SuperSpec: circuit design

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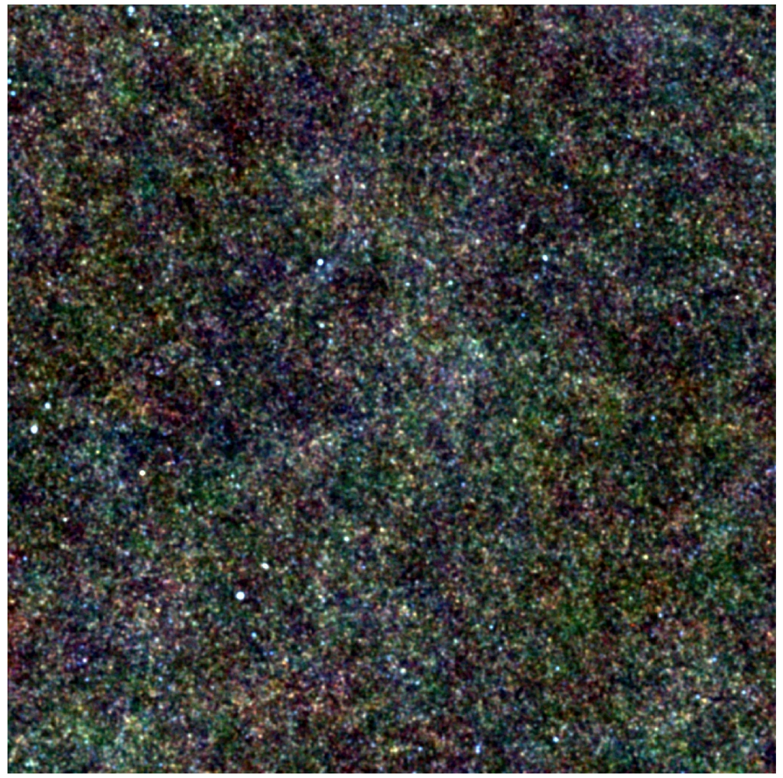
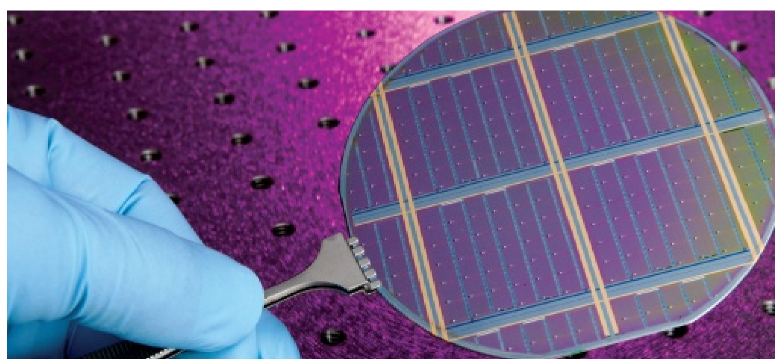
1 Compact Multiobject Spectrometer (MOS) for the (sub)mm band

Herschel detected over a quarter million IR-bright galaxies. Getting redshifts for them requires a powerful multi-object spectrometer (MOS) in the same bands.

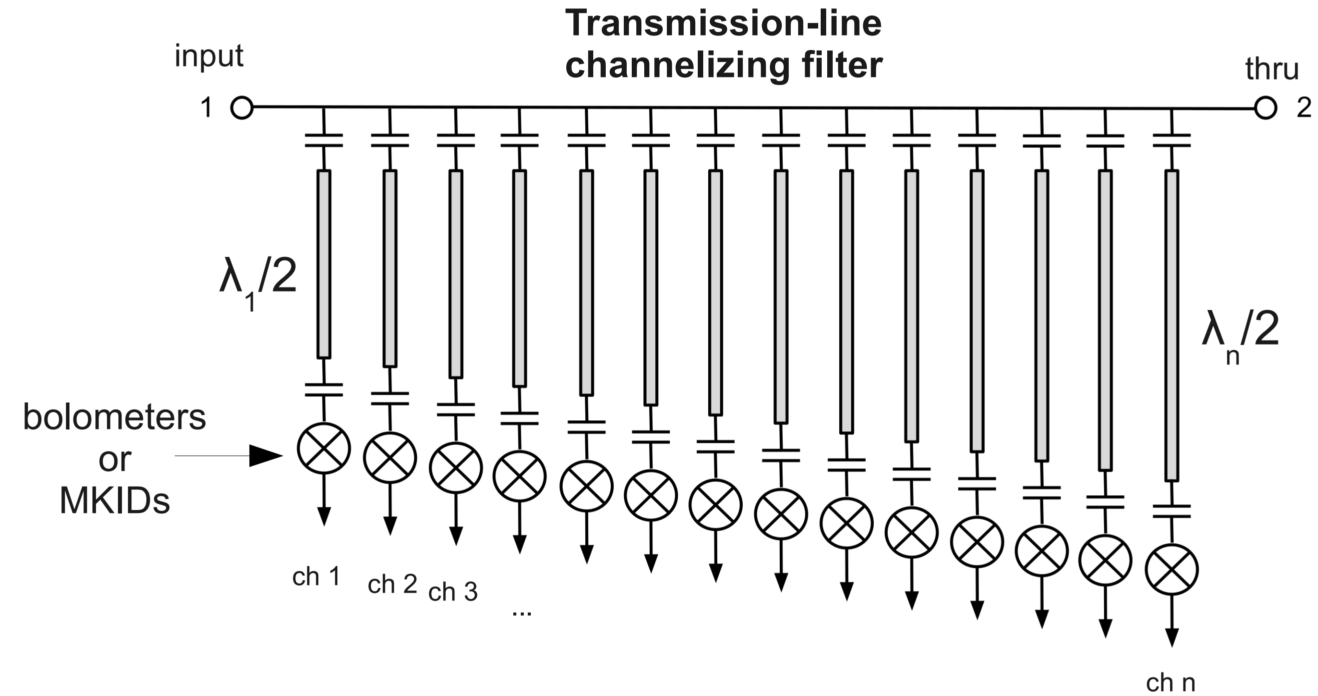
Bright C^+ and CO lines between 100µm and 1mm allow redshift identification and provide valuable new information for the Herschel population.

Low resolution R~600 spectrometers are well matched to the typical ~500 km/s linewidths of galaxies. Yet, even on CCAT, 100 to 1000 spectrometer channels will have to work in parallel to cope with the task of extensive (sub)mm redshift surveys.



