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# CIRCULAR POLARIZATION TECHNIQUES IN MICROSTRIP ANTENNAS

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## ABSTRACT

In this paper the design consideration for circularly polarized microstrip antennas is presented. Various techniques for circularly polarized radiation generation and bandwidth enhancement are also discussed. Generally, antenna radiates an elliptical polarization, which is defined by three parameters: axial ratio, tilt angle and sense of rotation. When the axial ratio is infinite or zero, the polarization becomes linear with the tilt angle defining the orientation. The quality of linear polarization is usually indicated by the level of the cross polarization. For the unity axial ratio, a perfect circular polarization results and the tilt angle is not applicable. In general, the axial ratio is used to specify the quality of circularly polarized waves. In a circular polarized antenna, the electric field varies in two orthogonal planes (x and y direction) with the same magnitude and a 90° phase difference.

The result is the simultaneous excitation of two modes, i.e. the TM10 mode (mode in the x direction) and the TM01 (mode in the y direction). One of the modes is excited with a 90° phase delay with respect to the other mode. A circular polarized antenna can either be right hand circular polarized (RHCP) or left hand circular polarized (LHCP). From this, it is clear what needs to be done in order to get circular polarization, namely: Split the signal in two equal parts; Feed one signal to a horizontal radiator and the other to a vertical radiator; Change the phase of one of the signals by 90°.

***Keywords:*** *Microstrip Antenna, Circularly polarized patch antenna, single feed, dual feed, orthogonal feed.*

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## I. INTRODUCTION

Antennas produce circularly polarized waves when two orthogonal field components with equal amplitude but in phase quadrature are radiated. Various antennas are capable of satisfying these requirements. They can be classified as a resonator and traveling-wave types [1]. A resonator-type antenna consists of a single patch antenna that is capable of simultaneously supporting two orthogonal modes in phase quadrature or an array of linearly polarized resonating patches with proper orientation and phasing. A traveling-wave type of antenna is usually constructed from a microstrip transmission line [2]. It generates circular polarization by radiating orthogonal components with appropriate phasing along discontinuities is the travelling-wave line.

## II. MICROSTRIP PATCH ANTENNAS

A microstrip antenna is a resonator type antenna. It is usually designed for single mode operation that radiates mainly linear polarization. For a circular polarization radiation, a patch must support orthogonal fields of equal magnitude but in-phase quadrature [3]. This requirement can be accomplished by single patch with proper excitations or by an array of patches with an appropriate arrangement and phasing [9].

Circularly Polarized Patch - A microstrip patch is one of the most widely used radiators for circular polarization. Fig. 1 shows some patches, including square, circular, pentagonal, equilateral triangular, ring, and elliptical shapes which are capable of circular polarization operation. However square and circular patches are widely utilized in practice [5-6].

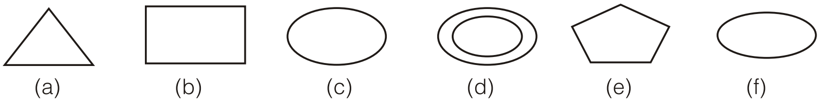

**Fig. 1 Various types of circularly polarized microstrip patch antennas: (a) triangular patch, (b) square patch, (c) circular patch, (d) ring, (e) pentagonal patch, and (f) elliptical patch [6]**

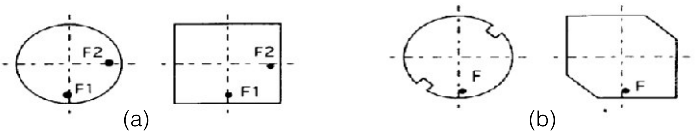

**Fig. 2 Two types of excitations for circularly polarized microstrip antennas: (a) dual-fed patch and (b) singly fed patch [7]**

A single patch antenna can be made to radiate circular polarization if two orthogonal patch modes are simultaneously excited with equal amplitude and out of phase with sign determining the sense of rotation. Two types of feeding schemes can accomplish the task as given in Fig. 2 [7]. The first type is a dual-orthogonal feed, which employs an external power divider network. The other is a single point for which an external power divider is not required.

