed at a location remote from the surveillance zone (it may be placed in the store offices, for example).

The preferred receiver 140 is a narrowband receiver like the receiver described in the copending Williams application. Such a receiver responds to a sum frequency return signal (1830 MHz) to the exclusion of the transmitter signals (905 and 925 MHz) and their harmonics. In other words, receiver 140 excludes the adjacent second harmonics (1810 and 1850 MHz) as well as higher harmonics. When a sum frequency signal (1830 MHz) exceeding a predetermined threshold amplitude is received by receiver 140, the receiver responds by admitting the signal to a demodulator or detector circuit. The threshold amplitude is a safeguard against false alarms due to spurious signals received from outside the surveillance zone. When one of the two transmitter signals is modulated, as is preferred, the return signal is also modulated. System reliability and sensitivity are further enhanced in this case by having the receiver 140 supply an output signal to alarm 144 only when the frequency of the modulating tone signal detected matches the frequency being transmitted as modulated from the transmitter for a predetermined fixed interval which is indicative of the actual presence of a tag 130 in the surveillance zone. Further details of the preferred receiver are given in the Williams application.

The preferred transmitter antenna arrays will now be described with reference to FIGS. 8 and 9. Since all four transmitter antenna arrays 101, 102, 103, 104 are structurally alike except for slight differences in size (arrays 102, 104 are slightly smaller than arrays 101, 103 because they radiate a signal of slightly higher frequency), only array 101 will be described in detail.

Referring to FIG. 8, transmitter antenna array 101 comprises a rectangular dielectric substrate 150 having a pair of spaced thin square metal patches 151, 152 and a feed network 153, on one side, and a thin metallic ground plane 154 (FIG. 9) on the opposite side. The pattern consisting of patches 151, 152 and feed network 153 may be formed by conventional etching techniques, i.e., by etching one side of a sheet of dielectric material which is metal (e.g., copper) clad on both sides. A preferred metal clad dielectric material is a polytetrafluoroethylene/glass laminate, copper clad on both sides and sold by Minnesota Mining and Manufacturing Company for microwave use under the trade name "CuClad 250". The dielectric material in this product has a dielectric constant of about 2.55.

Substrate 150 is thin, flat and of uniform thickness, so that patches 151, 152 are parallel to ground plane 154. A substrate thickness of 0.12 inch (0.30 cm) has been found suitable for transmitter arrays for signals of either 905 MHz or 925 MHz frequency. The spacing may be varied, but any such variations affect both resonant frequency and band width, as is known in the antenna art.

Patches 151, 152 are approximately but not exactly one-half wavelength (as measured in the dielectric material forming substrate 150) on each side. Good results have been obtained with patches about 0.48 wavelength on each side.

Each patch 151 or 152 and the portion of the ground plane 154 behind it acts as a leaky cavity resonator, i.e., a cavity resonator with so-called magnetic walls, which is tuned to the transmitter frequency which the patch radiates. All patches on an array are tuned to the same resonant frequency.

The primary direction of radiation from each patch (i.e., the dominant lobe) is along an axis perpendicular to the patch. In the embodiment shown in FIGS. 1 to 4 these primary axes of radiation are horizontal, i.e., across doorway 106 from one side to the other. In the embodiment shown in FIG. 5, the primary direction of radiation is vertically downward into doorway 106. Side lobes may also be radiated. Signal amplitude is greatest along the primary axis and in general decreases as the angle from the primary axis increases. Ground plane 154 prevents back radiation (i.e., radiation away from the surveillance zone) except for a small amount which goes around the edges. This is important for stores where tagged goods are near the doors.

