Integrated Optics and Photon Counting Detectors: Introducing µ-Spec

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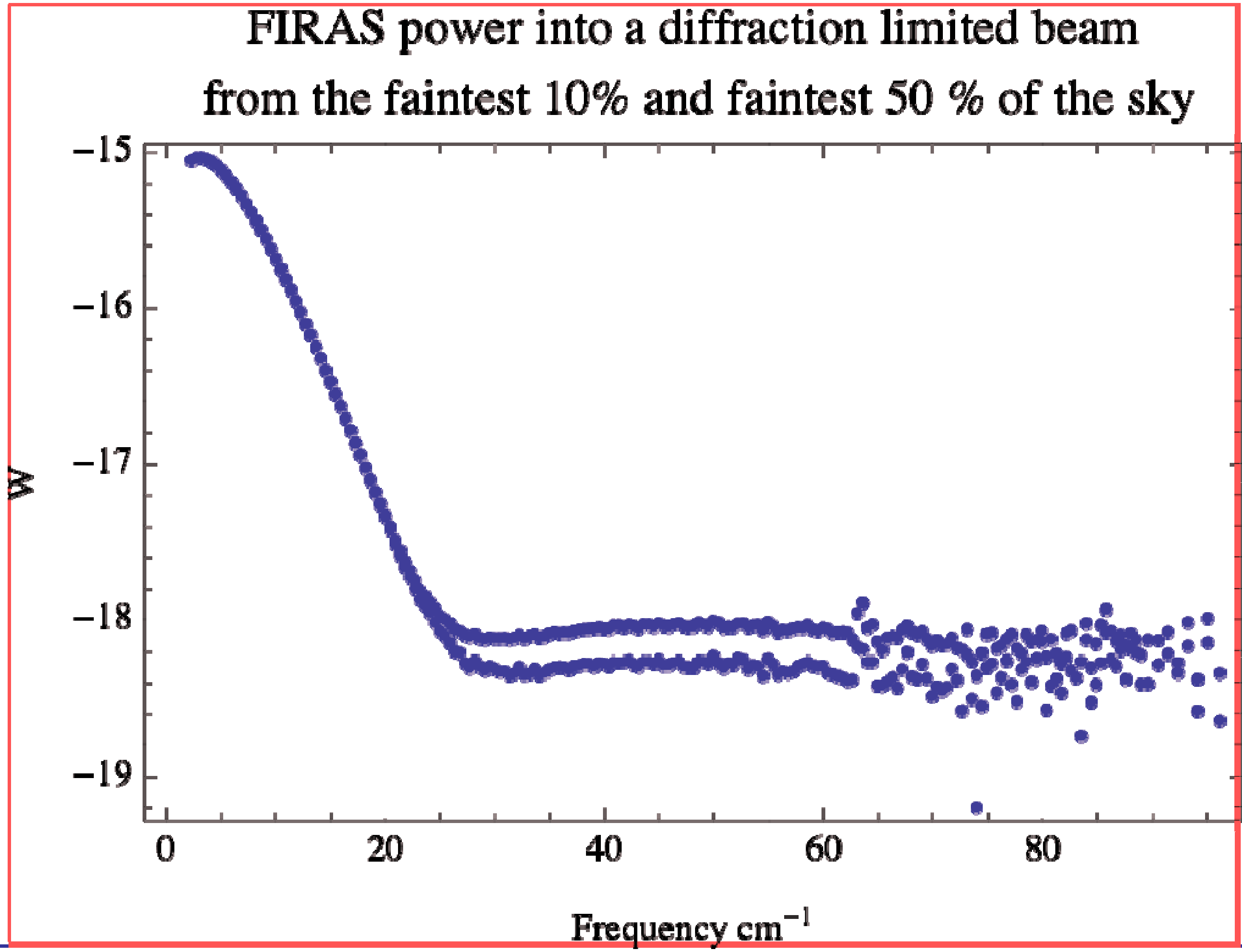
The Space Environment



Monochrometer or Multiplex Spectrometer?

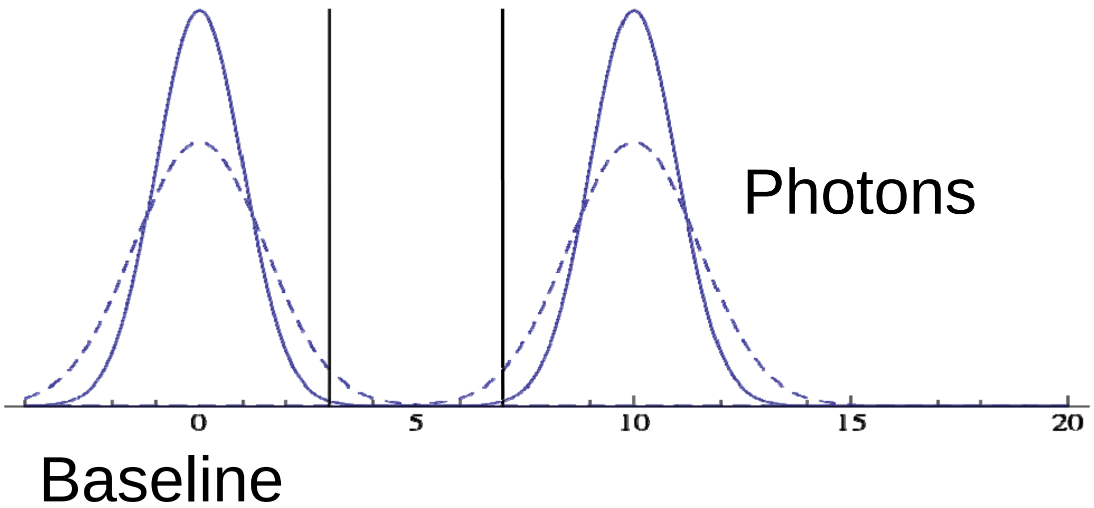
- Assume spectrum must be acquired in a time t_{spec}
- Dispersive instrument $\tau \sim t_{spec}$
- FTS $\tau \sim t_{spec}/R$
- $NEP_{FTS} \sim NEP_{Mono}$ Sqrt(R)

Sensitivity Requirements

- Energy Sensitivity ~ NEP Sqrt(τ)
  - Equal in the two cases
  - So, if you have access to appropriately low conductances or coupling strengths, the “degree of difficulty” is about the same in both cases.
- However, if t_{spec} becomes small, the required detectors move into a new regime.

