CO-CHANNEL PROTECTION LIMITATIONS OF THE CIRCULARLY POLARIZED (CP) ANTENNA-ARRAY

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ABSTRACT

Since the first experimental circularly polarized TV broadcast started in 1974 (Station WLS-TV, Channel 7, Chicago), the application of CP receiving antennas enjoyed growing interest among CATV engineers and system operators. This presentation is intended as an introduction to the reader on the concept of circular polarization, and will be followed by a review of methods to generate and receive CP electromagnetic waves. The discussion then focuses on the co-channel protection difficulties experienced with CP antenna-arrays, due to amplitude and phase distortions. Representative references are listed at the end of this paper, so the reader may conveniently interrupt this fast guided tour for more detailed studies in selected important topics.

DEFINITIONS

The electromagnetic field is composed of an electric (E) and magnetic (H) field vector. By definition, the polarization of the field is determined by the direction of the electric field vector. In case of linear polarization, such as a dipole above ground, the orientation of E coincides with the dipole. A horizontal dipole will emit horizontally polarized radiation. The vertical quarter-wave "whip" generates a vertically polarized field.

While in the case of linear polarization the direction of E remains always constant, (Fig. 1-a)

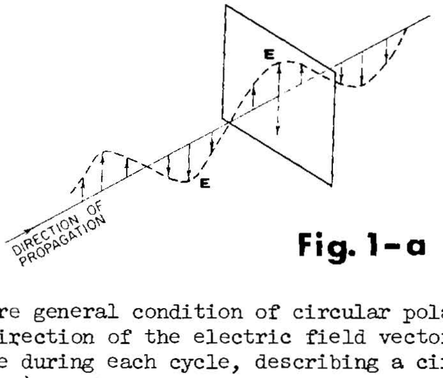


**Fig. 1-a**

in more general condition of circular polarization the direction of the electric field vector will change during each cycle, describing a circle (or ellipse) in the plane perpendicular to the direction of propagation. (Fig. 1-b).

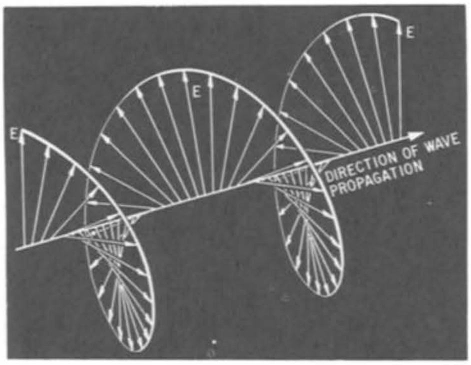


**Fig. 1-b**

If the rotation of the electric field vector is clockwise, as viewed in the direction of propagation, the polarization is defined as right-hand circular polarization. Similarly, a counter-clockwise rotation of the vector E will result in left-hand circular polarization. The FCC has ruled that the CP TV transmission in this country shall be right-hand circular.

Actually, circular polarization is very seldom circular. Most of the time the rotating electric vector will map an ellipse, with a certain minor-to-major axis ratio. (Fig. 2).

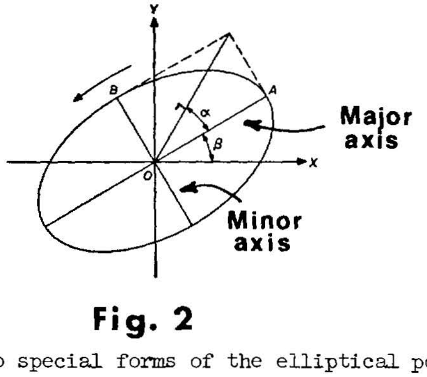


**Fig. 2**

The two special forms of the elliptical polarization are:

a. The case of linear polarization, when the minor-to-major axis ratio is zero, and the ellipticity approaches $\infty$ dB.

b. The case of circular polarization, when the minor-to major axis is one, and the ellipticity is ∅ dB.

GENERATION OF CIRCULAR POLARIZATION

Circular polarization can be generated by two crossed dipoles, feeding the dipoles with equal currents in "phase quadrature". ($90^{\circ}$ phase difference between the currents). A convenient way to achieve phase quadrature is to feed one of the dipoles through a cable which is $\lambda/4$ longer than the other feed line. (Fig. 3).

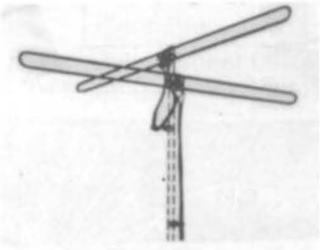

Fig. 3

An other approach requires the physical separation of the two crossed dipoles by $\lambda/4$. (Fig.4).

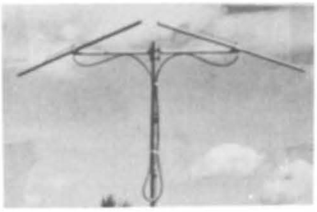

Fig. 4

The resulting field will again be circularly polarized.

A third method is the application of the helix. (Figure 5), radiating an unidirectional and circularly polarized beam.