The patches on an array, i.e., patches 151, 152 in the embodiment shown, are spaced apart in the longitudinal direction of the array. Whether a transmitter antenna array is installed vertically, as in FIGS. 1 to 4, or horizontally as in FIG. 5, the longitudinal axis of the array is parallel to normal direction of travel of a tag through the surveillance zone, which is horizontal the patches. By providing a plurality of appropriately spaced patches on each array, it is possible to minimize radiation of transmitter signals outside the surveillance zone. The signals radiated to either side of doorway 106 (and therefore to locations outside the surveillance zone) cancel each other out or at least minimize each other, so that very weak signals, and in some directions virtually no signals, are received outside the surveillance zone. On the other hand, the patches do radiate vertically throughout the entire height of doorway 106, (or across the width of doorway 106 in the embodiment of FIG. 5) since the patches are so placed that no interference in the vertical direction takes place. A preferred spacing between patches 151, 152 is about three-quarters of a wavelength as measured in air, center to center.

A two-patch antenna array 101 as shown, in which the patch-to-patch spacing is three-quarters of a wavelength, has a half power (-3db) beam width of 40° in the longitudinal direction of the array with minimal side lobes. The half power beam width in the transverse direction is about 60°. By comparison, a single patch antenna element has a half power beam width of about 60° measured in either direction. A helical antenna of known form also has a half power beam width of about 60°. Half power beam width is a useful measurement for comparing the directionality of different antennas, although it does not ordinarily coincide with the actual width over which a signal is effectively radiated or received.

More than two patches can be used when space permits. Use of more patches decreases the extent of overranging beyond the doorway (or beyond the space between the pedestals when they are used). Use of two patches as illustrated is based on the assumption that the depth of doorway 106 (i.e., the dimension in the direction of travel of an article) is two feet.

The patches may be spaced closer together than the preferred three-quarters of a wavelength when limited space requires this, or when it is desired to minimize the size of the array for reasons of cost (the substrate material is costly). This results in an increase in the longitudinal beam width (and therefore in less control over unwanted "spread" of the surveillance zone); however, the longitudinal beam width of a two-patch array in which the patch-to-patch spacing is less than ideal is less than the beam width of a single patch antenna.

Each of the arrays 101, 102, 103, 104 may be replaced by an antenna element having a single patch 151 and a ground plane 154, where the passageway to be protected is narrow. Such would be the case, for example, at an escalator landing or in a small shop situated on a street and having a narrow doorway. Such installation may also be used where necessitated by space limitations, as for example, when doorway 106 is in a wall substantially less than two feet thick. Use of a single antenna element in place of an array is not preferred for wider doorways. When a single antenna element (or a single element on each side of doorway 106) is used for each transmitter frequency, the signal of that frequency is radiated outside the surveillance zone due to the broader pattern from that element, without the extinction or attenuation which is achieved with a properly designed array.

The transmitter signal from transmitter 121, after amplification in amplifier 127, passes through the feed network 153 shown in FIG. 8. This feed network may be termed a parallel feed network since the patches are fed in parallel.

The feed network 153 has a single feed point 160. A coaxial connector 162 (FIG. 9), which may be conventional, supplies a transmitter signal to feed point 160. This connector has a center pin in contact with the feed network 153 at feed point 160, and an annular shield in contact with ground plane 154. The feed network 153 includes two metal strip branch conductors extending from feed point 160, and a pair of conductors, one of which is one-quarter wavelength longer than the other, extending from each of these branch conductors to the nearest patch 151 or 152. These conductors terminate at feed points which are at the mid-points of adjacent sides of patches 151, 152. In this manner the patches 151, 152 are elliptically or circularly (preferably circularly) polarized so as to minimize the effects of tag orientation. Also, patches 151, 152 radiate signals in phase. The resistances of the conductor strips in feed network 153 are such as to give satisfactory operation when operated with interconnecting cables having 50 ohm characteristic impedances.