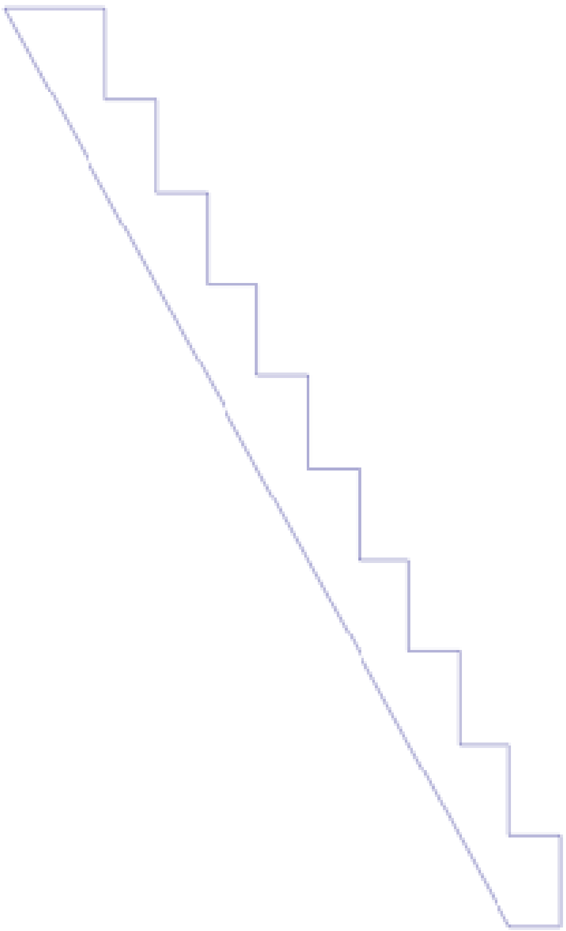
Counting Thresholds and Noise

- Changes in variance can cause errors in event efficiency or dark rate.



Photon events and baseline in a system with 10 σ sensitivity.

Grating Operation



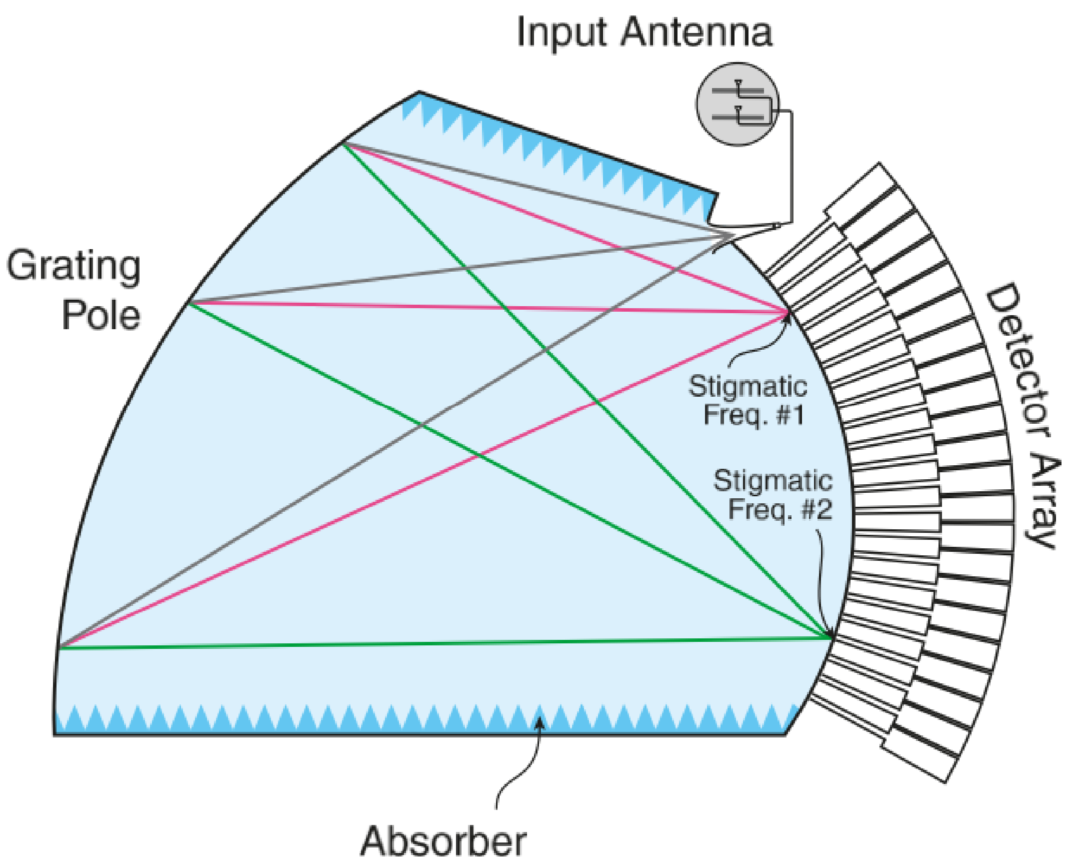
Plane wave scatters off grating

Grating divides amplitude into n equal parts with progressively increasing phase shift