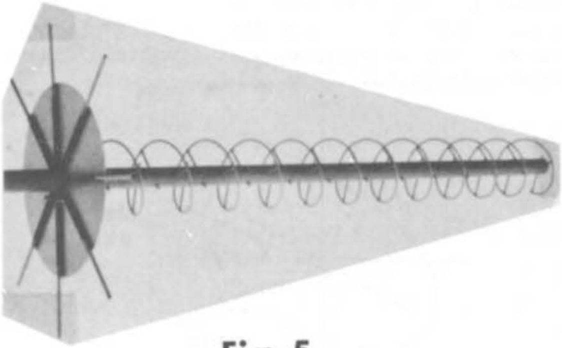

Fig. 5

Many other type of CP antennas, such as leaky wave, slotted line, open waveguide, etc. are frequently used in microwave communications or radar technology. Their concepts will not be discussed in this paper.

RECEPTION OF CIRCULAR POLARIZATION

Utilizing the principle of reciptrocity, the antennas shown for the generation of CP transmission could be also used for the reception of CP electromagnetic waves.

As a matter of fact, CP receiving antennas have been used for decades in CATV. Not to receive TV signals; but to receive FM signals. The popular FM turnstile antenna, Figure 3, operated in a planar mode (around the vertical axis), exhibits an omnidirectional horizontal radiation pattern, -3 dB gain in a single bay, and ∅ dB gain in a two-bay, vertically stacked configuration.

The CP receiving antenna of crossed Yagis or LP antennas, requiring a $\lambda/4$ phaseshift line between the horizontal and vertical bays, are operated in the axial mode. The phase lines, tuned to a single frequency, usually at the center of the frequency range of operation, provide the necessary phase quadrature only on that particular frequency. Consequently, on any other frequency the $\lambda/4$ line will introduce a moderate or considerable phase error. The calculation of gain, radiation pattern, beamwidth, or any other important performance parameter should use the same equations or principals as used in the development of single Yagis or LP antennas.

The helical antenna (helix) has been proven to be a practical and economical approach for producing circular polarization with excellent directivity, good gain, and a fairly wide impedance match. The gain of the helix, using the symbols of Figure 6, can be calculated by the following

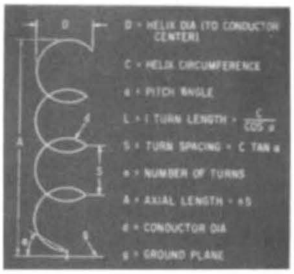


Fig. 6

equation:

$$G = 8.76 + 10 \log \left[ \left( \frac{C}{\lambda} \right)^2 \cdot \frac{nS}{\lambda} \right]$$

Note, that the above formula is applicable only for the axial mode of operation. The obtained gain (in dB) is relative to a linearly polarized isotropic source, and valid for $\alpha = 12.5^{\circ}$ $g = 0.8\lambda$ and $d \cong 0.002\lambda$.

The desirable helical antenna dimensions are:

$$g = 0.85\lambda$$
$$A = 1.6\lambda$$
$$D = \frac{\lambda}{\pi}$$

For UHF and VHF high-band application the above dimensions are feasable. However, considering the dimensions of the Channel 3 helical antenna, where g=164", A=25'8" and D=61½", a back-mounted and suitable for orientation helical antenna becomes too large (unsafe) for installation on the average size CATV tower.

CP RECEIVING ANTENNA-ARRAYS

The technical requirements for CP receiving antenna-arrays are just as stringent as those for the CP TV transmitting antennas. First, a CP receiving antenna should receive the CP radiation as effectively as possible. In other words: the array should have a good impedance match, and polarization ratio. Secondly, the array should be rugged and reliable. Thirdly, the antenna-array should provide adequate protection against co-channel interference.

Arrays of CP antennas require special attention when feeding two or four bays from hybrid couplers (two-way or four-way splitters). The antennas must be paired in the proper sense (right-hand). If not, the array will operate in a linear mode of polarization, or worst yet, may work in a left-hand CP mode, and not receive the right-hand polarized TV transmission at all.

GHOST REDUCTION

The primary objective of the circularly polarized TV transmission is the elimination (reduction) of ghosting. Consider the case of a typical ground reflection problem, as illustrated in Figure 7.

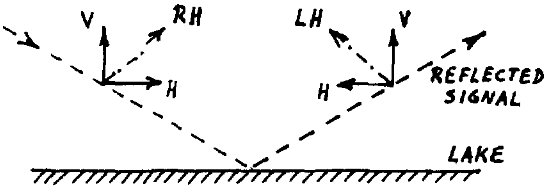


**Fig. 7**

A right-hand CP signal arrives from the left, suffering a total reflection from the surface of the lake. Note that the vertical component of the field has not changed in magnitude or in phase. However, the horizontal (H) component has suffered a 180° phase-shift. Consequently, the sense of polarization of the reflected wave changed to left hand, which cannot be received by the right-hand polarized CP receiving antenna. Circular polarization develops immunity against ghosting which is generated by off-the-air reflections.

Note: Should the TV transmission be polarized elliptically, which is actually an imperfect circular polarization, the cancellation of the reflection will be limited, depending on the axial ratio of the polarization.