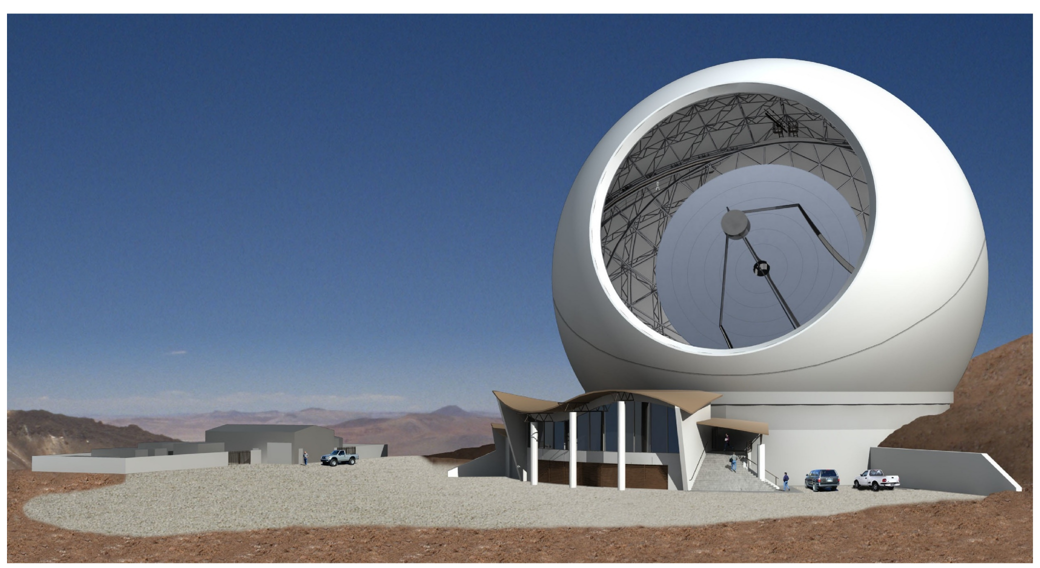


Above: A wafer containing (4) 6X6 MUSIC focal-plane arrays ready for dicing and delivery. Each array produces a 4-color image.



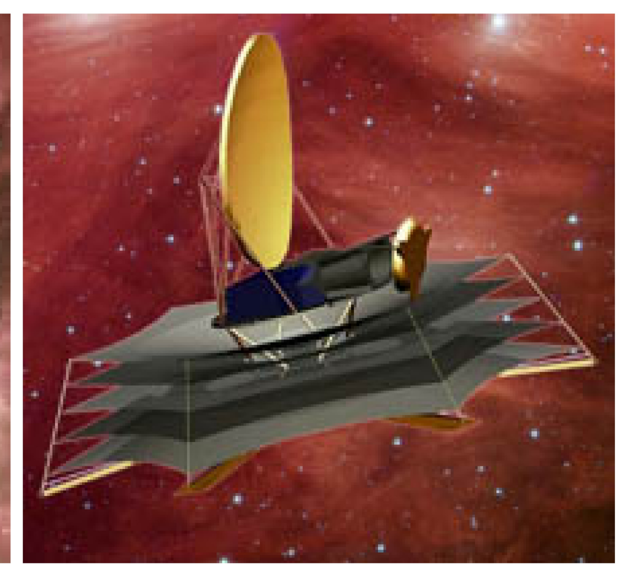
SuperSpec: A filterbank of sequentially tuned resonators couple select narrow bands into broadband power detectors, like a bolometers or MKIDs.

With thin film lithography, the entire channelizing structure of an octave-wide R=600 spectrometer can be reallized within 1 mm^2 for the 200 – 300 GHz band. If the required ~600 detectors can also fit onto an Fλ pixel, we could fill the focal-plane with wide-band spectrometer arrays using this technology. Imagine the MUSIC array (left) but complete with a 1000 channel spectrometer on each pixel!...