$E[x]=A/Sqrt(N)\ Exp[i(k\ R - n\ \phi)]/R$

Different Frequencies propagate as plane waves with different k-vectors

Transition to Integrated Optics



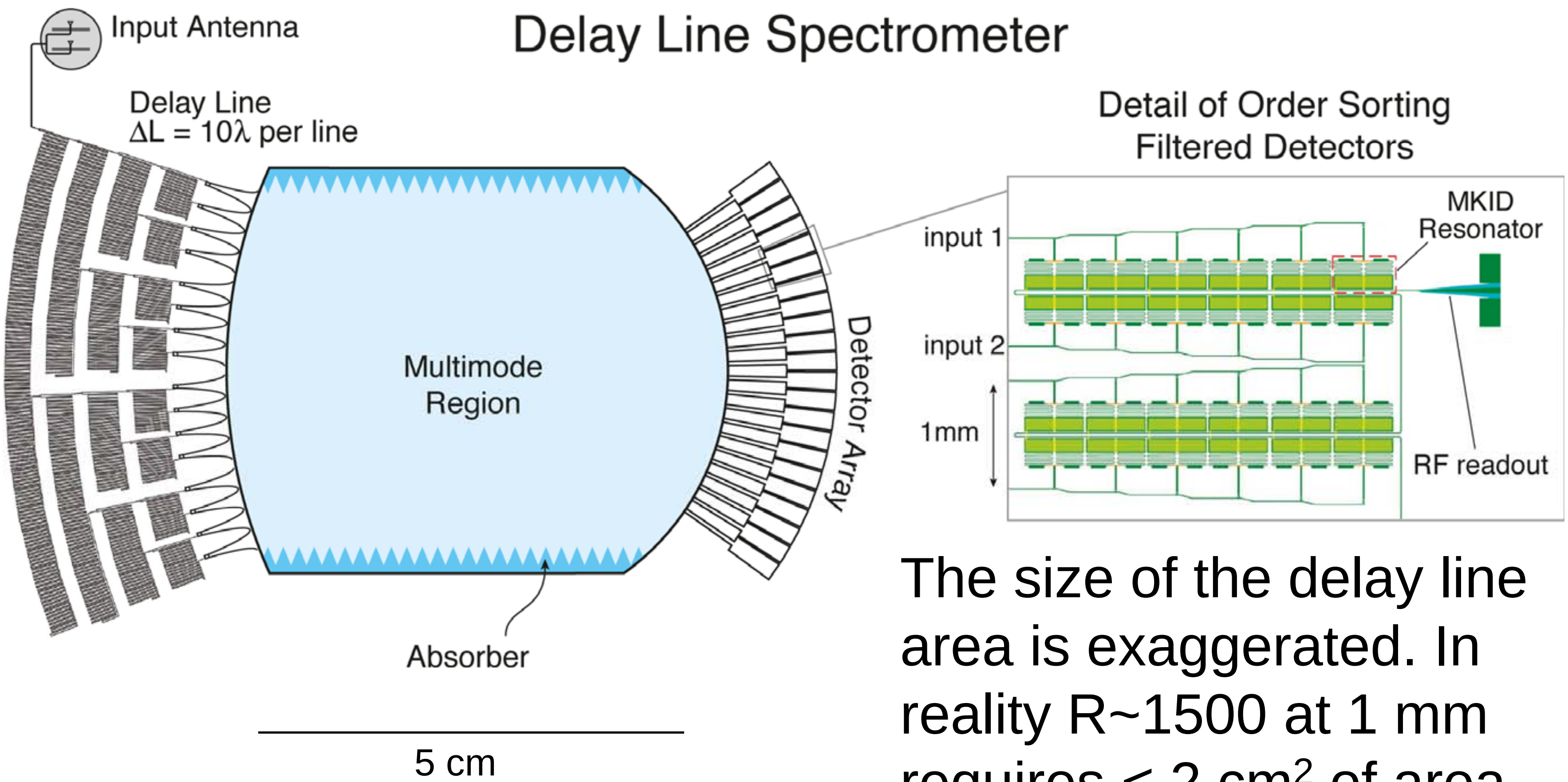
This is a 2-dimensional version of a Rowland spectrometer. The Caltech/JPL WAFIRS is a non-integrated version of this spectrograph.

Here, individual wavefronts are propagated as converging circular waves rather than plane waves, so no additional optics are required for imaging the spectrum

Limitations of Rowland Spectrograph

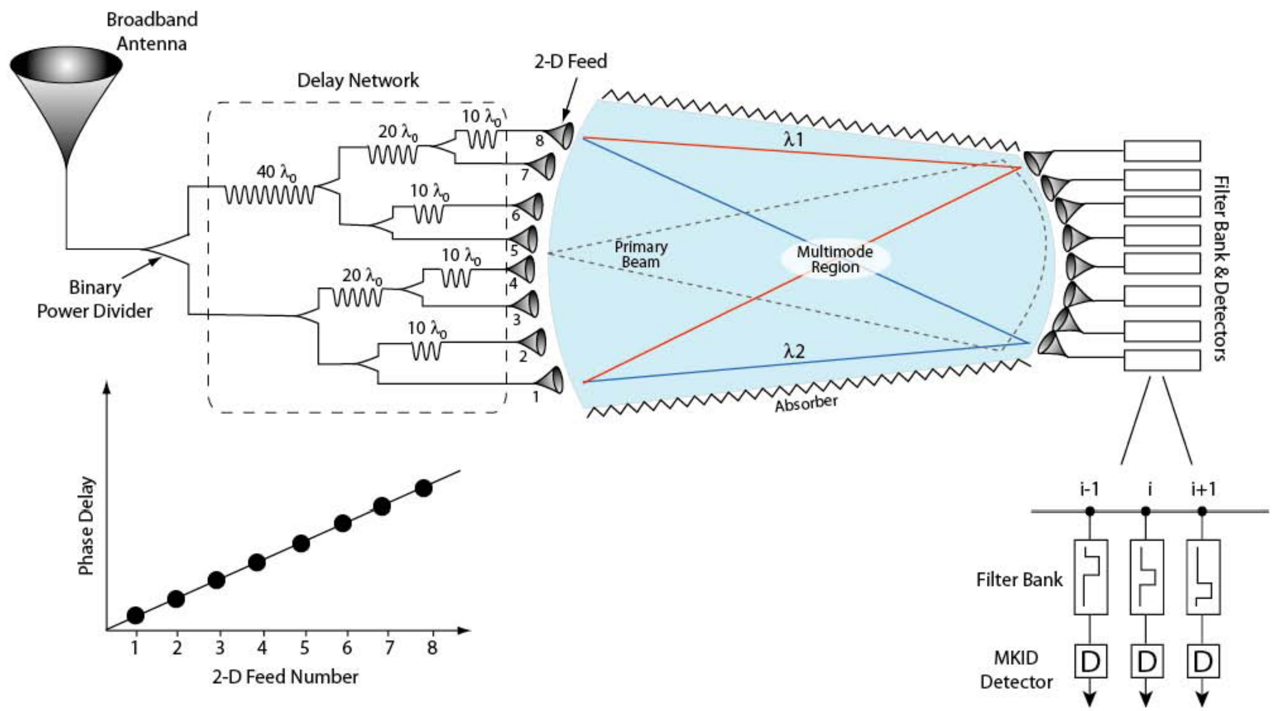
- Resolving power is set by total phase delay, which is of the order of the size of the instrument. Must be large for high resolution.
- Focal surface must have of order N detectors for full sampling of an octave at resolving power N. Since detectors must be of order λ in size, the transverse dimension must be large, similar to the length
- So: Spectrograph must be of order N λ x N λ

