CR Stochastic Cooling System: RF Components, Electrode Design

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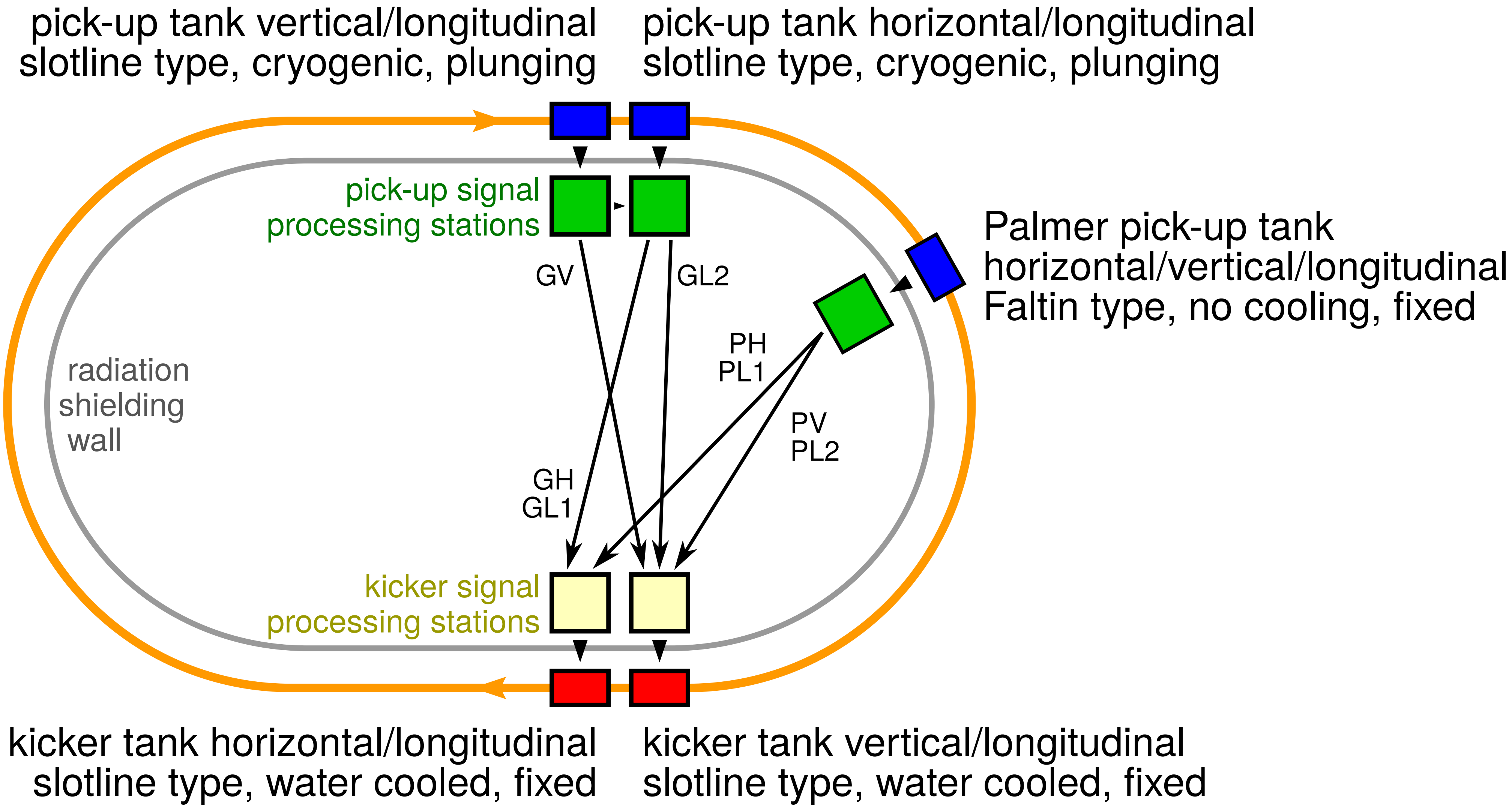
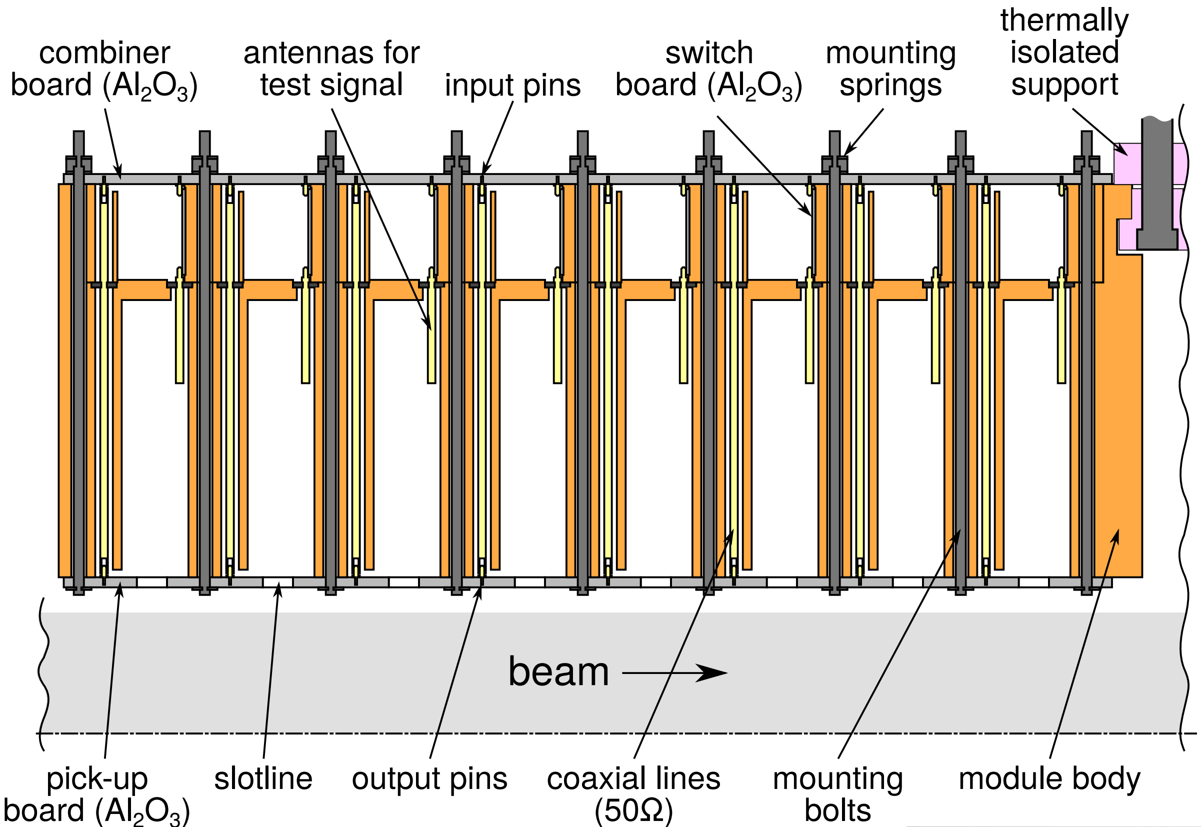
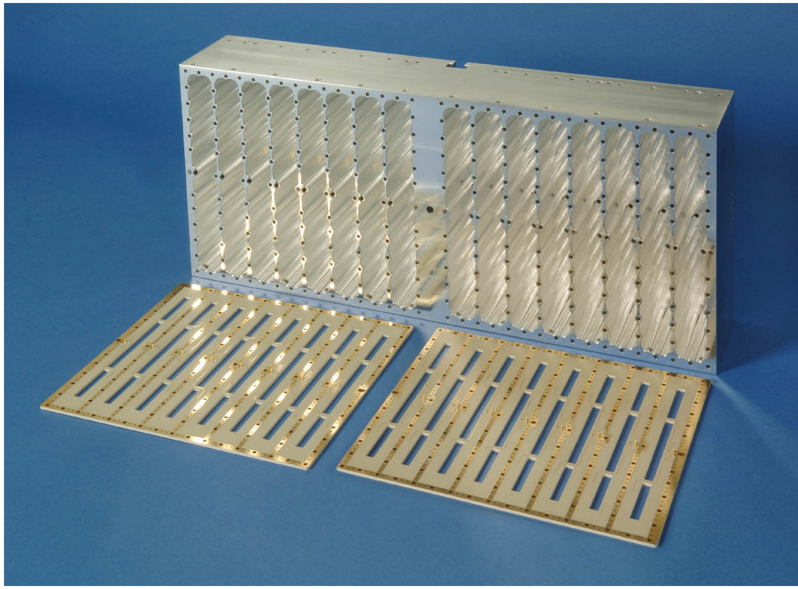
CR Stochastic Cooling Systems



Pick-up Module PU17

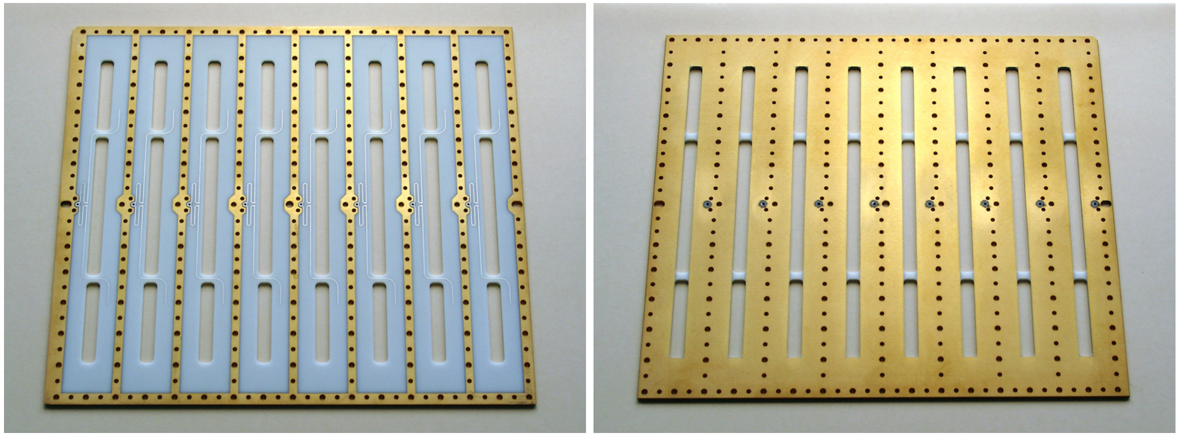


cross-section in the middle of a pick-up module



pick-up module body with two pick-up boards (Rogers TMM10i base material)