CCAT

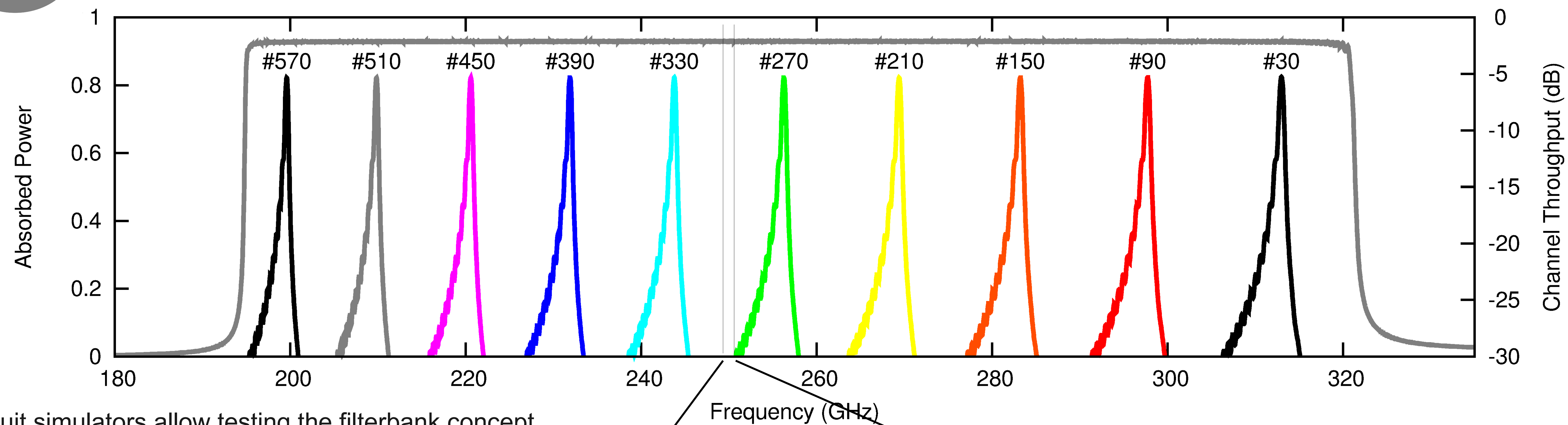
SPICA



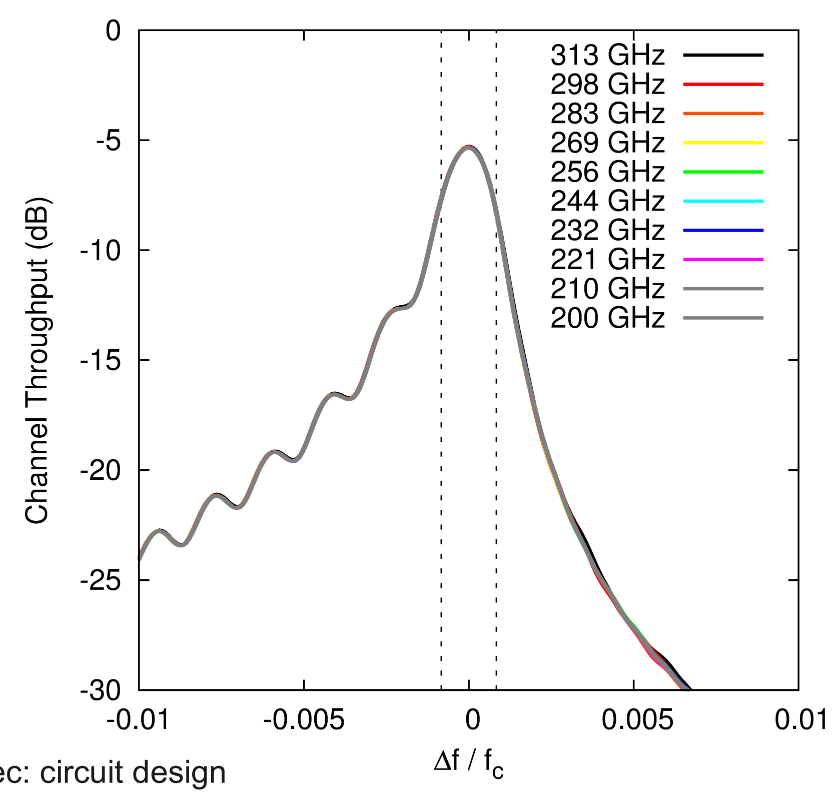
CALISTO/SAFIR

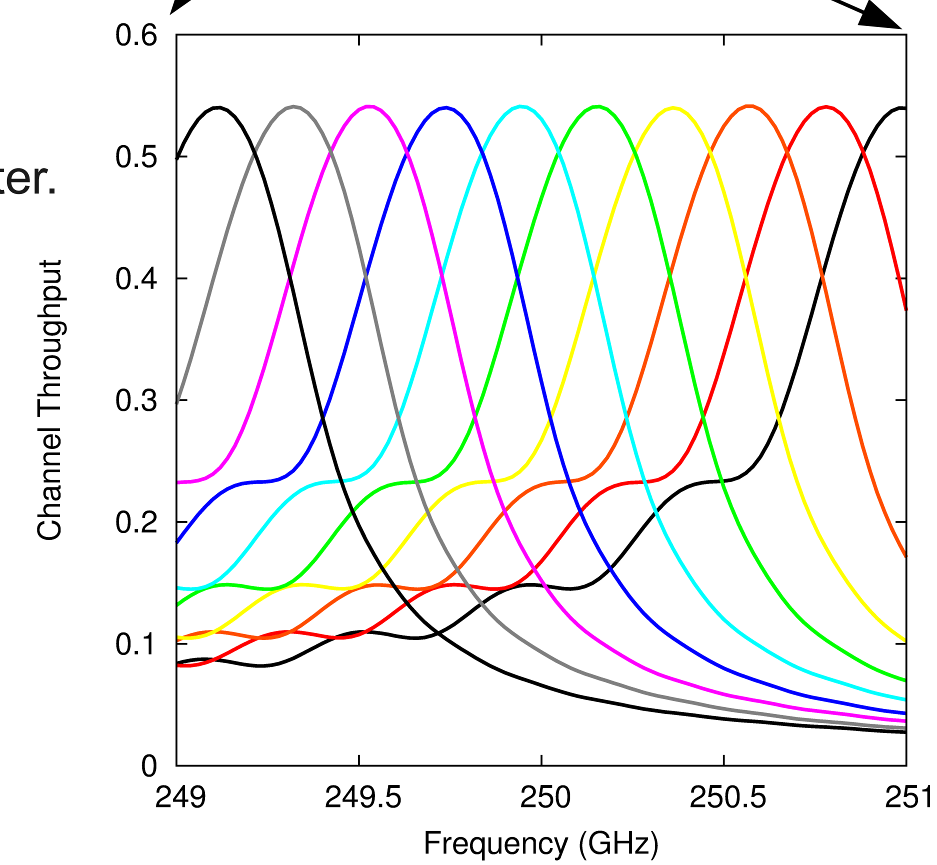
SOFIA

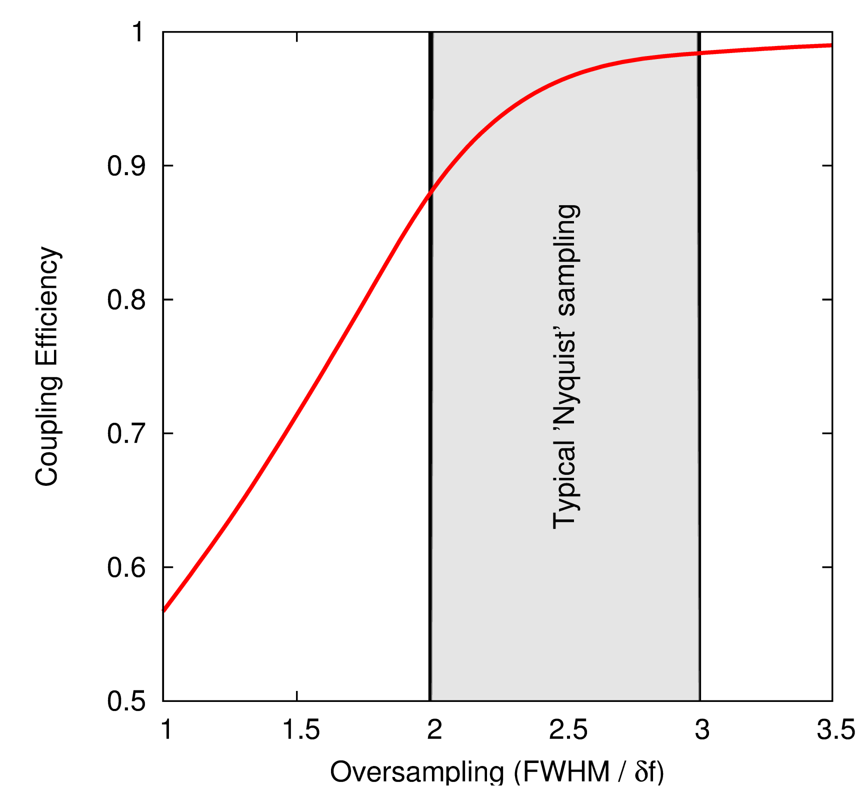
2 Concept design: performance



Circuit simulators allow testing the filterbank concept fast. Here, SuperMix predicts predicts extremely uniform input coupling, and identical channel responses in an octave bandwidth for an ideal R=600 design with 600 channels. Rather than being detrimental, interference among channels can actually enhance the spectrometer.