A preferred receiver antenna array 111 will now be described with reference to FIG. 10. Receiver antenna array 111 has a rectangular dielectric substrate 180 with a plurality of horizontally spaced thin square metal patches 181, 182, 183, 184 and a feed network 185 on one side, and spaced from a metallic ground plane 186 (FIG. 11) on the other side. The patches 181, 182, 183, 184 are arranged in spaced relationship along the longitudinal axis of the array. Receiver antenna array 111 is structurally similar to the transmitter antenna arrays, except that the receiver antenna patches 181, 182, 183, 184 are about one-half the size of patches 151, 152 in the transmitter antenna arrays 101, 102, 103, 104 in order to achieve the desired resonant frequency. Likewise the spacing between patches is also about half as great as the spacing between patches of the transmitter antenna arrays. Also, the substrate 180 of the receiver antenna array 111 is typically only half as thick as the substrates 150 for the transmitter antenna arrays. The ground planes 154, 186 of the transmitter and receiver antenna arrays 101, 111 respectively are typically the same size. It is therefore possible to fit four receiver antenna patches into the same space that is required for two transmitter antenna patches.

Receiver antenna array 111 may have either fewer or more patches than the four shown, depending on space available and cost considerations. Of course, fewer patches results in a greater longitudinal beam angle, which in turn results in less effective confinement of the receiver pickup zone. It is highly desirable for a receiver antenna array to have at least two patches, since even a two-patch array has a longitudinal beam width appreciably less than the beam width of a single patch antenna. The receiver antenna array 111, like the transmitter antenna arrays, is installed so that the longitudinal axis of the array is parallel to the normal direction of travel of an article through the surveillance zone.

The feed network 185 for receiver antenna array 111 is a parallel feed network similar to the feed network 153 for a transmitter array 101 (or 102, 103, or 104), except that one additional set of branch conductors is required because a receiver antenna array has four patches instead of two. The feed network 185 has a single feed point 190. The feed network 185 is such that patches 181, 182, 183, 184 are elliptically or (preferably) circularly polarized and the patches receive signals in phase. Also the impedances in the feed network 185 are such as to give satisfactory operation when operated with interconnecting cables having 50 ohm characteristic impedances. A coaxial connector (not shown), which may be conventional, supplies a signal from feed point 190 to receiver 140 through cable 142.

Patches 181, 182, 183, 184 are structurally similar to patches 151, 152, but may be circularly polarized in the opposite direction from the direction of polarization of the transmitter patches if desired. If the transmitter patches are polarized to the right, the receiver patches may be polarized to the left, and vice versa. This may be accomplished by locating the feed points for each patch 181, 182, 183, 184 on the top and right edges, instead of on the top and left edges as shown in FIG. 10.

Patches 181, 182, 183, 184, and the portions of the ground plane 186 behind the patches, act as cavity resonators tuned to a frequency reradiated by tag 130. When the transmitter frequencies are 905 and 925 MHz, one of the reradiated frequencies is 1830 MHz. Receiver antenna array 111 is advantageously tuned to this frequency.

The receiver antenna array 111 of this invention is highly selective to a predetermined frequency. In addition, because the receiver antenna array typically has four patches instead of two as in a transmitter antenna array of the same size, the receiver antenna "pickup" or signal reception zone is more closely confined to doorway 106 (or other desired surveillance area) than is the case with the transmitter antenna arrays. A four-patch receiver antenna array as shown herein has a half power beam width angle of about 18°, compared to about 40° in the two-patch transmitter antenna array shown. This makes it possible to place tagged merchandise close to the doorway 106 inside the store if desired; even if the tag picks up transmitter signals from the transmitter antenna arrays 101, 102, 103, 104, the return signal from the tag will not necessarily be picked up by the receiver antenna array 111. Also, a receiver antenna array 111 will not pick up return signals from tags which are close to the doorway on the exterior side thereof (for example, tags similar to tag 130 which were affixed to an article by another store in the same shopping mall and not removed from article before it was taken out of store).

Transmitter and receiver antenna arrays as shown and described herein, and having the characteristics given in Table 1 below, have been found to perform satisfactorily when operated with feed networks and interconnecting cables having 50 ohm characteristic impedances.