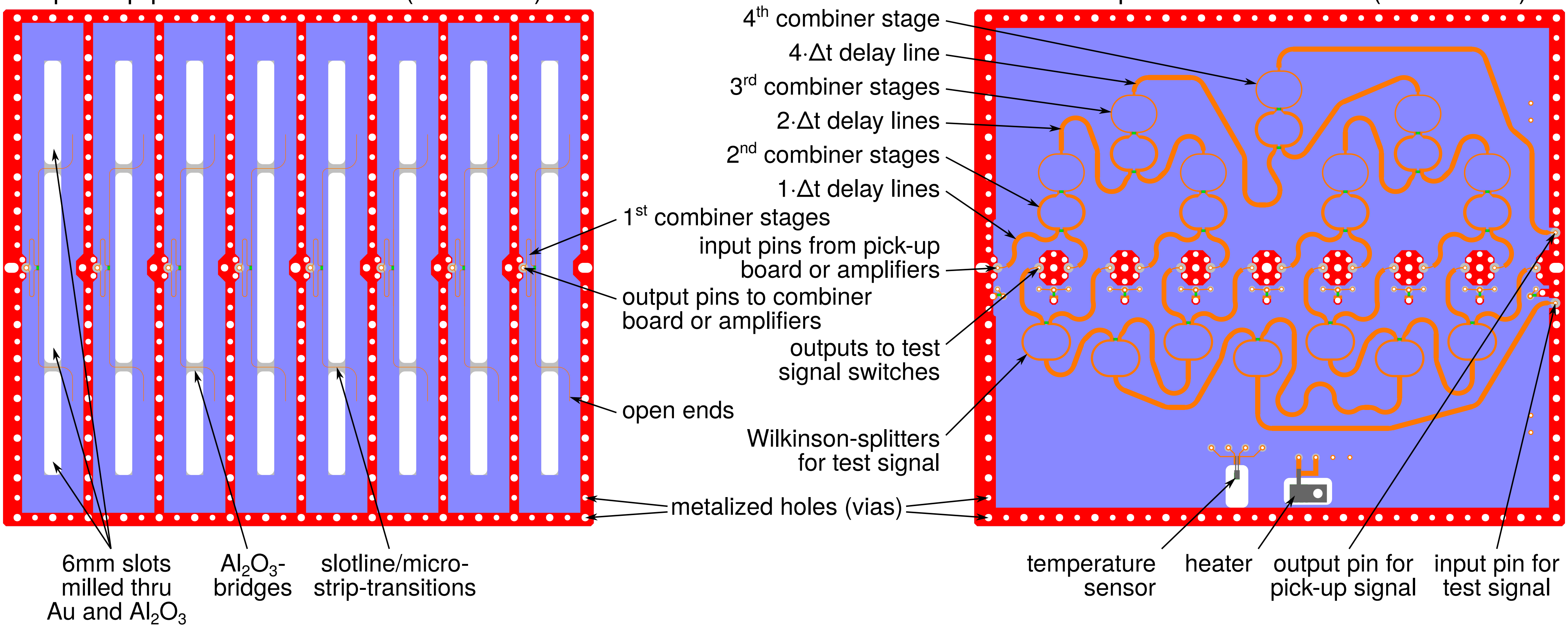
- two pick-up boards and two combiner boards mounted to a double module body
- test signal can be injected into each slotline for testing without beam
- pick-up/combiner boards: 1.905mm Al_2O_3 ceramic
- eight test signal switch boards: 635µm Al_2O_3 ceramic
- 2 sides · 8 modules · 8 slots = 128 slots/tank



pick-up board (Al_2O_3 ceramic) Au: sputtered, Ag: silk printed

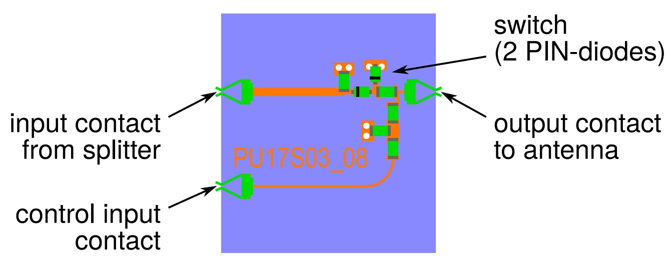
Pick-up Module PU17 PCBs

pick-up printed circuit board (PU17P02) combier printed circuit board (PU17C02L)



- 6mm wide, 146mm long slotlines for beam coupling with high impedance, flat frequency response, and large beam aperture
- two slotline/micro-strip-transitions per slot
- first signal combiner on pick-up pcb
- 8:1 combiner with fixed delays on combiner pcb
- delay lines calculated for pbars (β=0.97)
- simple robust test signal switch on thin pcbs

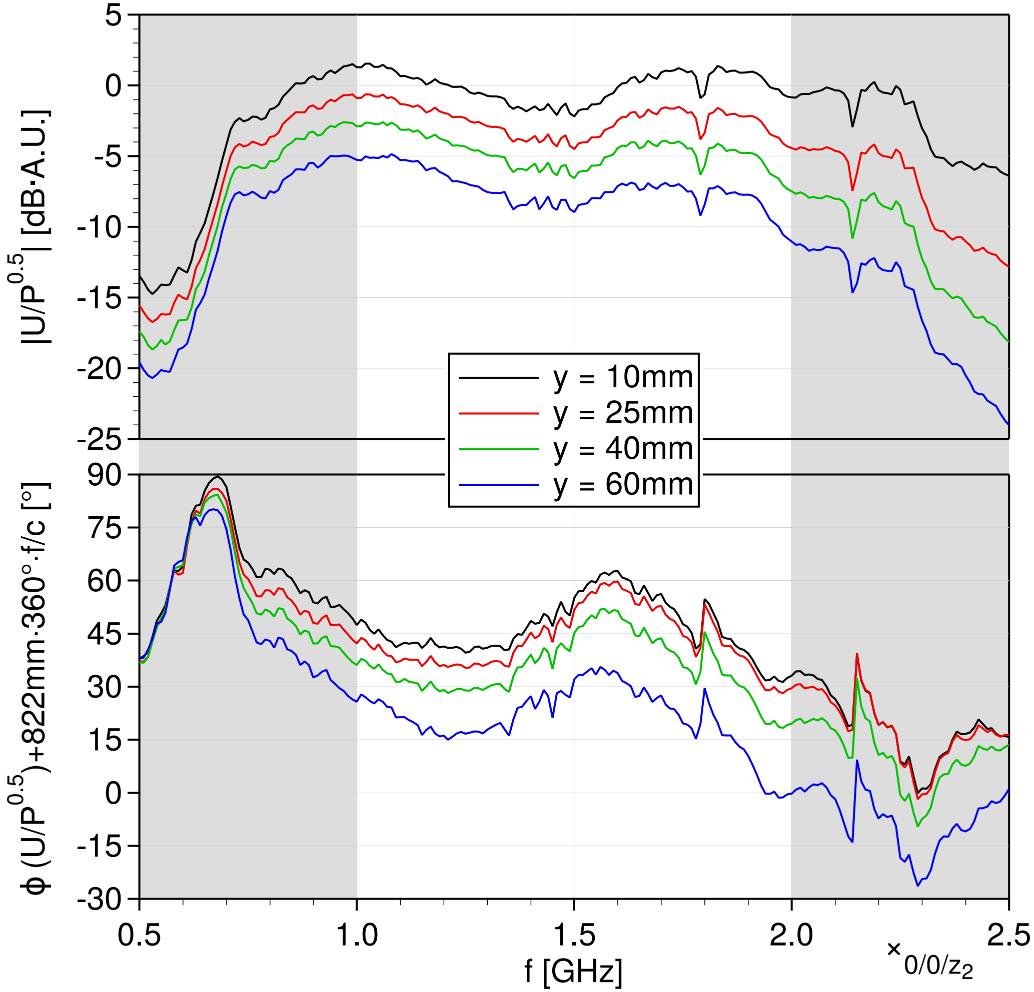
test signal swtich pcb (PU17S03, 635µm Al_2O_3)

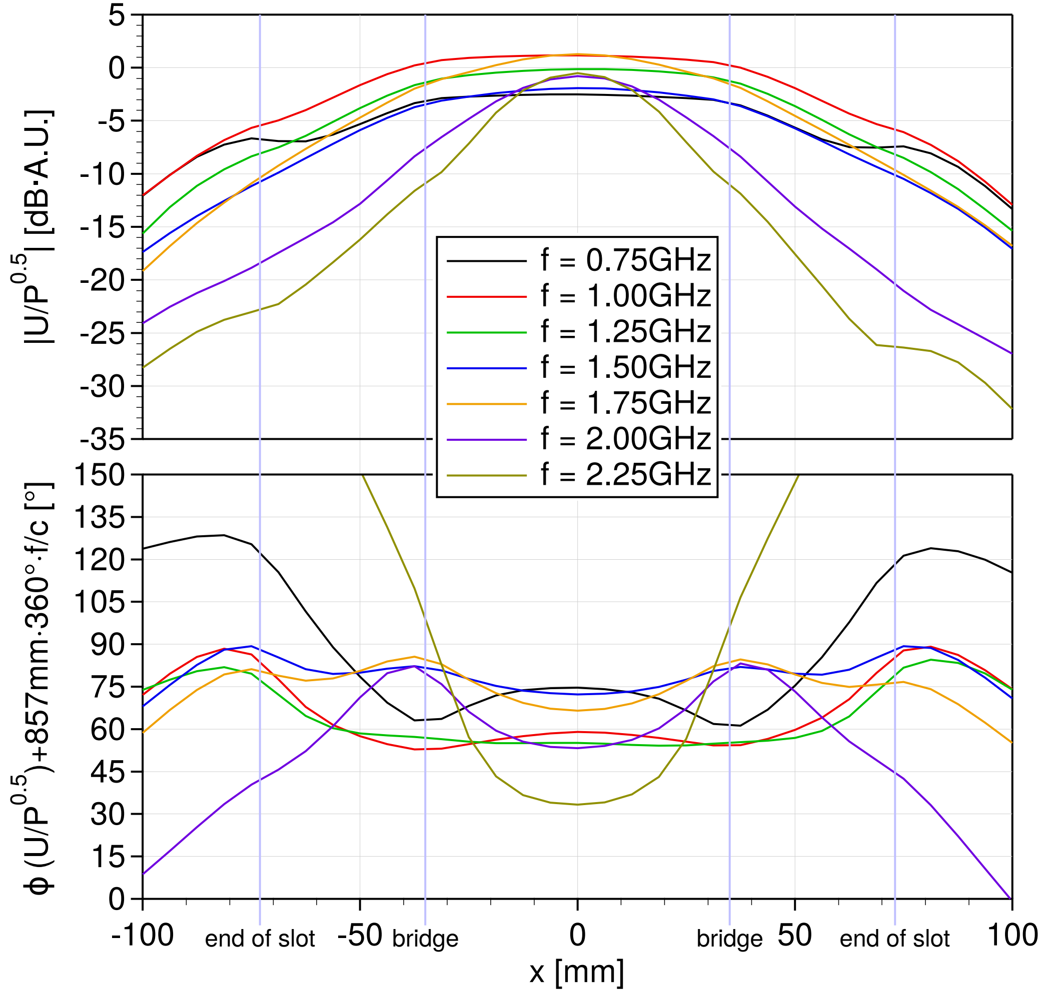


layers:

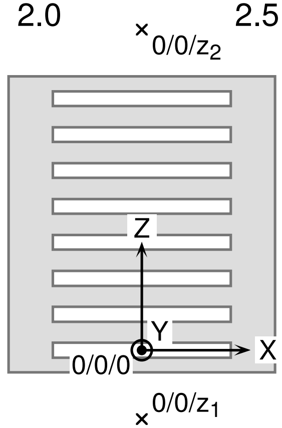
- Ag signal layer
- Au contact layer
- Al_2O_3 ceramic (base material)
- Au ground layer

