Broad Bandwidth Feeds for Reflector Antennas

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FASR FREQUENCY-AGILE SOLAR RADIOTELESCOPE

Challenges for FASR:

- Extremely wide bandwidth (100 MHz to 30 GHz)
- Small size of the antenna (diameter of 3 – 5 meters)
- Dual polarization
- “Acceptable” G/T
- Minimize number of moving parts

FASR FREQUENCY-AGILE SOLAR RADIOTELESCOPE

Gain of Reflector Antennas

$$G = \frac{4\pi A}{\lambda^2}\eta$$

$$\eta = \eta_I \, \eta_S \, \eta_P \, \eta_X \, \eta_B \, \eta_E$$

$\eta_I =$ Illumincation Efficiency

$\eta_S =$ Spillover Efficiency

$\eta_P =$ Phase Error Efficiency

$\eta_X =$ Crosspolarization Efficiency

$\eta_B =$ Blockage Efficiency

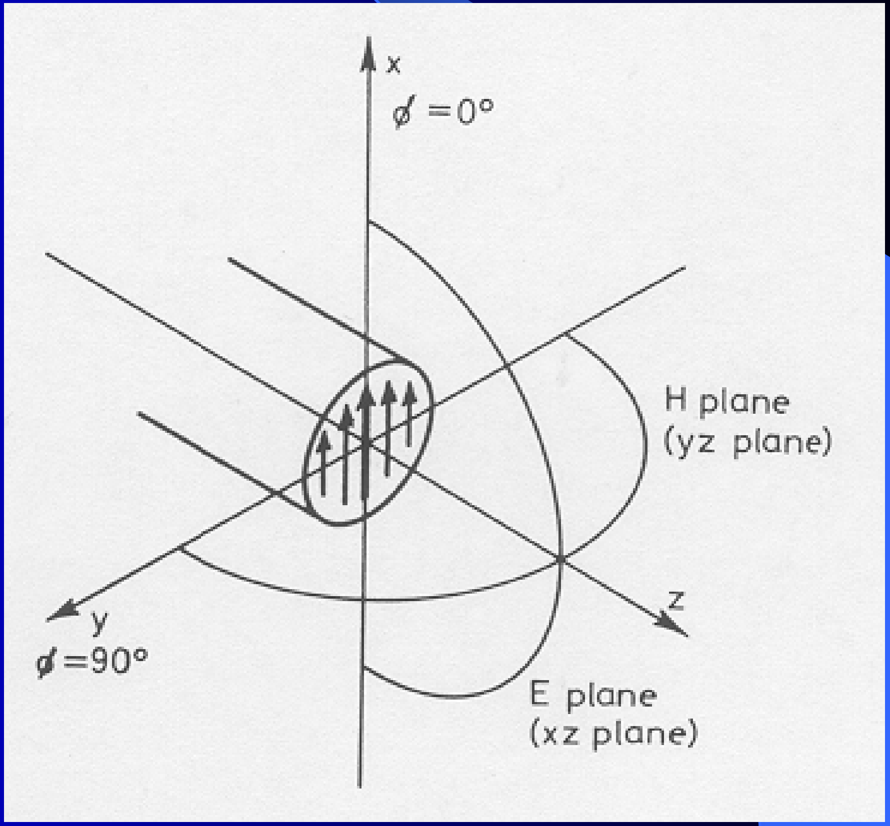
$\eta_E =$ Surface Error Efficiency

Gain of Reflector Antennas

Feed pattern is symmetric (E and H plane patterns are identical) $\eta_X = 1$

Common phase center for both planes $\eta_P = 1$

Illumination and spillover losses are the principal causes of gain degradation.



There is usually a compromise between the illumination and spillover.

If $\eta_I = 1$, then η_S is too low for a realizable feed.
This results in increased sidelobes.

Clarricoats, P.J.B. and A.D. Olver, Corrugated Horns for Microwave Antennas, Peter Peregrinus, Ltd., London, UK, 1984, p. 100.

Types of Feeds Presented Here

- Hybrid-Mode
- Dipole Above Ground Plane
- Frequency Independent Structures

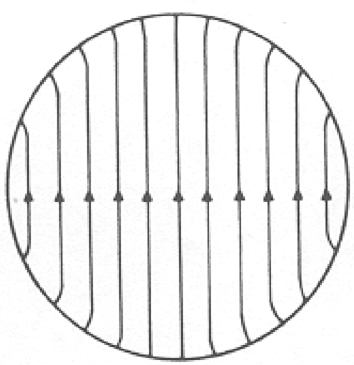
Hybrid-Mode Feeds

The *Hybrid-Mode Feed* offers a means to approach all of the objectives simultaneously.

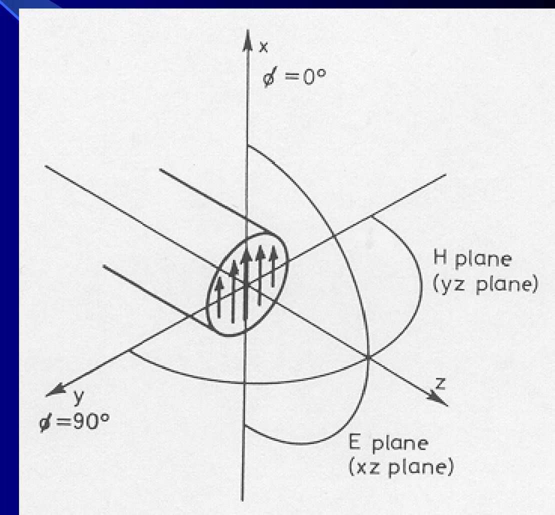
$$E = AJ_o(Kr)\hat{i}_x - \left(\frac{X-Y}{4}\right)\frac{U_o^2}{kr_1}J_2(Kr)(\cos 2\phi\,\hat{i}_x + \sin 2\phi\,\hat{i}_y)$$

Normalized reactance and admittance of the boundary at $r = r_1$

$$X = -j\frac{Z_\phi}{Z_o} = -j\frac{E_\phi}{H_z}\left[\frac{\varepsilon_o}{\mu_o}\right]^{\frac{1}{2}} \qquad Y = -j\frac{Z_o}{Z_z} = +j\frac{H_\phi}{E_z}\left[\frac{\mu_o}{\varepsilon_o}\right]^{\frac{1}{2}}$$

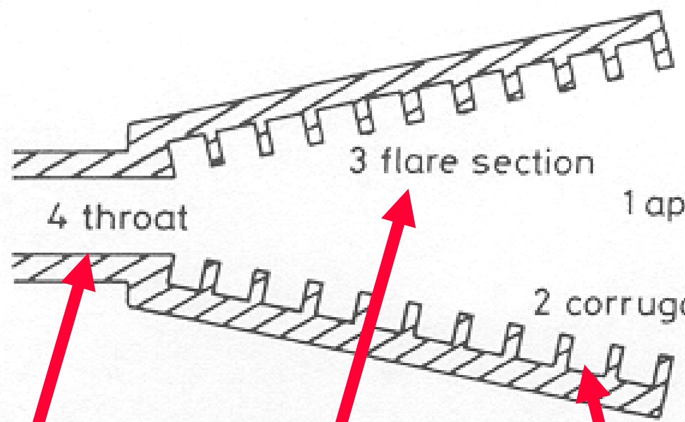


Transverse field patterns for dominant HE_{11} mode in cylindrical waveguide of radius r_1



Clarricoats, P.J.B. and A.D. Olver, Corrugated Horns for Microwave Antennas, Peter Peregrinus, Ltd., London, UK, 1984, p. 7.

Hybrid-Mode Feed – Corrugated Waveguide



Corrugated horn showing regions relevant for design

$$X = 0$$

$$Y = \tan\left(m \frac{\pi}{2} \frac{\Delta f}{f_o} \right) = 0 \quad \text{when}$$

m is an odd integer.