Table 1

	Transmitter arrays		Receiver array
Resonant frequency, MHz	905	925	1830
Patch size (length of each side), inch (cm)	3.97 (10.1)	3.88 (9.9)	1.96 (5.0)
Substrate thickness, inch (cm)	0.12 (0.30)	0.12 (0.30)	0.06 (0.15)
Spacing between adjacent patches, center-to-center	6.52 (16.6)	6.52 (16.6)	4.84 (12.3)

The transmitter antenna patch-to-patch spacings illustrated in Table 1 are less than ideal. They are for an array 13 x 7.5 inches. A preferred spacing is 9.67 inches (24.6 cm).

The system described herein is similar in operation to that described in copending application of Samuel Sensiper et al., filed August 1, 1983 and entitled "Electronic Article Surveillance System Having Low Profile Antennas". The two systems are also structurally similar, except that the system described in the copending Sensiper et al. application has antenna arrays which empty an air dielectric instead of a solid substrate, and which have coaxial cable feed networks located behind the ground planes. The microstrip arrays herein are easier to manufacture and are more rugged. On the other hand, the solid substrate material herein is costly. Each system has some advantages compared to the other.

Operation

When a purchaser of a protected article pays for it in the usual way, he or she will do so before reaching the surveillance zone, and the tag will be removed at the time of payment. The purchaser then passes freely through the surveillance zone and no alarm is sounded.

If a shoplifter attempts to take a protected article out of a store (or other protected premises) without having the tag 130 removed, he must pass through the surveillance zone in passing through doorway 106. As he does so, tag 130 picks up transmitter signals radiated from transmitter antenna arrays 101, 102, 103, 104, and reradiates a return signal (typically a sum frequency signal in the dual frequency system illustrated).

This return signal is picked up by receiver antenna 111 and conveyed to receiver 140. Receiver 140 will recognize the return signal as valid and cause alarm 144 to be actuated.

Modifications

The present invention may be utilized generally with EAS systems having at least one transmitter frequency above 500 MHz. Although the present invention may be used in EAS systems having transmitter frequencies lower than 500 MHz, such use is usually impractical because of the large size of transmitter antenna arrays required. While the dual frequency system of the Williams application is preferred and has been used for purposes of illustration, the antennas described herein could be used with other microwave EAS systems, such as those described in Gordon et al. U.S. Patent 3,895,368 or Welsh et al. U.S. Patent 4,063,229, both cited supra. However, the antenna system of the present invention is more effective in preventing unwanted spread of the surveillance zone in systems employing two microwave frequencies (such as the Williams system) than it is in systems utilizing a single microwave frequency (such as those described in Gordon et al. or Welsh et al.). This is because the strength of a signal reradiated by a tag 130 is proportional to the product of the amplitudes of the transmitter signals which the tag receives in the case of a dual frequency system. Transmitter signal amplitude diminishes as one goes outside the doorway region, and the product of the two transmitter signals diminishes even more rapidly. When the EAS system chosen uses both microwave and low frequencies, as is the case in the system of the Gordon et al. patent, the present antenna arrays are used only for the microwave signal.

Circular or other shaped patches may be used instead of square patches in both the transmitter and receiver antenna arrays.

Any desired arrangement of transmitter and receiver antenna arrays may be used. For example, one may place both transmitter and receiver antenna arrays on opposite sides of the surveillance zone, either in cabinets 109, 110 or in pedestals, and dispense with the overhead or ceiling receiver antenna array. (The Williams application shows such an arrangement). All arrays should be mounted so that the patches in each array are spaced apart in the direction of travel through the surveillance zone. Location of all transmitter antenna arrays on only one side of the surveillance zone is not preferred, because both the human body and objects in the surveillance zone produce "shadows" which would permit a tag to escape detection.