Pick-up Module PU17 Measurements



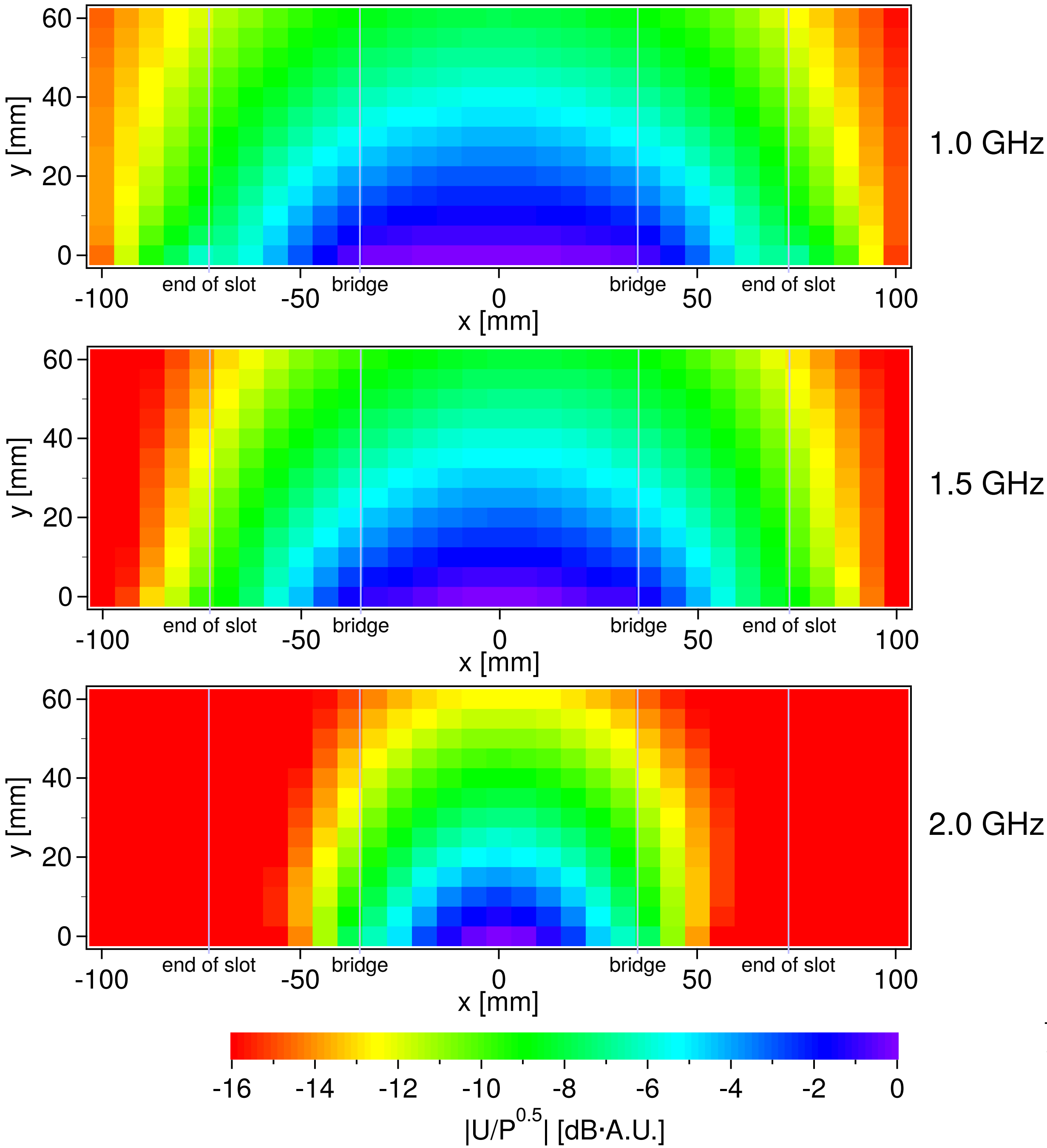


$$\frac{U}{\sqrt{P_V}} \sim \int_{z_1}^{z_2} S_{21}(z) \cdot e^{i\frac{\omega}{\beta \cdot c} \cdot z}\, dz$$



- port 1: output of combiner board PU17C03
- port 2: dipole near field probe above center of pick-up board PU17P03
- all cables and frequency dependencies of probe are calibrated out
- origin (x=0/y=0/z=0) is on surface of pu board in the center of slot 1

Pick-up Module PU17 Measurements

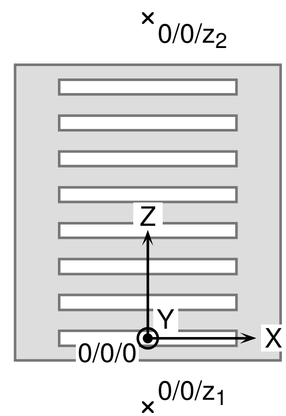


- complete pick-up module for the CR with all electrical and mechanical aspects has been designed
- first prototype has been built up (TMM-10i pcb material)
- field measurements show a good behavior of sensitivity and phase linearity versus frequency and displacement

problems:

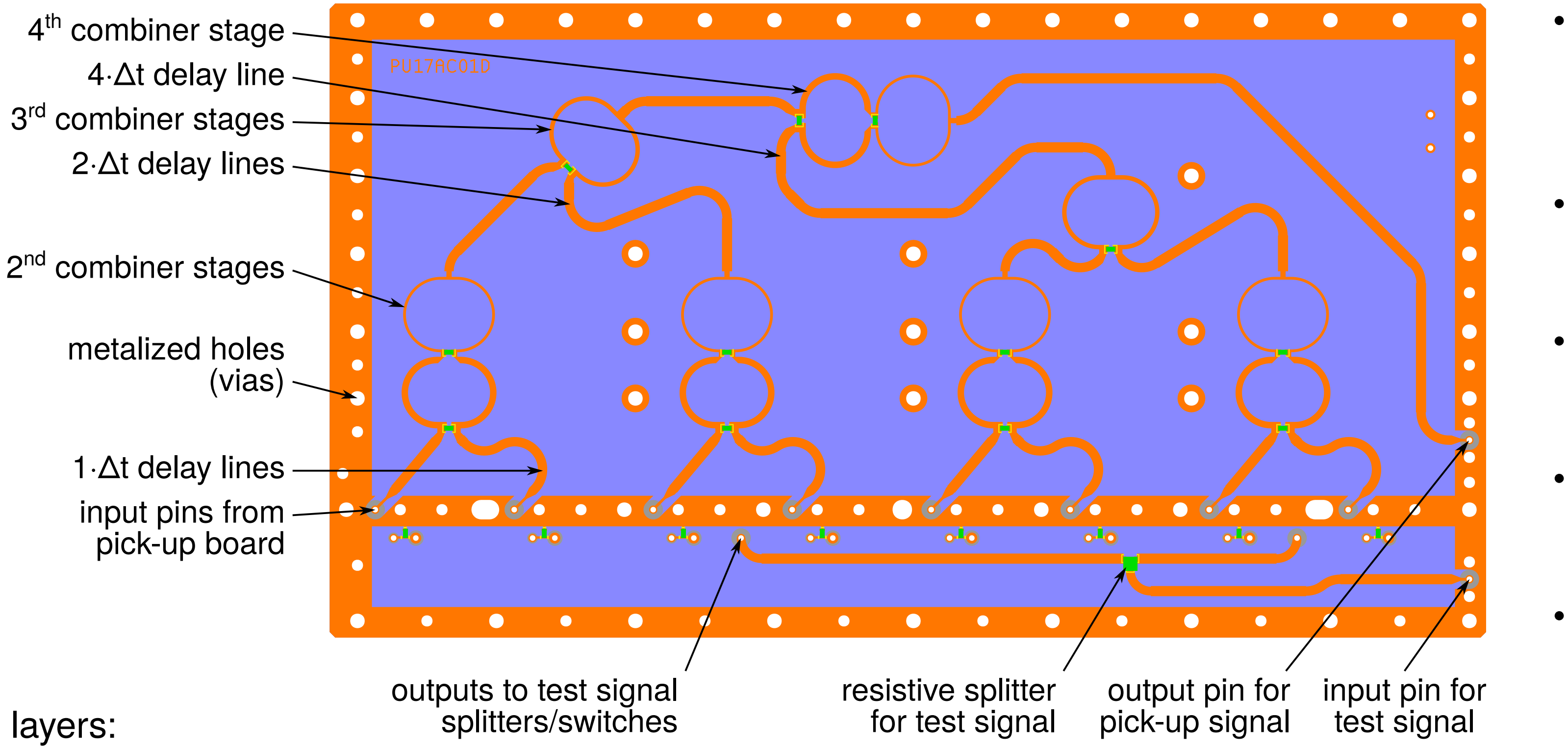
- resonances at 1.8GHz and 2.15GHz
  → modification of mounting springs
- coupling between test signal and pick-up signal in the combiner compartment too high
  → shielding wall between both sides
- thick Al_2O_3 boards are very expensive
  → alternate manufacturer or design
- probably not suitable as kicker structure (up to 40W/slot, 190µm microstrip lines)
  → alternative design for kicker

$$\frac{U}{\sqrt{P_V}} \sim \int_{z_1}^{z_2} S_{21}(z)\cdot e^{i\frac{\omega}{\beta\cdot c}\cdot z}\,dz$$



Pick-up Module PU17A

combier printed circuit board (PU17AC01D, 1.91mm Al_2O_3)

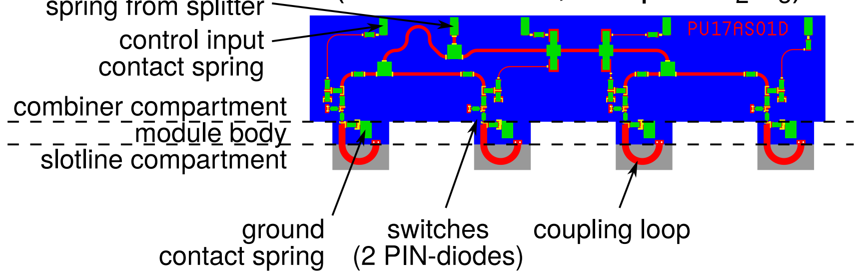


- continuous shield between signal combiner and test signal splitter
  → lower unwanted coupling
- larger distance between microstrip lines
  → potentially lower ripple
- resistive splitter instead of Wilkinson for test signal
  → less ripple and smaller
- temperature sensor and heater not part of this pcb
  → avoid difficult mounting
- smaller pcb with less number of holes (vias)
  → cheaper

layers:

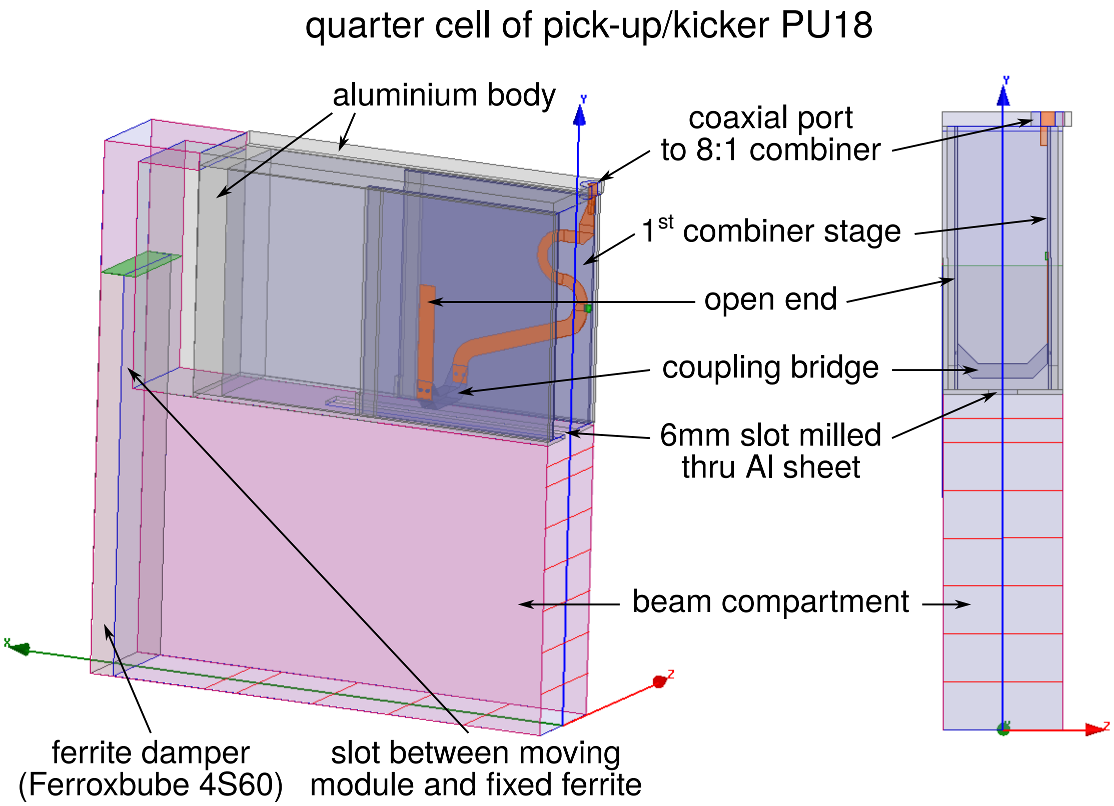
- glass solder resist
- Ag signal layer
- AgPt signal layer (switch PCB)
- Al_2O_3 ceramic (base material)
- Au ground layer (combiner)
- AgPt ground layer (switch PCB)

