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Variations on the Impulse-Radiating-Antenna Theme

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Abstract

The reflector IRA has a design based on a conical-transmission-line feed launching a fast-rising spherical TEM wave into a paraboloidal reflector focused at infinity. Various alterations can be made to the basic antenna design to accommodate mounting on conducting structures. An appropriate symmetry plane can be replaced by a locally flat portion of the structure on which the antenna is to be mounted. Alternatively, the reflector can be designed as a well (depression) in the local conducting structure.

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1. Introduction

The basic concept of an impulse radiating antenna (IRA) is an antenna which, when driven by a step-rising waveform, produces a similar step-rising field as an approximate plane wave on the antenna aperture, and thereby radiates an approximate impulse in the far field in the center of the beam. In reception such an antenna (on the beam center) receives a voltage waveform which is approximately the same as the incident-field waveform [5, 8]. (Ira (first declension, feminine, i pronounced as e in equal) is a Latin word meaning anger, ire, wrath.)

The different ways of producing the aperture field give different kinds of IRAs. A conical transmission line (TEM horn) consisting of two or more conducting cones (of arbitrary cross section, not necessarily flat plates) with a common apex can be used to launch a fast-rising dispersionless TEM wave from a pulse source at the apex. Truncating the horn at a plane some distance ℓ from the apex defines an antenna aperture. Placing a lens just behind the aperture one can concert the incident spherical wave to a plane wave at the aperture [2, 4, 7, 14, 17, 18]. One can call such antenna a lens IRA or LIRA. If, instead, the truncated conical transmission line is terminated at the rim of a paraboloidal reflector with the apex at the focal point we have a reflector IRA or RIRA [2, 4, 12, 18, 19]. This is a quite practical form since for large antennas the reflector is much less massive than the corresponding lens. Another way of producing a step-rising field on an aperture is via an array of connected antenna elements at the aperture [11, 13]. By adjusting the timing of the pulses on the various elements (analogous to adjusting phase for a single frequency on a phased array) one can make a plane wave at the aperture with a direction of propagation corresponding to the direction of focus at infinity, this being the center of the radiated beam. It is this electrical beam scanning which an array can give, albeit at a significant increase in complexity. Such an antenna can be referred to as an array IRA or AIRA.

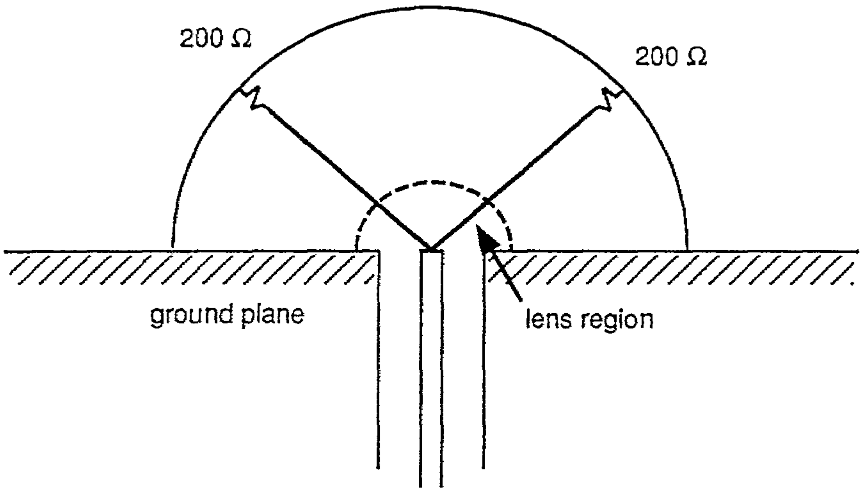
These three kinds or classes of IRAs can be further subdivided according to various design features. A recent paper [14] has some of the design options for TEM-horns/LIRAs including resistive terminations to improve the low-frequency properties and the use of a ground plane to give an antenna more suitable for use with a single-ended (asymmetric) source. The present paper explores some options for the reflector type of IRA which also utilize a local ground plane.