Co-polar bandwidth

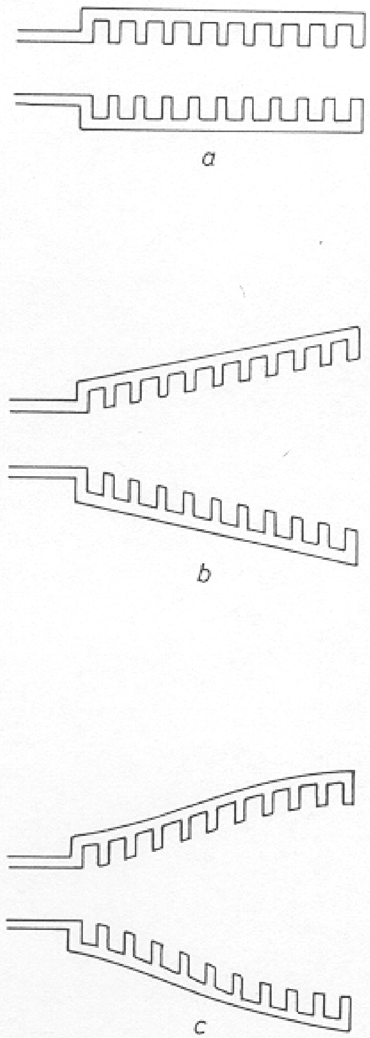
Position of the phase center and generation of higher order modes

Pattern symmetry and cross-polar characteristics

Impedance matching to the waveguide and mode conversion level

Clarricoats, P.J.B. and A.D. Olver, Corrugated Horns for Microwave Antennas, Peter Peregrinus, Ltd., London, UK, 1984, pp. 99-100.

Hybrid-Mode Feed – Corrugated Waveguide



Types of cylindrical corrugated waveguide feeds
a Open-ended waveguide
b Narrow flare angle horn
c Profiled horn

Large flare angle horn (scalar feed) gives a relatively large bandwidth with nearly constant co-polar radiation characteristics.

Thomas, James, and Greene (1986):

Scalar feed having 2.1:1 bandwidth.

James (1984):

Compact profiled horn having 2.4:1 bandwidth (requires some focus adjustment)

Clarricoats, P.J.B. and A.D. Olver, Corrugated Horns for Microwave Antennas, Peter Peregrinus, Ltd., London, UK, 1984, p. 21.

Hybrid-Mode Feed - Corrugated Waveguide

Absorber Lined Horn

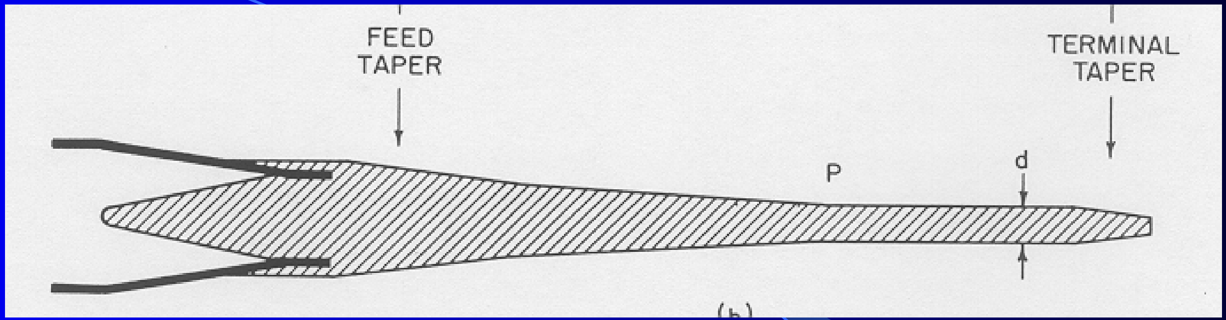
Knop, Cheng, and Ostertag (1986)

Demonstrated nearly balanced HE_{11} mode operation in a horn reflector. $\varepsilon' = 1.4$ and $\varepsilon'' = 0.56$ lined the upper part of the cone. Operation from 4 - 12 GHz was demonstrated (upper frequency limited by waveguide launcher.) Ohmic loss was 0.5 dB over the band.

Knop, C.M., Y.B. Cheng, and E.L. Ostertag, "On the Fields in a Conical Horn Having an Arbitrary Wall Impedance," ***IEEE Trans. Ant. and Propag.*****, Vol. 34, Sept. 1986, pp. 1092-1098.**

Hybrid-Mode Feed – Surface-Wave Antenna

Dielectric Waveguide (rod)



If $kr_1 >> 1$ and if the refractive index differs by only a small amount, Δn, from unity, then

$$X = \frac{1}{\sqrt{(2\Delta n)}}; \qquad Y = \frac{1}{\sqrt{(2\Delta n)}}(1+2\Delta n)$$

Thus,

$$(X - Y) = -\sqrt{(2\Delta n)}$$

This condition is frequency independent if the dielectric is free from dispersion over the operational bandwidth.

Unless delta-n is sufficiently large it is impossible to effectively launch the dominant mode of the dielectric waveguide – loose energy in the launcher.

Corrugated waveguide: Lower cross-pol over 2.5:1 bandwidth.

Dielectric waveguide: higher cross-pol over a much wider band.

BW= 4:1

Clarricoats, P.J.B. and A.D. Olver, Corrugated Horns for Microwave Antennas, Peter Peregrinus, Ltd., London, UK, 1984, p. 9.

Johnson, R. C. Antenna Engineering Handbook,, 3rd ed., McGraw-Hill, New York, 1993, p. (12-21).

Hybrid-Mode Feeds

Disadvantages for FASR:

- **Big and bulky (corrugated)**
- **High machining cost (corrugated)**
- **Bandwidth not large enough**
- **Polarizer bandwidth about 2.5:1**
- **Loss associated with dielectric material**

Dipole Above a Ground Plane

Conventional half-wave dipole

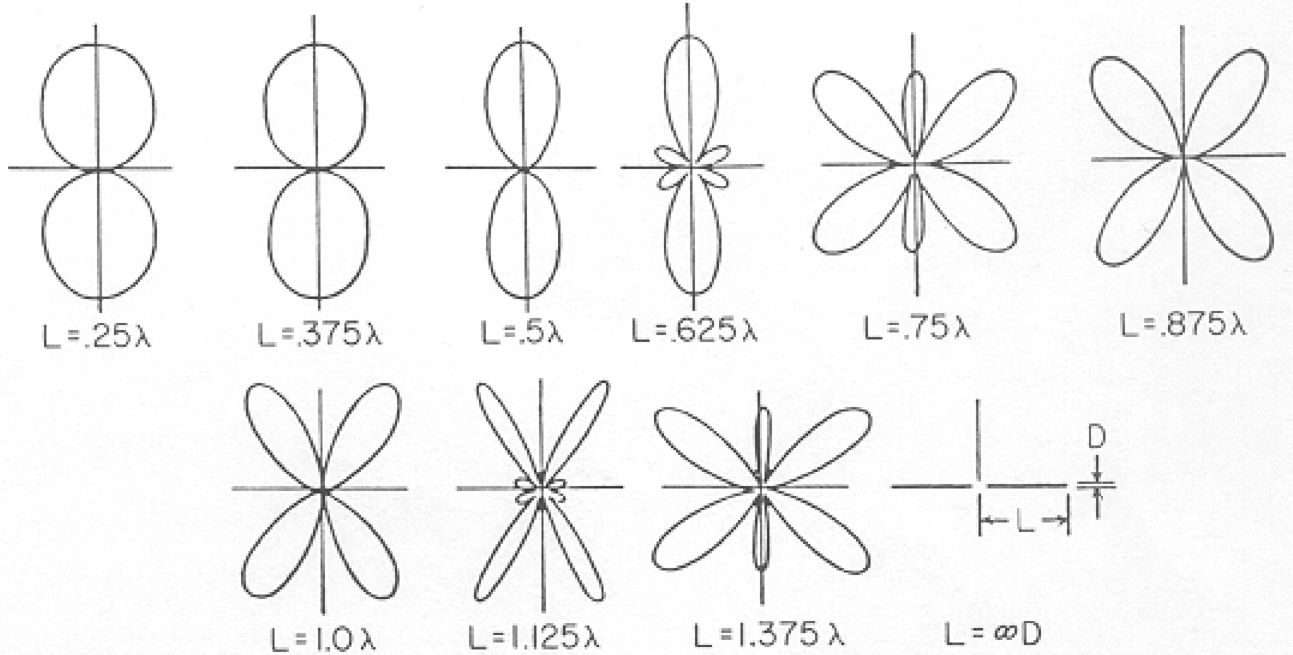


FIG. 4-8 Radiation patterns of center-driven dipoles if sinusoidal current distribution is assumed.

Johnson, R. C. Antenna Engineering Handbook,, 3rd ed., McGraw-Hill, New York, 1993, p. (4-12).