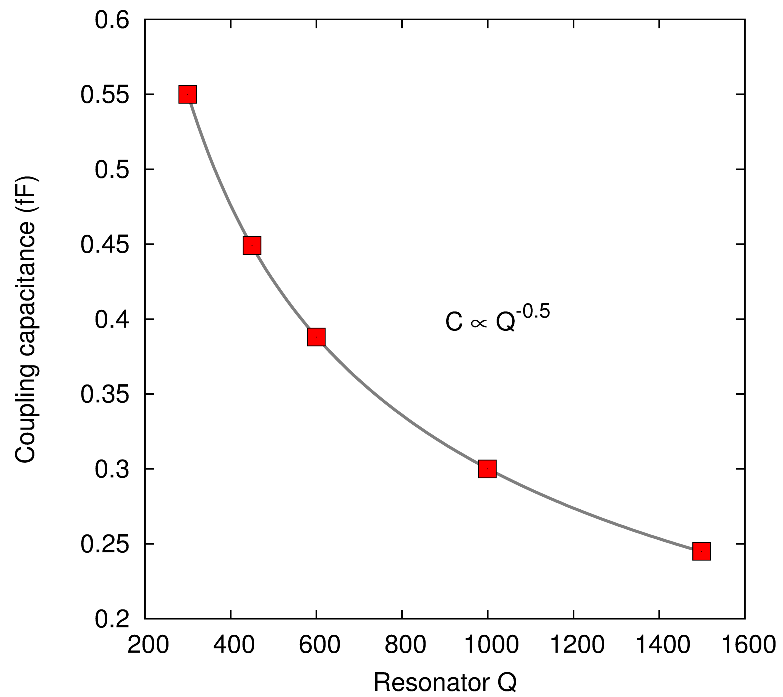


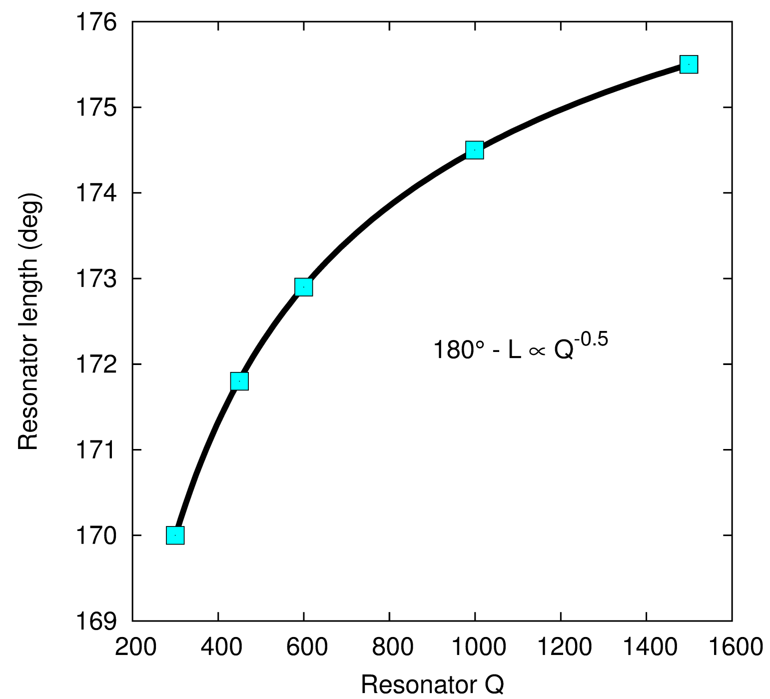




The channel spacing is smaller than the resolution by a factor of 2 (center panel). Such 'oversampling' is necessary to fully recover R=600 spectral information (cf. Nyquist theorem), and increases the efficiency of the spectrometer at the same time (above).

