Designing and testing an ultra-wideband receiver for the Green Bank Telescope

Alyssa Bulatek (Macalester College)

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Overview

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Radio receivers

Characterizing receiver efficiency

Waveguide window

Conclusions and future work

Motivation

Motivation

- NANOGrav times pulsars to find **gravitational waves**
- Pulsar signals subject to **dispersion**
  - Lower frequency light delayed more, arrives after higher frequencies
- Need pulsar TOA measurements at **widely-spaced** frequencies
- Currently requires using multiple receivers at different times, which reduces timing accuracy

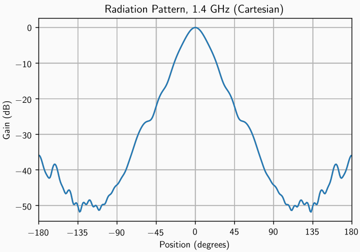
Project Goal

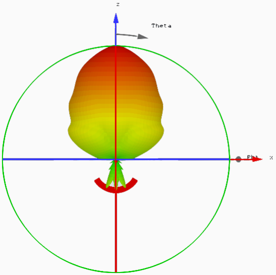
Design and build a receiver to perform wide-band pulsar timing measurements simultaneously, which will improve the sensitivity of pulsar timing observations with the GBT.

Radio receivers

Antennas, Gain, and Electromagnetic Reciprocity (oh my!)

- An antenna is a device which converts EM waves in free space into electric current in a conductor
- Gain as a function of position (3D) is the **far-field radiation pattern**
- Receivers can be treated as transmitters to make our calculations and conceptualizations easier





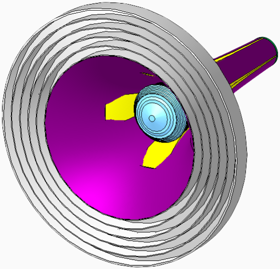
Design and Specifications

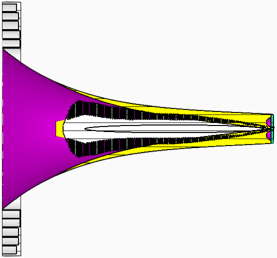
Frequencies: 0.7 – 4.2 GHz

Bandwidth: 3.5 GHz (6:1)

Dimensions: 1.5 m $\times$ 1 m

- **Ridges** lower the lowest receivable frequency
- **Corrugated skirt** reduces spillover at lower frequencies
- **Dielectric spear** reduces under-illumination at higher frequencies





Characterizing receiver efficiency

Receiver Efficiency

- **Feed efficiency** (e_{tot}) is proportion of radiation incident on telescope that gets received by feed
  - Depends on frequency, important to characterize
- Total feed efficiency can be broken up into **subefficiencies**

$$e_{tot} = e_{sp} \cdot e_{ill} \cdot e_{pol} \cdot e_{ph}$$

where

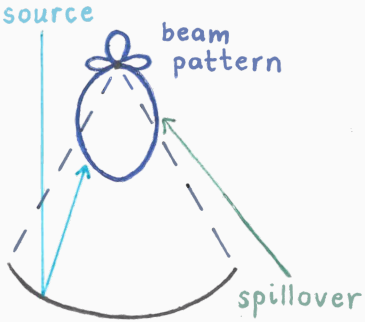
$$e_{sp} = \text{spillover efficiency}$$
$$e_{ill} = \text{illumination efficiency}$$
$$e_{pol} = \text{cross-polarization efficiency}$$
$$e_{ph} = \text{phase efficiency}$$

Design Goal

e_{tot} = **60–70%** at lower ν, **50%** at higher ν.

Spillover Efficiency

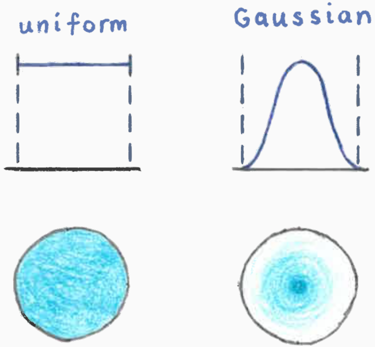
- Receiving, **spillover** is radiation accepted from beyond the edge of the dish
- Transmitting, **spillover** is radiation that “spills over” the edge of the dish



Illumination Efficiency

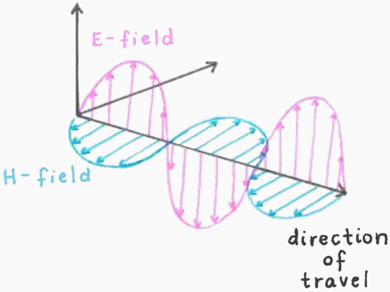
→ **Balance** between spillover and illumination

- Transmitting, the dish is not uniformly illuminated by the antenna (it falls off/tapers towards the edge of the dish)
    - -17 dB is optimum