**Dual-Orthogonal Fed circularly Polarized Patch:** The fundamental configurations of a dual-orthogonal fed circularly polarized patch using an external power divider is shown in Fig. 3. The patch is usually square or circular. The dual-orthogonal feeds excite two orthogonal modes with equal amplitude but in phase quadrature. Several power divider circuits that have been successfully employed for CP generation include the quadrature hybrid, the ring hybrid, the Wilkinson power divider, and the T-junction power splitter. The quadrature hybrid splits the input into two outputs with equal magnitude but 900 out of phase. Other types of dividers, however, need a quarter-wavelength line in one of the output arms to produce a 900 phase shift at the two feeds. Consequently, the quadrature hybrid provides a broader axial ratio bandwidth [8,10]. These splitters can be easily constructed from various planar transmission lines.

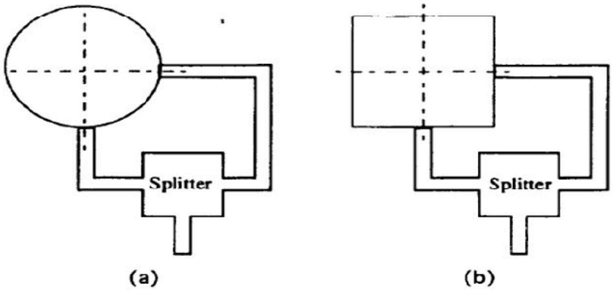

**Fig. 3 Typical configurations of dual-fed circularly Polarized microstrip antennas: (a) circular patch and (b) square patch**

**Singly Fed Circularly Polarized Patch:** Typical configurations for a singly fed CP microstrip antennas are shown in Fig. 4. A single point feed patch capable of producing CP radiation is very desirable is situations where it is difficult to accommodate dual-orthogonal feeds with a power divider network [11].

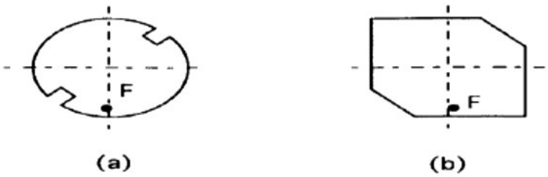

**Fig. 4 Typical configurations of singly fed circularly polarized microstrip antennas: (a) Circular patch and (b) Square patch**

Because a patch with single-point feed generally radiates linear polarization, in order to radiate CP, it is necessary for two orthogonal patch modes with equal amplitude an in-phase quadrature to be induced. This can be accomplished by slightly perturbing a patch at appropriate locations with respect to the feed.

Perturbation configurations for generating CP operate on the principle of detuning degenerate modes of a symmetrical patch by perturbation segments as shown in Fig. 5. The fields of a singly fed patch can be resolved into two orthogonal degenerate modes 1 and 2. Proper perturbation segments will detune the frequency response of mode 2 such that, at the operating frequency fo, the axial ratio rapidly degrades while the input match remains acceptable [12]. The actual detuning occurs either for one or both modes depending on the placement of perturbation segments.

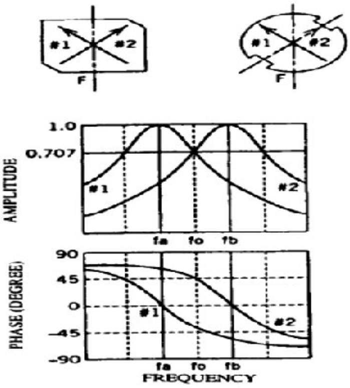

**Fig. 5 Amplitude and phase of orthogonal modes for singly fed circularly polarized microstrip antennas.**

A circular polarization can also be obtained from a single-point-fed square or circular patch on a normally biased ferrite substrate, as shown in Fig. 6. It demonstrates that a singly fed patch radiates both left hand circularly polarized (LHCP) and right hand circularly polarized (RHCP) at the same level and polarity of bias magnetic field; however, LHCP and RHCP have different resonant frequencies [13].