Instead of one or more transmitter antenna arrays, one may provide two or more separate transmitter antenna elements, each of which includes a patch and a ground plane, for each transmitter frequency. The elements in such instance are arranged in side-by-side relationship in the normal direction of travel. Similarly, two or more receiver antenna elements may in principle replace a receiver antenna array. However, in practice the need to have accurate phase relationships maintained between patches, and patch spacing matched to the wavelength of signals in order to minimize "overranging", makes it much better to use prefabricated arrays, as shown and described herein.

General

Antenna arrays according to this invention with their feed networks can be made less than two inches thick. (The antenna arrays themselves can be made less than one-quarter inch thick). Installation of the system therefore need not significantly decrease the effective width of the passageway to be protected. The system can be installed unobtrusively as illustrated or it can be installed conspicuously in free standing pedestals, provided in either case that the intervening non-conducting material of construction of the doorway or pedestal is not water-absorbing and is not so close that its dielectric properties materially affect the operation of the antennas. If a concealed doorway installation is chosen, the space requirements for the antennas are minimal.

Receiver antenna arrays according to this invention can be placed in high doorways or ceilings without losing their effectiveness and without undue spread of the signal reception zone beyond the doorway. (The zones of effective signal reception in the direction of travel may be approximated by planes which extend from the sides of the receiver antenna array. These planes make only a small angle with the vertical in the case of overhead receiver antenna arrays).

The surveillance zone can be confined more closely to the space desired, i.e., the space within or close to the exit passageway, than is the case with previous EAS antenna systems. Transmitter antenna arrays of this invention can be readily constructed to give chosen beam patterns which will control the spread of the surveillance zone.

Similarly, the receiver antenna array effectively picks up signals only from the surveillance zone. The received strength of signals from outside the surveillance zone is so low that the alarm will not sound, due to the arrangement of antenna patches which nullifies or greatly attenuates signals from outside the surveillance zone.

The receiver antenna is highly selective for a desired return signal frequency. The receiver antenna thus enhances the sensitivity of the receiver itself in discriminating between valid and spurious return signals.

One may use the antenna of this invention only for the transmitter antenna(s) or only for the receiver antenna, with another type of antenna being used for the other, if desired. Such installation, for example, may include an overhead receiver antenna array according to this invention with helical transmitter antennas on the sides of the surveillance zone. Of course, some of the advantages of this invention are lost in such case. For example, if one uses a receiver antenna of this invention with a prior art transmitter antenna, one loses some control over spread of the surveillance zone which the present transmitter antenna affords. If one uses transmitter antennas according to this invention with prior art receiver antennas, one confines authentic transmitter signals to the surveillance zone but does not screen out spurious return signals from outside the surveillance zone as effectively as one does when using a receiver antenna according to this invention. It is especially important to use receiver antennas according to this invention, since the improvement in reducing "overranging" is more marked in the case of receiver antennas than is the case with transmitter antennas, as already indicated.

A two-patch transmitter antenna array according to the present invention when used for radiating both transmitter frequency signals of a dual microwave frequency system such as that described in the Williams application, cuts the amount of "overranging" of each transmitter signal by approximately half as compared to a helical antenna arrangement. The antenna means of the present invention, when used for receiving a single return signal frequency, cuts the amount of "overranging" in the zone of effective reception by approximately three quarters. (Comparisons are based on comparative half power beam width angles). When the antenna arrays according to this invention are used for both the transmitter signals and the receiver, the amount of "overranging" is cut even more than when such antenna arrays are used for either transmitter or receiver antennas alone. The present invention therefore provides an effective means for diminishing the extent of "overranging", which has been a major source of false alarms in previous EAS systems.

While this invention has been described with reference to specific embodiments and possible modifications it will be apparent that other modifications can be made by those skilled in the art without departing from the present invention.