Dipole Above a Ground Plane

Conventional half-wave dipole

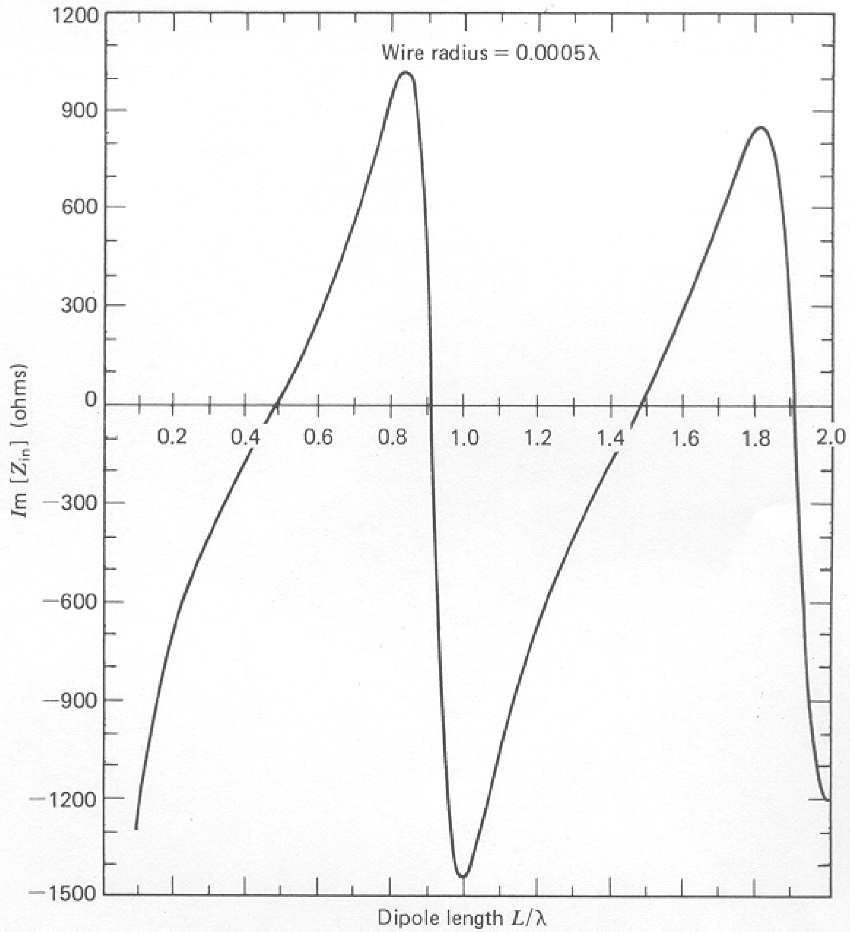


Figure 5-6 Calculated input reactance of center-fed wire dipole of radius 0.0005λ as a function of length L.

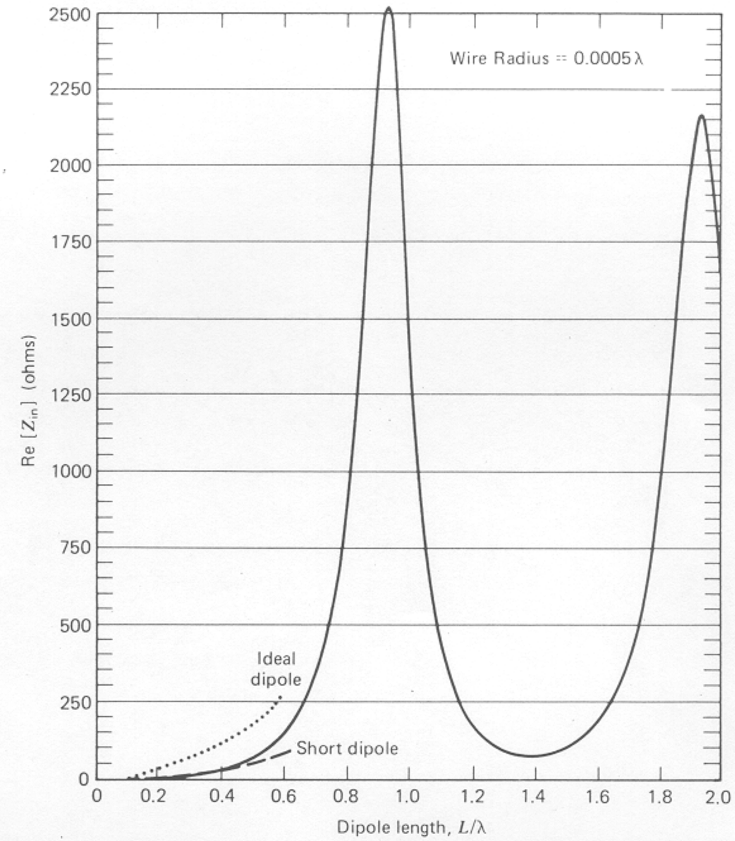


Figure 5-5 Calculated input resistance of a center-fed wire dipole of 0.0005λ radius as a function of length L (solid curve). Also shown is the input resistance $R_{in} = 80\pi^2(L/\lambda)^2$ of an ideal dipole with a uniform current distribution (dotted curve) and the input resistance $R_{in} = 20\pi^2(L/\lambda)^2$ of a short dipole with a triangular current distribution approximation (dashed curve).

Stutzman, W. and G. Thiele, Antenna Theory and Design, Wiley, New York, 1981, pp. 199-200.

BW=1.09:1

Dipole Above a Ground Plane

Fat Dipole

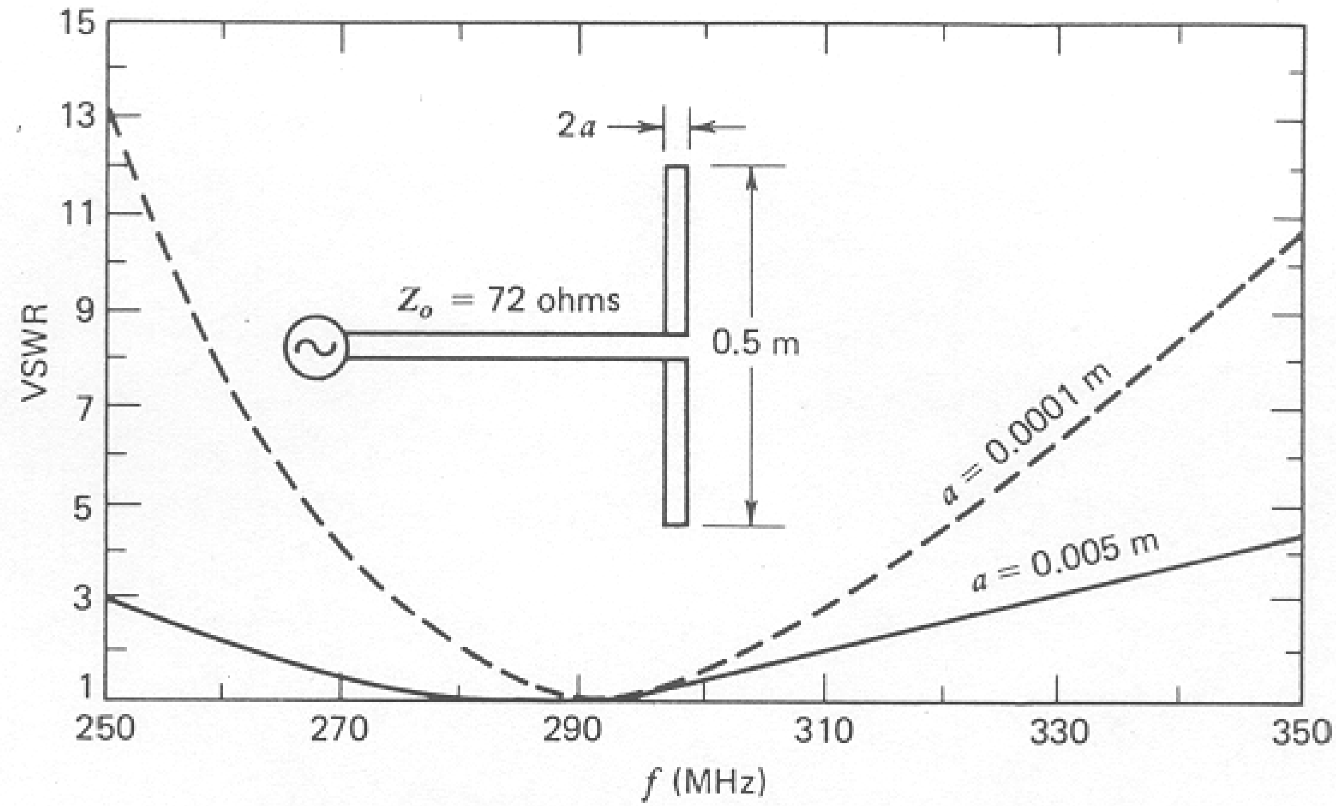


Figure 5-7 Calculated VSWR as a function of frequency for dipoles of different wire diameters.