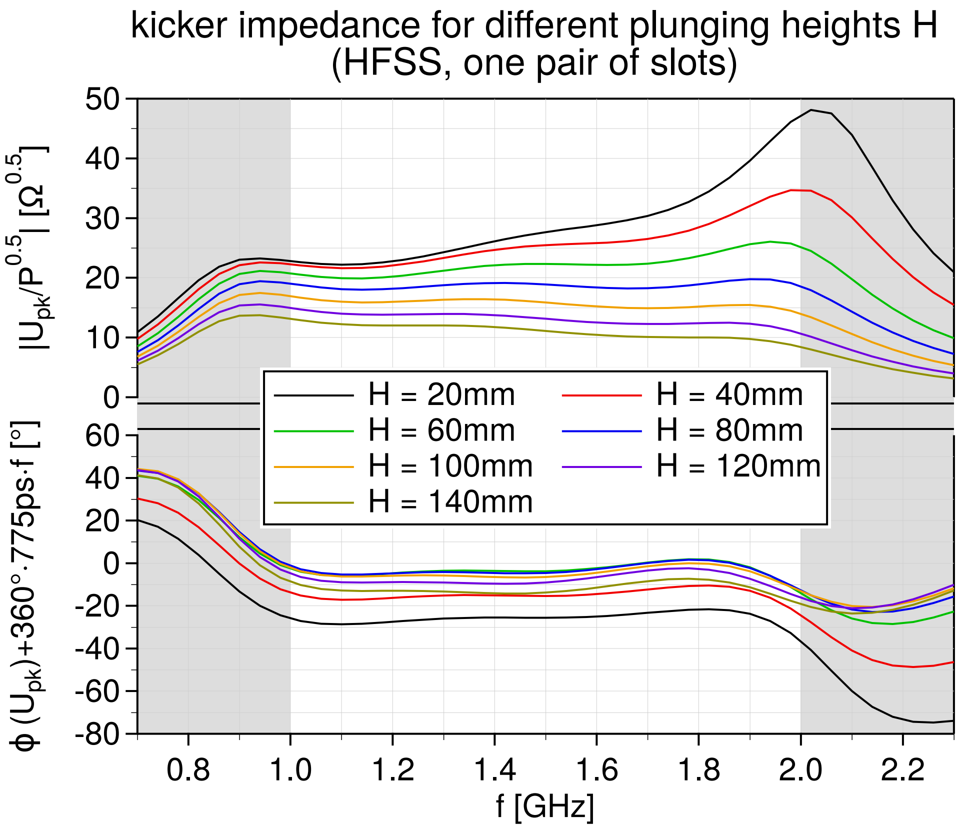
splitter/switch pcb
(PU17AS01D, 635µm Al_2O_3)



- coupling loops instead of coupling antennas
  → mecanically more simple and robust better flatness
- resistive splitter 1:4
  → less ripple and smaller
- two larger pcbs instead of eight small pcbs
- more robust contact springs

Pick-up/Kicker Electrode PU18

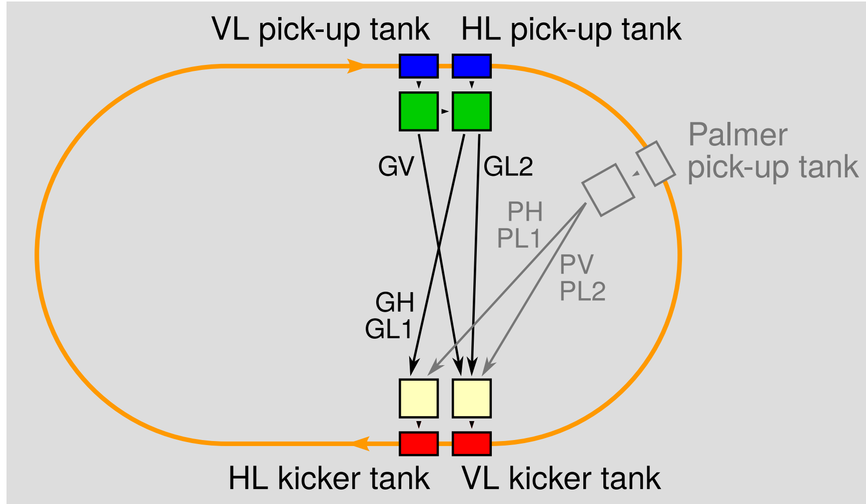


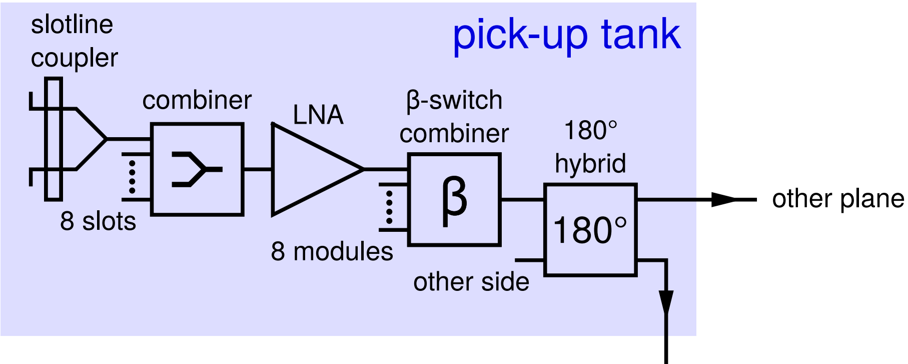


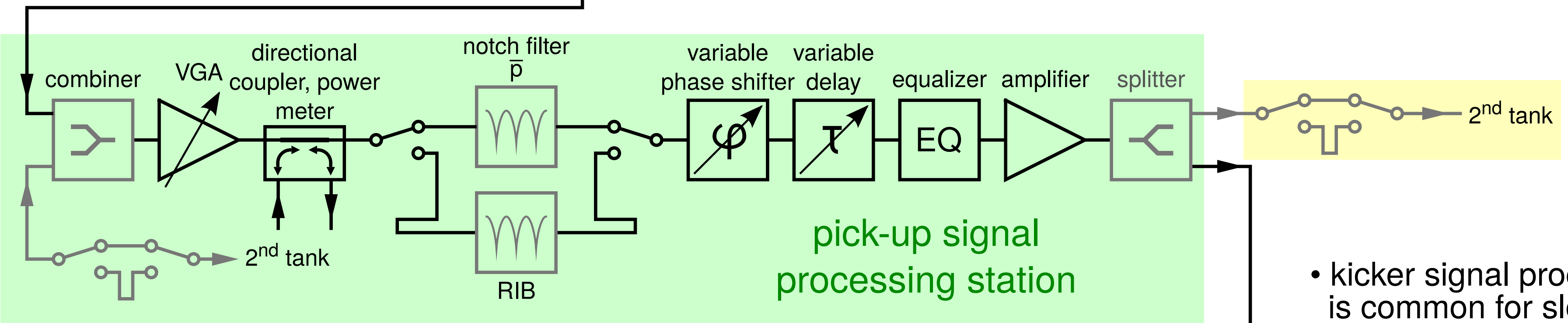
- suspended ground microstrip lines instead of normal microstrip lines
  → lower effective dielectic constant → larger structures, lower losses
  → thin (635µm) instead ot thick (1.905mm) Al_2O_3 ceramic → many potential manufacturers, much cheaper
- first HFSS calculations only, no hardware, no measurements
- comparable performance expected, in terms of bandwidth, sensitivity/phase flatness, width, and impedance
- could be an alternative in case of fabrication problems (ceramic) or problems at high power (kicker)

Signal Processing for Slotline Pick-ups

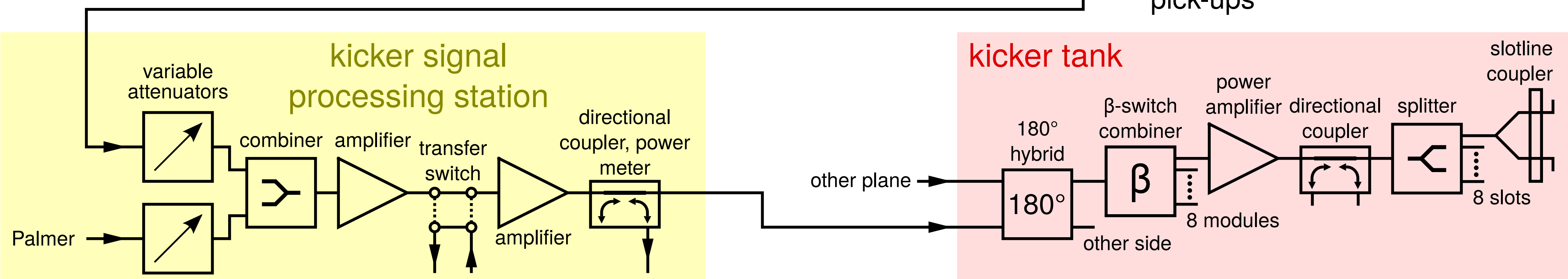
- for each signal processing path (longitudinal, horizontal, vertical)
- grayed components are only present in the longitudinal path
- some intermediate amplifiers and attenuators not shown
- longitudinal path: notch filter cooling or TOF cooling