3 Channel Tuning



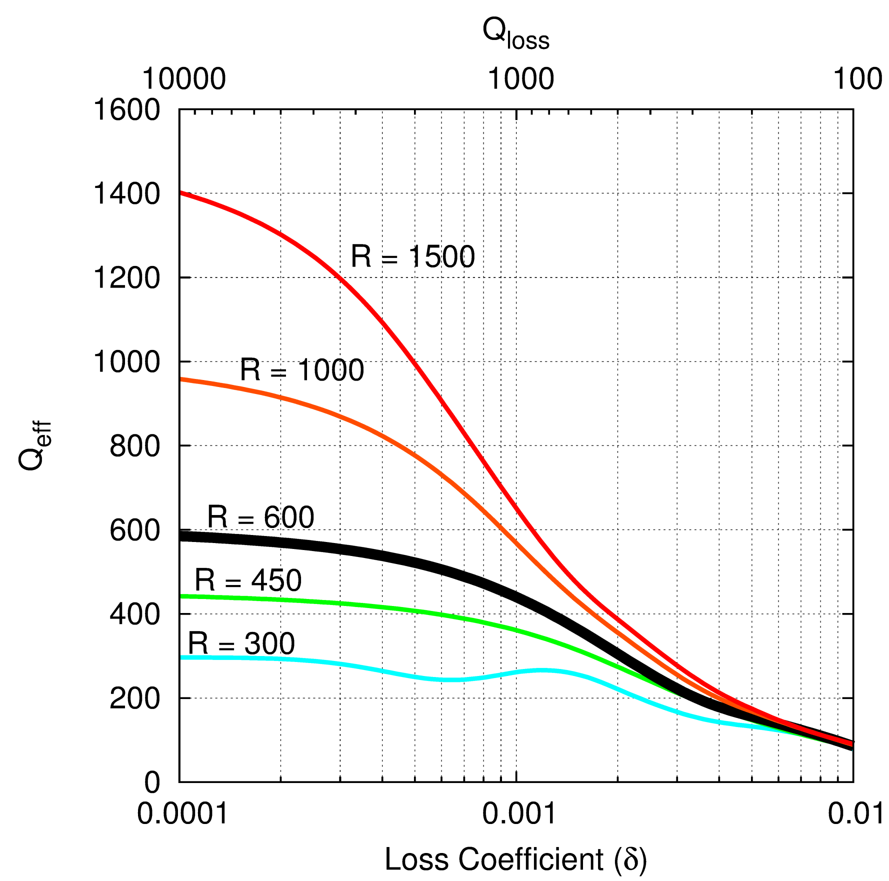


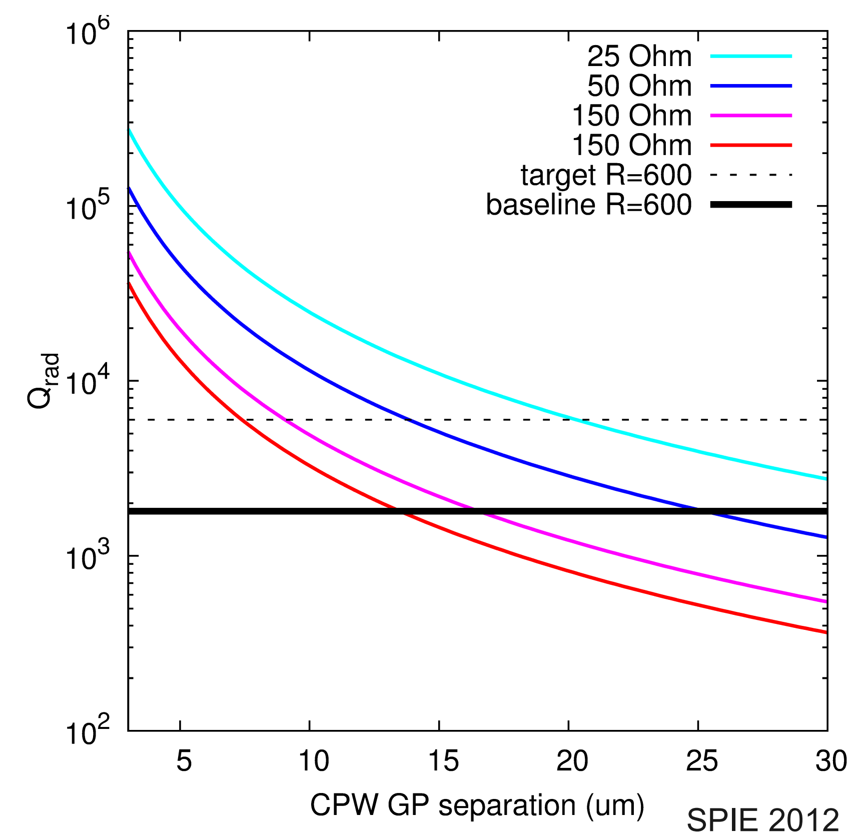
Numerical simulations of the full spectrometer circuit, with 600 channels, illuminate simple relations for the optimal sizing of resonator couplings (here capacitive) and resontators lengths. Thus, perfect tuning becomes easy for any resolution and frequency. These findings agree well with the predictions in the Kovács & Zmudzinas memo (Caltech, 2011). The required capacitances are in the range for proximity coupling between lines printed with deep-UV lithography at JPL.

Transmission line losses 4

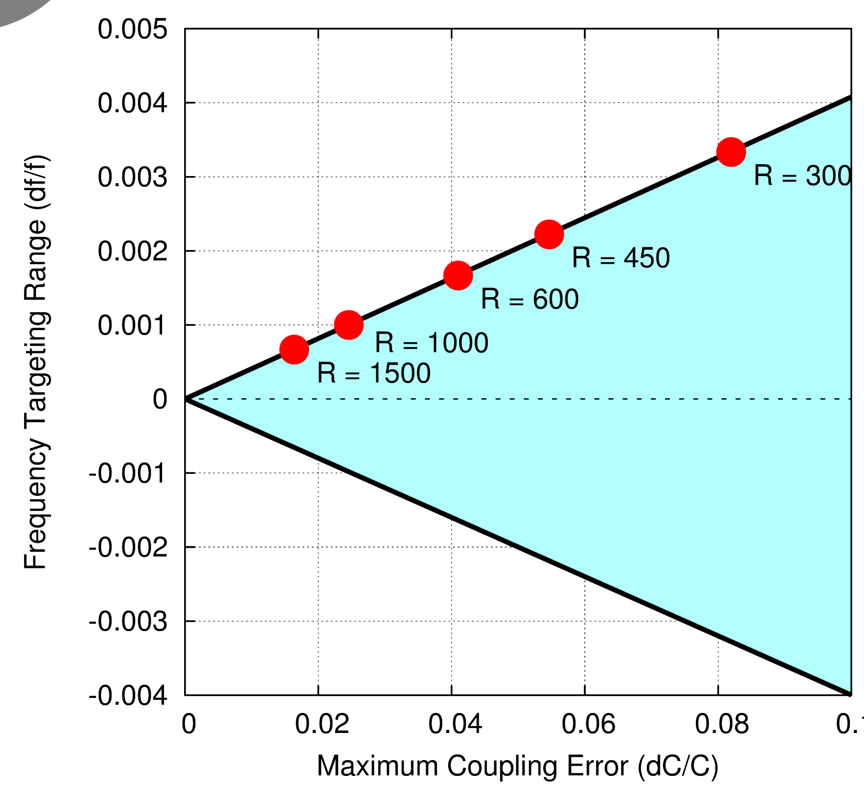
Transmission line losses limit the resolutions we can achieve with this type of spectrometer. We need to keep the loss quality factor Q_{loss} at least a factor of ~3 above than the desired spectral resolution R, and preferably and order-of-magnitude higher (left panel).