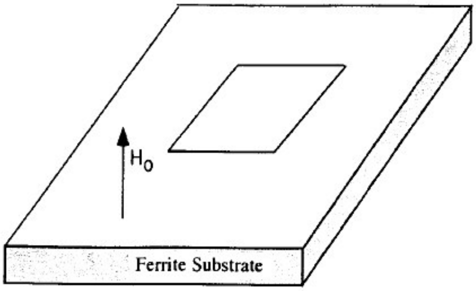

**Fig. 6 Geometry of a rectangular patch antenna on a normally biased ferrite substrate.**

At the same operating frequency, the sense of polarization can be reversed by reversing the polarity of bias field. The axial ratio bandwidth is found to be larger than the impedance bandwidth. The radiation efficiency is on the order of 70%. Dual circular polarization has also been achieved using a singly fed triangular or pentagonal microstrip antenna [14]. A schematic diagram of an isosceles triangular patch and its feed loci is shown in Fig. 7. A triangular patch radiates CP at dual frequencies, $f_1$ and $f_2$, with the separation ratio depending on the aspect ratio b/a. As shown in Fig. 7, RHCP can be changed to LHCP at each frequency by moving the feed location Γ1 to Γ2 or from Γ4 to Γ3. The aspect ratio b/a is generally very close to unity; hence, a triangular patch is almost equilateral. A pentagonal patch in Fig. 8, with the aspect ratio c/a as a design parameter, also behaves in a similar manner. It radiates RHCP when the feed point is on Γ2 or Γ3 and LHCP for the feed on Γ1 to Γ4.

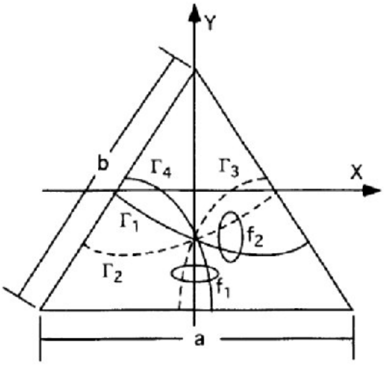

**Fig. 7 Schematic diagram of an isosceles triangular patch and the feed loci for circular polarization radiations: Γ1 and Γ4 for RHCP; Γ2 and Γ3 for LHCP.**

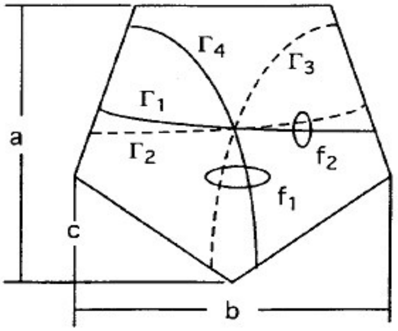

**Fig. 8 Schematic diagram of a pentagonal microstrip patch and the feed loci for circular polarization radiations: Γ1 and Γ4 for LHCP; Γ2 and Γ3 for RHCP.**

## III. ARRAYS OF LINEARLY POLARIZED PATCHES FOR CIRCULARLY POLARIZED RADIATION

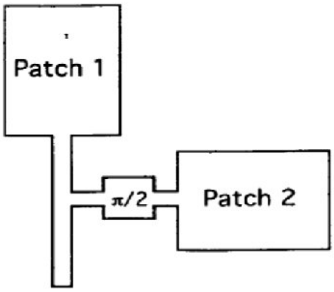

**Fig. 9 Possible arrangement of two linearly polarized patches for circular polarization radiation**

Two linear LP patch antennas can be orthogonally arranged as shown in Fig. 9 with one of the patches being fed 900 out of phase. The disadvantages of this configuration are larger space requirements and rapid degradation of CP with angle off the boresight as a result of spatial phase delay due to different path lengths from the phase centers of the two radiating elements [15]. An alternative arrangement in Fig. 10 by Huang significantly improves the CP quality. The axial ratio bandwidth of the array substantially increases. The cross-polar are significantly suppressed on the two principle planes, the x-z and the y-z planes, but this is not true on the two diagonal planes.

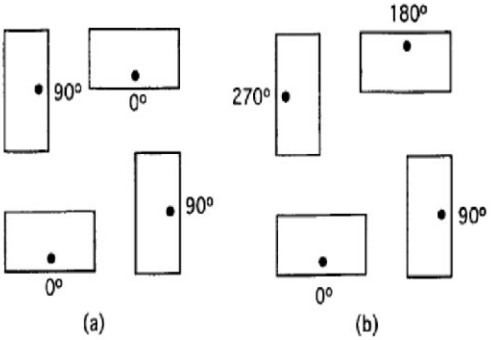

**Fig. 10 2x2 microstrip arrays with LP elements for CP generation: (a) narrow-band arrangement and (b) wide-band arrangement.**

## IV. OTHER TYPES OF CIRCULARLY POLARIZED ANTENNAS

Other types of CP antennas are compact in their feed requirements and radiating element configurations. These types are CP antennas, which can be easily constructed from microstrip lines, are described next.