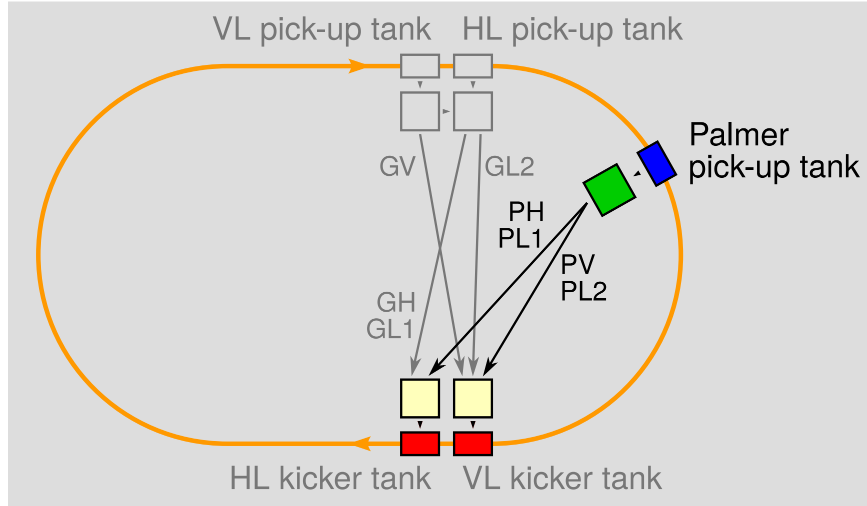


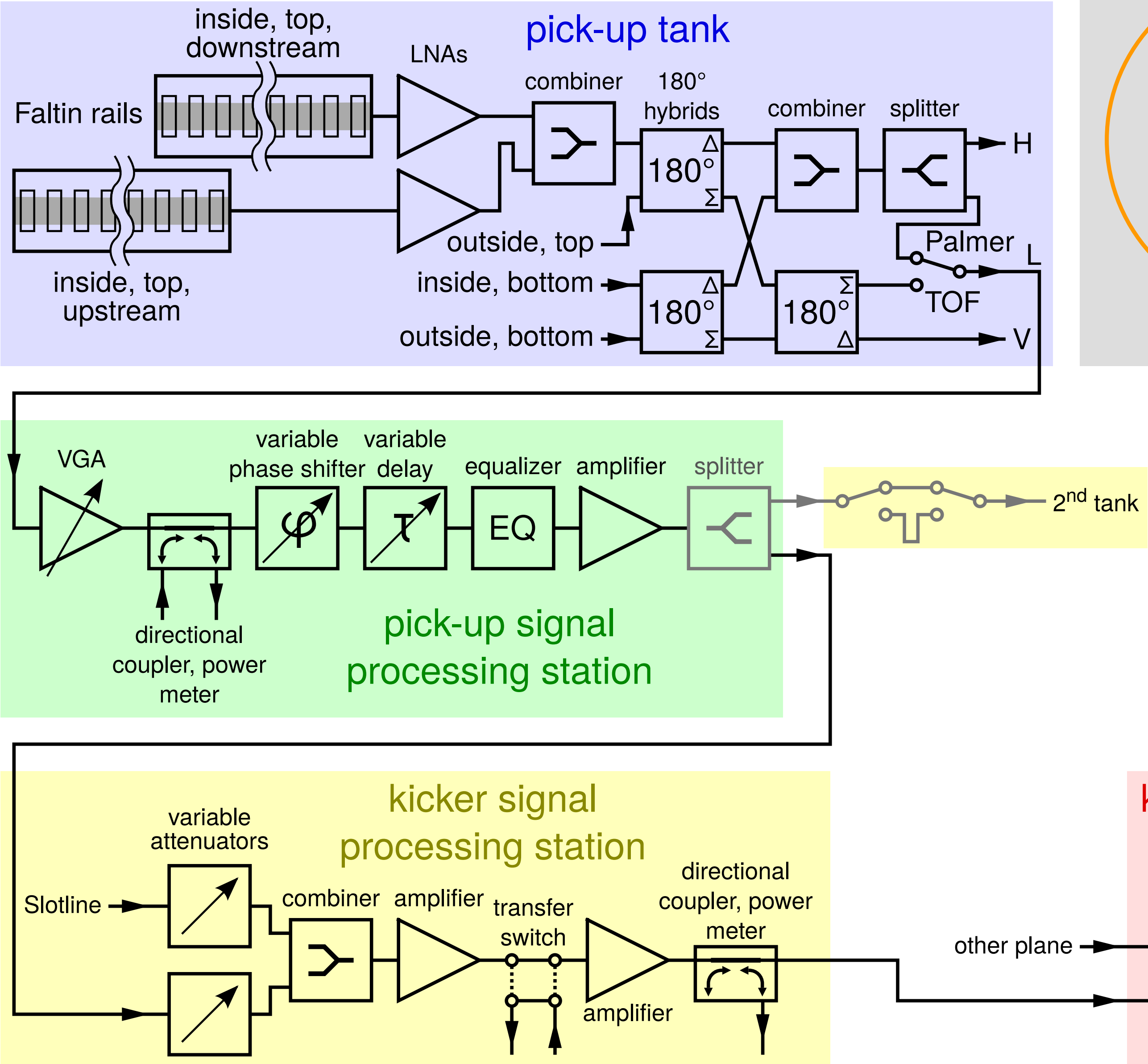


- kicker signal processing and tank is common for slotline and faltin pick-ups

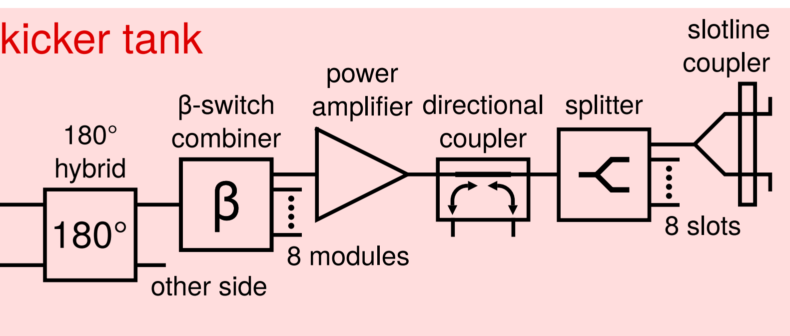


Signal Processing for Faltin Pick-up





- signal processing behind pu-tank for each path (longitudinal, horizontal, vertical)
- grayed components only in longitudinal path
- some intermediate amplifiers and attenuators not shown
- longitudinal path: palmer cooling or TOF cooling
- kicker signal processing and tank is common for slotline and faltin pick-ups

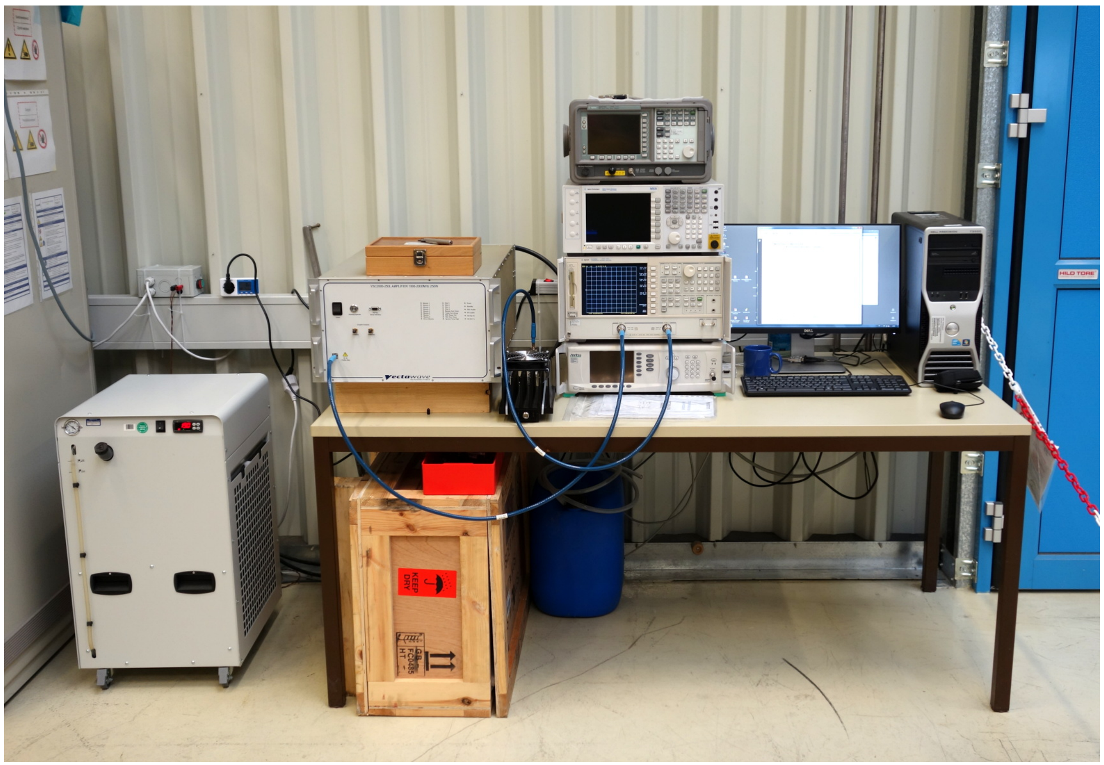


Power Amplifier

requirements:

- highly linear class A nominal 250W water cooled 1-2GHz amplifier
- gain flatness ≲±1dB, phase flatness ≲±10°
- 1dB compression point ≳54dBm, 3^{rd} order intercept point ≳64dBm
- reflection factors ≲-9.5dB at input and ≲-13dB at output
- signal delay ≲16ns
- non-problematic out-of-band behavior (no gain with wrong phase)
- internal power supply, input connector SMA, output 7-16
- remote control: on/off/standby (RS-422)
- remote diagnostic: on/off/standby temperature, drain current limit
- internal directional coupler at output for diagnostic

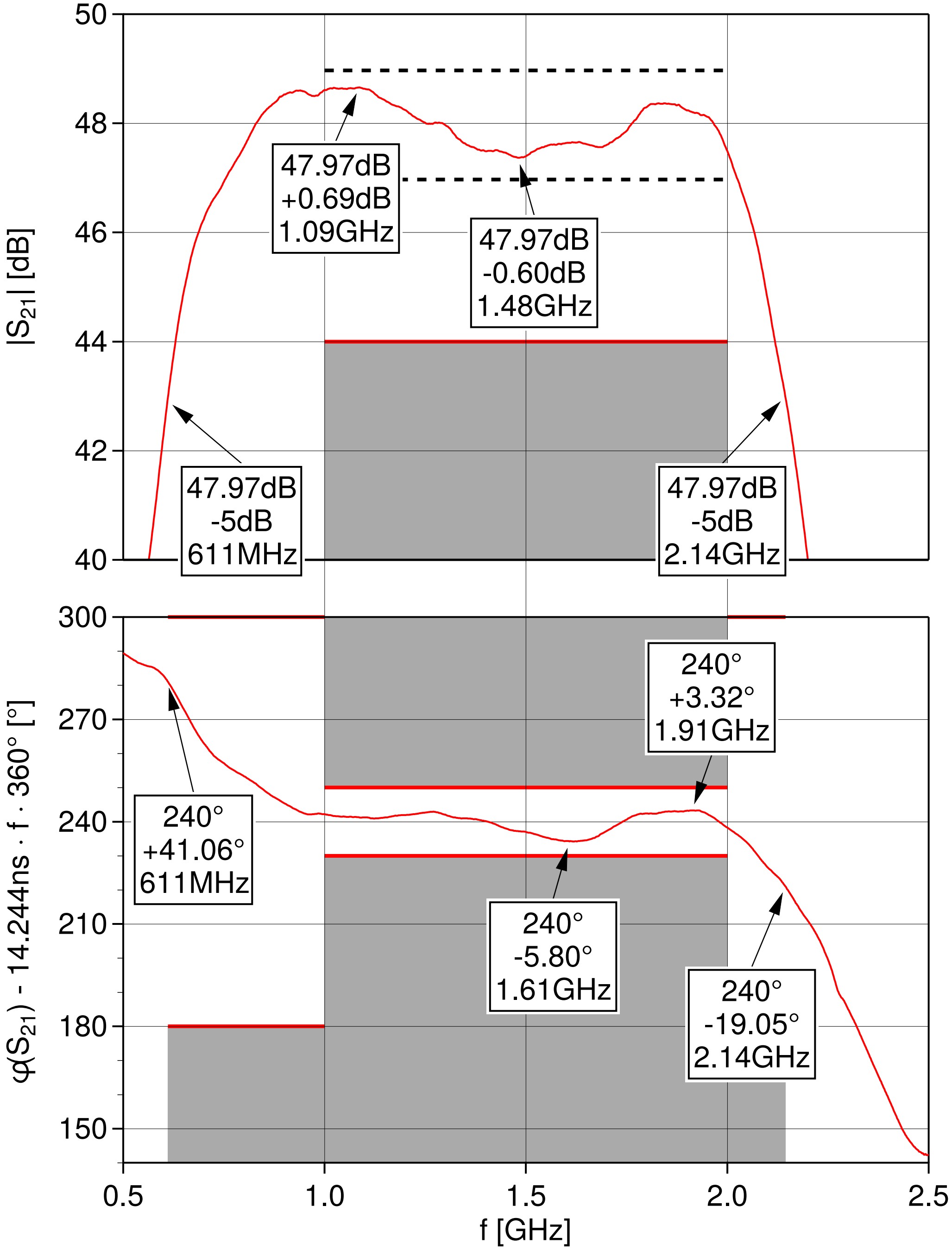
→ prototype fulfills requirements (SAT), series production ordered