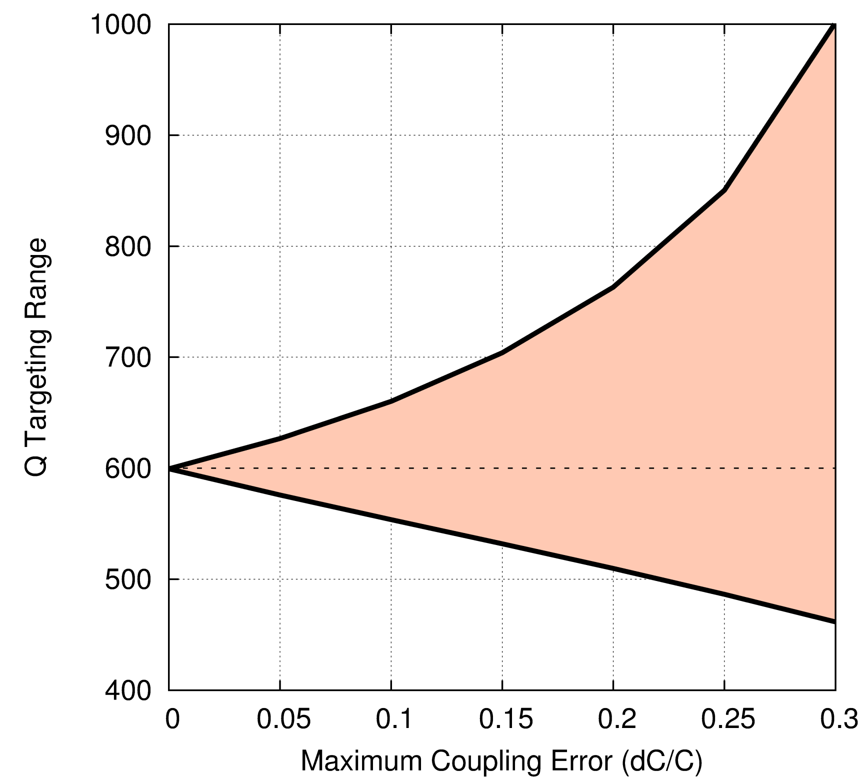
The radiative loss in coplanar waveguide (CPW) lines is estimated by Vayonakis & Zmuidzinas (Caltech memo, 2012), and shown on the right panel. To build an effective R~600 spectrometer with CPW resonators (and feedline!) the ground-planes are be separated by ~10μm or less. For microstrip lines, where the loss is due to the dielectric, the desired qualities can likely be achieved with SiN or amorphous Si.

