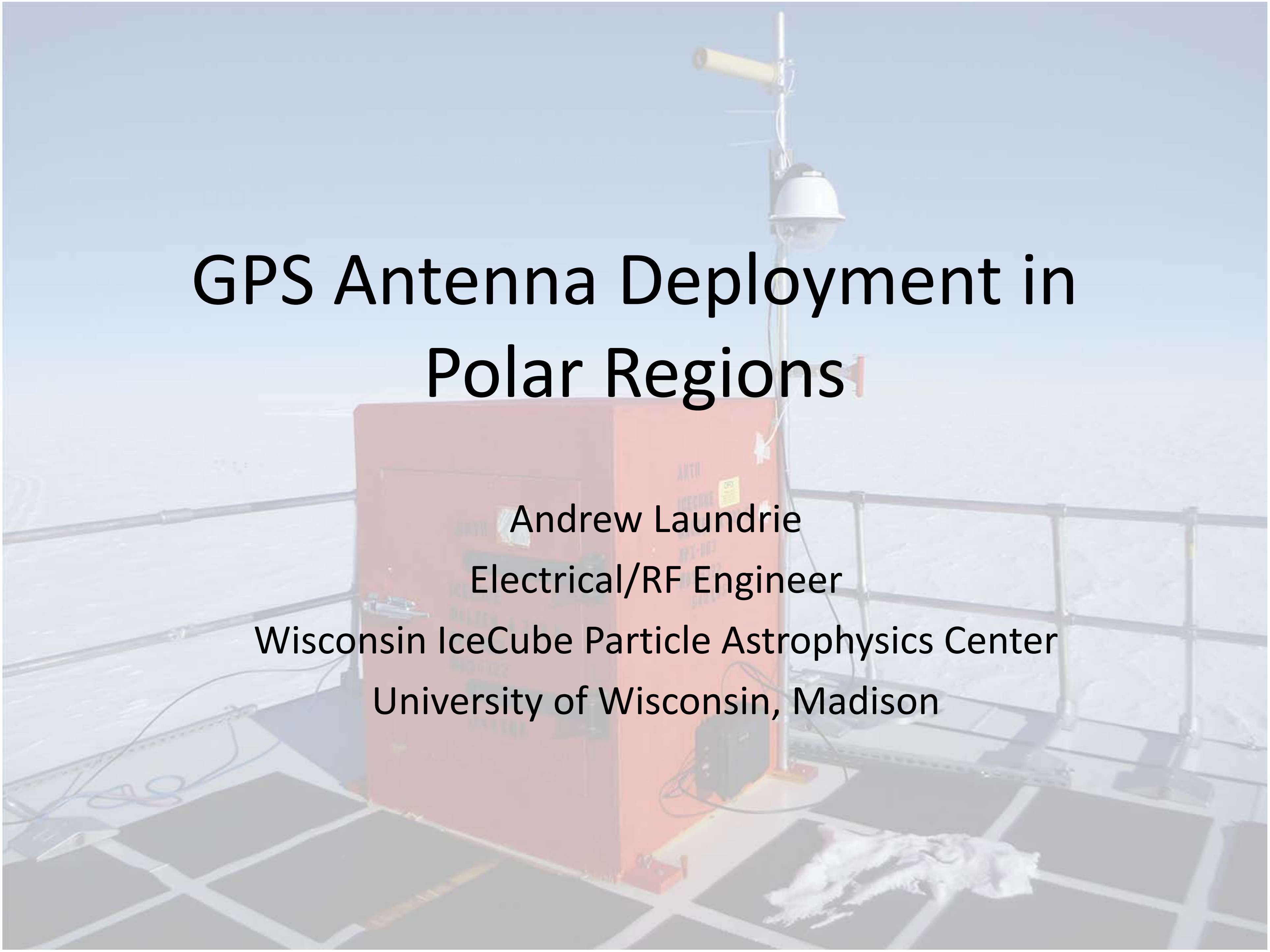

GPS Antenna Deployment in Polar Regions

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Outline

- GPS signal power budget
- Things that reduce received power
- Cohabitation of GPS and other antennas
- Multipath fading
- Cold-temperature performance
- Examples

GPS Power Budget

- RF power is usually specified in units of decibels, or dB, relative to some reference power (most often the milli-Watt --- units are in dBm)
- Power (dBm) = 10*log(Power/1mW)
- A 10:1 power ratio is the same as 10 dB
- 10 dBm is equal to 10 mW
- A 2:1 power ratio is 3 dB
- Attenuation of 1/10 in power is -10 dB

GPS Power Budget

- Transmit power: 45 Watts
- Transmit antenna gain: 12 dBic
- Altitude: 20200 meters
- For a lossless receive antenna having gain of 0 dBi, no obstructions, no multipath fading, and 2 dB atmospheric attenuation, received signal power is -126 dBm
- Power required for fast GPS acquisition is -135 dBm; for slow acquisition it may be -147 dBm (receiver-dependent)

GPS Power Budget

- Free-path gain margin for fast acquisition is somewhere around 10 dB
- You can lose 10 dB, or 90 percent of the available power, and still operate OK
- RX antenna gain will improve the gain margin
- RX Amplifier gain only helps you overcome cable losses, it does not improve the gain margin because thermal noise is also amplified.