C L A I M S

1. An electronic article surveillance system comprising transmitter means for generating at least one microwave signal, transmitter antenna means for radiating said at least one microwave signal into a surveillance zone, tag means comprising at least one tag adapted to be attached to a protected article and operable to receive said at least one microwave signal and to reradiate a return signal, receiver antenna means for receiving said return signal, and receiver means for detecting said return signal and actuating an alarm when a tag is present in said surveillance zone, characterized in that at least one of said antenna means comprises an antenna having a dielectric substrate, at least one metallic patch or one side of said substrate, and a metallic ground plane on the opposite side of said substrate, and said patch and said ground plane together forming a signal radiating or receiving structure.

2. An electronic article surveillance system according to claim 1, characterized in that said at least one antenna means includes at least two patches arranged in spaced apart side-by-side relationship along the normal direction of travel of an article through said surveillance zone and resonant at the same predetermined frequency.

3. An electronic article surveillance system according to claim 1, characterized in that said at least one antenna means includes one or more antenna arrays, each antenna array including a dielectric substrate, a plurality of metallic patches on one side of said substrate, said patches being spaced apart in the normal direction of travel through the surveillance zone, and a metallic ground plane on the opposite side of said substrate, said patches and the adjacent portions of the ground plane forming cavity resonators, each array being tuned to a single resonant frequency.

4. An electronic article surveillance system according to claim 1, characterized in that said antenna element is circularly polarized.

5. An electronic article surveillance system according to claim 1, characterized in that said metallic patch is a

square patch.

6. An electronic article surveillance system according to claim 1, characterized in that said transmitter antenna means comprises an antenna having a dielectric substrate, at least one metallic patch on one side of said substrate, a metallic ground plane on the opposite side of said substrate, said antenna being resonant at a predetermined transmitter signal frequency.

7. An electronic article surveillance system according to claim 1, characterized in that said transmitter antenna means includes one or more antenna arrays, each antenna array including a dielectric substrate a plurality of metallic patches on one side of said substrate, said patches being spaced apart in the normal direction of travel through the surveillance zone, and a metallic ground plane on the opposite side of said substrate, said patches and the adjacent portions of the ground plane forming cavity resonators, each array being tuned to a single resonant frequency.

8. An electronic article surveillance system according to claim 7, characterized in that said transmitter antenna means includes at least two antenna arrays tuned to different resonant frequencies.

9. An electronic article surveillance system according to claim 1, characterized in that said receiver antenna means comprises an antenna having a dielectric substrate, at least one metallic patch on one side of said substrate, and a metallic ground plane on the opposite side of said substrate, said antenna being resonant at a predetermined return signal frequency.

10. An electronic article surveillance system according to claim 1, characterized in that said receiver antenna means comprises an antenna array having a dielectric substrate, a plurality of metallic patches on one side of said substrate, said patches being spaced apart in the normal direction of travel through the surveillance zone, a thin metallic ground plane on the opposite side of said substrate, said patches and said ground plane together forming a resonant structure.

11. An electronic article surveillance system according

to claim 1, characterized in that

(a) said transmitter antenna means includes at least one antenna having a dielectric substrate, at least one metallic patch on one side of said substrate, and a metallic ground plane on the opposite side of said substrate, said patch and

(b) said receiver antenna means includes at least one antenna having a dielectric substrate, at least one metallic patch on one surface of said substrate, and a metallic ground plane on the opposite surface of said substrate, said antenna being resonant at a return signal frequency.

12. An electronic article surveillance system according to claim 1, characterized in that

(a) said transmitter antenna means includes at least one antenna array having a dielectric substrate at least two thin metallic patches on one side of said substrate, said patches being spaced apart in the normal direction of travel through said surveillance zone, and a thin metallic ground plane on the opposite side of said substrate, and

(b) said receiver antenna means includes an antenna array having a dielectric substrate, a plurality of thin metallic patches on one side of said substrate, said patches being spaced apart in the normal direction of travel through said surveillance zone, and a thin metallic ground plane on the opposite side of said substrate.

13. An electronic article surveillance system according to claim 12, characterized in that said transmitter antenna means includes at least two antenna arrays tuned to different transmitter frequencies.

14. An electronic article surveillance system according to claim 7, characterized by including parallel feed networks for said patches.