µ-Spec Allows Dramatic Reduction in Spectrograph Size



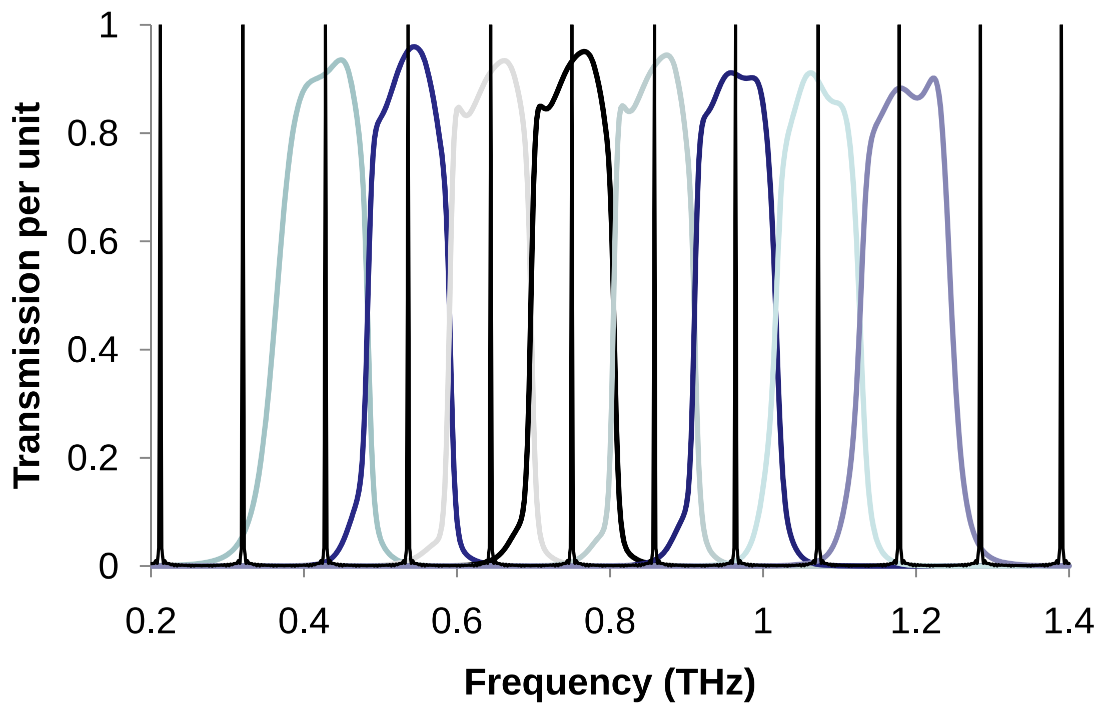
The size of the delay line area is exaggerated. In reality R~1500 at 1 mm requires < 2 cm^2 of area.