BW= 1.18:1

Stutzman, W. and G. Thiele, Antenna Theory and Design, Wiley, New York, 1981, p. 203.

Dipole Above a Ground Plane

Sleeve Dipole

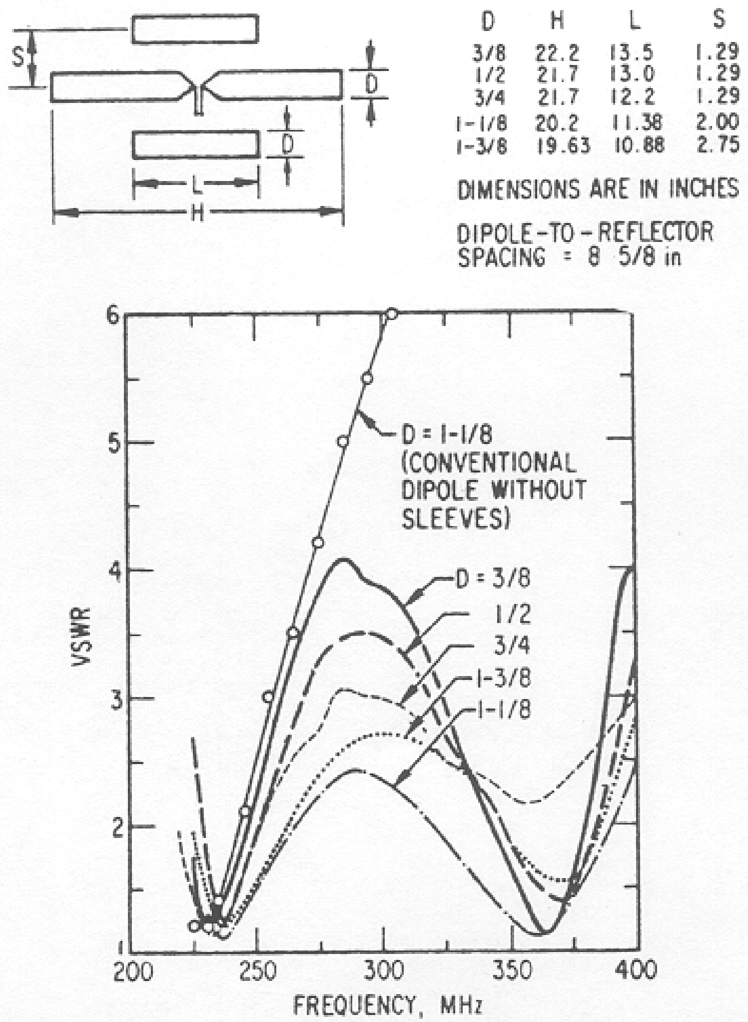


FIG. 4-23 VSWR response of open-sleeve dipoles for various dipole and sleeve diameters.

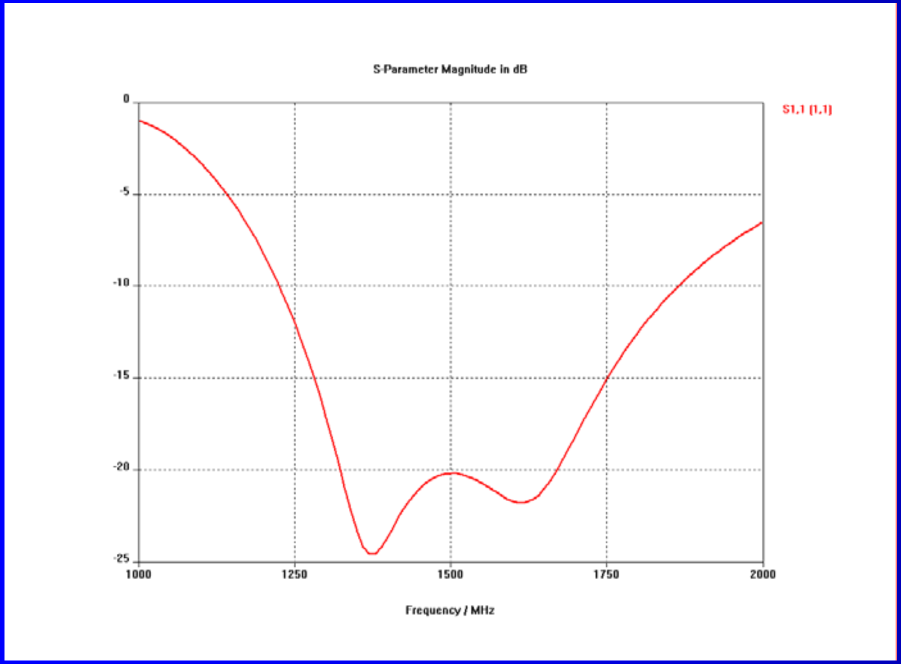
Johnson, R. C. Antenna Engineering Handbook,, 3rd ed., McGraw-Hill, New York, 1993, p. (4-21).

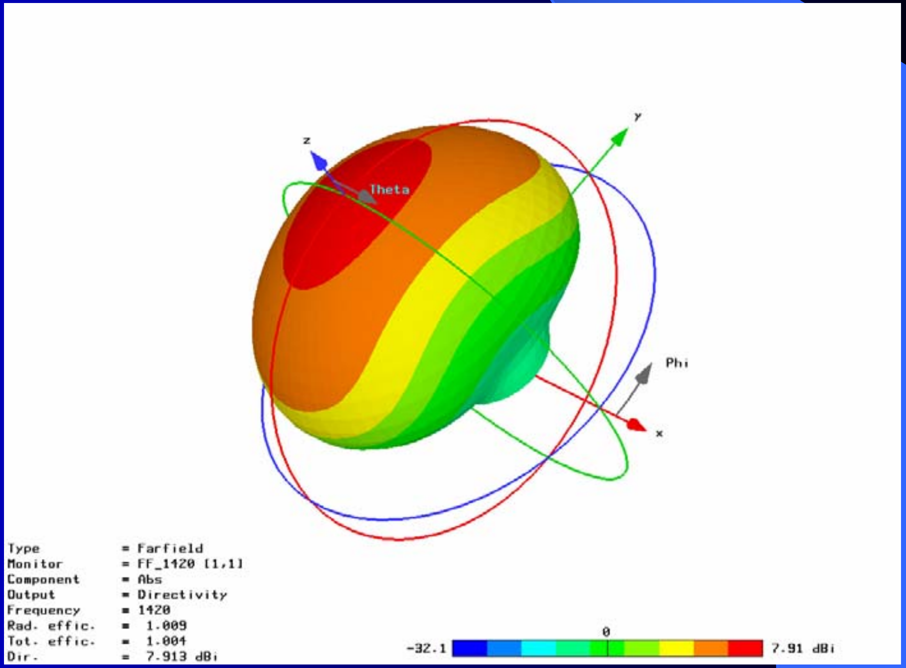
BW= 1.67:1

Dipole Above a Ground Plane

Folded, Fat Dipole

BW= 1.53:1





Dipole Above a Ground Plane

Short Backfire Antenna

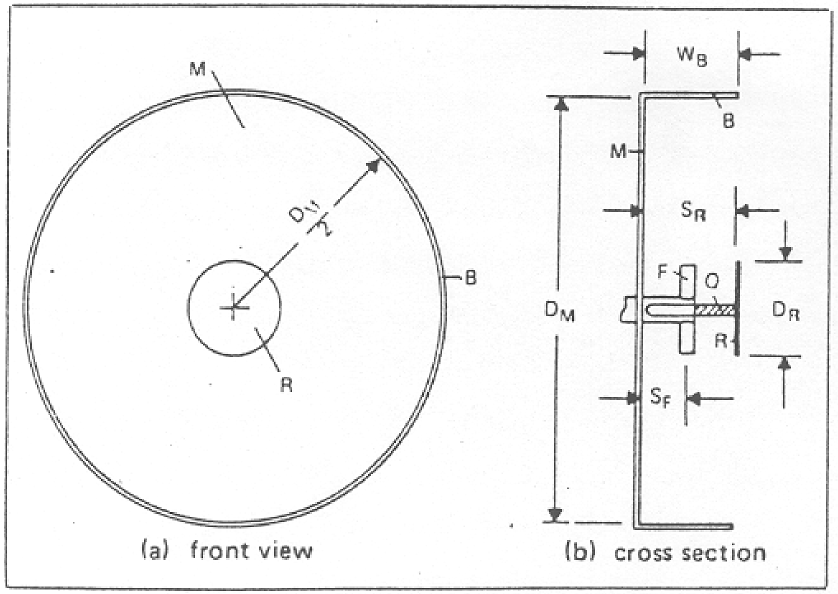


Fig. 1 3 GHz model of SBF antenna.