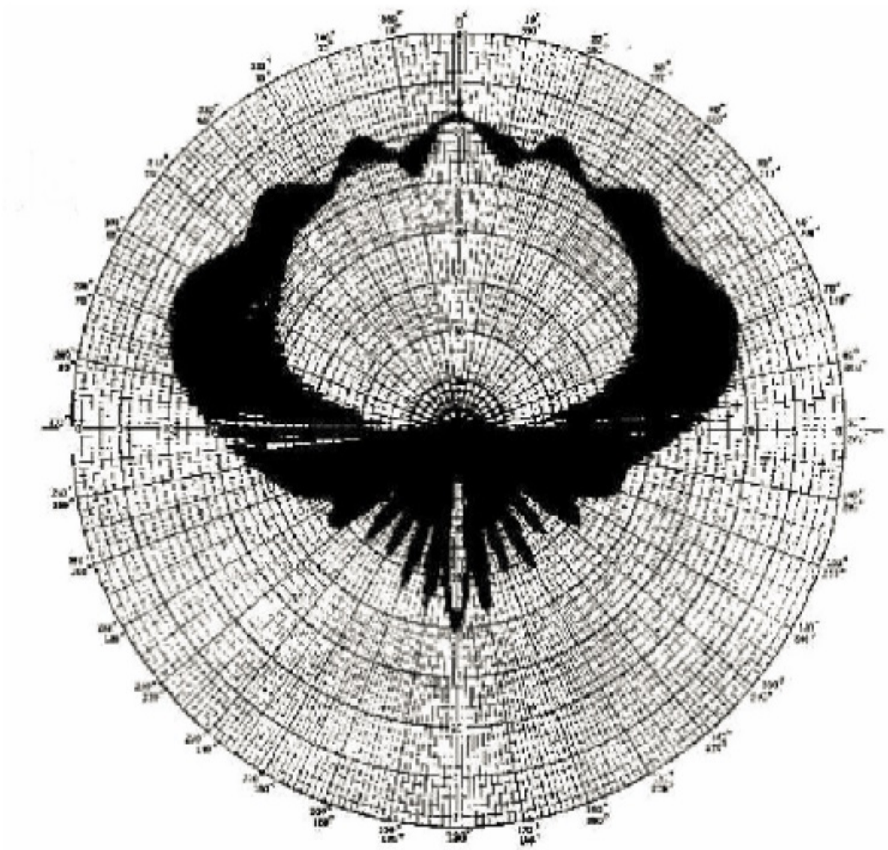
Things that reduce gain margin

- Low satellite elevation (polar regions)
- Antenna noise
- Polarization loss (deviations from RCP)
- Obstacles in the transmission path
- Detuning of the antenna
- Nearby transmitters (Iridium, etc)
- Multipath fading

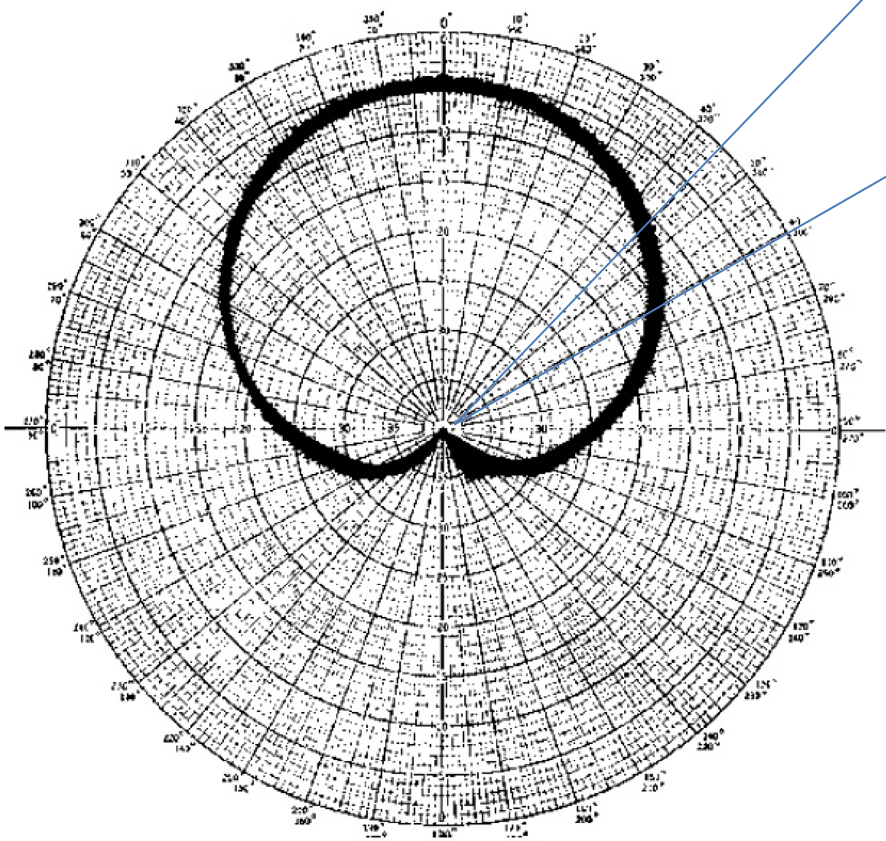
Low satellite elevation

- At the poles, maximum satellite elevation is about 45 degrees above the horizon
- Range of usable elevations: 30 to 45 degrees
- Loss of antenna gain in satellite antenna ~2 dB
- Potential loss of gain in receive antenna ~3 dB
- Conclusion: Geography alone reduces the gain margin to just 5 dB for typical hardware
- → Not a lot of room for more signal loss!

Transmitter antenna gain may be 2 dB low at some angles



Receiver antenna loss at low elevation: about -3 dB relative to zenith



Usable elevations at poles about 30 to 45 degrees

Receive antenna probably attenuating too much at elevations under 30 deg. (for most standard antennas and receivers)

Still have 5 dB of gain margin?