2. The Half Reflector IRA

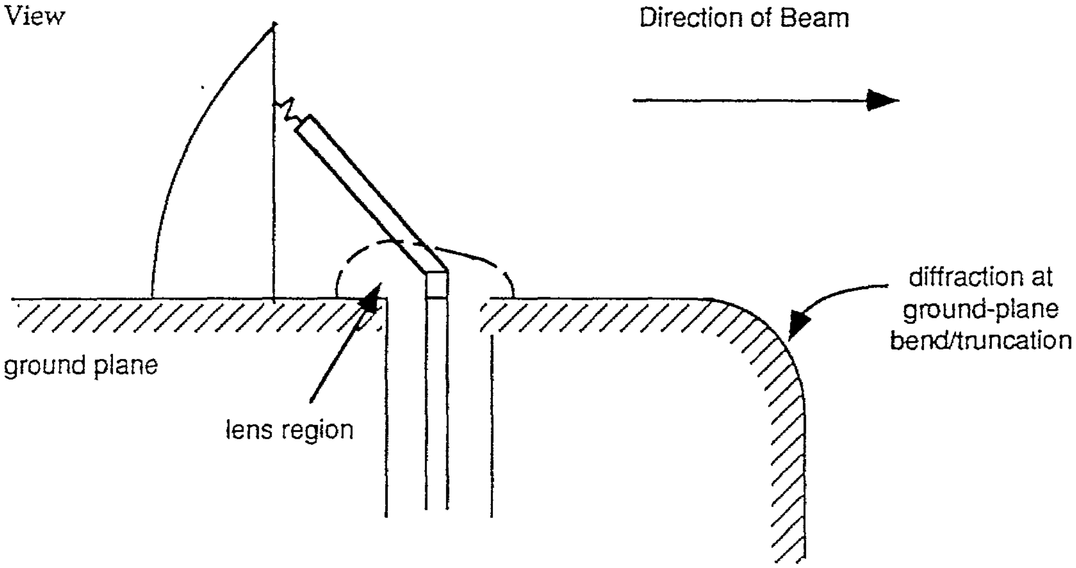
For some applications one can utilize the symmetry plane orthogonal to the electric field (symmetry plane with respect to which the fields are antisymmetric [15, 20]) as a ground plane. Considering the case of a circular reflector with four feed arms (to give, e.g., a 200 Ω feed) then half of this antenna with a ground plane has two feed arms with a feed impedance of 100 Ω (with respect to the ground plane) as illustrated in fig. 2.1.

One advantage of such an antenna configuration is its use with a single-ended pulser. As indicated in fig. 2.1 the pulser can even be behind the ground plane (i.e., on the side away from the reflector) with the pulser case (local ground) electrically part of the ground plane. This allows a coaxial pulser output to connect to the antenna in a way which, for small F/D reflectors, has the wave propagating in a direction which is more suited to launching on the antenna feed. One can still use a dielectric lens (with high-dielectric-strength properties) as part of the feed [10]. In addition one may wish to use a lens as in fig. 2.1C to transition from the plane wave on the coax to the expanding spherical wave on the first part of the antenna feed. As illustrated, this lens is of higher dielectric constant to slow the wave turning from the coax outer conductor onto the ground plane. Various shapes and combinations of permittivities are possible [9]. One might also consider the use of a sharpening switch at or near the junction of the coax center conductor and the feed arms to reduce the rise time from that of the incident wave in the coax.

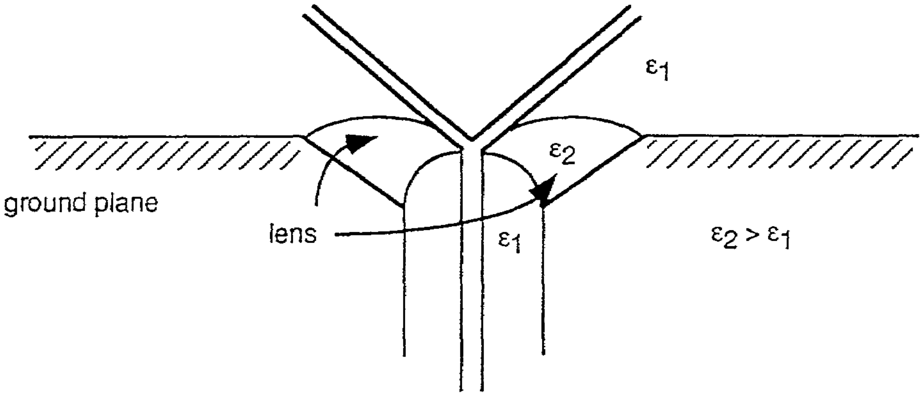
The foregoing discussion is based on a symmetrical circular reflector for which a ground plane can be inserted containing the axis of revolution. An IRA can also be designed with an offset fed reflector [2]. One can still have the ideal paraboloidal surface, but one uses a section of a paraboloid of revolution which is not centered on the rotation axis [16]. As such, this is more appropriately referred to as a partial (instead of half) reflector IRA. As illustrated in fig. 2.2, one can still have a plane through the focal point of the reflector which is still the apex of the conical transmission line, this plane being the location of a ground plane. The field incident on the reflector is the spherical TEM mode characteristic of the conical transmission line consisting of the feed arms (one or more) and the ground plane. The wave can be launched from a switch at the conical-transmission-line apex (reflector focus) or from a pulser feeding through the ground plane at this position. Note that the reduction of symmetry inherent in the offset feed changes the considerations concerning numbers of feed arms and feed impedances depending on the size, shape, and section of the paroboloid that one uses. In practice the ground plane is not infinite in extent, but is truncated at suitable distances away from the feed point and ray paths to the reflector.