**Microstrip Spiral Antennas [15]:** To obtain a wide bandwidth, the concept of conventional spiral antennas has been applied to microstrip spiral design. A conventional spiral radiates good CP because small residual current remains after the active zone, which corresponds to a spiral arm with a wavelength circumference [15]. However, Wood found that this was not true for the case of microstrip spirals. The decaying of a current in microstrip spirals in the active region was not large enough to prevent significant interference radiation from successive turns in the spiral that adversely affected CP performance. Hence, Wood's design took on the form of a sector of a circular transmission line and one turn of a loosely wound spiral with a feed at one end and a matched termination at the other as shown in Fig. 11. The antennas achieve the bandwidth of 40% with axial ratio of less than 3 dB at the cost of reducing the average radiation efficiency to 50%. Wang experimented with microstrip spirals using microwave absorbing material placed half inside the truncated spiral and half outside to dissipate the residual energy. They were able to achieve a bandwidth of 6:1 for patterns [11].

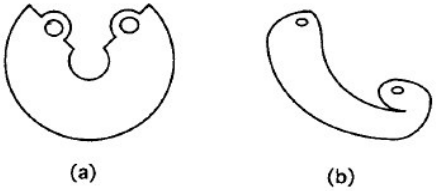

**Fig. 11 Circular polarized curved microstrip line antennas: (a) sector of circular microstrip transmission line and (b) spiral microstrip line antenna.**

**Array of Composite Elements [16]:** A circular polarization can be produced from an array of composite electric and magnetic radiation elements that radiate mutually orthogonal fields with 90° phase difference. One such array consists of standing-wave fed slots and strip dipoles as shown in Fig. 12. It is composed of strips on a thin substrate, slots in the ground plane, and a microstrip feed line terminating in a short circuit [16]. The strip and the slots are a half wavelength long and are spaced at a quarter-guide wavelength apart along feed line to provide the 90° phase difference requirement. When the strips and the slot are located at the maximum points of voltage and current standing waves, the array can efficiently produce CP in the broadside direction.

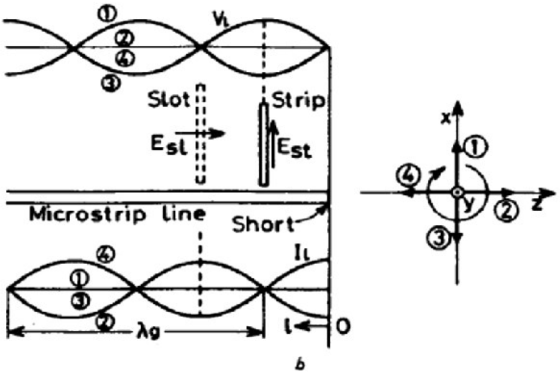

**Fig. 12 Array of composite elements for circular polarization.**

**Traveling-Wave Arrays [16]:** Alternating design of CP printed antennas is in the form of a linear traveling-wave array consisting of microstrip transmission line excitation of microstrip CP radiating elements. The residual power at the end of the microstrip feed line is dissipated in a termination to prevent reflection that otherwise can adversely degrade CP quality. The element spacing is generally greater then $\lambda_0/2$; thus, it is possible to use previously described resonator-type CP elements in the design. However, CP radiating elements can also be constructed from orthogonal arrangement of linearly polarized (LP) radiators as depicted in Fig. 13, which shows traveling-wave printed dipole and slot arrays.

In the dipole array, each unit cell consists of inclined half-wavelength printed dipoles arranged along both sides of a microstrip feed line. The spacing Ds between adjacent dipoles in each unit cell is a quarter-guide wavelength. The spacing Dp between unit cell and the inclined angle a are determined from the desired main beam direction. Slot array arrangements can be determined in a similar manner. However, the operation of the slot array requires a reflector under the substrate for back radiation suppression.