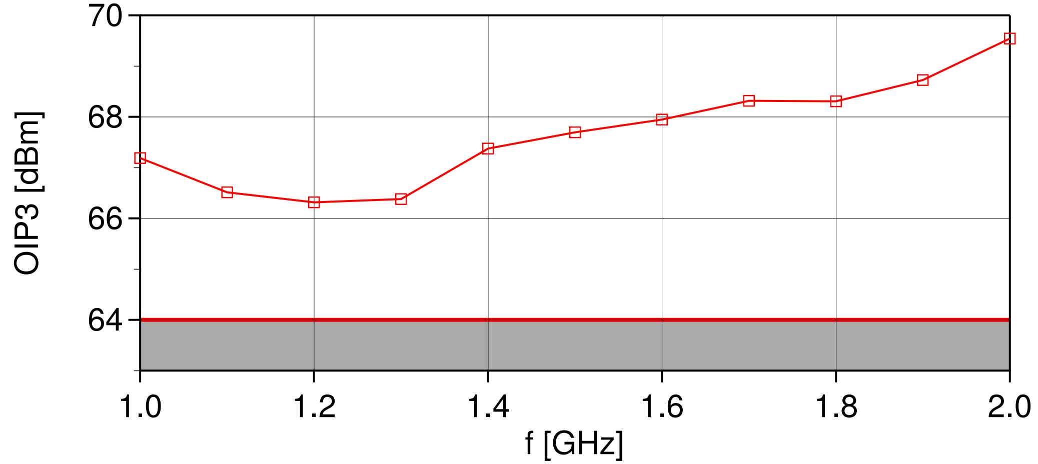


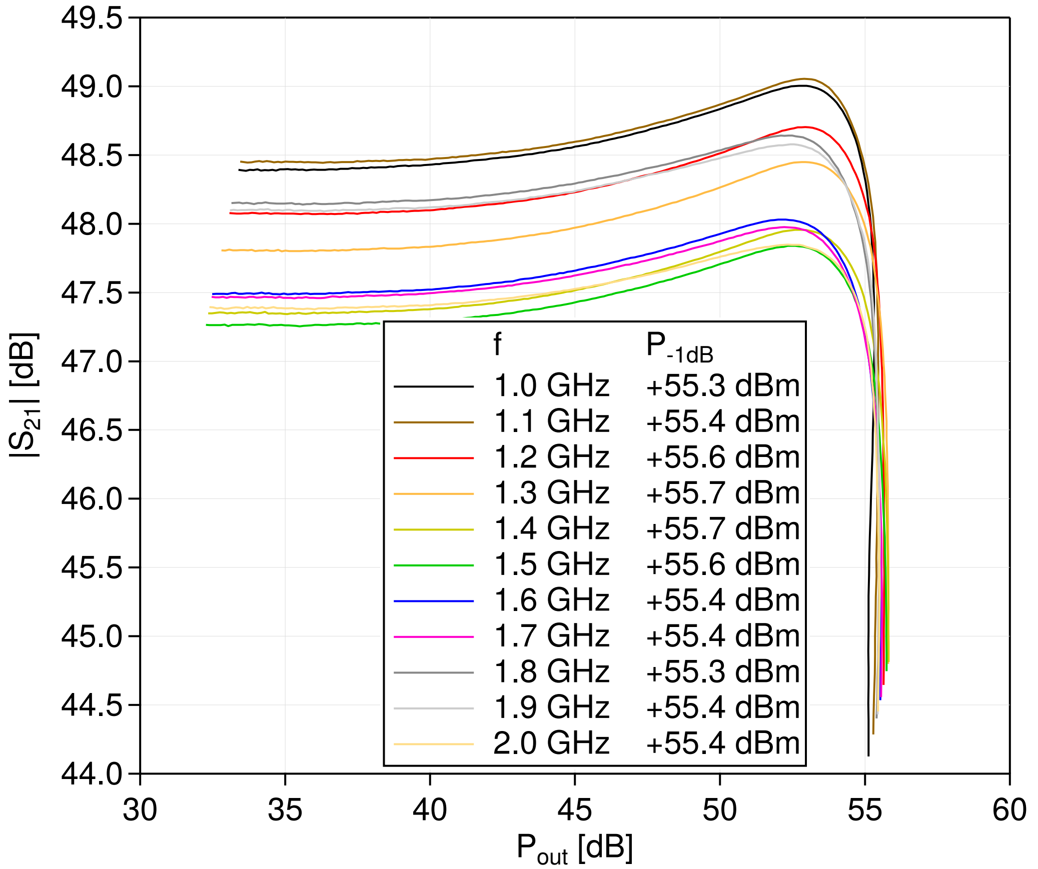
intake control/measurements for prototype and series:

- test bench with automated measurement program
- test equipment: recirculating water chiller, network analyser, 2^{nd} RF generator, spectrum analyser, noise figure analyser, RF power meter (not in picture), 500W load, directional coupler, and a lot of small parts
- first measurements: all S-parameters (0.5-2.5GHz), compression points, 3^{rd} order intercept points, noise figure, spurious products, directional coupler coupling, power consumption, power factor,
- long time test: gain/phase at alternating output power, cw frequency, and water temperature, four weeks for prototype and random sample of series, one week for the rest
- test protocol automatically generated by program

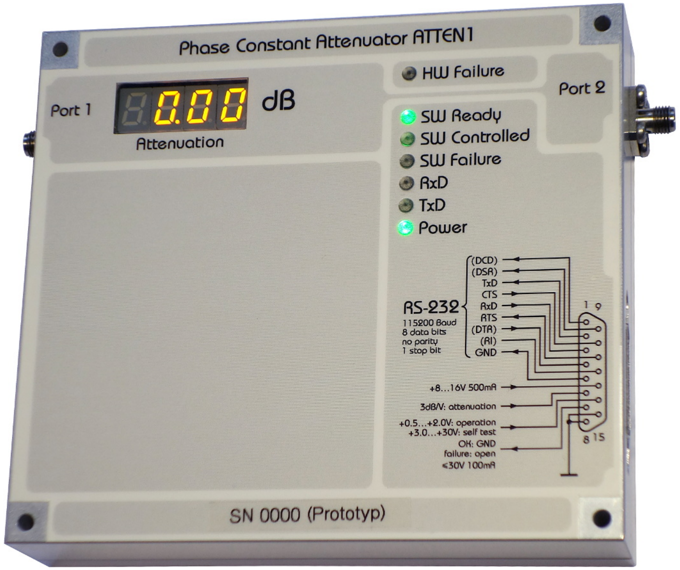
Power Amplifier Measurements

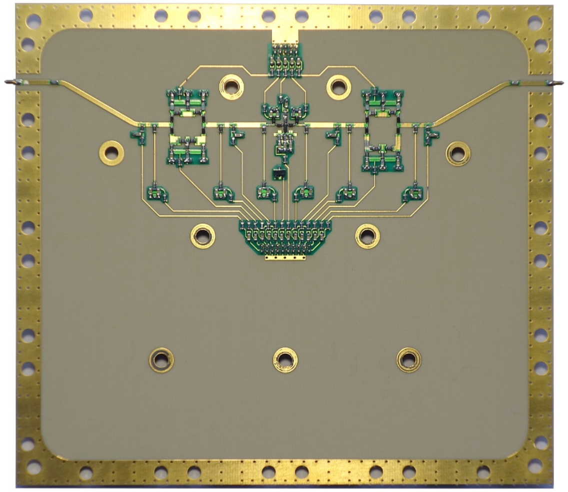






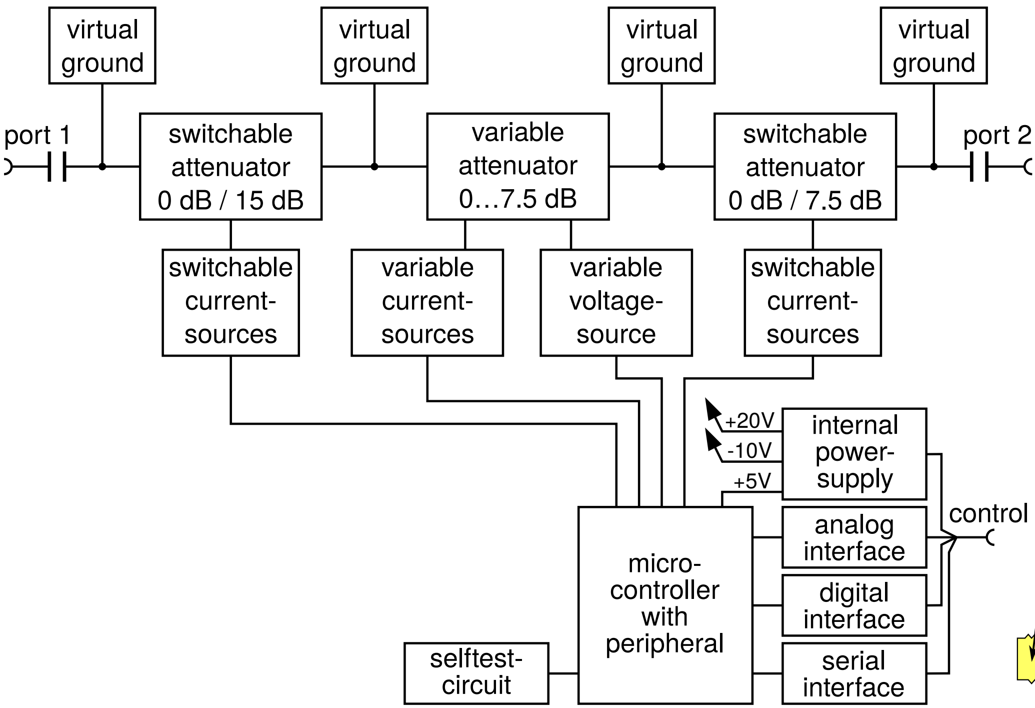
Variable Attenuator



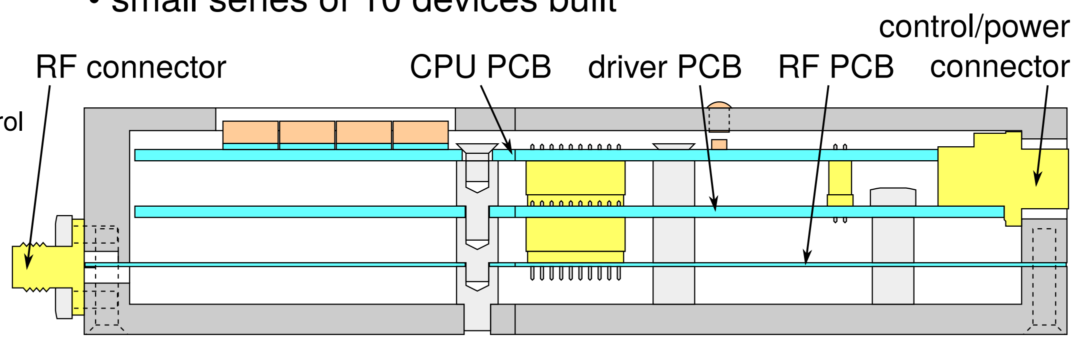


requirements:

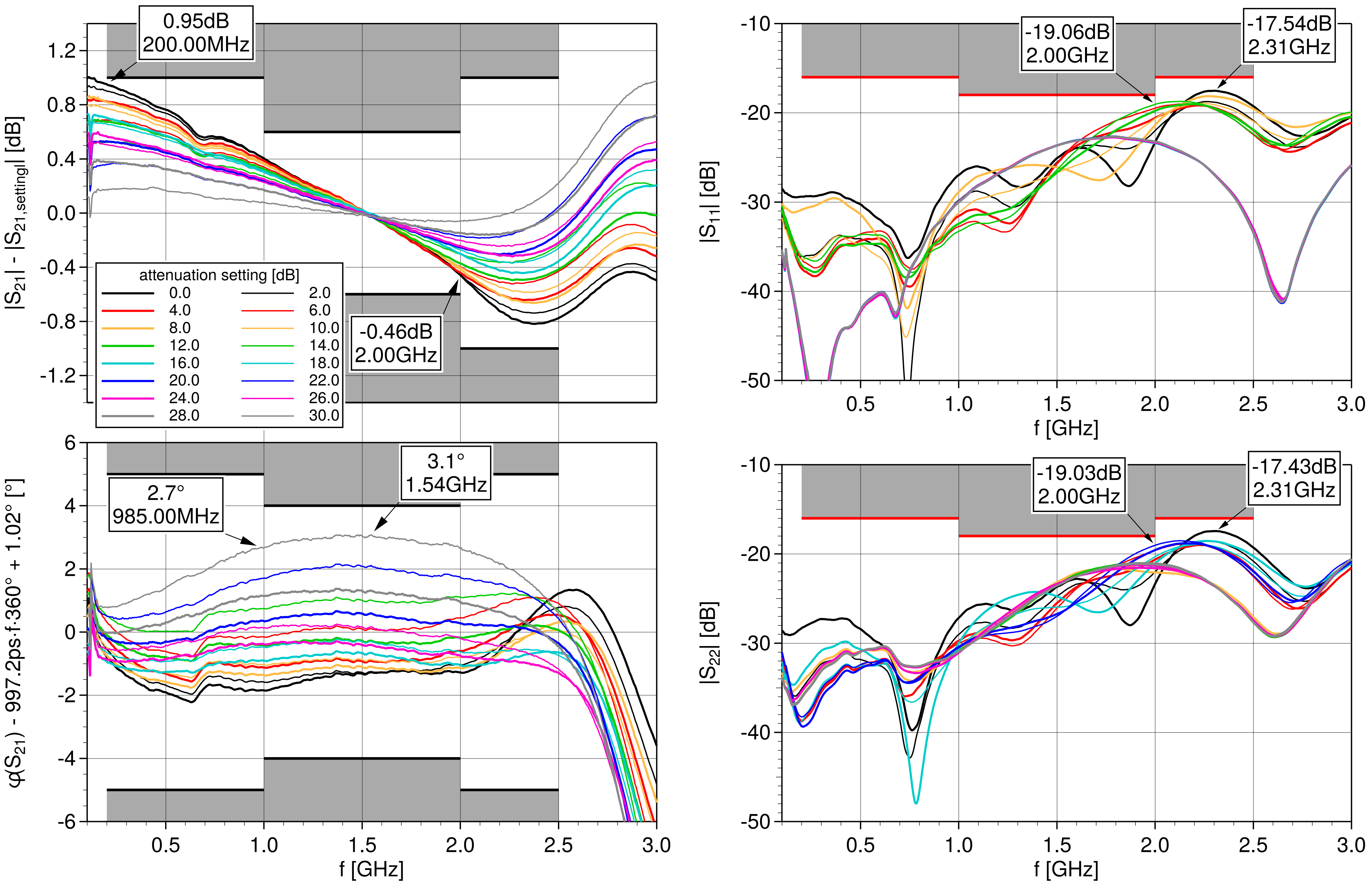
- phase constant variable attenuator 1-2GHz
- rampable without glitches to lower attenuation
- low phase non-linearity
- absolute attenuation error ≲0,6dB
- mean phase error ≲1.5°
- relative phase error ≲4°
- reflection factor ≲-18dB
- delay 0.96ns-1.02ns
- signal off setting ≲-60dB
- self test capabilities
- RS-232 for slow control and diagnostic
- trigger input for start of ramp



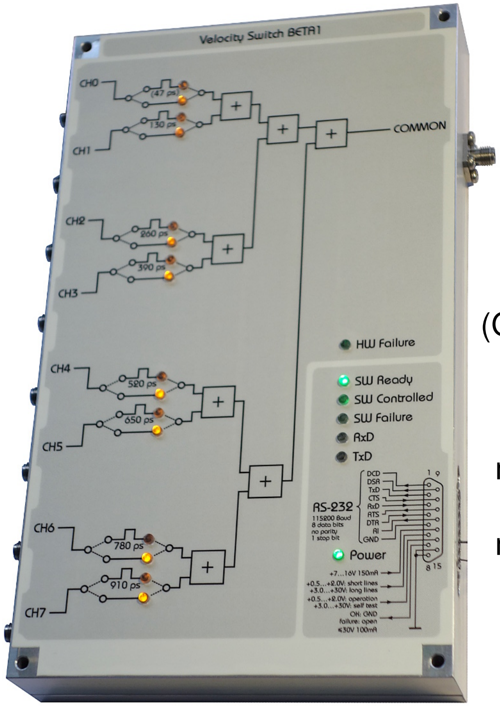
- 2 switchable attenuator stages: PIN diodes, 2 resistor Ts
- 1 quasi-continuous variable attenuator stage: PIN diode T, two varactor diodes for delay compensation
- soft switching voltage and current sources
- microcontoller for control, calibration, and self diagnostic
- nearly continuous shielding between RF and control
- mounted into aluminium split block housing
- small series of 10 devices built

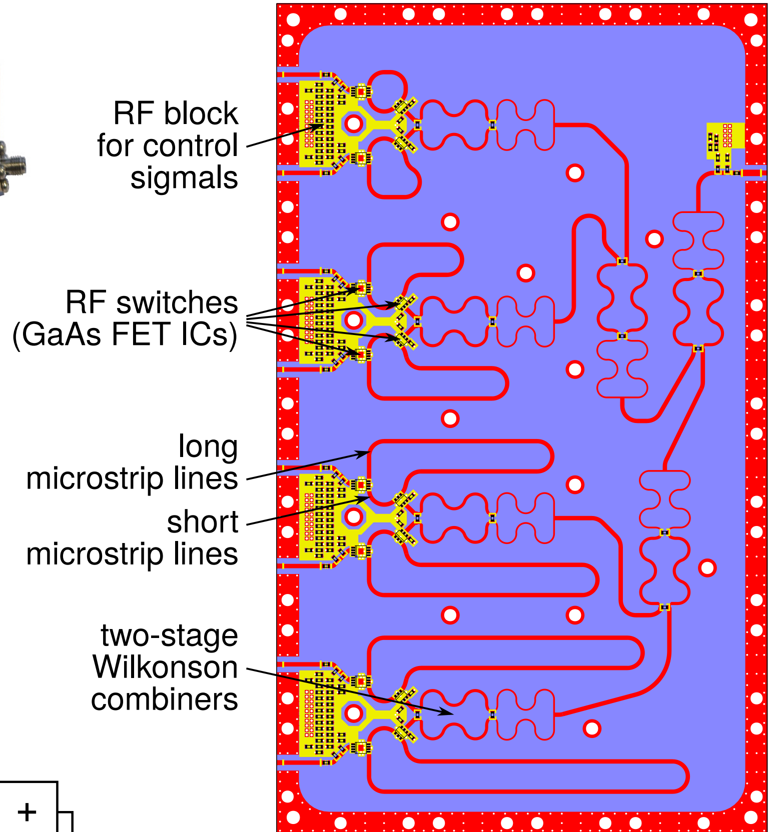


Variable Attenuator Measurements



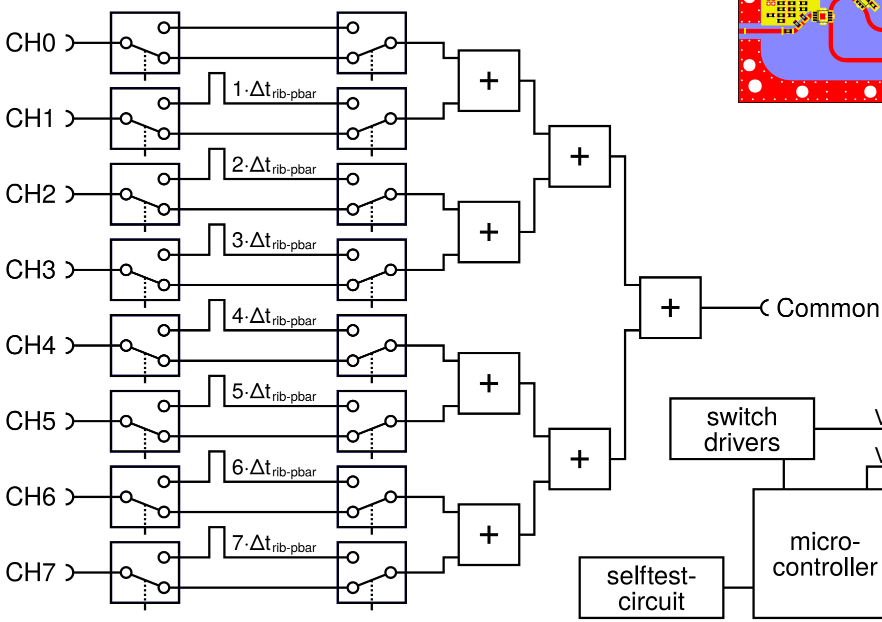
β-switch

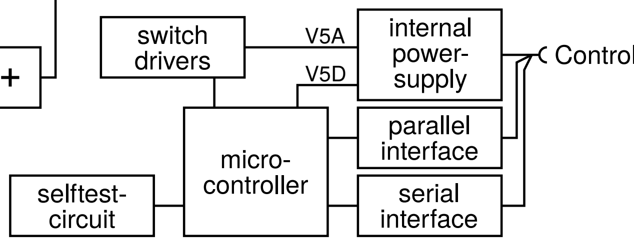


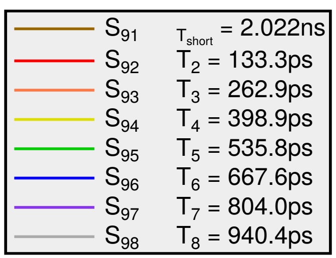


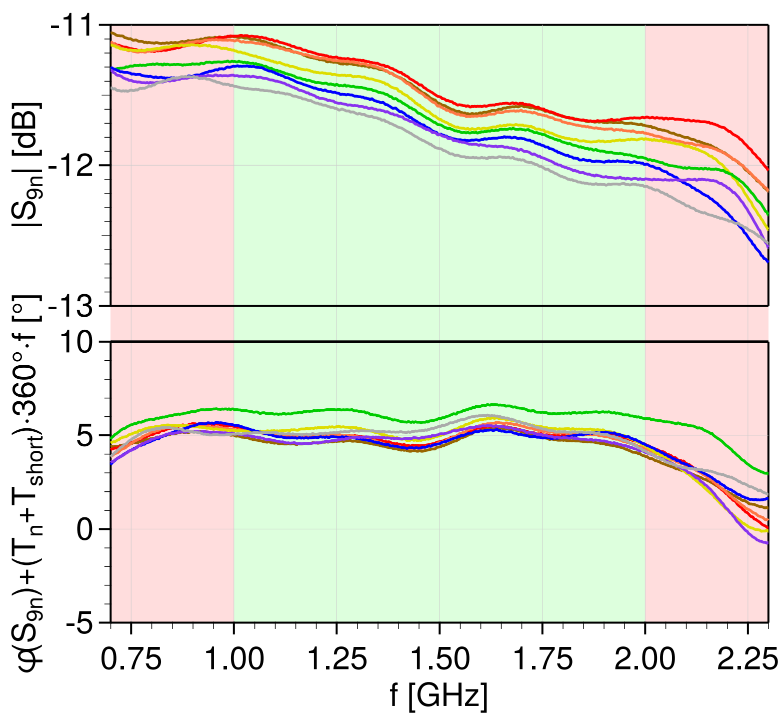
requirements:

- phase correct combination of 1-2 GHz signals from 8 pick-up-modules for pbars (β=0.97) and ribs (β=0.83)
- amplitude flatness ≲±0.6dB
- phase flatness ≲±1.5°
- additional delay ribs 130ps · channel number
- delay error ≲7.5ps
- 1dB compression point (Common) ≳28dBm
- reflection CHn ≲-15dB, Common ≲-12dB
- self test capabilities
- RS-232 for slow control and diagnostic