- Antenna noise will reduce the gain margin further, typically by 2 dB
- The Noise Figure indicates how much noise is added by the antenna element, input filters, and the early amplifier stages
- A noise figure under 1 dB could mean there isn’t much filtering before the first amplifier
- Poor filtering before the first amplifier may result in saturation and severe distortion caused by nearby transmitters (Iridium, wifi, Zigbee, etc)

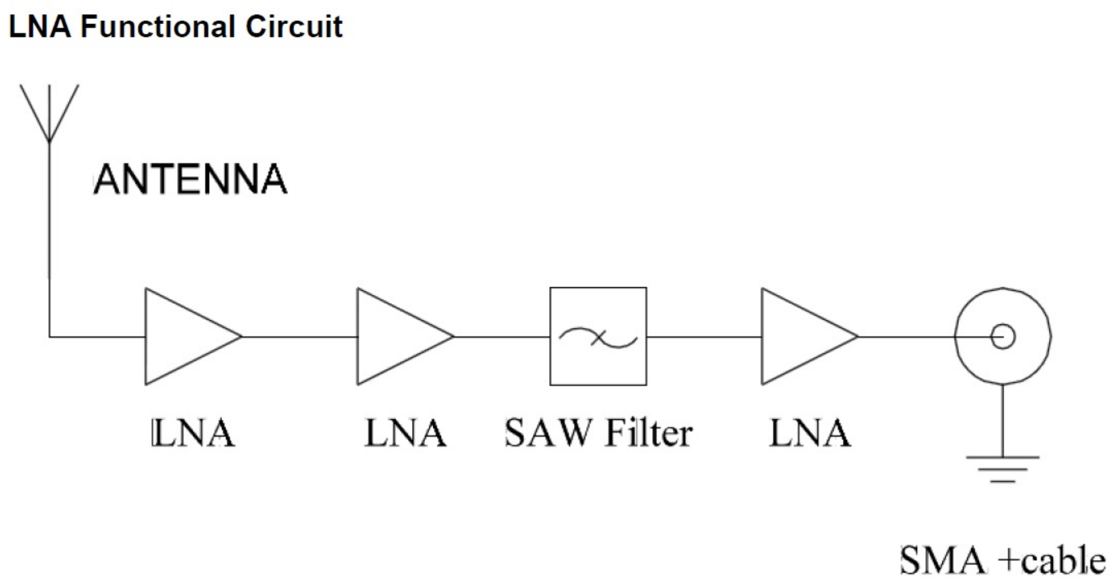
Still have 3 dB of gain margin?

- Mismatched polarization between transmit and receive antennas could cause 3 dB additional loss, but probably it’s not more than 2 dB
- This leaves just 1 dB of margin before some satellites may become more difficult to acquire and track
- Higher-quality antennas and receivers may provide more wiggle room for things like buried antennas, enclosed antennas, or cluttered environments

Antenna selection criteria

- Most GPS receivers have noise figures of 10 dB or worse, relying on active antennas or in-line amplifiers to provide clean and strong signals to overcome the excess receiver noise
- That much signal gain, plus a few more dB, is needed between the antenna element and the receiver. More is needed to overcome losses over long cables.
- An active antenna with amplifier gain of 20 dB or more is usually adequate for a cable lengths of several meters. “Total” antenna gain is often around 30 dB, which includes the antenna element’s gain.

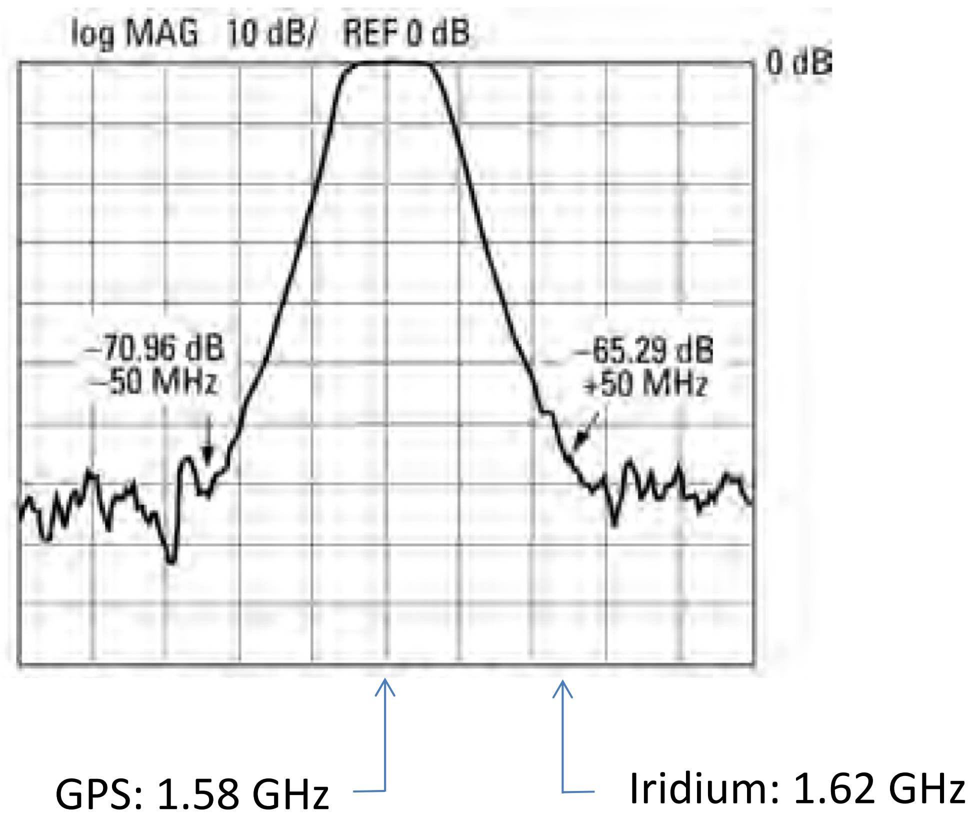
Antenna selection criteria (other considerations)



This block diagram is for a typical antenna having a noise figure of 1.5 dB

The lack of good input filtering could be a problem if a transmitter is near!