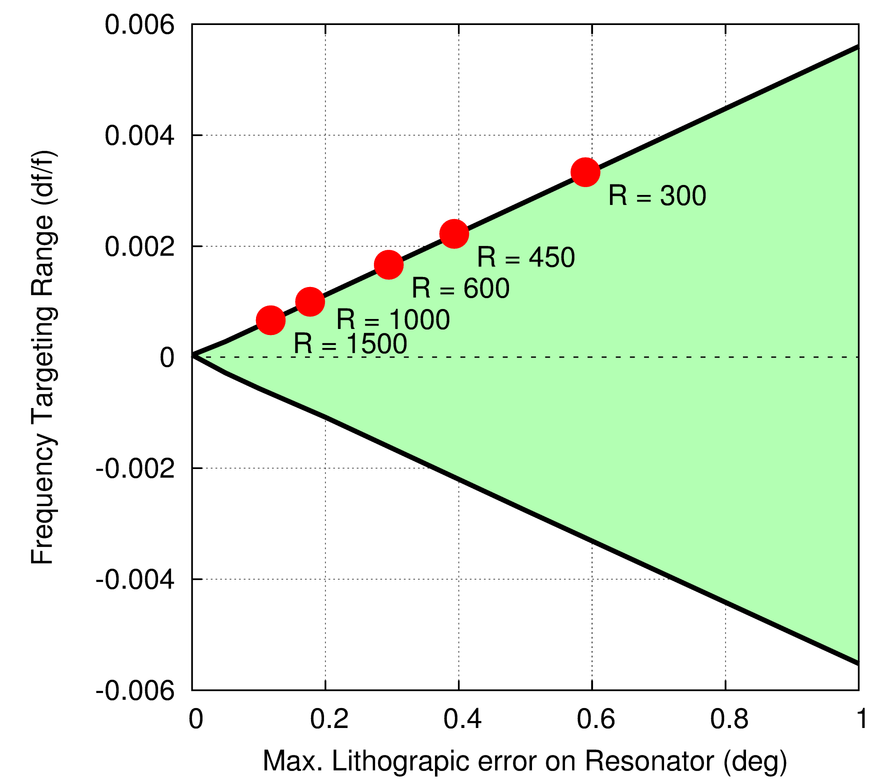




5 Fabrication Tolerances

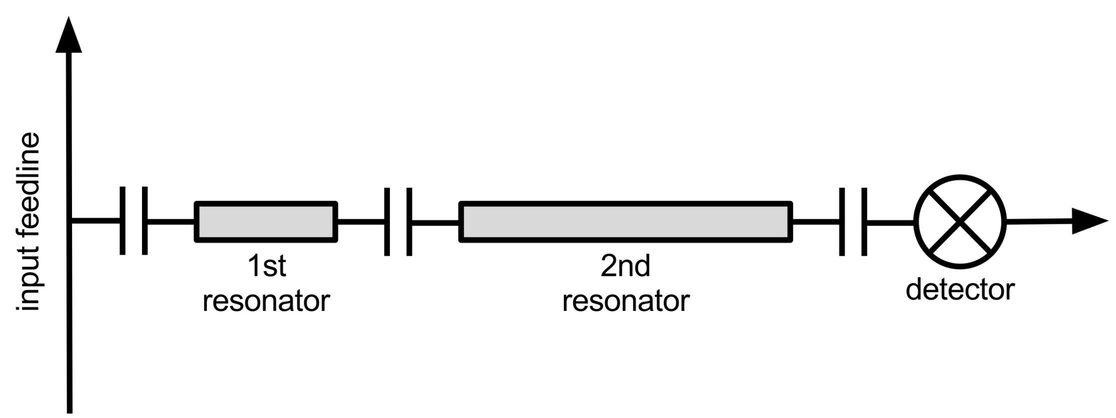


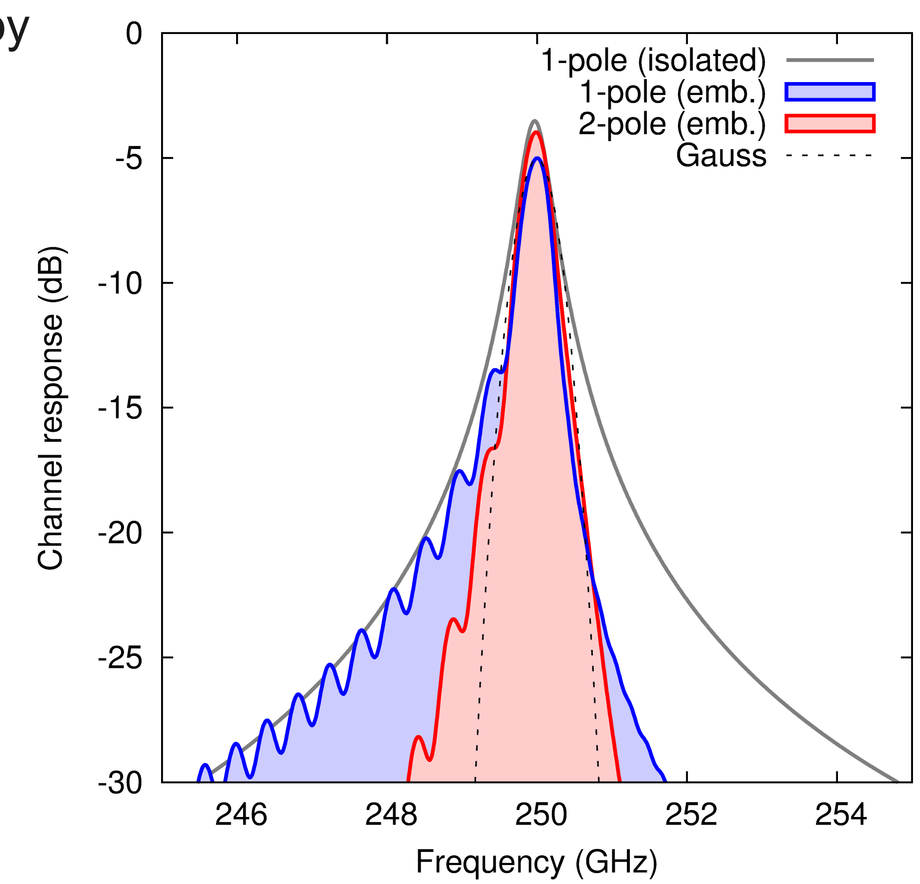


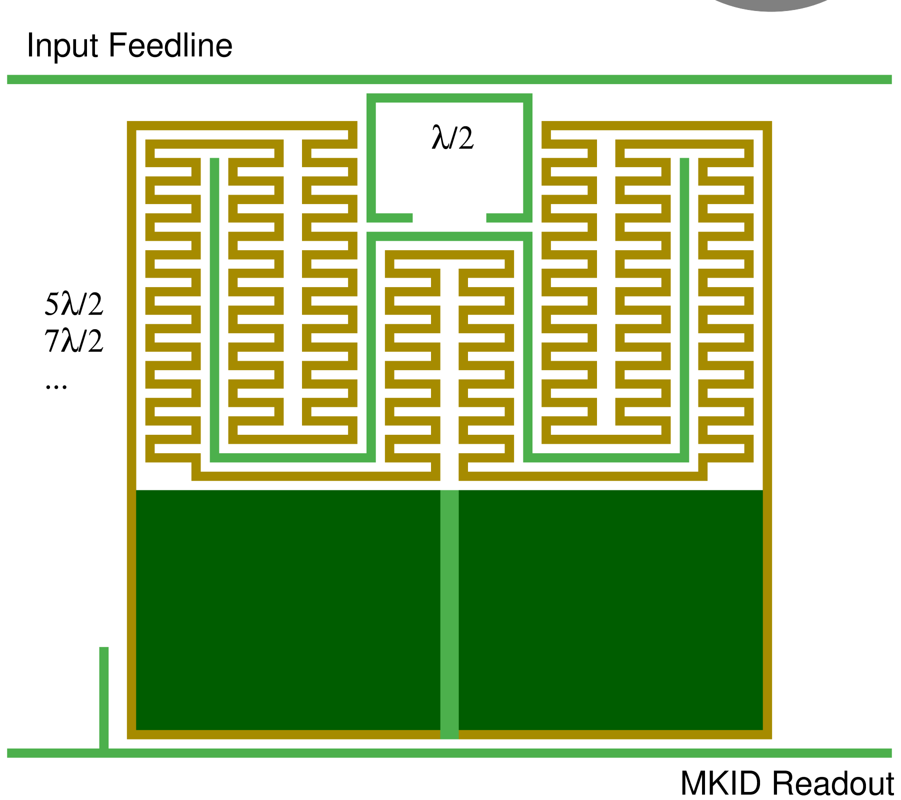


Above: Fabrication tolerances place another practical limit to the resolutions these spectrometer can achieve. Resonator couplings (here capacitive) especially have to be accurately targeted if channel ordering are to remain monotonic, and with uniform resolutions. Red dots indicate the maximal targeting errors before a channel moves by more than its width.

