RADIO TELESCOPES and MEASUREMENTS at RADIO WAVELENGTHS

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**RADIO TELESCOPES**

Distinguishing Features:
1. Collect only a single mode of the electromagnetic field
2. Angular resolution limited by diffraction
3. Coherent devices used for detection, so are sensitive to phase of the incident signal

Note: Distinguishing feature #3 becomes blurred at submillimeter wavelengths where incoherent detectors which directly measure incident power (e.g., bolometers) are used.

**Analysis:**

This is an electromagnetic field problem

Components are:
- Antenna
- Feed System
- Receiver

Normal radio astronomy operation is in the "receive" mode

**Analysis using The RECIPROCITY THEOREM**

The relative sensitivity of the antenna + feed to signals coming from different directions is the same as the relative angular distribution of power radiated if you replace the receiver by a transmitter.

We carry out analysis in "transmit mode" in which power from feed system illuminates the antenna, which in turn radiates into different directions.

**The MODES of the electromagnetic field**

- are the configurations of E and H which satisfy Maxwell’s equation
- depend on geometry of conductors and dielectrics
- An object with dimensions >> λ has many spatial modes
- As its dimensions are reduced → λ, you get finite set of modes. You can arrange a situation where only ONE mode can propagate =>

**SINGLE MODE SYSTEM**
NOTE ON POLARIZATION:

- Single mode system has only one well-defined polarization state.
- In some cases may be "standard", e.g. linearly polarized.
- Desired polarization can be achieved by combining signals from 2 single mode transmission lines with appropriate amplitude and phase.

THE FEED SYSTEM

- Couples radiation from the antenna to the receiver.
- Is itself fundamentally an antenna system, but has one input being a single mode transmission line and the other input being free space.
- Radiation pattern of feed horn determines illumination of the antenna.

A TYPICAL FEED SYSTEM

(Think reciprocally here!)

- Takes field configuration in single mode transmission line (waveguide).
- Gradually expands transverse dimensions to the desired aperture size.
- Lets field radiate from aperture to illuminate the main reflector (or whatever antenna is being used).

Key points to remember:

1. Radiation from feed system is itself determined by diffraction from feed.
2. The critical issue is to illuminate the antenna as you wish.
3. Many feeds have radiation pattern which is fairly close to Gaussian form. This is very convenient.

E_{nf}(r) = {\hat{E}}_{nf}(r) \hat{A}(r)

Normalized Gaussian Pattern

f(p) = \frac{\hat{E}(p)}{\hat{A}(p)}

Because of diffraction, the far field pattern will not be uniform (over here).
Different amounts will go in different directions.
Remember reciprocity theorem! If you move a receiver, you will be essentially just posed like as if it moved. But you have a distribution of received radiated power coming from different elements. Even if you move a reflector.
$P(0,0)$ is taken as the direction bounds which give you maximum power or maximum brightness (called boreight direction by radar engineers).

Normalized from Radar to Visibility Relation is that on boreight.

For comparison: 100 dB/10 dB $P_f$.

$P_f$ (dB) = $10 \log_{10} \left[ \frac{P_f}{P_i} \right]$

- $0 \, \text{dB}$
- $-10 \, \text{dB}$
- $-15 \, \text{dB}$
- $-20 \, \text{dB}$

Stable levels typically $-20 \, \text{dB}$

Gaussian illumination

Unlocked aperture

Beam width is not trivial issue, but Gaussian shape is de facto gaussian between points where $P_f = 0.5$

$\Delta \Theta_p = 4^\circ$ for example.
RECEIVING DISCUSSION OF POISSON TRANSFORM RELATIONSHIP IS GENERATION.

FOR CIRCULAR UNIFORMLY ILLUMINATED ANTENNA WITH GAUSSIAN ILLUMINATION HAVING EDGE TAPER \( T_e (48) \)

\[ \Delta \text{Effect} = \frac{[1.02 + 0.0135 \, T_e (48)] \lambda}{D} \]

MAX STRONG PEL TO MAIN JEEP MAX

\[ \text{Effective Area} = \frac{A}{A_{\text{Circular}}} \]

\[ h = \frac{20 \, \text{d} \, \text{MHz}}{\lambda} \]

\[ E_{\text{eff}} = \frac{A_{\text{eff}}}{A_{\text{Circular}}} \]

Sphere/Planar Efficiency

\[ E_{\text{eff}} = \frac{A_{\text{eff}}}{A_{\text{Circular}}} \]

\[ \text{Planar Efficiency} \]

\[ E_{\text{eff}} = \frac{\lambda}{A} \]

\[ \text{Gaussian Illumination} \]

\[ \text{Aperture Efficiency} \]

\[ E_{\text{eff}} = \frac{1 - e^{-2 \lambda}}{1 - e^{-2 \lambda}} \]

\[ E_{\text{eff}} = \frac{\lambda}{A} \]

\[ \text{Gaussian Illumination} \]

\[ \text{Aperture Efficiency} \]

\[ E_{\text{eff}} = \frac{1 - e^{-2 \lambda}}{1 - e^{-2 \lambda}} \]
**Antennas and Extended Sources**

*Antenna Temperature* is defined as the power radiated by the antenna divided by the antenna's area.

\[ T_A = \frac{P_{rad}}{A} \]

Where \( P_{rad} \) is the radiated power and \( A \) is the antenna's area.

*Antenna Solid Angle* is used to express power radiated by an antenna having any kind of source.

\[ \Omega = \frac{P}{\lambda^2} \]

Where \( P \) is the radiated power and \( \lambda \) is the wavelength.

**Theorem:** For any single mode radiating system,

\[ \Omega = \lambda^2 \]

This is because if we have a given source, the radiation in a sphere of radius \( \lambda \) will uniformly radiate any given direction, making its effective area \( \lambda^2 \).

**In general, sources do not produce a uniform pattern.**

To determine the antenna's efficiency, we can use the following equation:

\[ T_A = \frac{P_{rad}}{P_{in}} \]

Where \( P_{in} \) is the input power and \( P_{rad} \) is the radiated power.

If \( \theta = \omega \cdot \beta \), where \( \omega \) is the main beam, \( \beta \) is called the main beam efficiency,

\[ T_A = \frac{T_{in}}{\beta} \]

This gives the antenna's efficiency, which can be used to determine the input power from the radiated power.
BLOCKAGE - THINK IN TERMS OF DIPOLE TRANSITION OF
APERTURE RAKE FIELD

\[ \varepsilon_F = \mathcal{F}(\varepsilon_{\text{in}}) \]

\[ P_{\text{in}}(\theta, \phi) = |E_{\text{in}}|^2 \]
CONCLUSIONS

While it is obviously important for design engineers to understand antennas and feed systems, it is also important that radio astronomers who want to get the most from their single dish antenna appreciate these issues.

Antennas are phase transformers coupling free space to single mode transmission lines.

You need to think of antennas as diffraction-limited, single mode, single-polarization systems.

The antenna illumination pattern, which is typically close to a Gaussian, determines performance parameters:

These include:
- efficiency
- beam width
- side lobe levels

You should be aware of the insidious effects of spillover, near- and far-sidelobes, and feed system scattering.

All of these affect the interpretation of your data!

A further issue in the short-wavelength portion of any antenna’s operating range is surface errors, which:
- reduce aperture & beam efficiency
- increase sidelobe levels
- broaden the main beam