Antenna selection criteria



This late-stage SAW filter response may be adequate to suppress low-power interference from an Iridium satellite, but it will may not prevent amplifier saturation if an Iridium antenna is nearby.

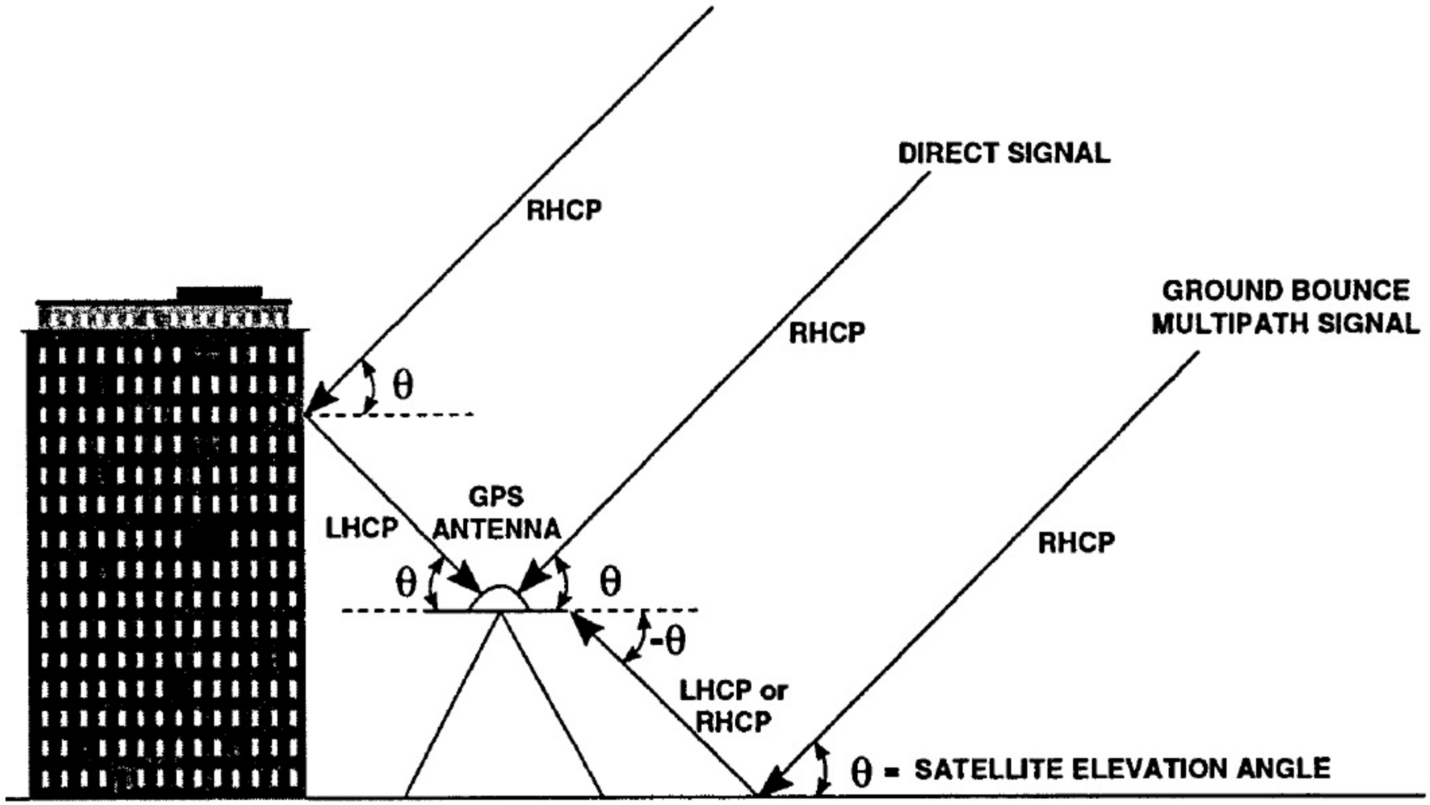
GPS / Iridium Cohabitation

- Cohabitation of GPS and Iridium antennas requires either very good antennas (with choke rings to reduce coupling between antennas), or antennas with adequate out-of-band filtering before the first amplifier
- Saturation of the first low-noise amplifier caused by strong interference may generate *intermodulation* products; the interference "spills over" from one band into the other
- Subsequent filtering will not remove intermods

GPS / Iridium Cohabitation

- An RF system analysis that would predict performance is complex, and it requires lots of antenna specifications that must be measured by end-users in most cases
- It's usually more practical to test system performance in the desired configuration, and take measures to correct problems based on knowledge of potential issues