A. Front View

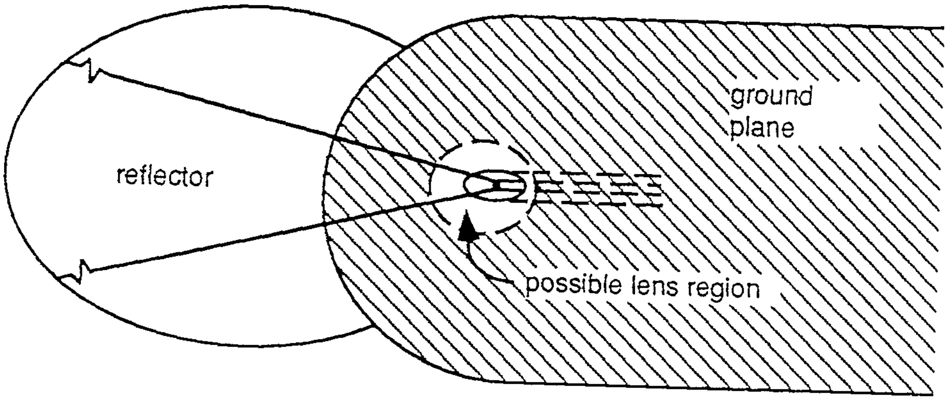


B. Side View

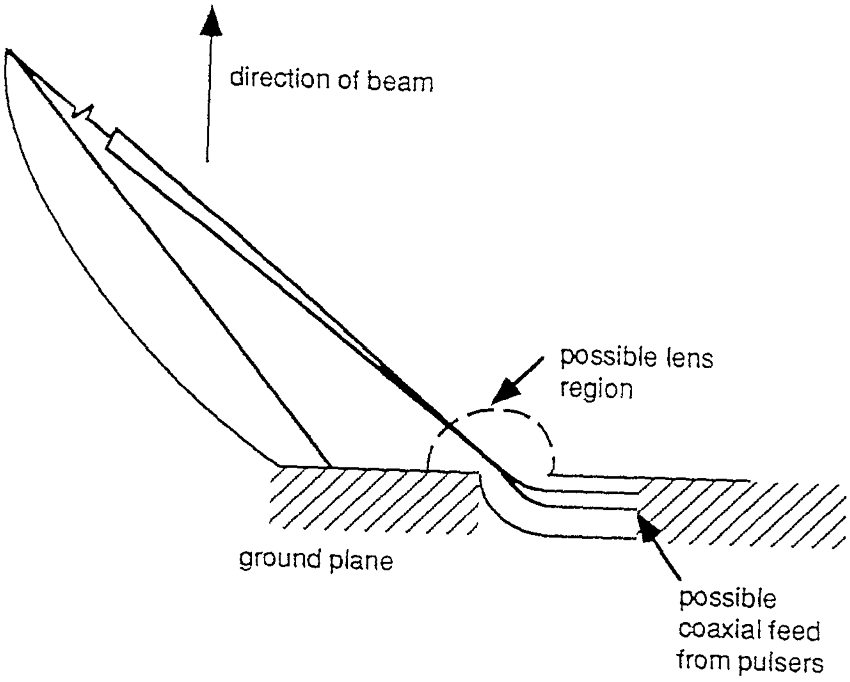


C. Transition of coaxial feed through ground plane

Fig. 2.1 Half Reflector IRA with Feed Through Ground Plane



A. Front view



B. Side view

Fig. 2.2 Offset Fed Reflector IRA with Ground Plane

3. The Well Reflector IRA

In some situations one may wish to mount a reflector IRA on a large conducting surface (e.g., an aircraft skin) to transmit and/or receive in a direction approximately perpendicular to the local conducting surface. Thinking of this surface as a ground plane let us consider what kind of antenna one should have for the lower frequencies in the pulse. In reception consider a normally incident plane wave on an infinite perfectly conducting plane (ground plane) denoted as S. as illustrated in fig. 3.1A. The boundary condition of zero tangential electric field makes the total electric field near S (distances away from S small compared to a radian wavelength $\bar{\lambda}$) small compared to the incident electric field. An electrically small antenna responding to the electric field on or near S will then have a very small response. On the other hand, the total magnetic field on or near S (also for distances small compared to $\bar{\lambda}$) is approximately twice the incident magnetic field. An electrically small antenna (loop) responding to the magnetic field on or near S will then have its response doubled.

One can look at this another way by considering electrically small antennas on or near S in transmission. Consider an electrically small electric dipole $\vec{p}$ parallel to S as indicated in fig. 3.1B. For low frequencies the current on an electric dipole is quite small, the electric dipole moment being simply described as charge times distance [1]. The proximity of S produces an image electric dipole

$$\vec{p}_{image} = -\vec{p} \tag{3.1}$$

due to the requirement of zero tangential electric field on S, giving an antisymmetric type of field distribution with respect to S [15, 20]. As a result the effective electric dipole moment is