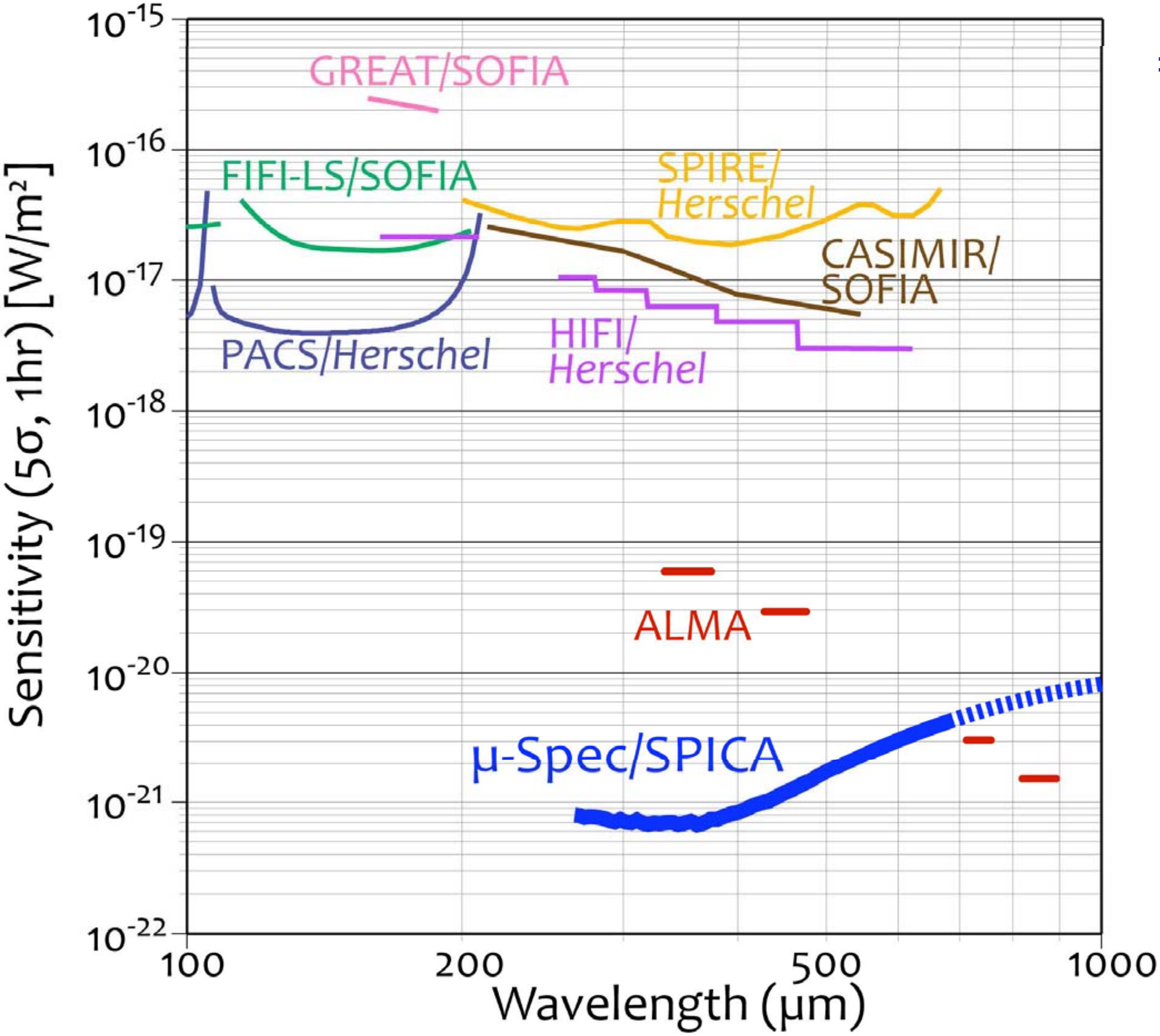
μ-Spec Concept



Output Filter Bank

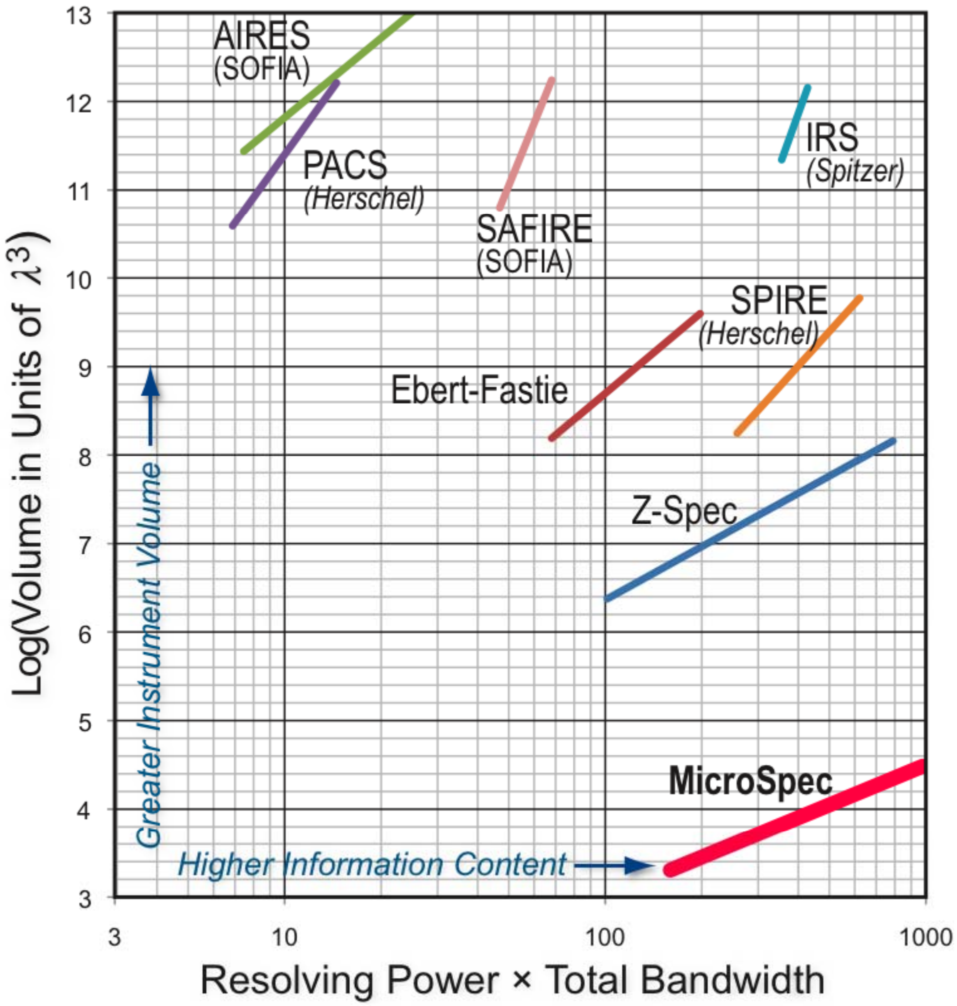
- Each output of the spectrometer receives signals at different wavelengths from different orders of the grating
- Each output has a channelizing filter bank which directs the different orders to their detectors.





GREAT/SOFIA
FIFI-LS/SOFIA
SPIRE/
Herschel
CASIMIR/
SOFIA
HIFI/
Herschel
PACS/Herschel
ALMA
µ-Spec/SPICA
Sensitivity (5σ, 1hr) [W/m²]
Wavelength (µm)
10-15
10-16
10-17
10-18
10-19
10-20
10-21
10-22
100
200
500
1000

Context



MicroSpec (µ-Spec), the instrument being proposed, is orders of magnitude smaller than present instruments of comparable performance.

Adapted from a Matt Bradford slide.