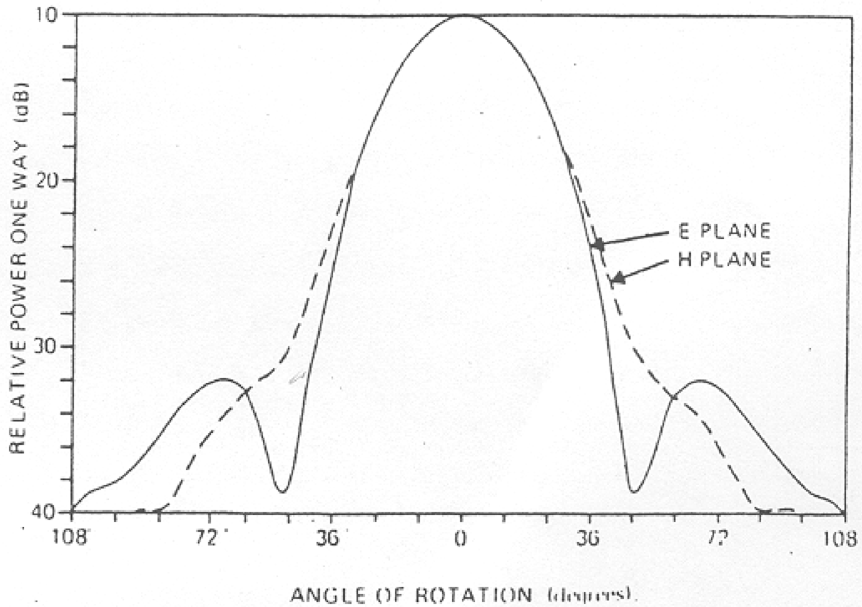


Fig. 2 Radiation patterns of 3 GHz SBF antenna.

Ehrenspeck, H.W. "The Short Backfire Antenna," ***Proc. of the IEEE*****, v. 53, Aug. 1965, pp.1138-1140.**

Srikanth, S. and G. Behrens, "A New Short Backfore Antenna as a Prome Focus Feed for the GBT", GBT Memo. #187, May 13, 1998.

BW= 1.35:1

Dipole Above a Ground Plane

Disadvantages for FASR:

- Bulky
- Narrow bandwidth
- Large spillover

Frequency Independent Antennas

Provided the antenna is made of practically perfect conductors and dielectrics, the impedance, polarization, pattern, etc. are <u>invariant to a change in scale</u> that is in proportion to the change in wavelength.

If the shape of the antenna is determined <u>entirely by angles</u> (invariant to scale), the performance would have to be independent of frequency.

<u>Truncation</u> of the shape from that of infinite extent should also give good performance (current should decrease with distance from the terminals).

$$\text{Self - Complementary Design} \Rightarrow \quad Z_{AIR} = Z_{METAL} = \frac{\eta}{2} = 188.5\,\Omega$$

Operational bandwidth:

- **lowest frequency limited by the maximum dimension**
- **upper frequency limited by the input terminal region**
- **bandwidths can be 10:1 or greater.**

Frequency Independent Antennas

Log Periodic

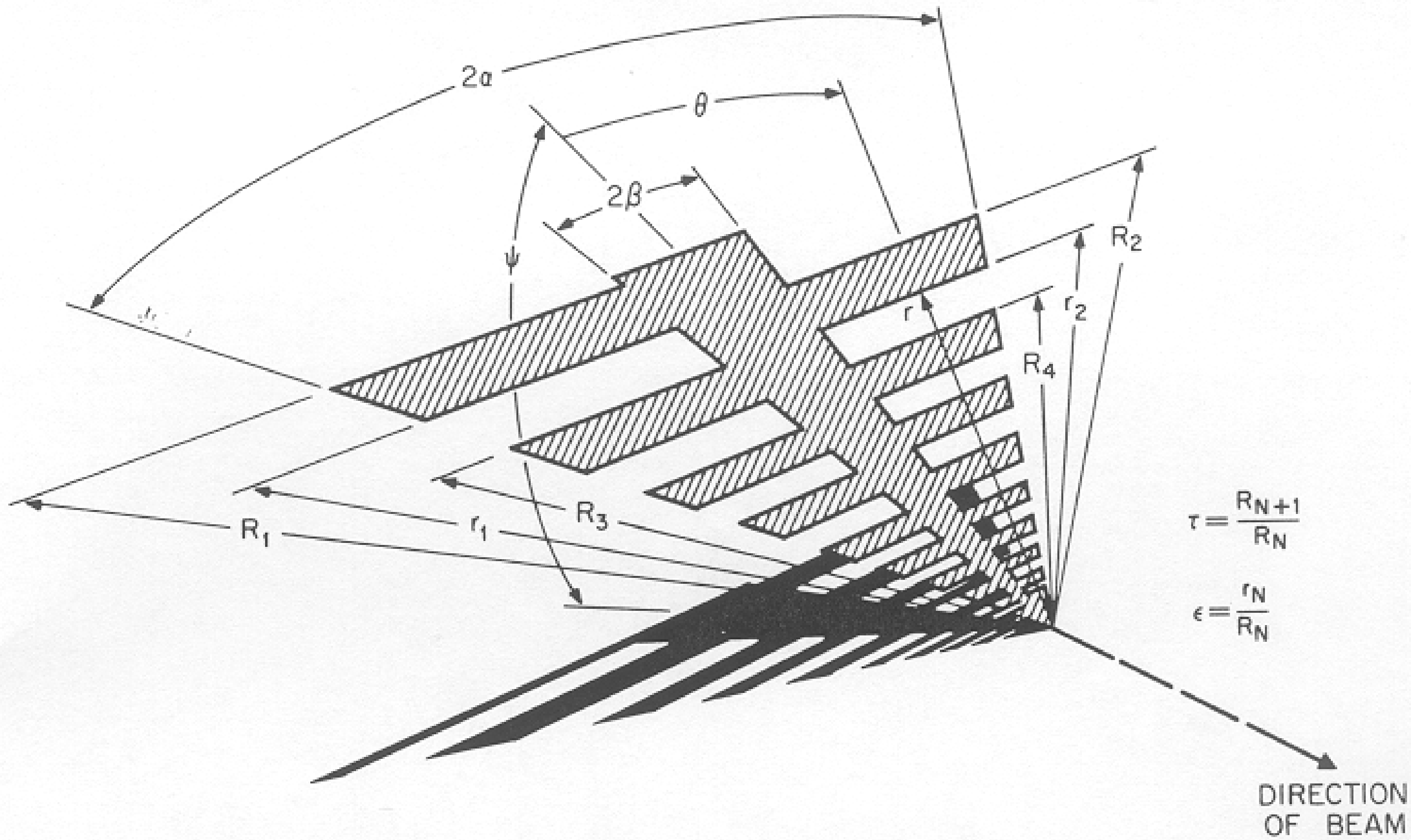
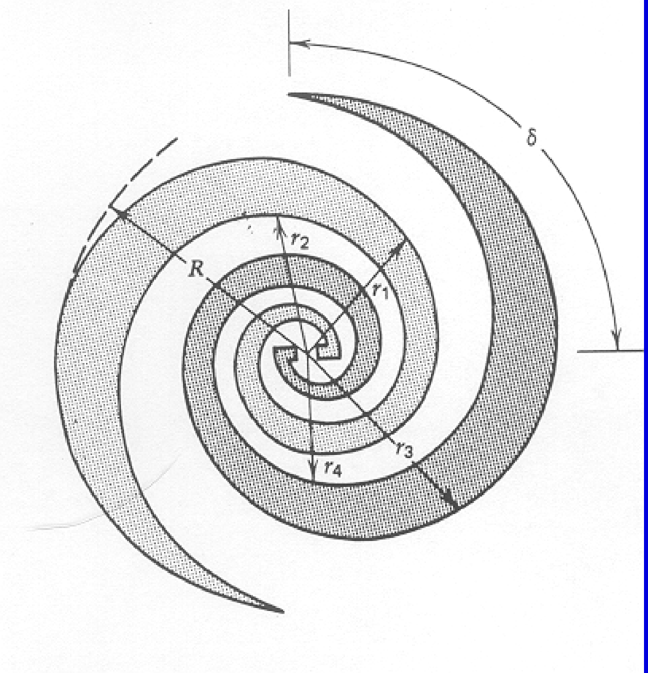


FIG. 14-30 Trapezoidal-tooth log-periodic antenna. *(© 1958, IEEE.)*

Johnson, R. C. Antenna Engineering Handbook,, 3rd ed., McGraw-Hill, New York, 1993, p. (14-30).