Two-stage Resonators 6

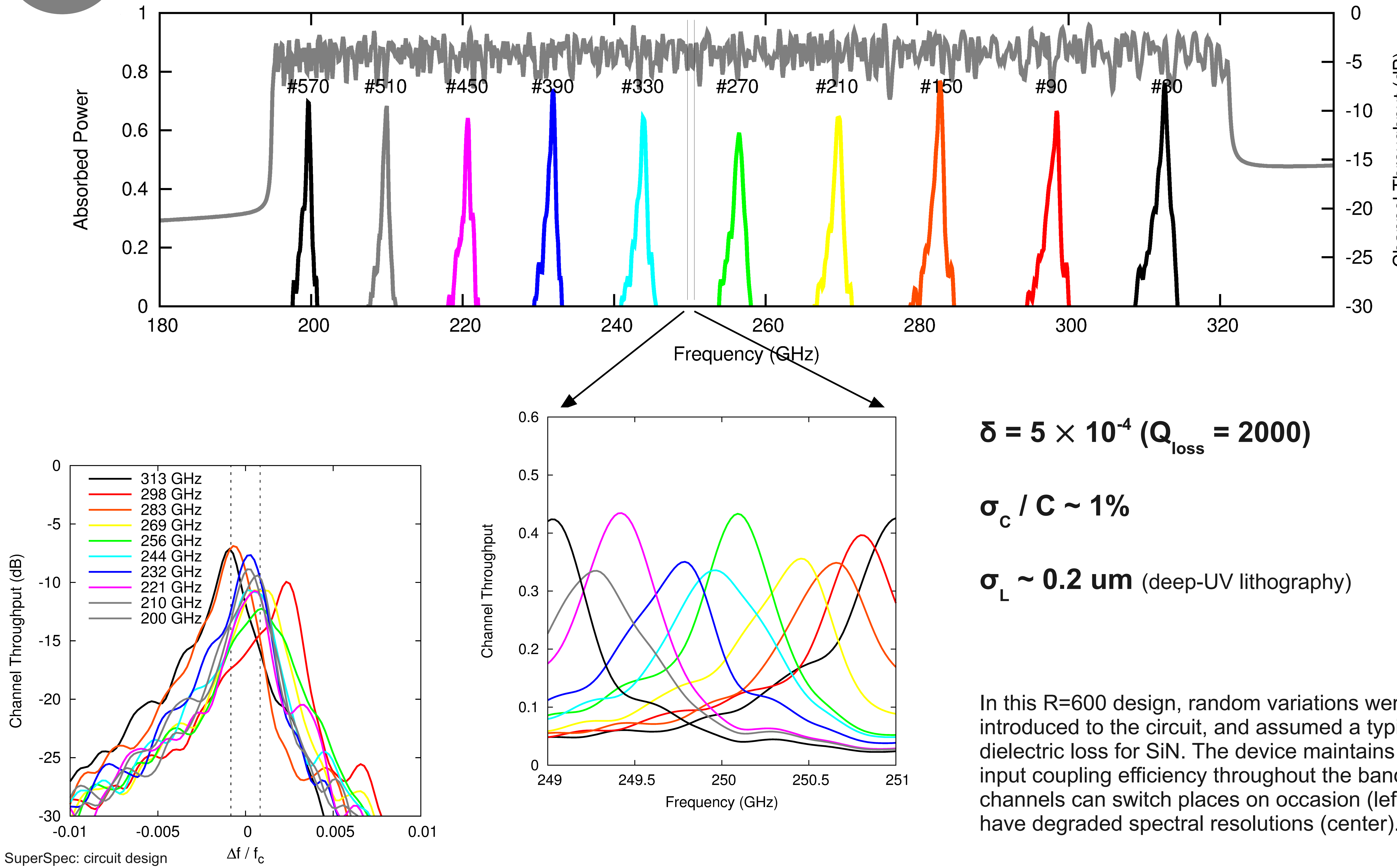






Below: Cross-talk between channels can be reduced with a 2nd resonator stage (left and center). It also allows increasing the absorbing length for the detector (e.g. MKID), if necessary, by making the 2nd resonator longer (right panel).

7 What to expect: imperfect devices



$\delta = 5 \times 10^{-4}$ **(Q_{loss} = 2000)**

σ_C / C ~ 1%

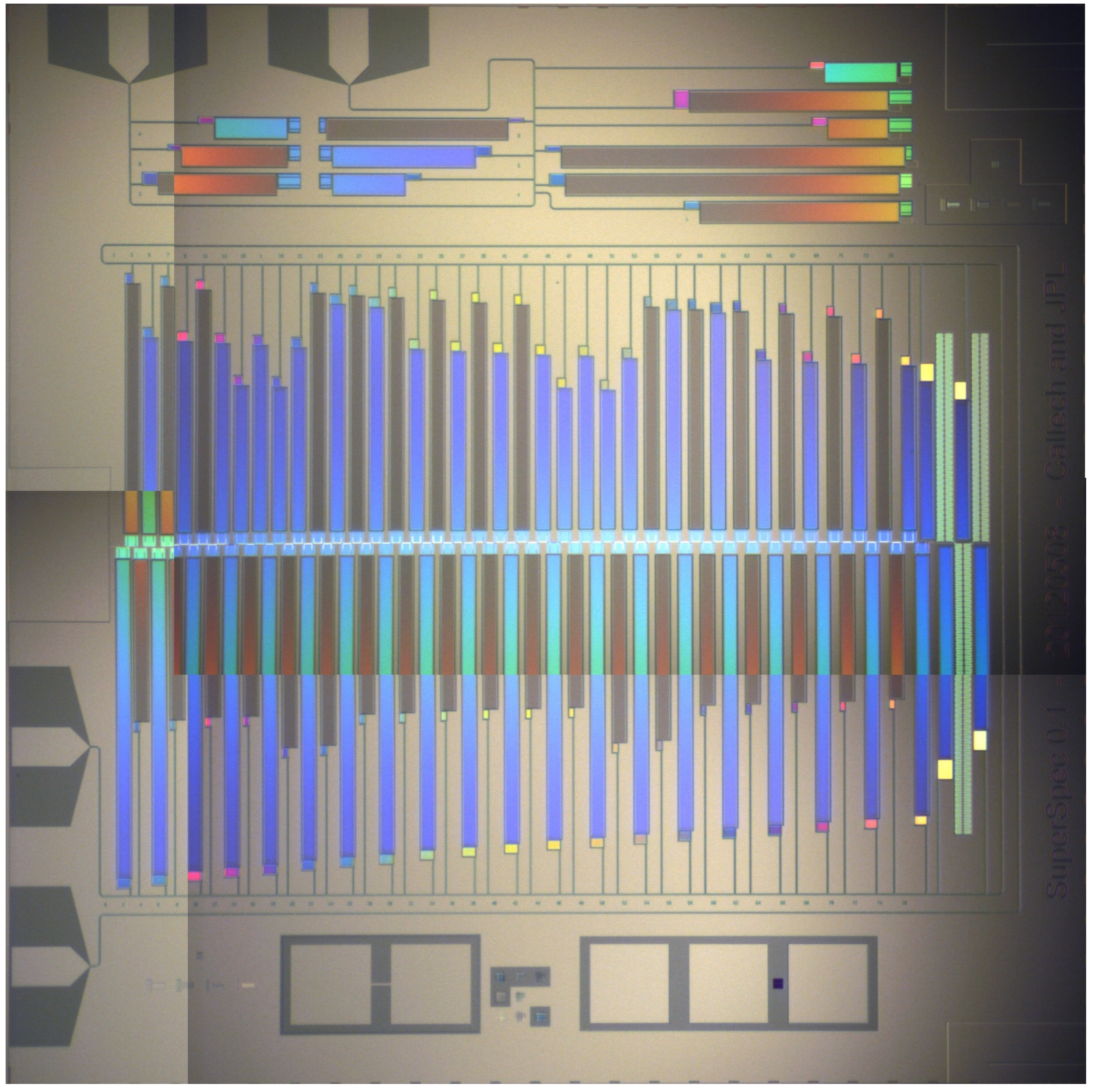
σ_L ~ 0.2 um (deep-UV lithography)

In this R=600 design, random variations were introduced to the circuit, and assumed a typical dielectric loss for SiN. The device maintains good input coupling efficiency throughout the band, but channels can switch places on occasion (left), or have degraded spectral resolutions (center).

SuperSpec: circuit design

8 Conclusions

- An R=300 to R=600 spectrometer is possible with typical transmission line losses and fabrication tolerances.
- An octave-wide channelizer can fit within ~1mm^2, a small fraction of an Fλ pixel in the mm-band.
- Filter structure works with any power detector (bolometer or MKID).
- Sampling with 2 – 3 channels per resolution can be ~100% efficient.
- Couplings must be accurate to a fraction of 1%.
- Lithography must be accurate to <0.5μm between nearby resonators.
- A second resonator can improve channel profiles, reduce cross-talk, and provide more space to absorb power into the detector (bolometer or MKID).



A mosaic image of a test device under the microscope...