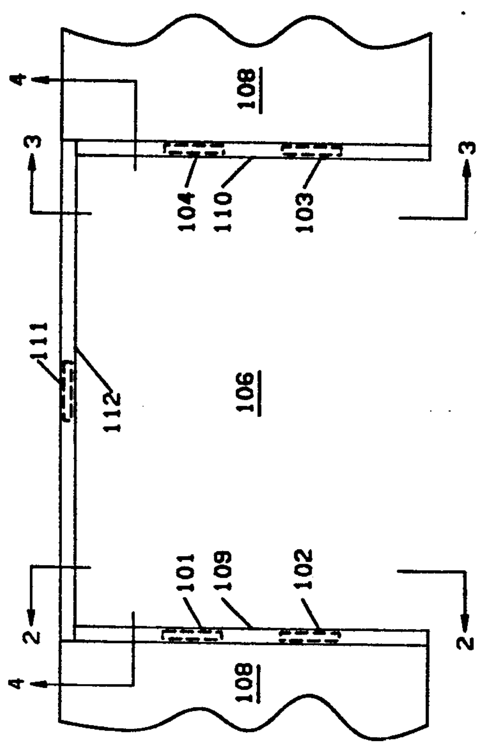


FIG. 1

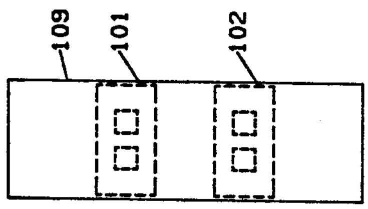


FIG.2

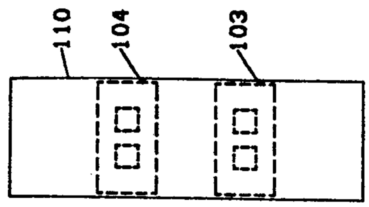


FIG. 3

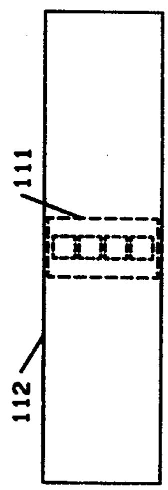


FIG. 4

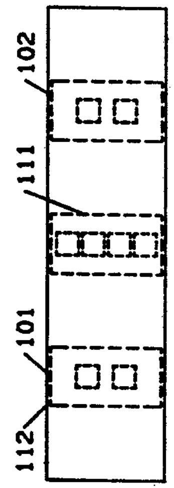
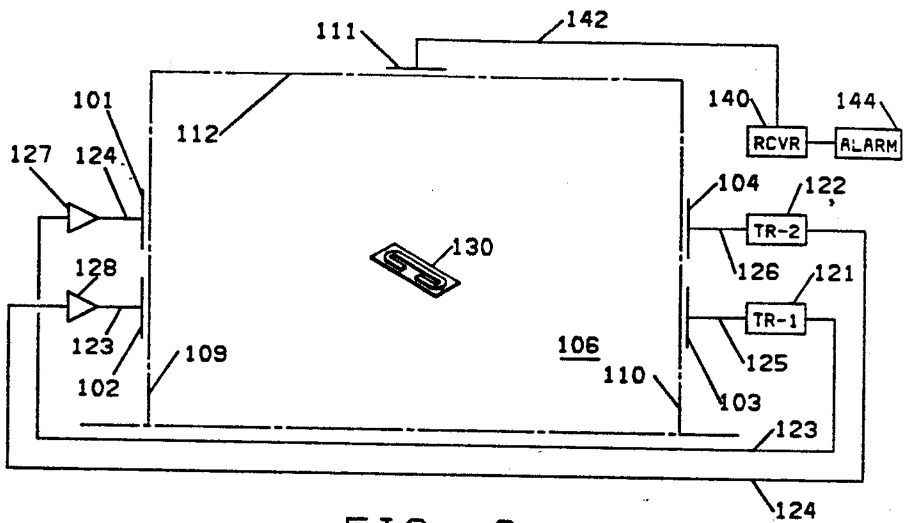