Other designs of traveling-wave arrays utilize a radiating property at discontinuities the are periodically introduced in traveling-wave transmission lines. In these designs, CP radiating element in each unit cell of the arrays is constructed from bending a microstrip feed line into an appropriate meander. Different design configurations reported in literature include rampart line antennas, chain antennas, square-loop-type microstrip line antennas, and crank-type microstrip line antenna.

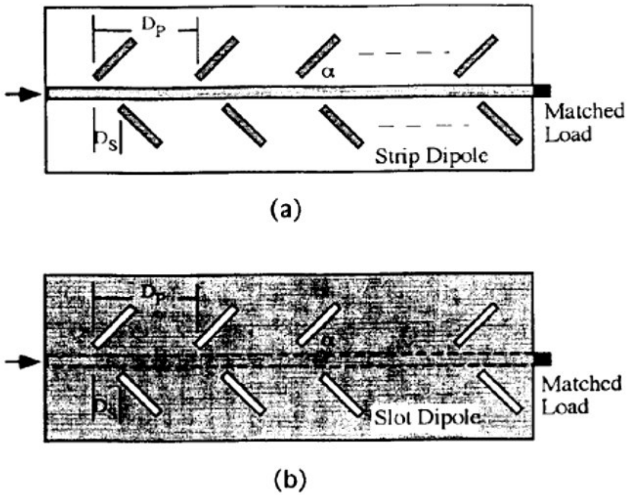

**Fig. 13 Traveling-Wave printed arrays for circular polarization: (a) dipole array and (b) slot array.**

The rampart line antenna consists of four rectangular bends in each unit cell. The crank-type microstrip line antenna is simply two parallel rampart lines of the same dimensions with one line shifted by half a period. This arrangement results in better frequency characteristics for the axial ratio and radiation pattern. For the chain antenna, its fundamental element is built from a V-shape circularly polarized radiating element and U-shape phase shifters while each unit cell of the square-loop. In the design, the period of the unit cell is less than 0 to avoid grating lobes, and the electrical line length in each unit cell should not be equal to a multiple of a guide wavelength to eliminate the situation in which small reflections can be combined in phase to produce a high return loss. These antennas radiate RHCP when they are fed from the left. The sense of the polarization is reversed when they are fed from right.

## V. SINGLY FED CIRCULARLY POLARIZED MICROSTRIP ANTENNAS (RECTANGULAR-TYPE)

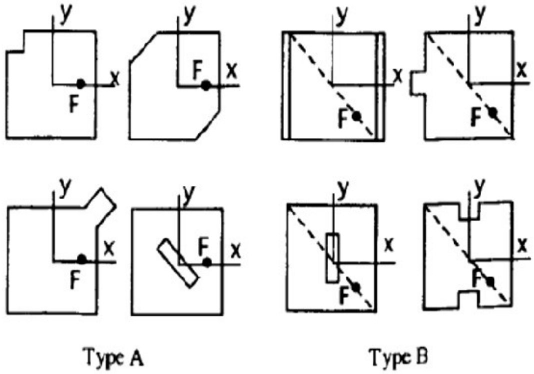

**Fig. 14 Various types of microstrip antenna perturbations for circular polarization generation**

The following derivation is for different types of perturbations. They have been classified into type A and type B depending on the feed location. From Fig. 14 it is type A when the feed location is either on the x or y axis, where is in type B, the feed is placed on the diagonal axis of the patch. Note that the feed is always located diagonal to perturbation segments that are appropriately selected to produce two orthogonally degenerate modes in the patch for CP radiation.

The fundamental configuration of the patch and it's coordinate system are shown in Fig. 15. The square patch is considered to be an electrically thin cavity with perfect magnetic walls at the boundaries, $x= \pm a/2$ and $y= \pm a/2$. In the figure, F is the feed point and $\Delta S$ represent the total sum of the perturbation segments and may consist of single or multiple segments [17].