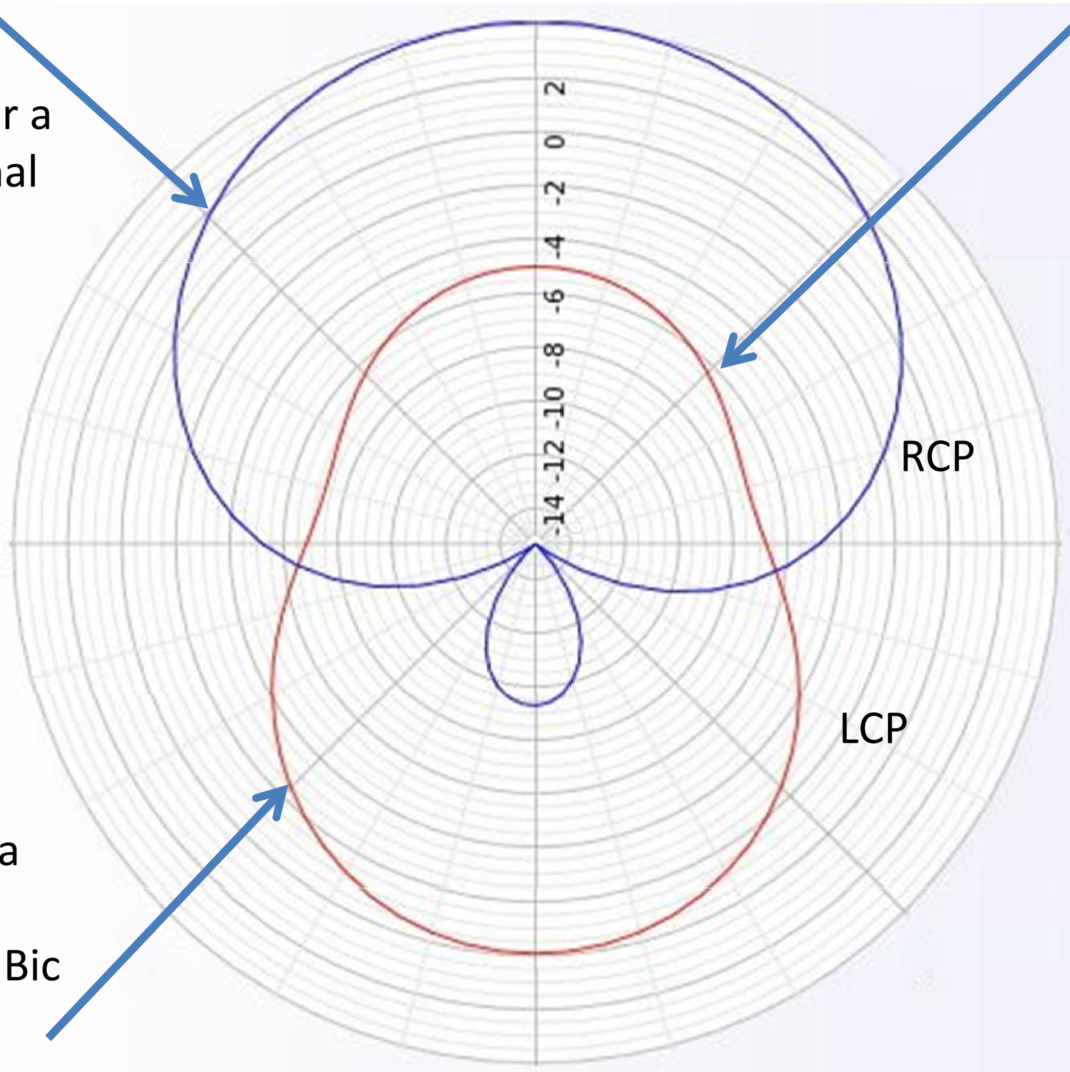
Multipath fading



Suppression of cross-polarized multi-path from above is usually very good.
The cross-pol response from below (ground bounces) may not be so great.

Choke-ring antennas suppress multipath signals by disrupting lateral waves from sides

Low-cost GPS antenna with no choke ring:



Antenna gain for a direct RCP signal is +2 dBic

Antenna gain for a wall-bounced LCP signal is -6 dBic

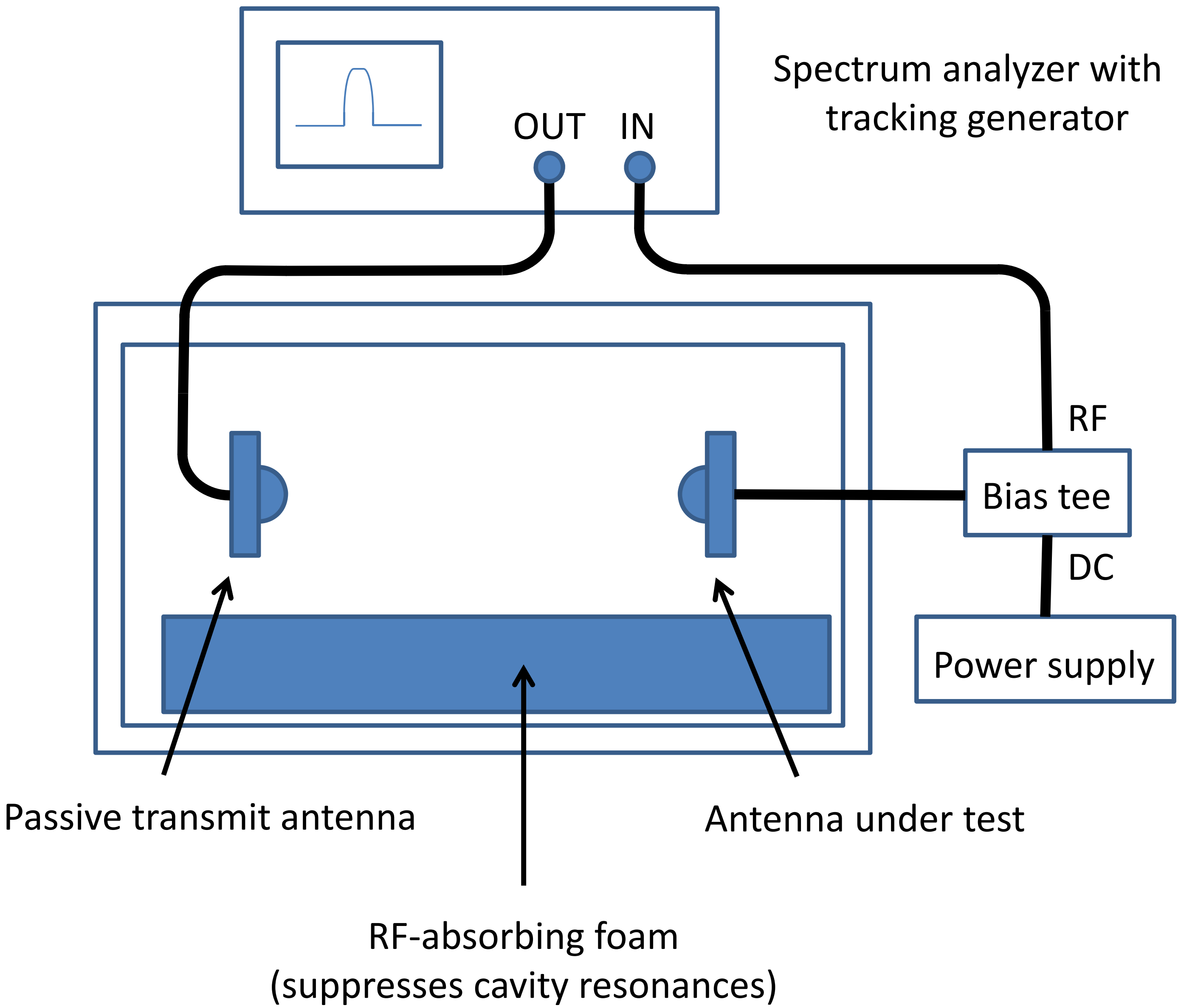
Antenna gain for a ground-bounced LCP signal is -2 dBic

Multipath fading

- Multipath signals can add constructively or destructively, depending on the relative phase of the two signals
- Adjusting the height of the antenna can reduce the depth of fading from ground bounces by eliminating cases where the signals are nearly 180 degrees out of phase
- The best height will depend on the antenna, and must be determined experimentally

Thermal issues

- Most modern GPS antennas use temperature-compensated materials
- A typical patch antenna shows no discernable change in performance when cooled from room temperature to -50C
- Amplifiers and filters may drift when cooled to extreme temperatures
- Antennas can be tested in a chest freezer to check for major changes in performance


Spectrum analyzer with tracking generator
OUT
IN
RF
Bias tee
DC
Power supply
Passive transmit antenna
Antenna under test
RF-absorbing foam
(suppresses cavity resonances)