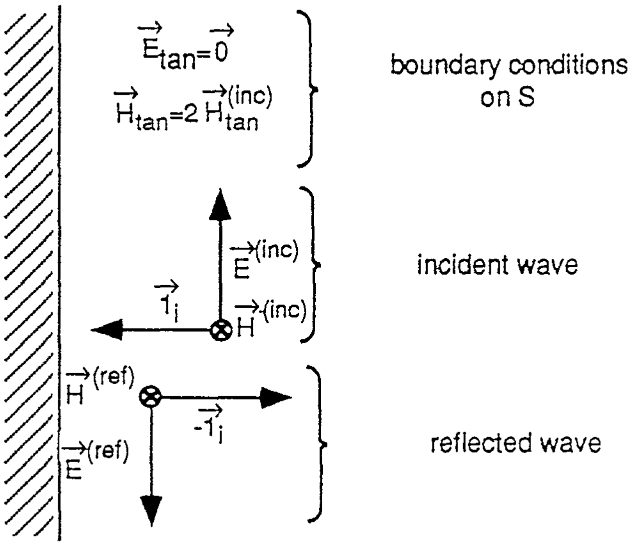
$$\vec{p}_{eff} = \vec{p} + \vec{p}_{image} = \vec{0} \tag{3.2}$$

As a result the radiation of such an electric dipole near S (again a distance away from S small compared to $\bar{\lambda}$) is dramatically reduced. On the other hand, an electrically small magnetic dipole $\vec{m}$ is basically a loop with a current enclosing an area, the charge being quite small. The proximity of S produces an image magnetic dipole

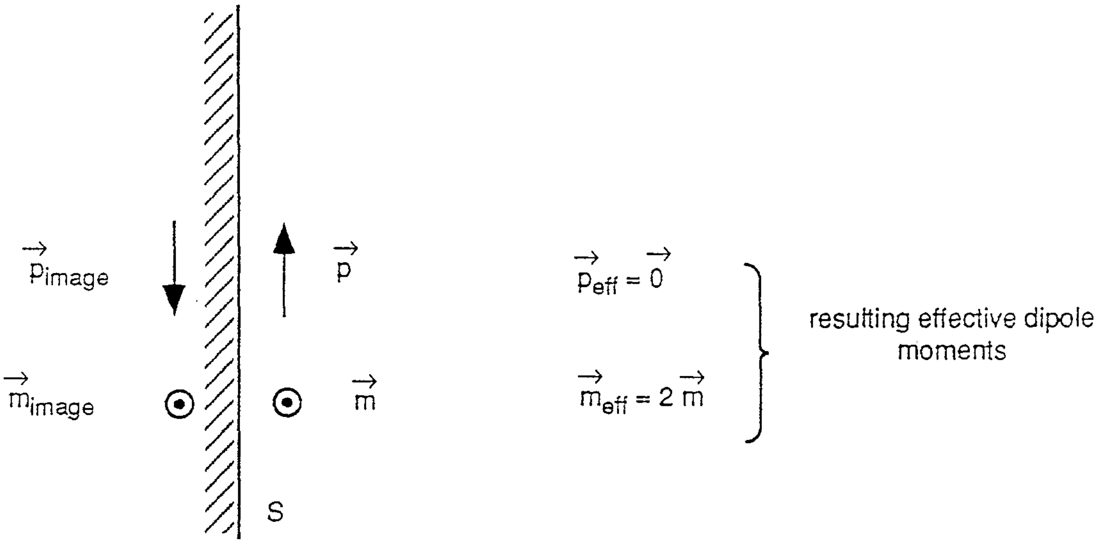
$$\vec{m}_{image} = \vec{m} \tag{3.3}$$

consistent with the antisymmetric type of field distribution with respect to S. The effective magnetic dipole moment is

$$\vec{m}_{eff} = \vec{m} + \vec{m}_{image} = 2\vec{m} \tag{3.4}$$



A. Reception plane wave (normally incident)



B. Radiation from dipoles (parallel to S)

Fig. 3.1 Effect of Ground Plane on Low-Frequency Antenna Performance

As a result the radiation of such a magnetic dipole near S is enhanced. For both transmission and reception perpendicular to S, then a magnetic-dipole antenna near S is far superior to an electric-dipole antenna for low frequencies such that the antenna dimensions and distance from S are electrically small.