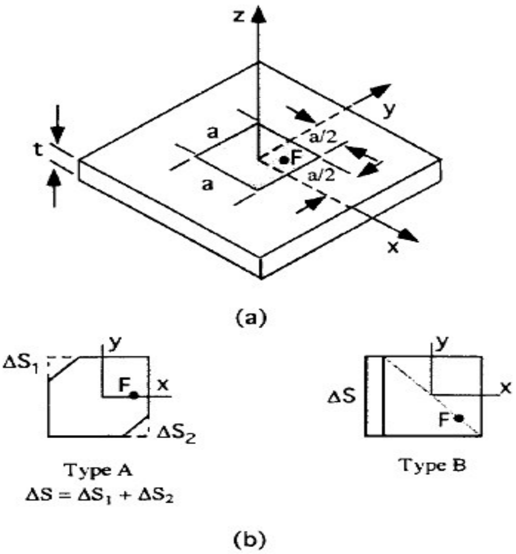

**Fig. 15 Configuration of singly fed microstrip patch antennas: (a) patch diagram and (b) type A and type B microstrip patch perturbations.**

The introduction of perturbation segments will affect the cavity model field and its eigen value, which can be determined from a stationary formula given by:

$$k'^2 = \frac{\int_{S+\Delta S} \nabla\phi' \cdot \nabla\phi' \, dS}{\int_{S+\Delta S} \phi'^2 \, dS} \qquad \ldots(1)$$

Where $\phi$ and $k'$ are the new model field and the new eigen value $\phi'$ can be expanded as

$$\phi' = P\phi_d + Q\phi_b \qquad \ldots(2)$$

Where P and Q are unknown expansion coefficients that have to be determined to make equation 1 stationary. Substituting (2) in (1) gives

$$k'^2 = \frac{\int_{S+\Delta S} (P\nabla\phi_a + Q\nabla\phi_b) \cdot (P\nabla\phi_a + Q\nabla\phi_b) \, dS}{\int_{S+\Delta S} (P\phi_a + Q\phi_b)^2 \, dS} = \frac{U(P, Q)}{V(P, Q)} \qquad \ldots(3)$$

Following the Ritz-Galerkin method, P and Q can be determined

$$\left.\begin{aligned} \frac{\partial U(P, Q)}{\partial P} - k'^2 \frac{\partial V(P, Q)}{\partial P} &= 0 \\ \frac{\partial U(P, Q)}{\partial Q} - k'^2 \frac{\partial V(P, Q)}{\partial Q} &= 0 \end{aligned}\right\} \qquad \ldots(4)$$

from Equation above will result in a set of homogeneous equations that have nontrivial solutions only if the determinant vanishes. Exact parameters of the determinant depend on the type of feed and perturbation placements. It can generally be written in the form

$$\det\begin{vmatrix} k^2 + q_1 - k'^2(1+p_1) & q_{12} - k'^2 p_{12} \\ q_{12} - k'^2 p_{12} & k^2 + q_2 - k'^2(1+p_1) \end{vmatrix} = 0 \qquad \ldots(5)$$

## VI. DESIGN PROCEDURE FOR CP PATCH WITH A SINGLE-POINT FEED

The general design procedure can be summarized as follows:

1. Determine the uploaded $Q_0$ of the patch, which depends on dimensions a, substrate thickness t, and the substrate dielectric constant er. For better accuracy $Q_0$ should be selected to ensure the patch radiation efficiency $\eta > 90\%$.
2. Determine the amount of perturbation ($\Delta S/S$) for the type A and type B as follows:

   For Type A

   $$\left|\frac{\Delta S}{S}\right| = \frac{1}{2Q_0}$$

   For Type B

   $$\left|\frac{\Delta S}{S}\right| = \frac{1}{Q_0}$$
3. The location of the feed point on the axis can be selected to provide a good match; alternatively, a quarter-wavelength transformer can be used for matching purpose.
4. Depending on whether each type of the antenna is type A or type B, the sense of CP can be changed by switching the feed axis.

## VII. DUAL-ORTHOGONAL FEED CIRCULARLY POLARIZED MICROSTRIP ANTENNAS

Use of a dual-feed technique is the most direct way to generate CP radiation from a square patch. The two orthogonal modes required for the generation of CP can be simultaneously excited using dual-orthogonal feeds. In designing, a patch is first matched to the feed lines by either appropriately selecting the feed locations or through the use of impedance transformers. The two feeds are then connected to the output ports of a power divider circuit, which provides the required amplitude and phase excitations. Various types of power divider circuits that have been successfully employed in a feed network of a CP patch are discussed in this section.