Frequency Independent Antennas

Spirals



Stutzman, W. and G. Thiele, Antenna Theory and Design, Wiley, New York, 1981, p. 284.

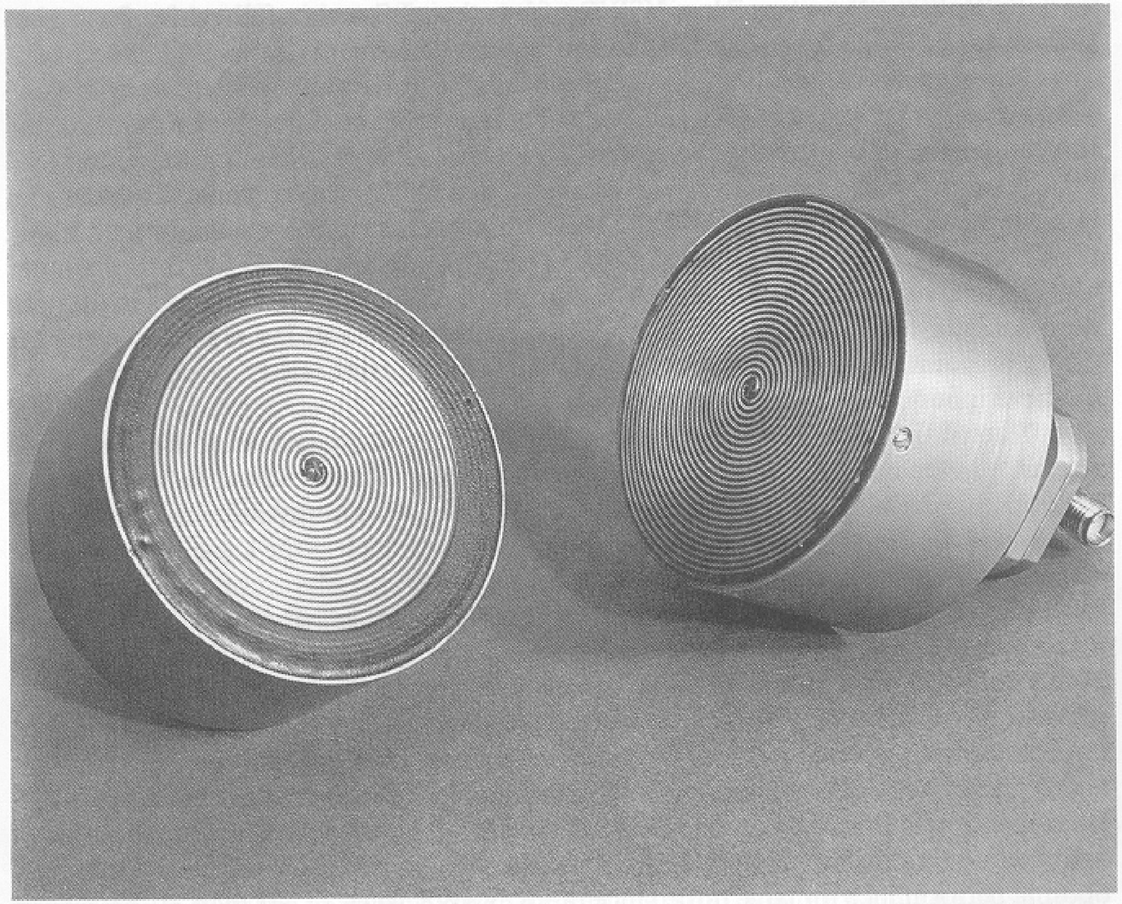


FIG. 14-22 Two 2-in-diameter complementary archimedean spirals terminated with absorber paint and a 100-Ω resistor; arm width $W = 0.022$ in. *(Courtesy Loral Randtron Systems.)*

Johnson, R. C. Antenna Engineering Handbook,, 3rd ed., McGraw-Hill, New York, 1993, p. (14-25).

Frequency Independent Antennas

Absorber Loaded Cavity

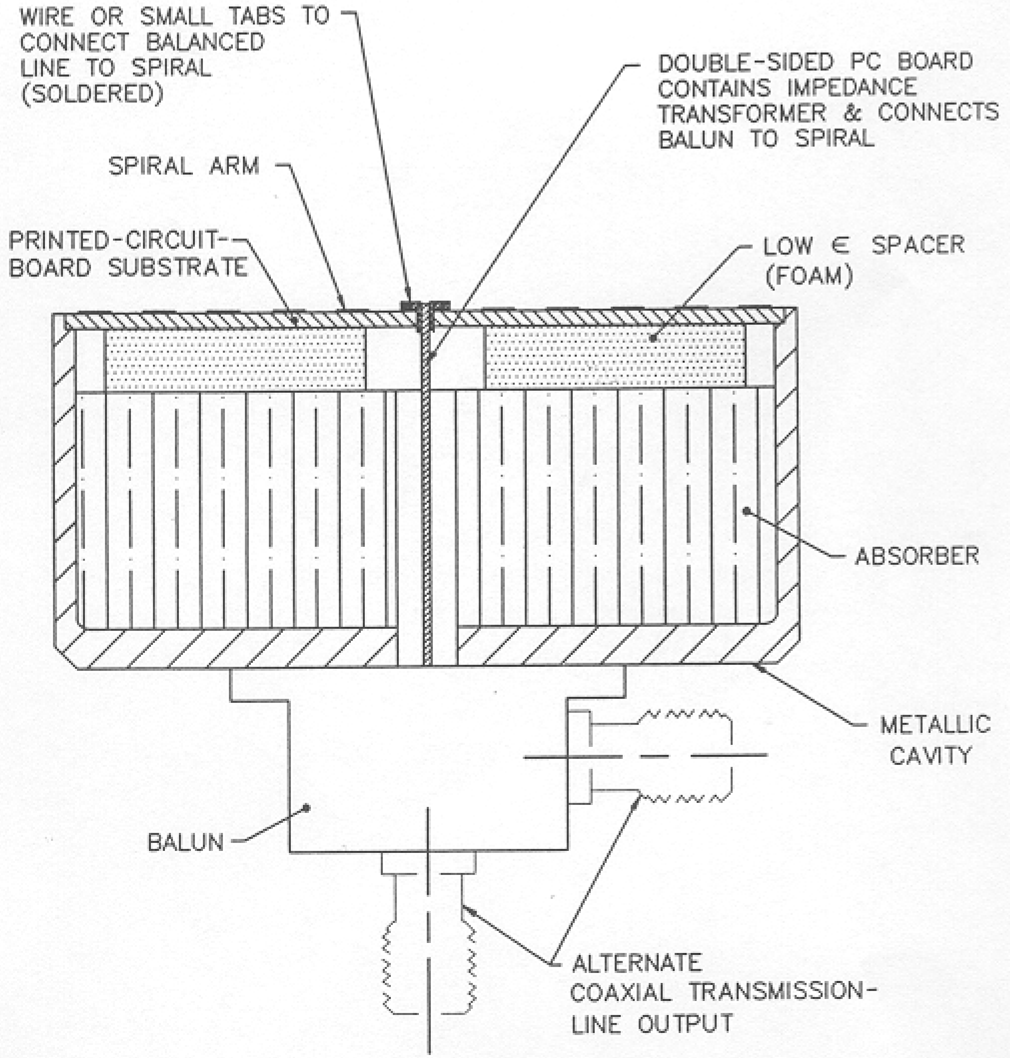


FIG. 14-14 Absorber-loaded cavity-backed two-arm archimedean-spiral antenna.

Johnson, R. C. Antenna Engineering Handbook,, 3rd ed., McGraw-Hill, New York, 1993, p. (14-18).