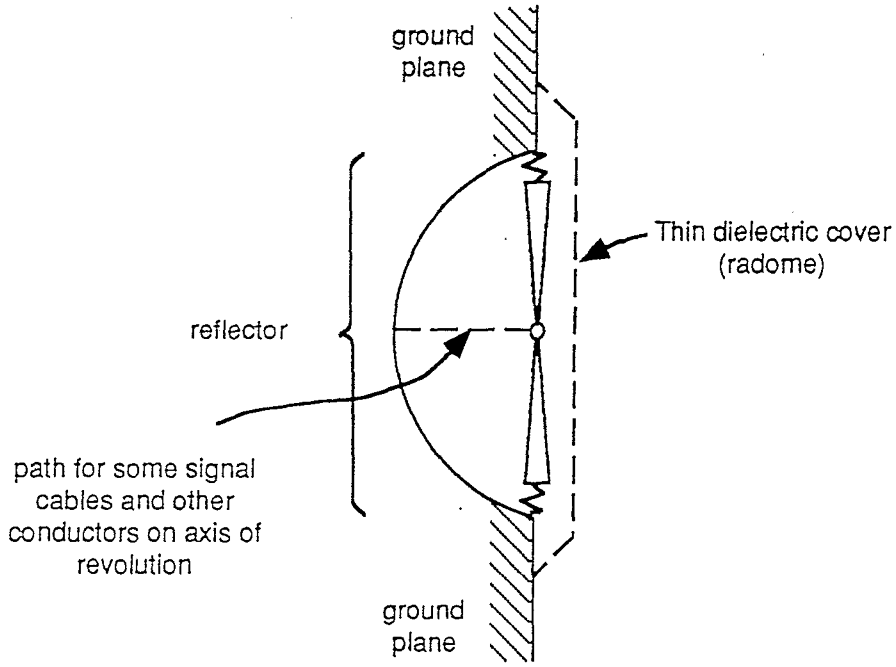
So our problem is to design an antenna, perhaps mounted on S, which behaves as a magnetic dipole for low frequencies, has good properties for high frequencies for which the antenna is electrically large, and transitions well between the high- and low-frequency performance (e.g., is not resonant). A reflector IRA behaves as a combined electric and magnetic dipole at low frequencies [2]. As per the above discussion, the electric-dipole part is suppressed, but the magnetic-dipole part is doubled, compensating thereby for the lack of electric-dipole response. It is also very highly directive for the high frequencies and transitions well between high- and low-frequencies with good pulse fidelity (low dispersion). Let us consider now how one might incorporate a reflector IRA into a ground plane (such as an aircraft fuselage).

To begin, let the paraboloidal reflector be made as a depression or well in the ground plane, e.g., as illustrated in fig. 3.2. Summarizing for a paraboloidal reflector truncated by a plane perpendicular to the rotation axis (giving a circular rim) we have [6]

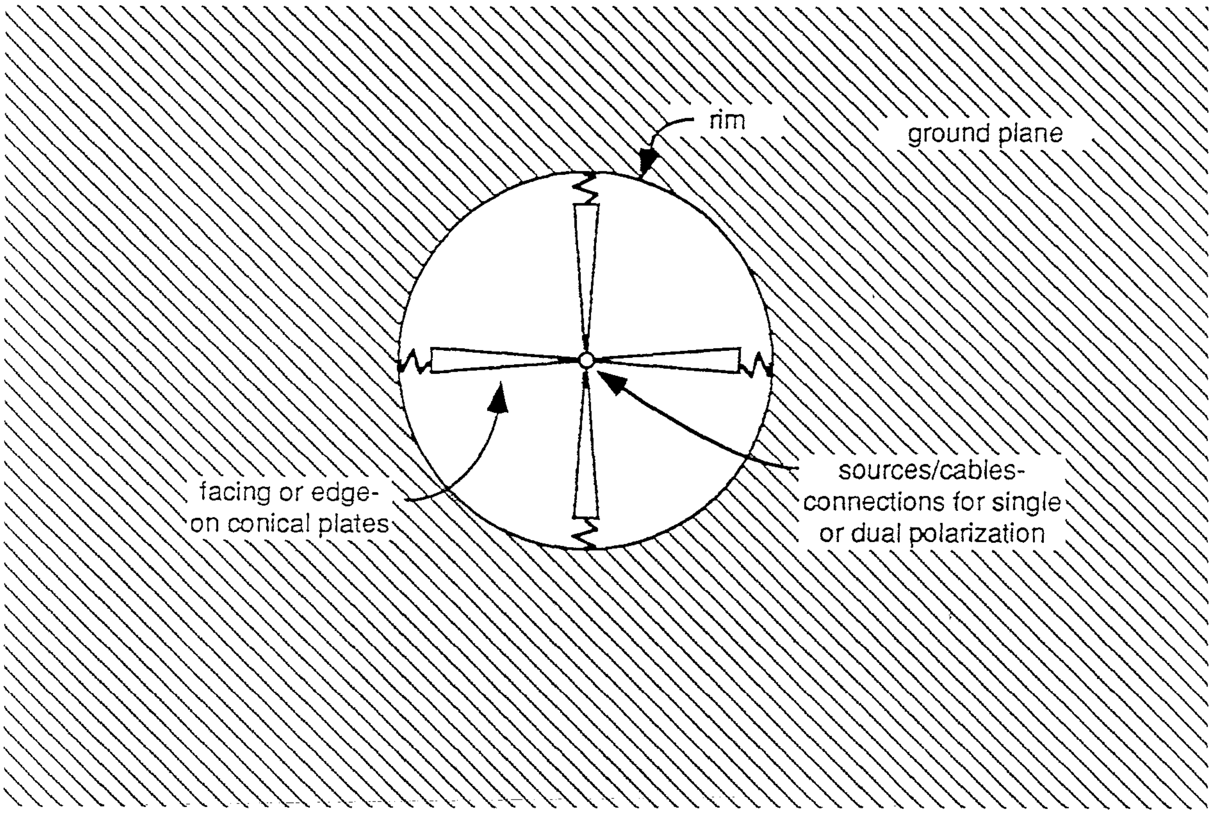
$D \equiv$ diameter of dish
$F \equiv$ focal length of dish (distance from center of dish to focal point, this being the apex of the conical transmission line) (3.5)
$d \equiv$ depth of dish (distance from center of dish to truncation plane)