**The Quadrature Hybrid:** Referring to Fig. 16(a), the quadrature hybrid is a four-port network. Typically, the input is at port 1 and the output ports 2 and 3, while port 4 is terminated in a match load. Alternatively, port 4 can be the input and port 1match –terminated while the output remains at ports 2 and 3. With a high degree of symmetry, the operation of the hybrid is not affected when ports 1 and 4 are interchanged with ports 2 and 3. The basic properties of the quadrature hybrid can be deduced directly from the scattering matrix, which is given by:

$$[S] = \frac{-1}{\sqrt{2}}\begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix}$$

As a power divider in a CP patch feed network, the input is connected to port 1and 4 is match-terminated or vice versa, depending on the required sense of CP rotation. The output from ports 2 and 3 is then fed to the patch. The signal is evenly divided in amplitude but in phase quadrature at ports 2 and 3. Mismatch at the patch will return to the absorbing load at ports 4, thus a good match is maintained. Because ports 2 and 3 are uncoupled, good isolate, generally exceeding 20 dB, also exists between the outputs. Consequently, the axial is not degraded. A 3- dB quadrature hybrid can be designed using the expressions of a four-port direct-coupled power divider. The characteristic impedances $Z_a$ and $Z_b$ of a quarter-guide wavelength shunt and series arms are obtained as

$$Z_b = \frac{Z_0}{\sqrt{2}},$$

$$Z_a = Z_0$$

**The 180-Degree Hybrid:** The ring hybrid, or a rat-race, is a 180-degree hybrid junction, as shown in Fig. 16 (b). It is four-port network with the scattering matrix for the ideal 3-dB case given by

$$[S] = \frac{-j}{\sqrt{2}}\begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{bmatrix}$$

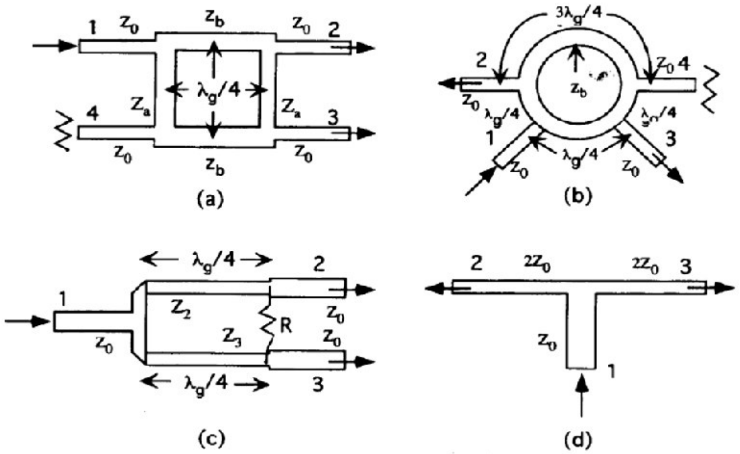

**Fig. 16 Schematic diagrams of power dividers (a) Quadrature Hybrid, (b) ring hybrid, (c) Wilkinson power divider, (d) T-Junction power divider.**

The input at port 1 is equally split in amplitude and phase at the output ports 2 and 3, which are connected to the patch dual-orthogonal feeds. A quadrature phase different between the two orthogonal excitations can be achieved by a quadrature-wavelength differential line length between the two-output lined. Because of the 900 phase shift between the output arms, any reflections from the patch tend to cancel at the output port 1 so that the match remains accepted. However, the combined mismatch at port 4 should be absorbed by a matched load to prevent potential power division degradation of the hybrid which, otherwise, can affect axial ratio performance. Because ports 2 and 3 are uncoupled, the isolation between the outputs is good. It is usually better than 20dB. When ports 4 becomes the input and port 1 is match-terminated while keeping everything else the same, the sense of CP rotation is changed. The line parameters can be obtained from the general design equations of a hybrid-ring coupler. The characteristic impedance of the ring $Z_b$ is found to be $Z_0$ for a 3-dB split.