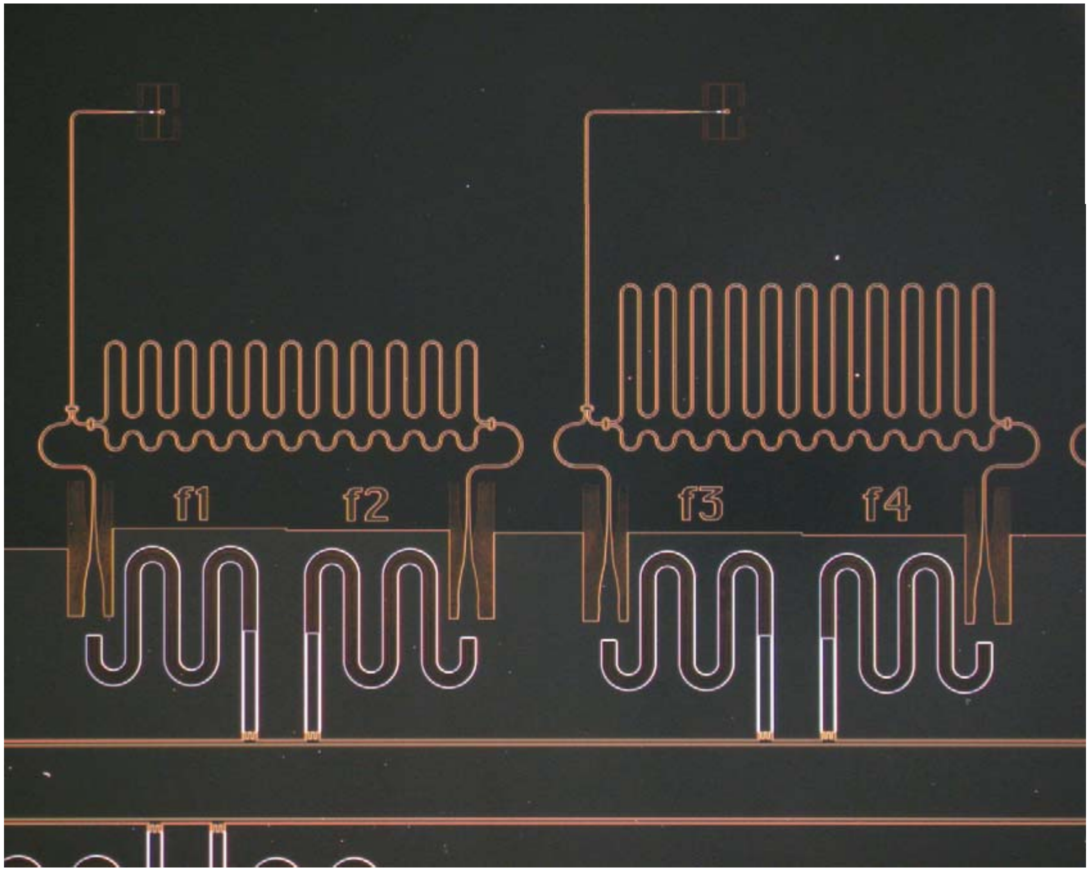
µ-Spec: Features

- Is the first fully integrated high performance spectrometer system
- Can couple to large two dimensional arrays of detectors in a very small volume
- Can operate up to 700-1200 GHz
  - Set by available superconductors
- Can provide R ~500 by fabrication tolerances, > 1500 by delay line trimming
- Can be mass produced
- Optics can be highly corrected to provide diffraction limited imaging of the spectrum

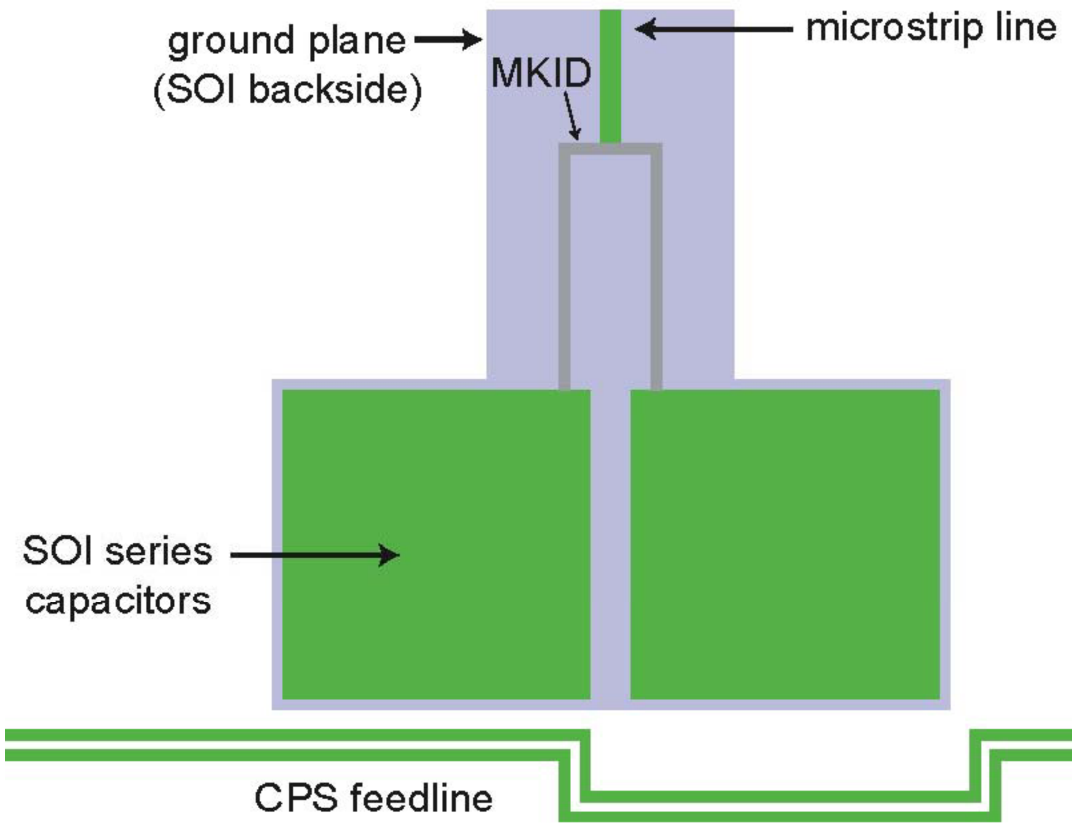
Status

- All basic elements have been produced
  - Nb transmission lines with single crystal Si dielectric show low loss
    - $Q_{dielectric} > 1000$ at 35 GHz
  - Tolerances are acceptable
    - R~500 possible by tolerance alone
  - No other complicated circuit elements
  - Relatively simple fabrication process
    - Needs only 3 metal layers