FIG. 5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RCVR
144
ALARM
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124
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TR-2
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103
123
124

FIG. 6

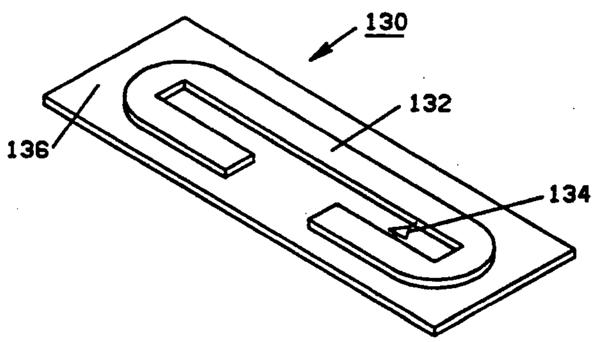
130
132
136
134

FIG. 7

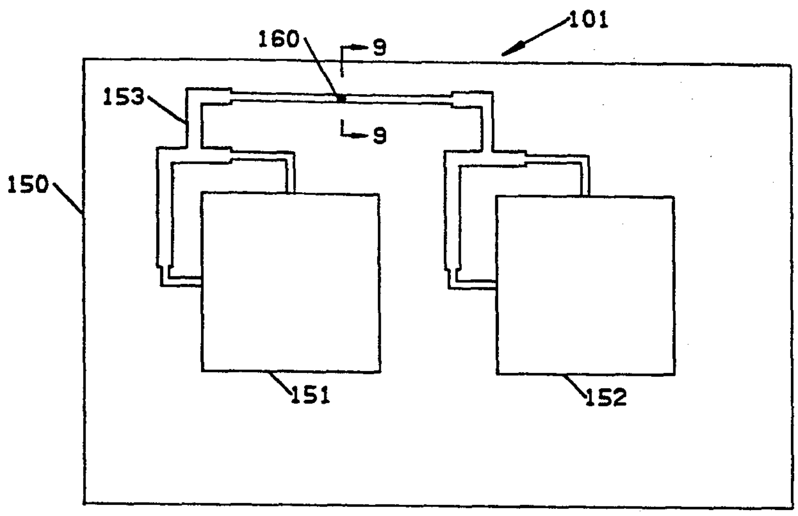

FIG. 8

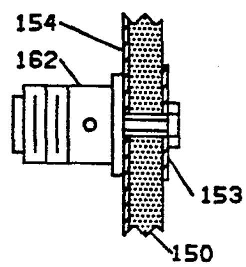

FIG. 9

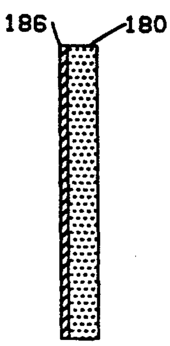

FIG. 11

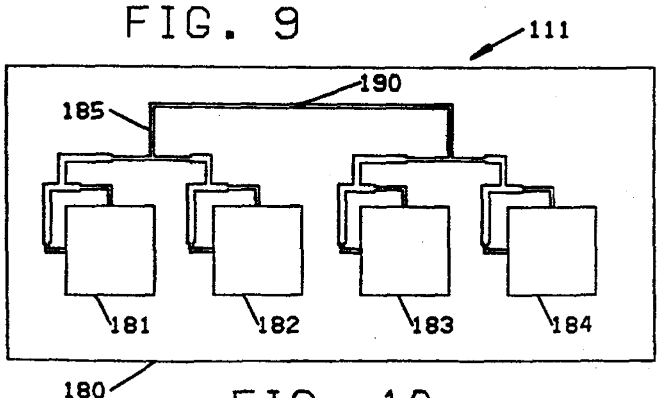

FIG. 10