**The Wilkinson Power Divider:** The Wilkinson power divider is generally an N- way hybrid splitter with arbitrary power division. In a CP feed network application, a Wilkinson will be considered to be a three-port device with the scattering matrix for the ideal case given by

$$[S] = \frac{-j}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

As depicted in Fig. 16(c), the input at port 1 is evenly divided in amplitude and phase at output ports 2 and 3. Similar to the ring hybrid previously described, at 90° phase differences at the dual feeds can be realized by a quarter-wavelength differential line length between the output arms of ports 2 and 3. As a result of a 90° phase shift between the two output arms, any reflection at the patch appears as odd mode excitation, which is dissipated in the isolation resistor. Hence, a good match is maintained, but the antenna efficiency may decrease. Good isolation between output ports 2 and 3 also prevents axial ratio degradation by the patch mismatch. The line parameters for an equal-split Wilkinson power divider can be determined from design equations of the split-T power divider. They are given by

$$Z_2 = Z_3 = \sqrt{2}\,Z_0$$

$$R = 2Z_0$$

**The T-Junction Power Divider [17]** The T-junction power divider as shown in Fig. 16(d) behaves similarly to a three-port Wilkinson except there is no isolation between output ports 2 and 3. Hence, the axial ratio is adversely affected by reflections tend to cancel each other at the input due to a quarter-wavelength difference between the two output arms. For equal split, the characteristic impedances in the T arms are given by

$$Z_2 = Z_3 = 2Z_0.$$

Because a 3-dB quadrature hybrid produces fields with equal amplitudes and 90° phase without the need for a quarter-wavelength line extension in one of the feed arms, this results in a broader VSWR and axial ratio bandwidth as compared to other types of splitters.

## VIII. DESIGN PROCEDURE OF DUAL ORTHOGONAL FEED CP PATCH ANTENNA

The design procedure for a dual orthogonal feed CP patch antenna can be summarized as follows [14]:

1. Design a patch using two orthogonal feeds. Depending on applications, various types of feeding techniques can be employed, including direct contact methods such as probe or microstrip line feed and non-contacting feeds of proximity and slot couplings. Matching can be achieved by appropriately choosing the feed location and dimensions or by using impedance transformers.

2. A power divider network is selected and designed. The output ports are connected to antenna feeds. Impedance transformers can be used if necessary. In design, it is preferable to minimize the coupling between the two feeds for a better axial ratio performance. If the coupling between the two feeds remains strong, a splitter with good isolation such as the quadrature hybrid or the Wilkinson divider is required for good quality.

## IX. CONCLUSION

From this, it is clear what needs to be done in order to get circular polarization, namely:

- Split the signal in two equal parts.
- Feed one signal to a horizontal radiator and the other to a vertical radiator.
- Change the phase of one of the signals by 90°.

Splitting the signal in half can be done with a Wilkinson power divider or similar splitter. If a square patch is fed with two feed points, a vertical and a horizontal radiator are created concurrently. By creating the 90° delay in one of the signal lines and connecting each signal to one feeding pin of the patch, a circularly polarized antenna is created. Though this works well, the splitter and delay line take up valuable board space, and they also tend to radiate and degrade radiation pattern. Thus, circular polarization can be achieved by building a patch with two resonance frequencies in orthogonal directions and using the antenna right in between the two resonances at f0. It is important that the two modes are excited equally strong and with a 90° phase difference. A number of ways exist to implement this, but cutting two corners off the element the so-called corners truncated patch is a technique widely used in GPS antennas. However, that this technique inherently has a lower circular polarization bandwidth than the double fed patch, whose polarization bandwidth is mainly limited by the splitter phase shifter bandwidth. The quality of the circular polarization is commonly quantified as the axial ratio (AR), expressed in dB. A 3-dB axial ratio is considered sufficient for most applications. The axial ratio is mostly optimal at broadside (in the direction of z axis) and degrades towards lower elevations (away from z axis). The degree of degradation is highly dependent on the antenna geometry. Most antenna vendors only specify one axial ratio value or an axial ratio variation versus frequency, and they don’t say anything about axial ratio variation versus elevation. Another way of expressing the quality of circular polarization is showing the co and cross polar radiation patterns. The copular radiation pattern is the radiation pattern of the wanted polarization, and the cross polar radiation pattern is the radiation pattern of the unwanted opposite polarization.

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