Interferometers Are Used to Test Loss



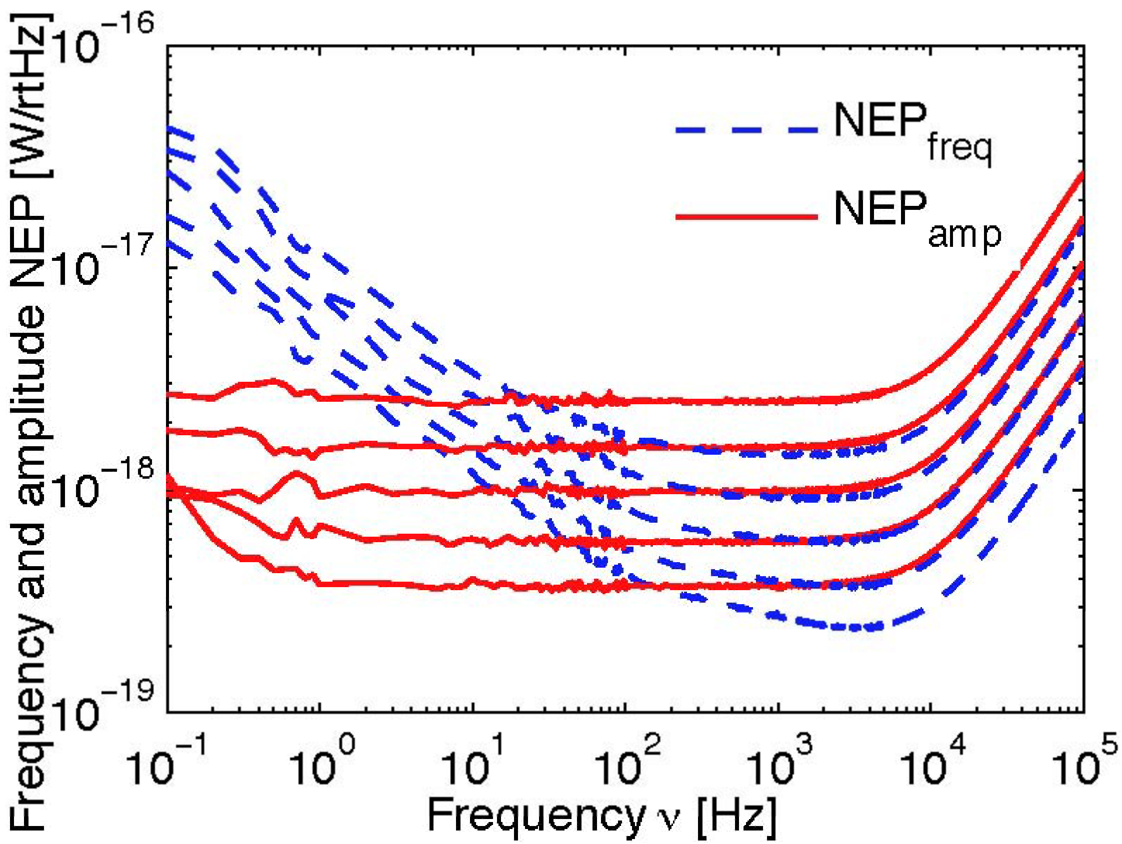
MKID Concept



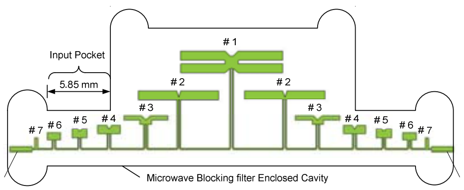
Instrument Characteristics

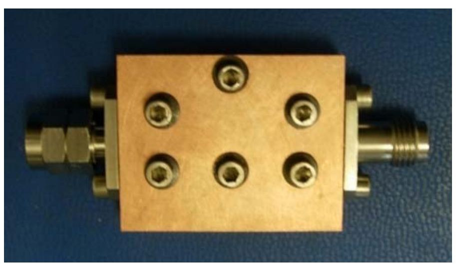
Spectral Range	150 – 700 GHz Phase I Up to 1.2 THz in second phase
Resolving Power	$\lambda/\delta\lambda \sim 1500$
Angular Resolution	Diffraction Limited
Sensitivity	Background Fluctuation Limited
TRL	~ 2
Sky Coverage	Single spatial beam
Size	4 x 4 x 1 in.
Operating temperature	< ~1K