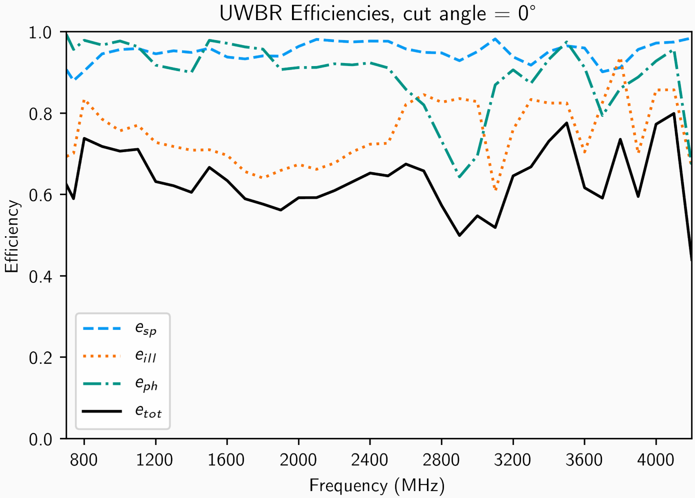


Cross-polarization and Phase Efficiencies

- Transmitting, fields generated by feed interact destructively at aperture



Efficiencies from Model



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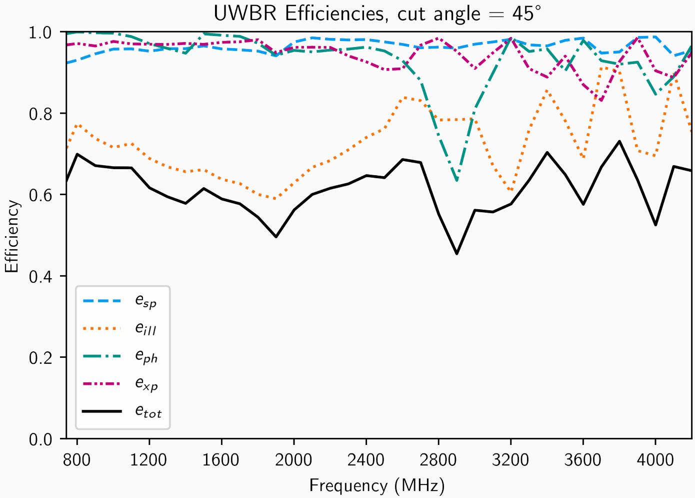

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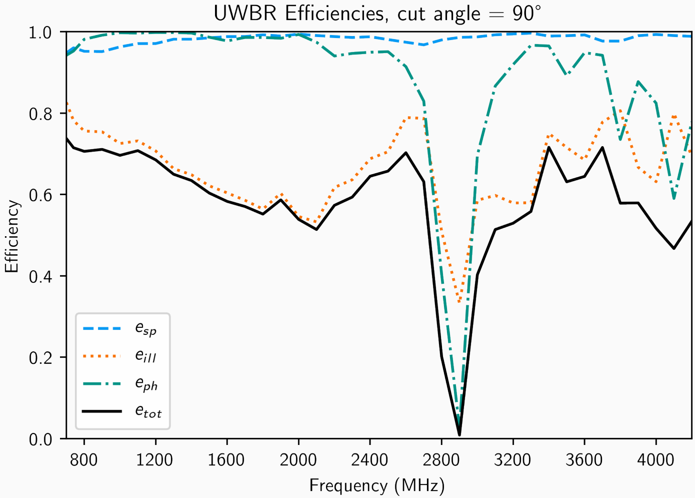
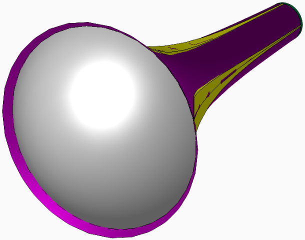
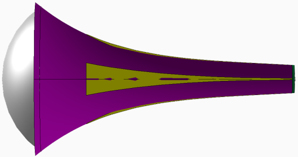


Waveguide window

Waveguide Window

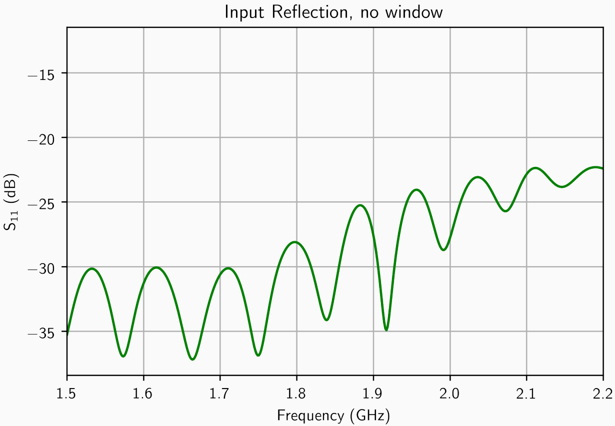
- Receiver will be cooled with He to 15 K
- Radio-transparent window on front of dewar
  - Layers of fused quartz fabric bonded with optical epoxy
  - Vacuum infusion
- Large vacuum force on window (∼20,000 lbs)
  - Window must be curved





Reflections

$$S_{11} = \frac{\text{reflected signal}}{\text{transmitted signal}}$$



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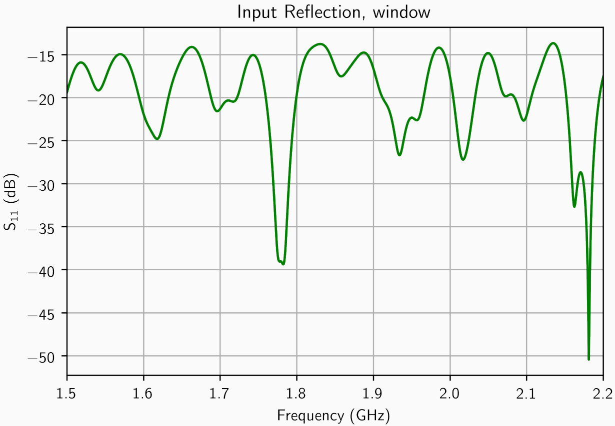

Conclusions and future work

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Conclusions

- UWBR **meets efficiency goals** in its “frozen” design state.
- Window **has minor effect** on circuit properties of feed horn.

Future Work

- Characterizing and building a digital model of differential amplifier (LNAs, notch filters, hybrid combiner)
- Testing loss characteristics of window (also destructive test)
- GBT memo to address varying edge angle of reflector
- Modal-based analysis of radiation patterns (Honors thesis)

Thank you!

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