Frequency Independent Antennas

Conical Log-Spiral

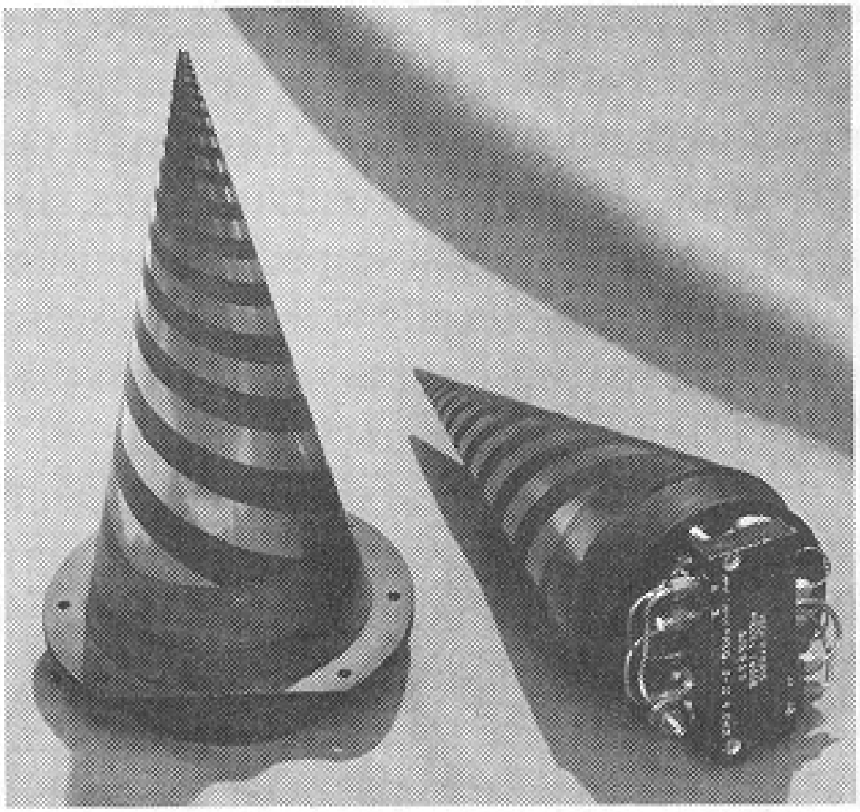


FIG. 14-29 Four-arm conical log-spirals excited in mode 2 for circularly polarized omnidirectional pattern, 2 to 12 GHz. *(Courtesy of GTE Sylvania Systems Group.)*

Johnson, R. C. <u>Antenna Engineering Handbook,</u>, 3rd ed., McGraw-Hill, New York, 1993, p. (14-33).

Frequency Independent Antennas

Sinuous

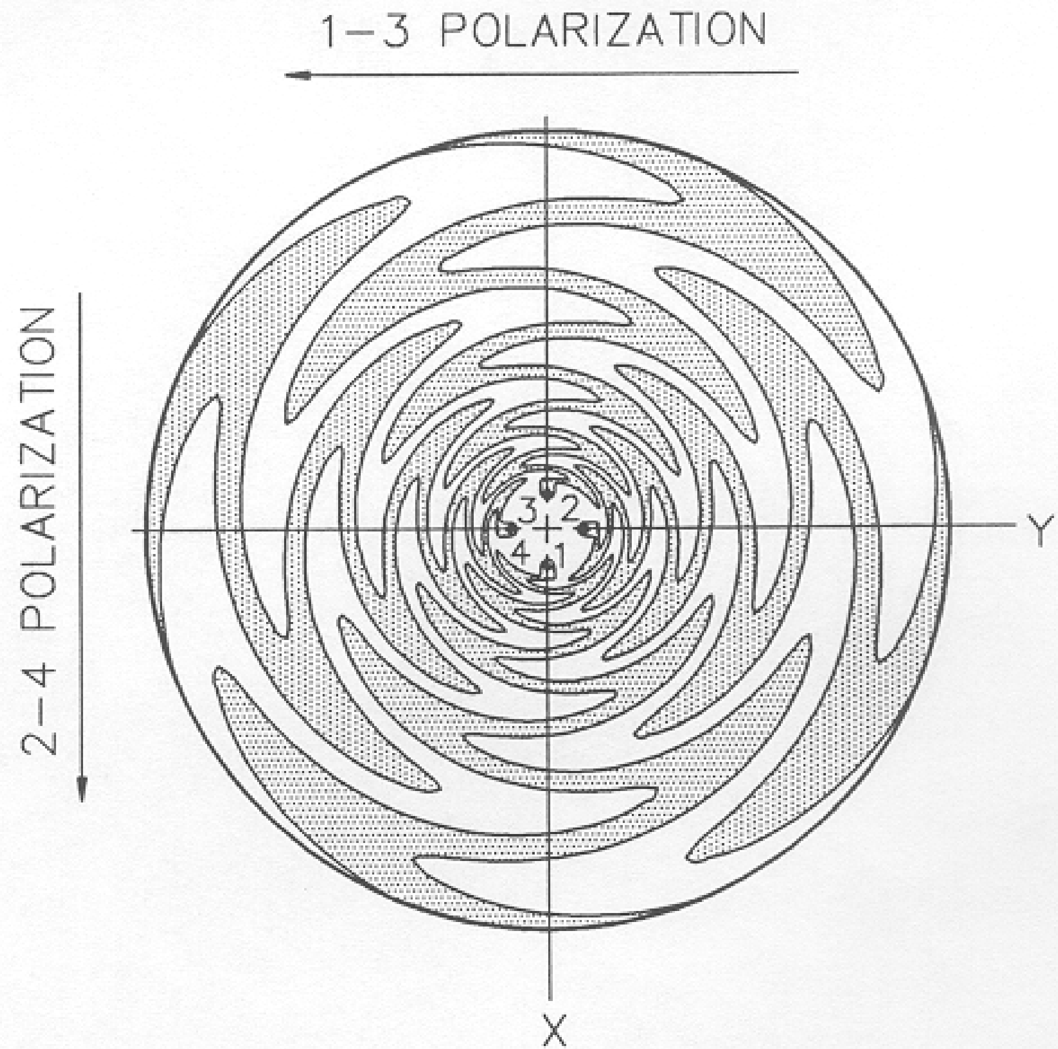


FIG. 14-52 Four-arm sinuous aperture.

Johnson, R. C. Antenna Engineering Handbook,, 3rd ed., McGraw-Hill, New York, 1993, p. (14-56).

Frequency Independent Antennas

Sinuous

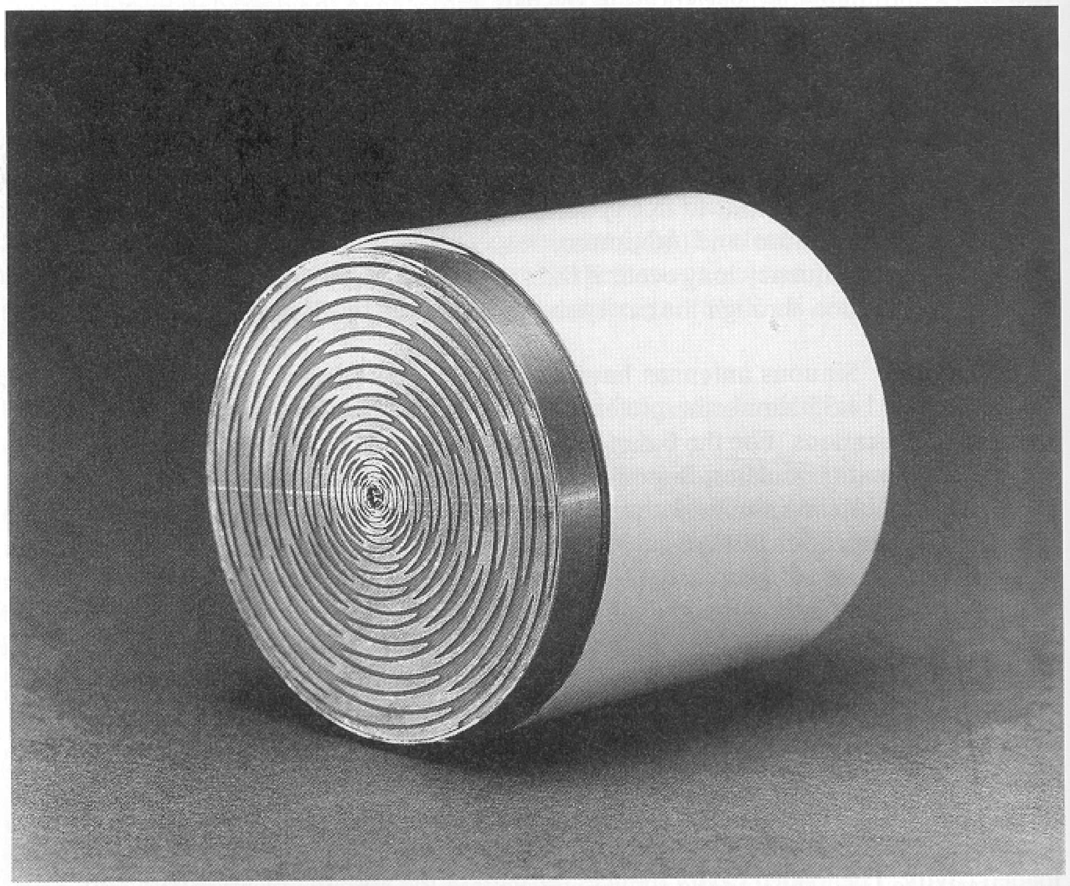


FIG. 14-54 A 2-in-diameter sinuous antenna, $\tau = 0.75$, $\alpha = 45°$, and $\delta = 22.5°$. *(Courtesy Loral Randtron Systems.)*

Johnson, R. C. Antenna Engineering Handbook,, 3rd ed., McGraw-Hill, New York, 1993, p. (14-60).

