Broad Bandwidth Feeds for Reflector Antennas

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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
Gain of Reflector Antennas

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

\[ \eta = \eta_I \eta_S \eta_P \eta_X \eta_B \eta_E \]

- \( \eta_I \): Illumination 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)

Common phase center for both planes

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

There is usually a compromise between the illumination and spillover.

If $\eta_1 = 1$, then $\eta_S$ is too low for a realizable feed. This results in increased sidelobes.

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 \( r = r_1 \)

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

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

Hybrid-Mode Feed – Corrugated Waveguide

\[ X = 0 \]
\[ Y = \tan \left( m \frac{\pi}{2} \frac{\Delta f}{f_0} \right) = 0 \quad \text{when} \quad m \text{ is an odd integer.} \]

Co-polar bandwidth

Position of the phase center and generation of higher order modes

Impedance matching to the waveguide and mode conversion level

Pattern symmetry and cross-polar characteristics

Hybrid-Mode Feed – Corrugated Waveguide

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)

Knop, Cheng, and Ostertag (1986)

Demonstrated nearly balanced HE\textsubscript{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.

Hybrid-Mode Feed – Surface-Wave Antenna

Dielectric Waveguide (rod)

If $kr_i >> 1$ and if the refractive index differs by only a small amount, $\Delta n$, from unity, then

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

Thus,

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

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

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

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

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

BW = 4:1


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.
Dipole Above a Ground Plane

Conventional half-wave dipole

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

Figure 5-5 Calculated input resistance of a center-fed wire dipole of 0.0005\( \lambda \) 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).


\( BW=1.09:1 \)
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
Dipole Above a Ground Plane

Sleeve Dipole


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.


BW= 1.35:1
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 invariant to a change in scale that is in proportion to the change in wavelength.

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

Truncation 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

Frequency Independent Antennas

Spirals


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.*)
Absorber Loaded Cavity

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

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.)

Frequency Independent Antennas

Sinuous


FIG. 14-52 Four-arm sinuous aperture.
Frequency Independent Antennas

Sinuous

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

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.

Frequency Independent Antennas

Sinuous Antenna on a Cone

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
Conclusions

For FASR:

- **Frequency independent antennas** 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 **sinuous** version of frequency independent structures.
- Integration of feed terminals with LNAs and balun.
- Prototyping highly recommended!