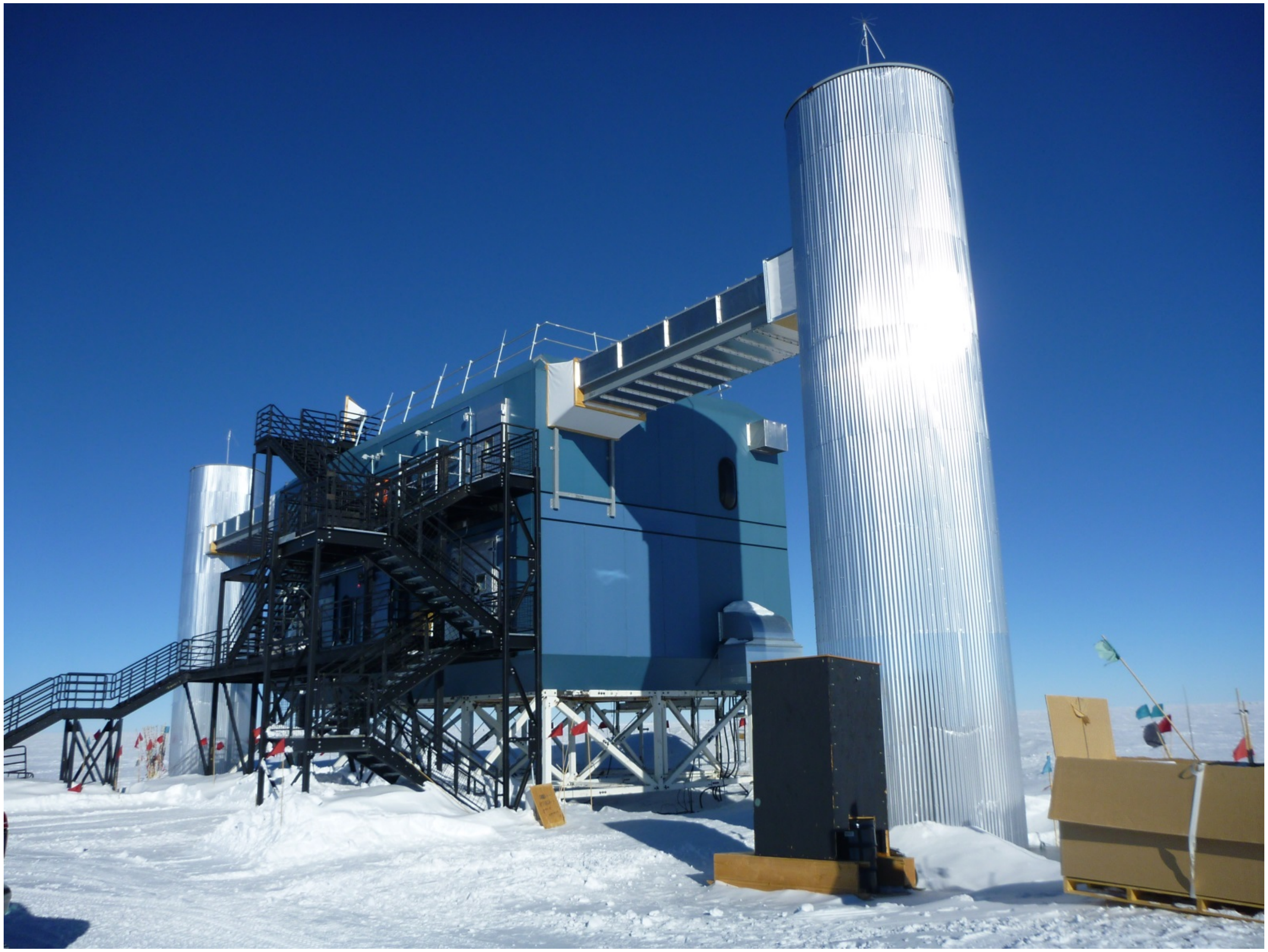
Low-temperature tests

- Look for changes in the transfer function over temperature (use low power levels)
- Observe harmonics at higher power levels
- Check for spurious oscillations
- Observe changes in the noise floor
- Cycle temperatures
- Limit thermal shocks to avoid damage

Antenna enclosures

- Plywood and styrene foam insulation are well-established construction materials for GPS
- Urethane foam absorbs RF; do not use!
- Reflections from nails and screws are trivial
- Avoid lateral cable runs
- Maintain 6 inches or more separation between passive antennas
- Give more clearance for transmitting antennas

Antenna enclosure case study




ANTB
ICECUBE
HALZEN A 333 S
NPX-DR3
ROS 6322
640 LBS
ANTB
DR3
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HALZEN A 333 S
NPX-DR3
ROS 6322
640 LBS


STUD
258
KD-HT
antenna
WARNING


ANTB
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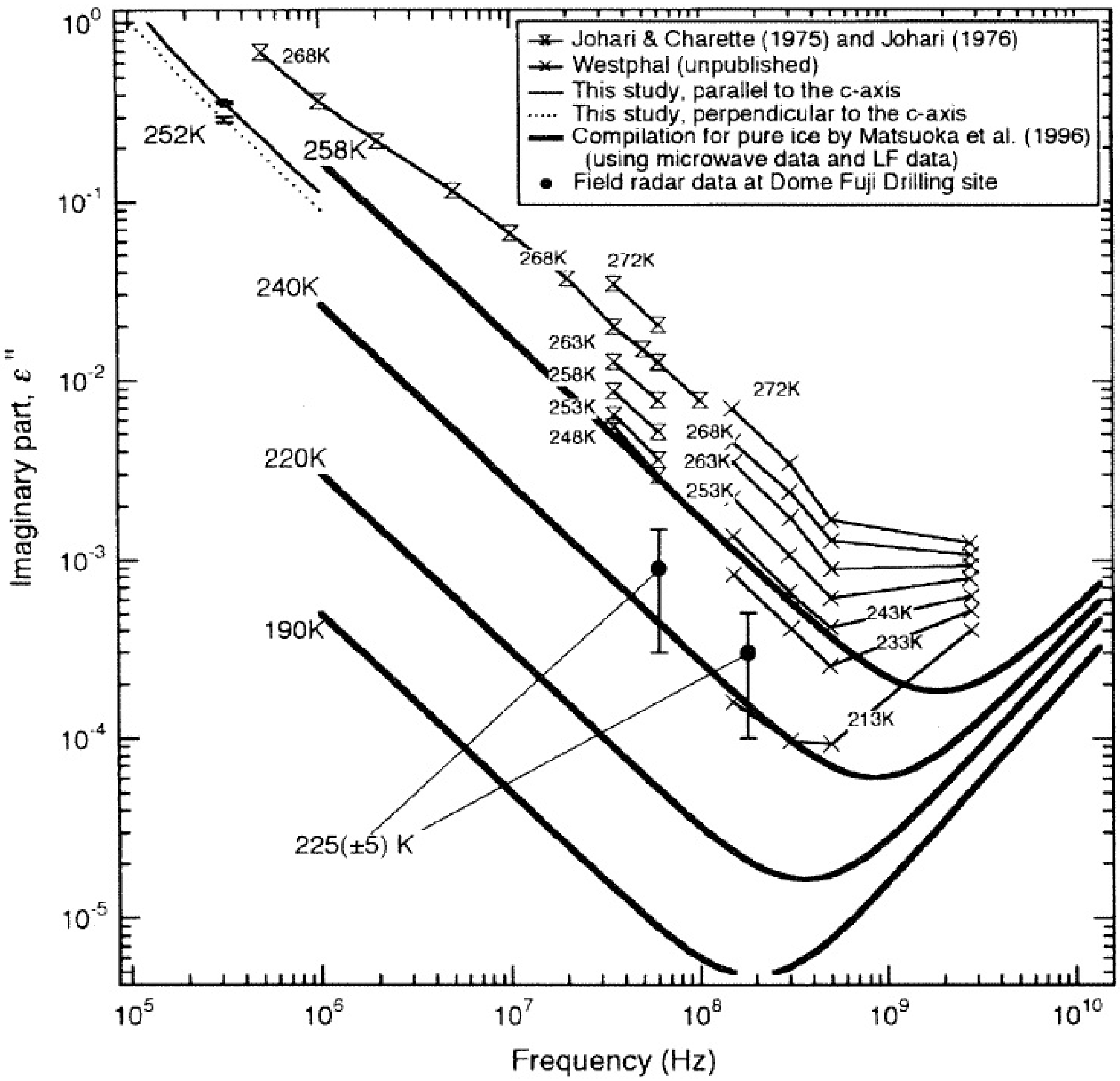
NPX-DR3
ROS 6322
640 LBS
DR3
ANTB
ICECUBE
HALZEN A 333 S
NPX-DR3
ROS 6322
640 LBS