CO-CHANNEL PROTECTION DIFFICULTIES

The reduction or elimination of ghosting is a highly desirable objective, achieved by the application of CP receiving antenna-arrays. However, the other paramount requirement, adequate co-channel protection, must not be sacrificed.

Co-channel interference protection is basically an antenna radiation pattern problem. What really counts is the horizontal (E) plane pattern of the receiving array, no matter whether the TV transmission was horizontally, vertically or circularly polarized.

The creation of deep and accurately placed (relative angle) null requires:

a. Absolute symmetry of the radiators
b. Freedom of reflections
c. Frequency independent phase-shift.

The radiators (antennas) of the array must provide equal amplitude signals to the combiners. For instance, a 30 dB deep null 40° off the main beam requires less than 0.35 dB amplitude difference between the two sides of the horizontally stacked two-bay array. It is suggested that antenna models, although identical, but produced at different times, should not be considered for array application.

Antenna-arrays are usually tested under "free space" conditions on the manufacturer's antenna test range. In the real world of CATV, diamond antenna-arrays are always mounted on tower legs, (36" to 40" face towers), and supported by long (resonating) crossarms. Quad-arrays of Yagis are generally antenna-gate mounted, which have long horizontal and vertical bars. Consequently, the antenna-arrays are exposed to reflections, generated by the cross-bars of the tower, the tower legs, crossarms, antenna-gates or booms, microwave reflectors, or any other CATV antenna-arrays, mounted unreasonably close to each other. The reflections cause amplitude and phase cancellations. The effects are unpredictable and difficult to calculate.

The third disruption of the optimum radiation pattern performance is caused by the $\lambda/4$ phase quadrature line, which is frequently dependent.

Numerical values of phase errors, as function of frequency (channel) of operation are given in Table 1.

| | CHANNEL | PHASE ERROR |
|---|---|---|
| | 2 | 20.0° |
| LOW-BAND LP ANTENNA | 3 | 9.2° |
| PHASE-LINE TUNED TO CH 4 | 4 | 0.0° |
| | 5 | 11.3° |
| | 6 | 17.0° |
| | 7 | 8.0° |
| | 8 | 5.3° |
| HIGH-BAND LP ANTENNA | 9 | 2.4° |
| PHASE-LINE TUNED TO CH 10 | 10 | 0.0° |
| | 11 | 2.4° |
| | 12 | 5.3° |
| | 13 | 8.0° |

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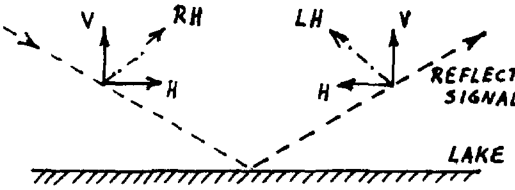


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As an other example, consider the problem of determining the effect of varying amplitude and phase on the far-field radiation pattern of a four-bay, horizontally stacked antenna-array, designed for $10^o$ and $21^o$ co-channel angle protection. ($H=2.87\lambda$ and $H=1.4\lambda$).

The array factor; expressed for even number radiators:

$$E = \frac{1}{N}\left[\sum_{n=1}^{N} a_n (n - 0.5)\psi\right]$$

where: $N$ = number of radiators (antennas)

$$\psi = 2\pi \frac{d}{\lambda} \sin\Theta + \delta$$

$\Theta$ = the angle to the normal of the array-axis

$a_n$ = the amplitude of the n-th radiator

$\delta$ = relative phase-shift between radiators

$\lambda$ = wavelength

In a horizontally stacked antenna-array the relative phase-shift between adjacent elements must be:

$$\delta = -2\pi \frac{d}{\lambda} \sin\Theta_o$$

to ascertain the main beam of the radiation pattern normal to the array-axis (at $\Theta_o$). Substituting $\delta$ into $\psi$

$$\psi = \frac{2\pi d}{\lambda}(\sin\Theta - \sin\Theta_o)$$

The calculated radiation pattern of the four-bay antenna-array, assuming $0^o$ phase-shift and 0 dB amplitude variation is shown by the solid curve of Fig. 8.

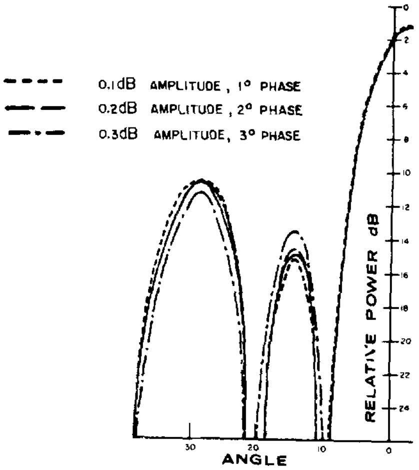


**Fig. 8**

The various dashed lines exhibit the distorted radiation patterns resulting from moderate phase and amplitude errors.

As illustrated, the deviations from the error-free condition generate no serious variations in the amplitude of the shoulders. However, the shifts in the radiation pattern nulls must not be neglected.

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