Frequency Independent Antennas

Sinuous

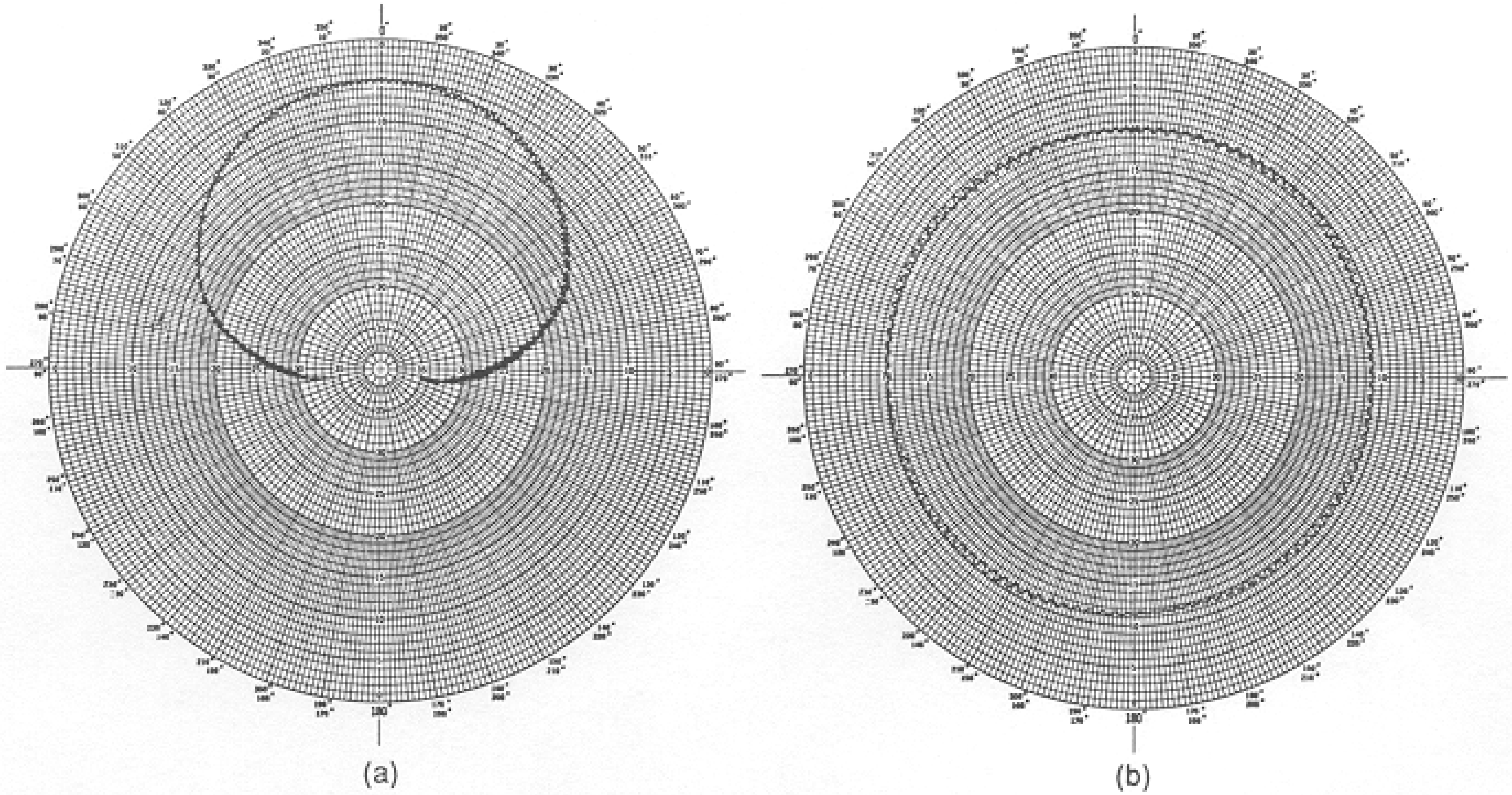


FIG. 14-55 (*a*) Principal-plane pattern of a 2-in-diameter sinuous antenna at 10 GHz. (*b*) 60° conical-cut pattern of a 2-in-diameter sinuous antenna at 10 GHz.

Johnson, R. C. Antenna Engineering Handbook,, 3rd ed., McGraw-Hill, New York, 1993, p. (14-61).

Frequency Independent Antennas

Sinuous Antenna on a Cone

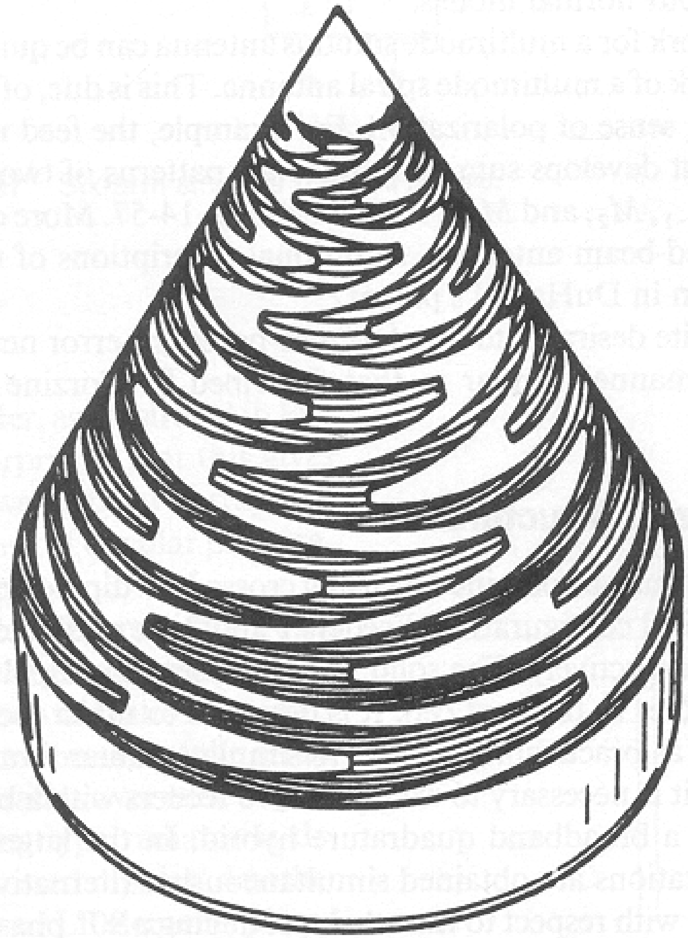


FIG. 14-56 Six-arm conical sinuous antenna.

Johnson, R. C. Antenna Engineering Handbook,, 3rd ed., McGraw-Hill, New York, 1993, p. (14-61).

Frequency Independent Antennas

Disadvantages for FASR:

- **Integration of feed, LNA and balun**
- **Could be lossy (affect G/T)**
- **Dual-polarization**
- **Gain varies with frequency for fixed position conical**

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Conclusions

For FASR:

- <u>Frequency independent antennas</u> are the only practical option to cover FASR frequency range.
- Use a cavity backed structure for wide instantaneous bandwidth.
- Accept gain reduction associated with fixed position cone.
- Consider <u>sinuous</u> version of frequency independent structures.
- Integration of feed terminals with LNAs and balun.
- Prototyping highly recommended!

FASR FREQUENCY-AGILE SOLAR RADIOTELESCOPE