$$\frac{d}{F} \equiv \frac{D^2}{16F^2}$$

The example in fig. 3.2 is for $F/D = 0.25$ (giving $d/F = 1$) for which case the conical-transmission-line feed is located at what was the position of the ground plane prior to the replacement of that portion by the well consisting of the paraboloidal reflector. The rim of the paraboloid is electrically bonded to the ground plane so that the surface topology is preserved. As illustrated in fig. 3.2B, one can have two pairs of arms to give dual polarization (in transmission and/or reception), reduce the feed impedance to about 200 Ω (by connecting the pairs in parallel), and/or use various of the techniques discussed in [3]. While the use of coplanar plates (edge-on in fig. 3.2B) is desirable from the point of view of reducing aperture blockage, there are other issues to consider. These include mechanical support and the possible use of a dielectric cover (radome) approximately flush with an aircraft skin to minimize perturbation of the



A. Side View



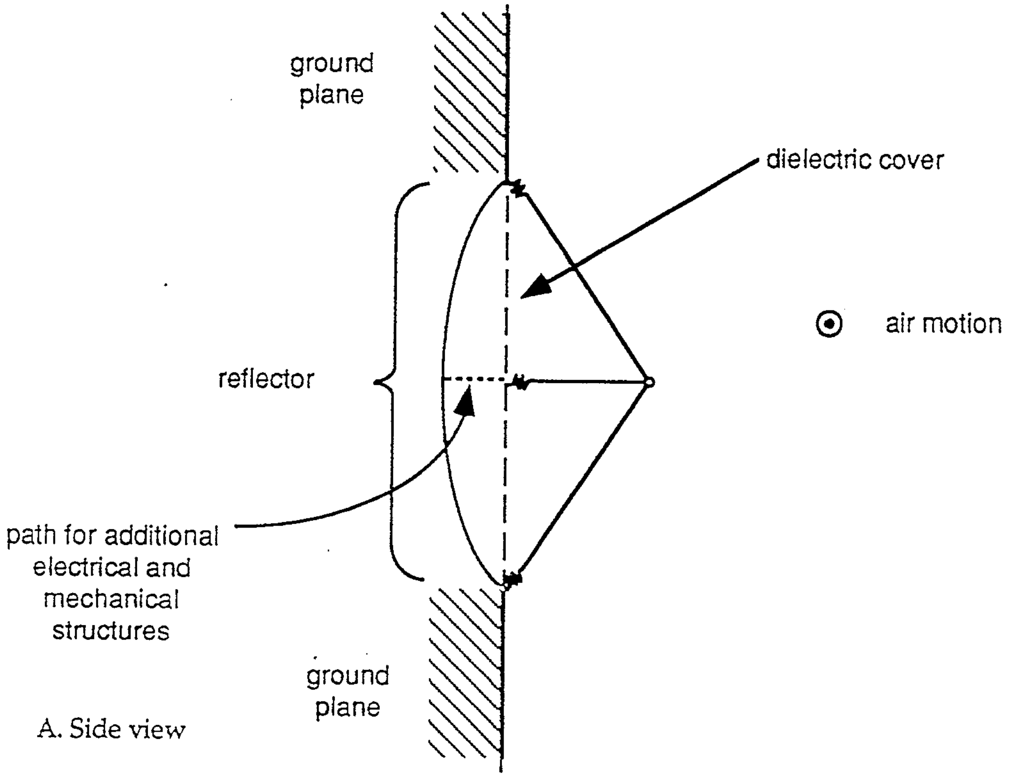
B. Front View

Fig. 3.2 Fully Recessed Well Reflector IRA (F/D=0.25) airflow. As one goes to larger F/D (> 0.25) the antenna feed protrudes beyond the ground plane. A dielectric radome then also protrudes as a blister. Aerodynamic considerations need to be applied to such a blister on an aircraft.