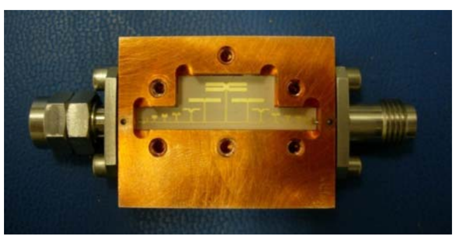
Caltech/JPL MKID Noise

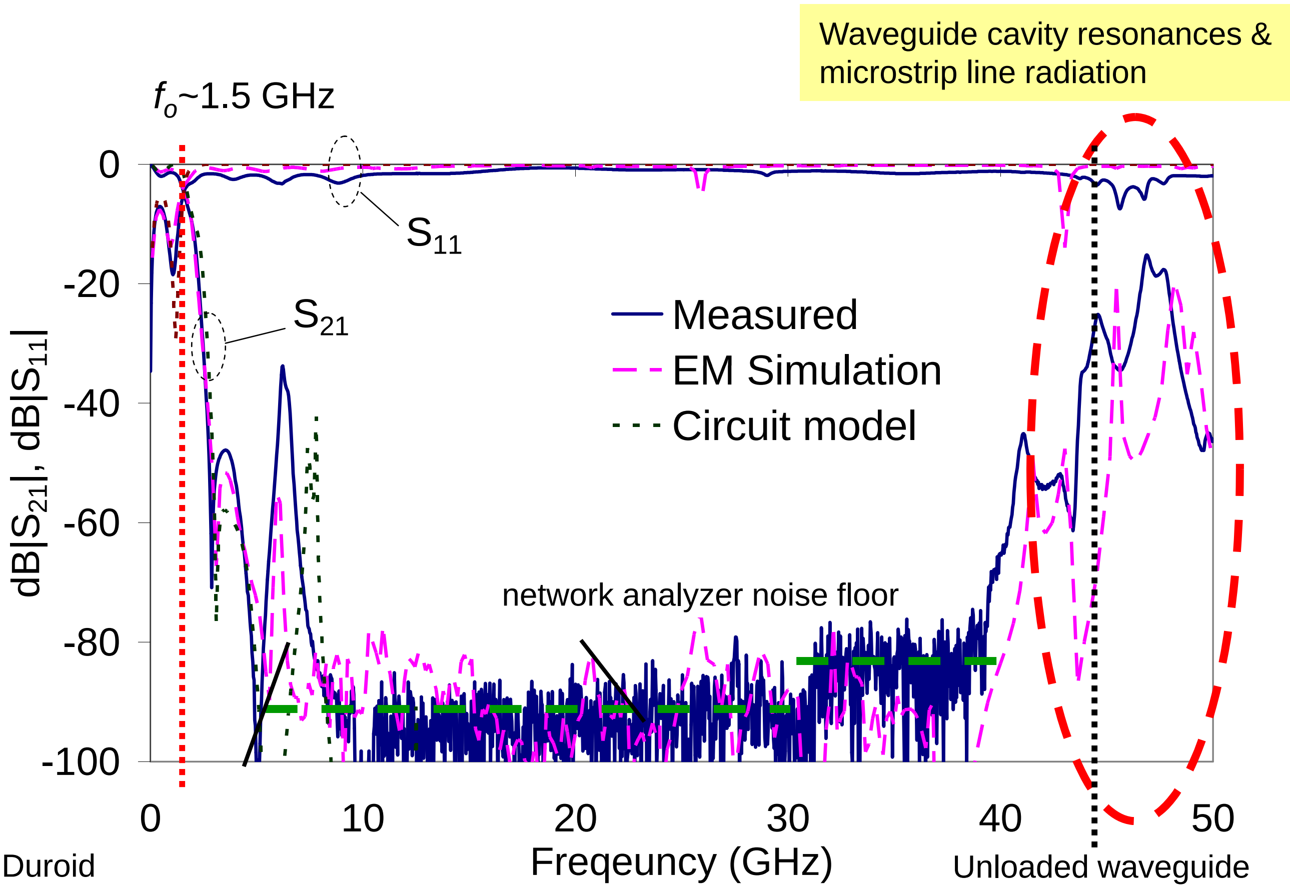


Thermal Blocking Filter: GHz…







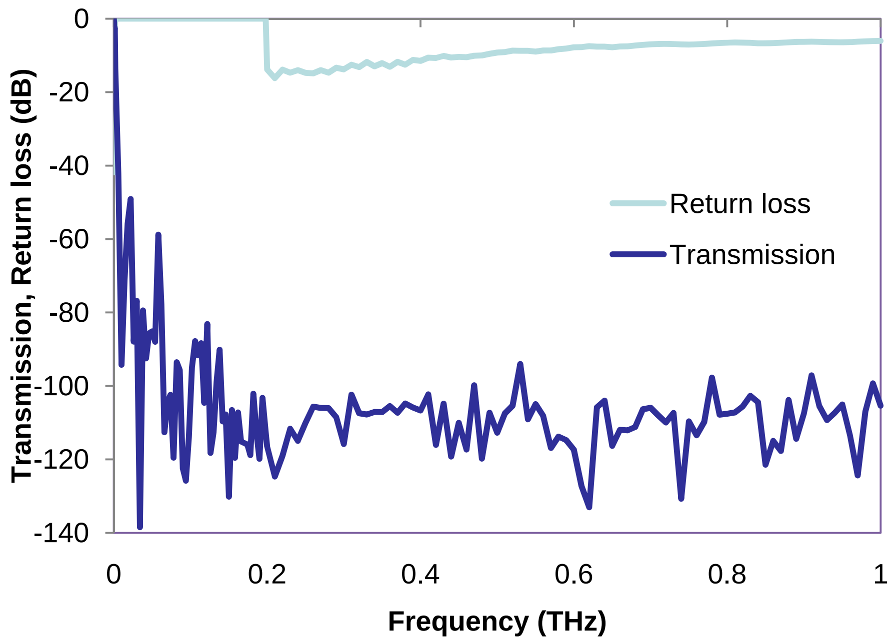


Thermal Blocking Filter on ~125um Duroid
Measured DC parameters:

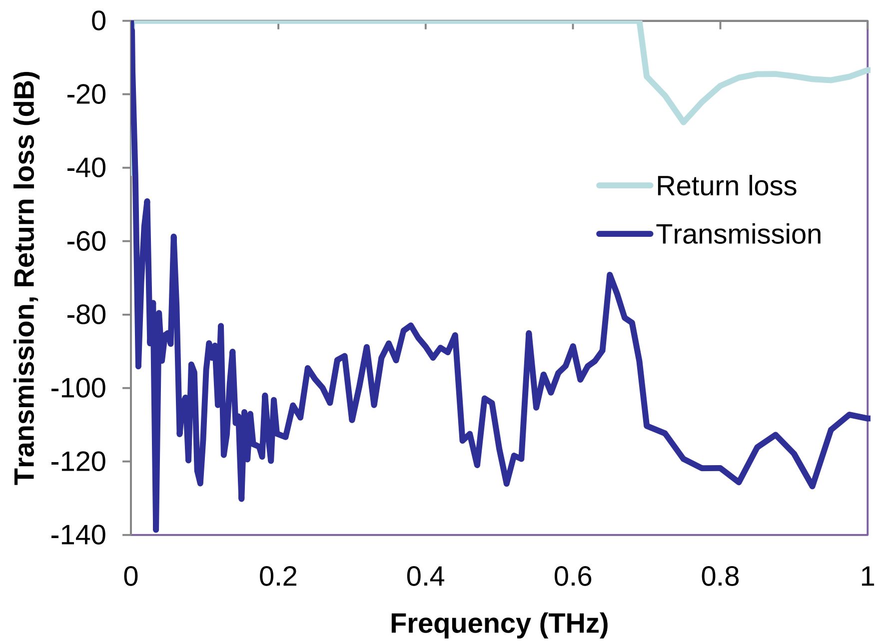
- Capacitance ~ 22.4pF
- Inductance ~ 49nH (@1MHz)
- Series Resistance ~ 0.92ohm (@300K)
- Series Resistance ~ 0.27ohm (@4K)

REFERENCE: U-Yen, K. and Wollack, E.J., “Compact Planar Microwave Blocking Filter,” 2008, 38th European Microwave Conference, Amsterdam, Netherlands, in press.

Thermal Blocking Filter: Nb and Al…



Blocking filter response with conductor substrate: Superconducting Al microstrip & PEC ground plane



Blocking filter response with conductor substrate: Superconducting Nb microstrip on PEC ground plane

Benefits of Integrated Optics

- Compact
- Provide highly protected environment for photon counting detectors
  - Single mode in, power divided
  - Microstrip has low loss
  - Highly filtered interfaces
  - Can be almost completely boxed at operating temperature.

Summary

Integrated optics provide ideal environment for low-NEP photon counting detectors in the THz region

Provide practical technique for using large arrays of detectors for THz spectrometers

Enables very compact instruments; > 100 spectrometers, > 10^5 pixels