Buried antennas

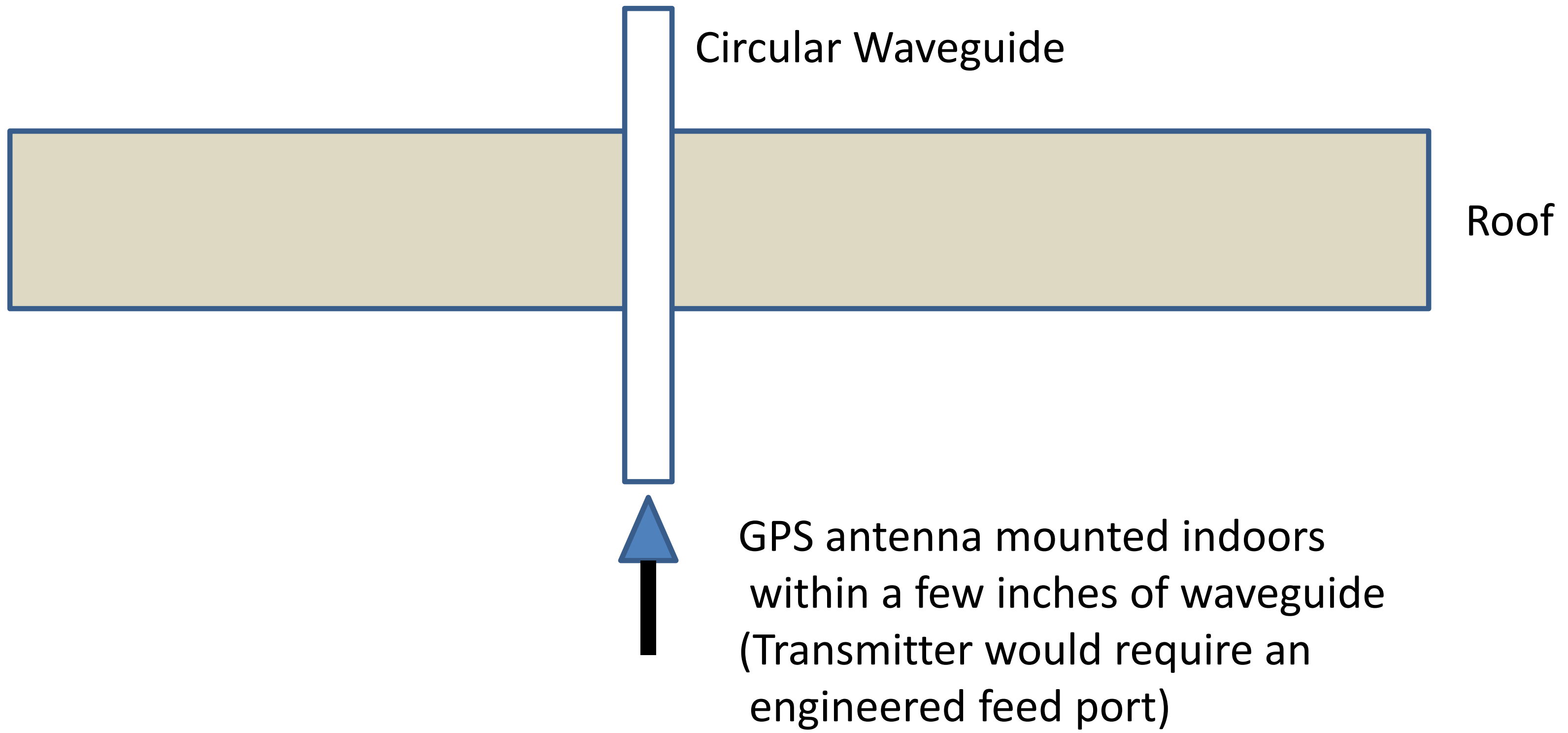
- Uniform snow and ice are fairly transparent at GPS and Iridium frequencies, at low temps <-10C
- Some signal loss from surface reflections and from degradation of polarization (a few dB?)
- ARA stations at South Pole use low-cost GPS antennas buried directly in the snow at about 1m depth -- No reported issues with timing modules
- Scattering and refraction caused by density variations may dominate attenuation at depths of 10m or more (not much data on this at 1.6 GHz)



Fujita et al, A summary of the complex dielectric permittivity of ice in the megahertz range and its applications for radar sounding of polar ice sheets

GPS / Iridium "light pipes"

- Experiments were performed at UW to demonstrate the feasibility of mounting GPS antennas indoors with circular waveguide to transport signals through the roof of structures
- The antenna pattern of an open-ended waveguide is similar to that of a patch antenna
- Signal polarization is preserved, slightly more gain
- Waveguide would to be about 5 inches diameter, filled with foam polyethylene for insulation



Main benefits:

No enclosure required on roof to keep antennas warm

Easier to service antenna in some cases

Disadvantages:

One waveguide per antenna required

Some signal loss/leakage due to imperfect coupling