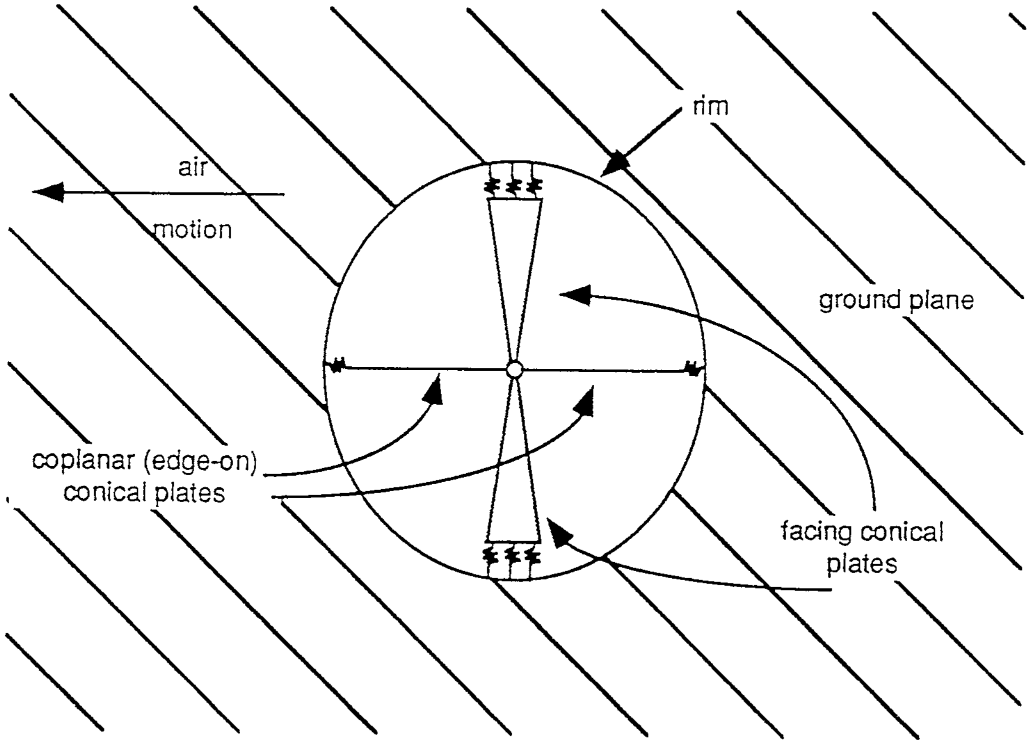
One can further lengthen the feed arms in the presence of air flow as indicated in fig. 3.3. The dielectric cover can remain as a mechanical (i.e., not electrical) continuation of the ground plane to cover the well. The feed arms can be oriented such that the planes of the conical plates are parallel to the air flow. For the four-arm feed illustrated in fig. 3.3, the two coplanar plates are suitable for horizontal polarization while the two facing plates are suitable for vertical polarization. The symmetry is reduced from the previous case in fig. 3.2 (four-fold axis with axial symmetry planes, C_{4a}) to C_{2a} (two-fold axis with axial symmetry planes). Note also that the rotation axis can still be used for signal cables and mechanical support provided these are packaged and shaped for aerodynamic considerations.

One can also consider mechanically scanning reflector IRAs as discussed in [2]. As illustrated in fig. 3.4, one can use a two-conical-plate feed which is pivoted at the two connections to the reflector rim and ground plane. In addition, one may have conductors on the symmetry plane, such as from the center of the dielectric (with pivot point colinear with the previous two). The mechanical pivoting can be accomplished by cantilevers (behind the ground plane) attached through the ground plane to the feed arms. The mechanical connections to the feed arms need to be dielectric or otherwise of high impedance (such as by use of an inductive choke) as they pass by each resistive feed-arm termination. Another approach would involve other structures (including conductors if desired) on the symmetry plane and hence perpendicular to the electric field. Such structures can mechanically move through the reflector, dielectric cover, and/or ground plane to change the scan angle. One can also consider dual-polarization feeds that mechanically scan, but at a significant increase in complexity (e.g., telescoping feed arms and/or sliding termination assemblies). For such scanning reflector IRAs, one may wish to modify the reflector shape since the feed-arm conical apex is no longer fixed on the reflector rotation axis (perpendicular to the ground plane). Some compromise shape to achieve optimal focusing over a range of scan angles might be more appropriate.

Combining the well reflector of this section with the half reflector of Section 2, one can have a configuration as in fig. 3.5. In this case the reflector is recessed in the fuselage which is not necessarily flat but has some curvature in the vicinity of the antenna. Utilizing a conducting wing surface where it meets the fuselage as another ground plane (in the sense of Section 2) the direction of radiation and/or reception is parallel to this wing surface. As in fig. 3.5, the antenna can be mounted under the wing; it

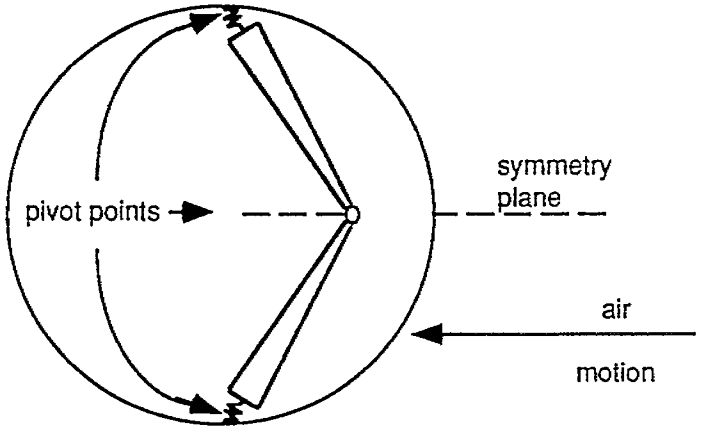


A. Side view

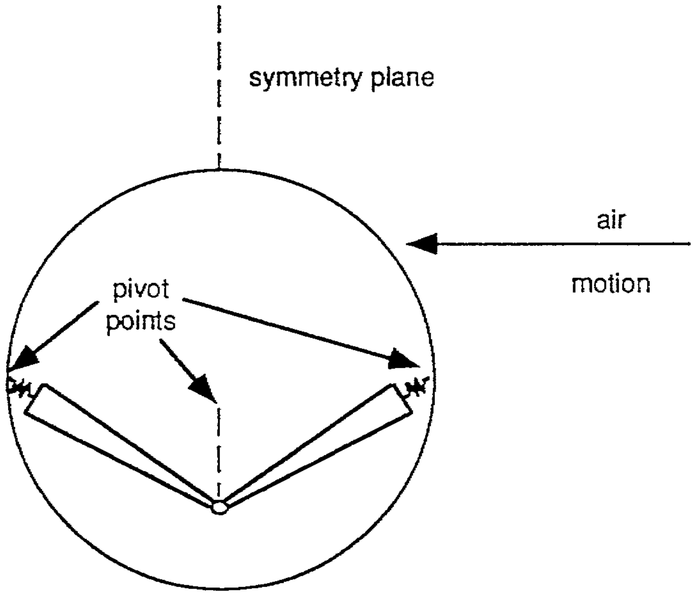


B. Front view

Fig. 3.3 Well Reflector IRA with Feed Conductors Protruding from Ground Plane



A. Horizontal scanning (facing feed-arm plates)



B. Vertical scanning (coplanar feed-arm plates)

Fig. 3.4 Feed Configurations for Mechanical Scanning

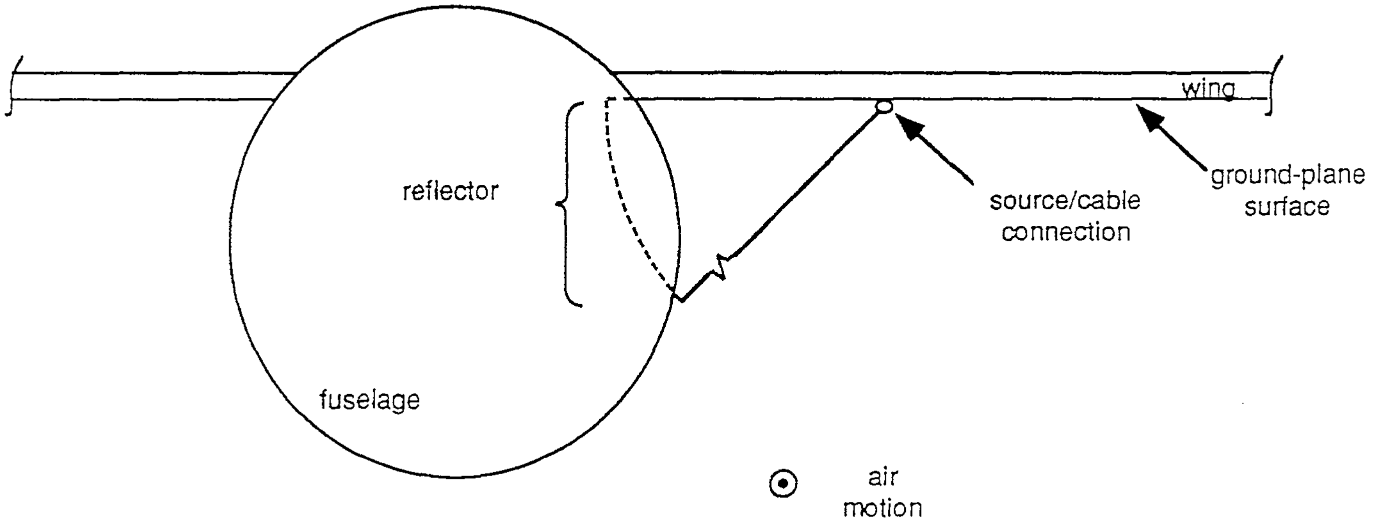


Fig 3.5 Half Reflector IRA Utilizing Fuselage and Wing

can also be mounted on top of the wing. The feed arm occupies a position similar to a strut on some high-wing aircraft. The feed-arm conical plate is again oriented with its plane parallel to the air flow. At the termination (at the reflector rim and fuselage) and at the feed apex where the signal is fed and/or received, one needs to consider both the electrical-isolation and mechanical-strength properties.

4. Concluding Remarks

Starting with the basic concept of the reflector IRA, there are then various modifications that one can make to adapt the antenna to mount on various structures. By utilizing one of the symmetry planes of a circular reflector IRA one has the half reflector IRA on a ground plane with the beam (direction of transmission or reception) parallel to this ground plane. By use of an offset feed, this is further generalized to other beam directions. For cases that one may wish to make the reflector effectively part of a conducting surface (local ground plane) with transmission and/or reception approximately perpendicular to this surface, one can make the reflector as a well in the ground plane. Various options concerning the feed-arm locations (recessed or protruding) are also available.

This paper is a companion of [14] where some variations on the lens IRA and TEM horn for various applications were considered. Basic design considerations for an array IRA have been developed in [11, 13]. Variations on such an array design, suitable for mounting on conducting structures can also be developed, similar in some cases to those discussed in the present paper.

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