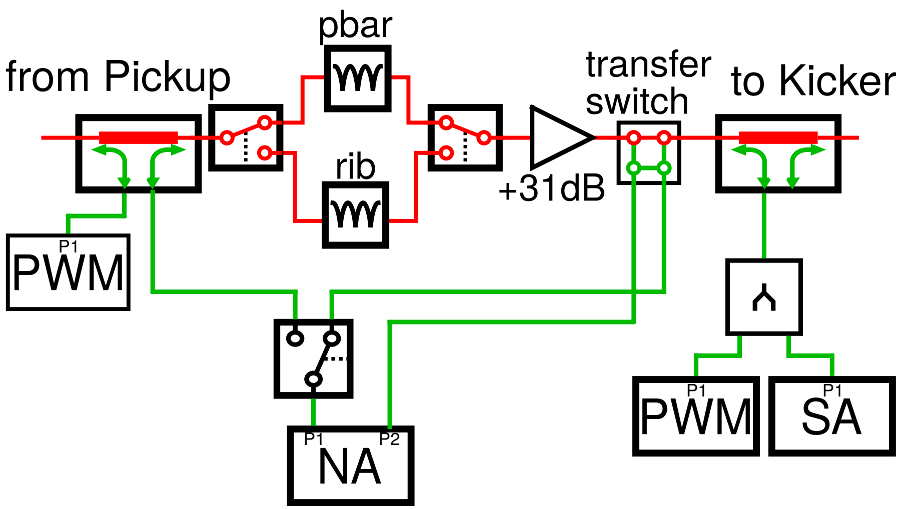






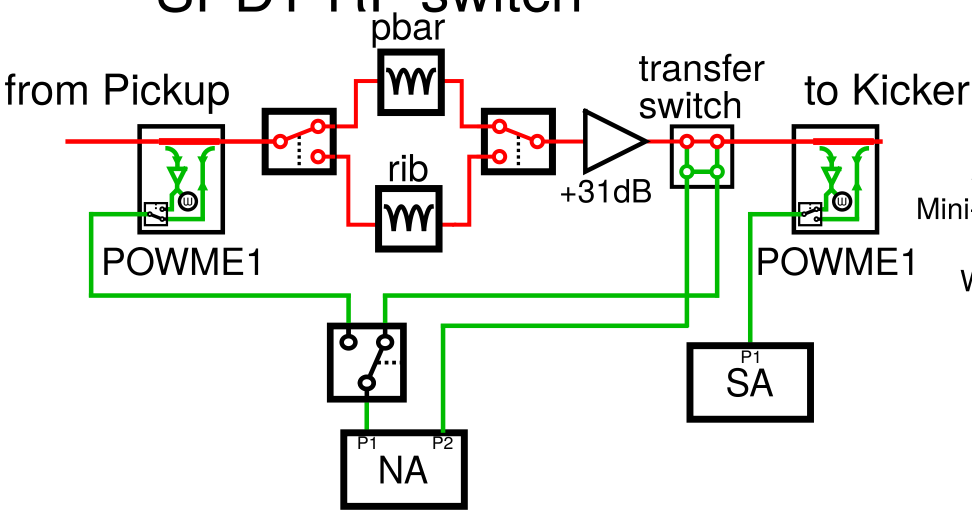


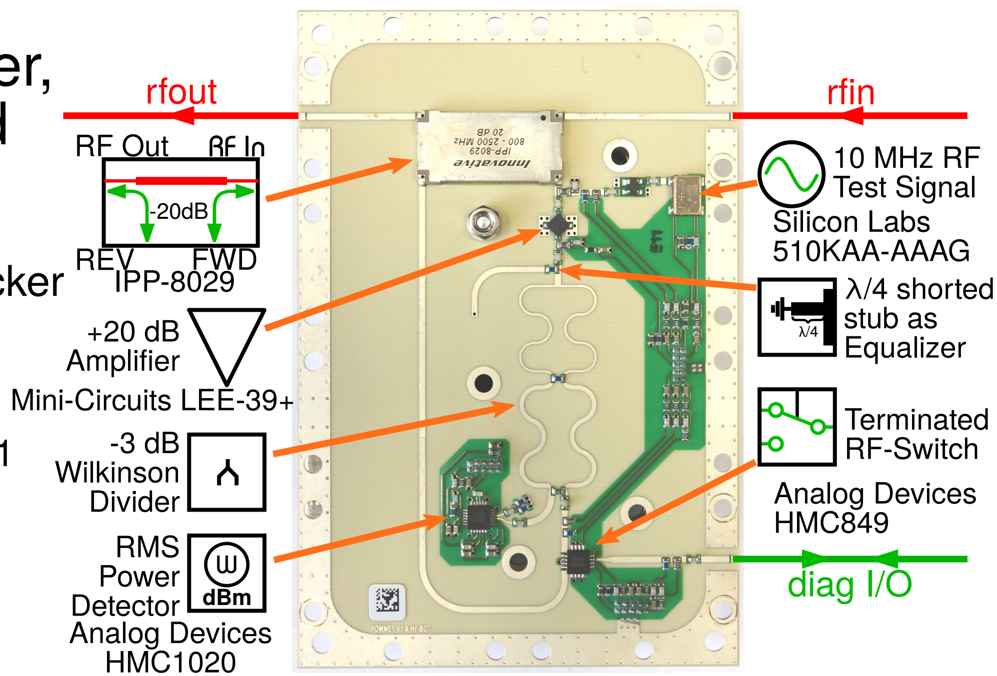
Embedded Power Meter POWME1



Idea: Combining multiple parts of the diagnostic system into a compact, low cost RF device with short electrical length, low non-linear phase response, low amplitude ripple and high reliability and included self-test functionality.

Replacing 5 RF componets: bi-directional coupler, amplifier, 3dB splitter, power meter and SPDT RF switch





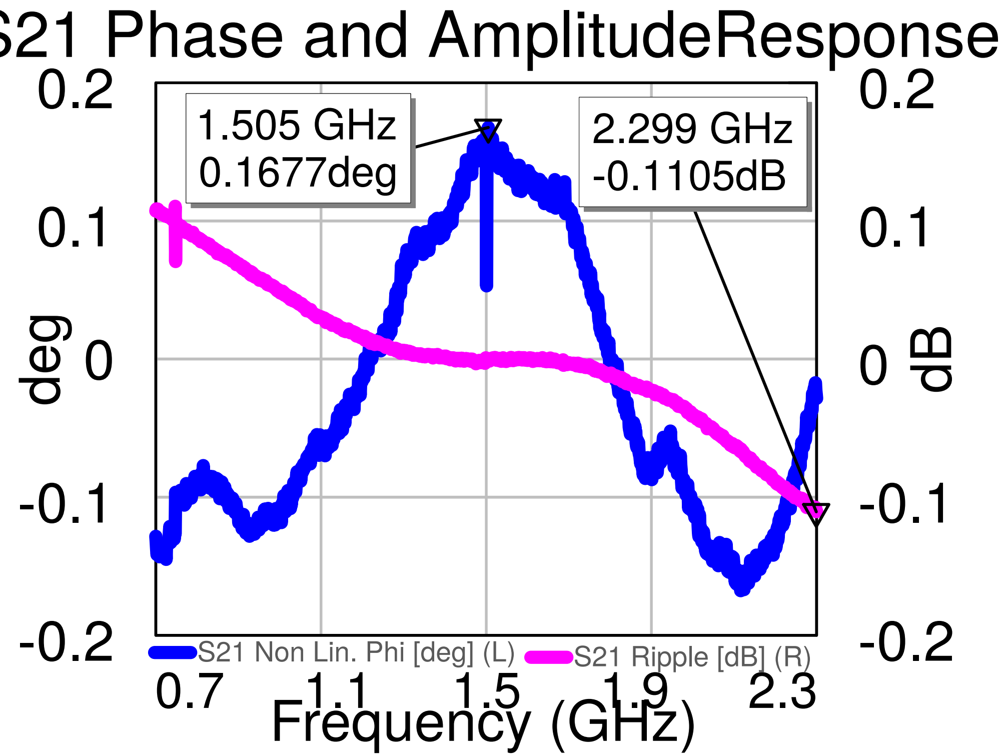
Embedded Power Meter POWME1

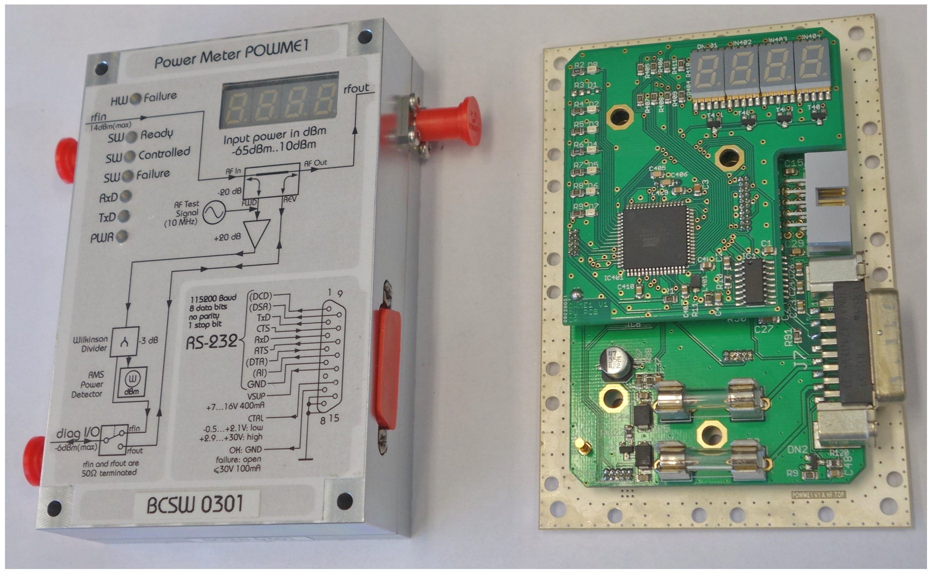
Features:
-Wide bandwidth 0.7...2.3GHz
-Non-linear phase response of less than ±0.17°
-Amplitude ripple of less than ±0.12dB

RF RMS Power Measurement:
-High dynamic range -64..11dBm
-Power measurement error (typ) of less than 0.3dB over dynamic range.
-Power measurement error (typ) of less than ±1dB over frequency range.

Self Test:
Full selftest support of its own RF systems. This includes a high frquency test of the amplifier, 3dB splitter, RMS power meter and a DC test of the SPDT switch and directional coupler output ports.

Series:
Batch of 20 units were build + enough spare parts for additional 10 units.
All were programmed, calibrated and measured.

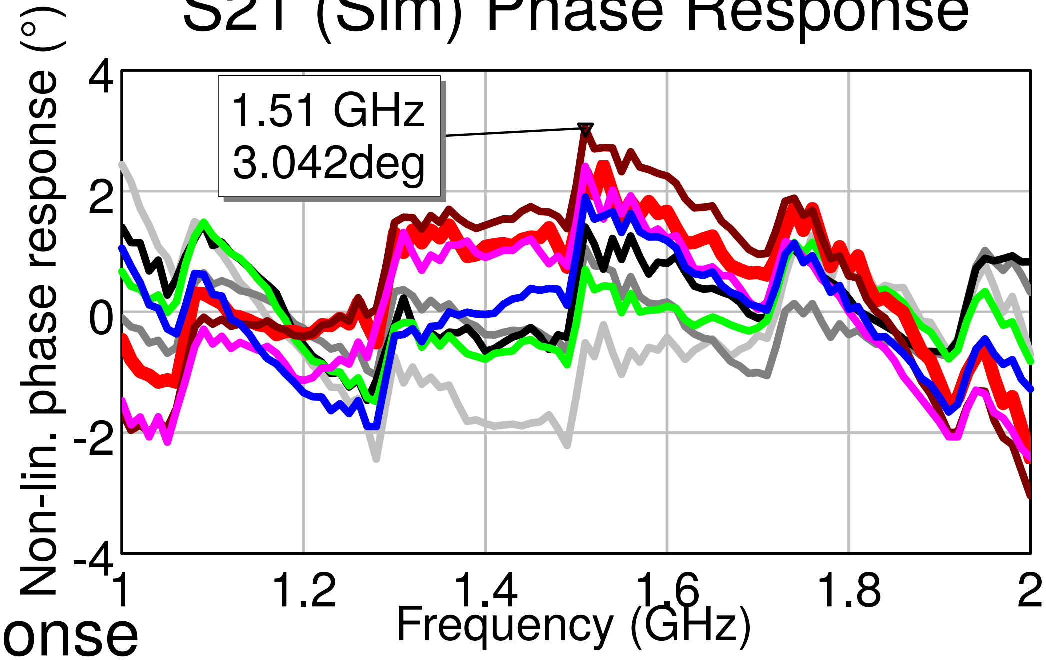




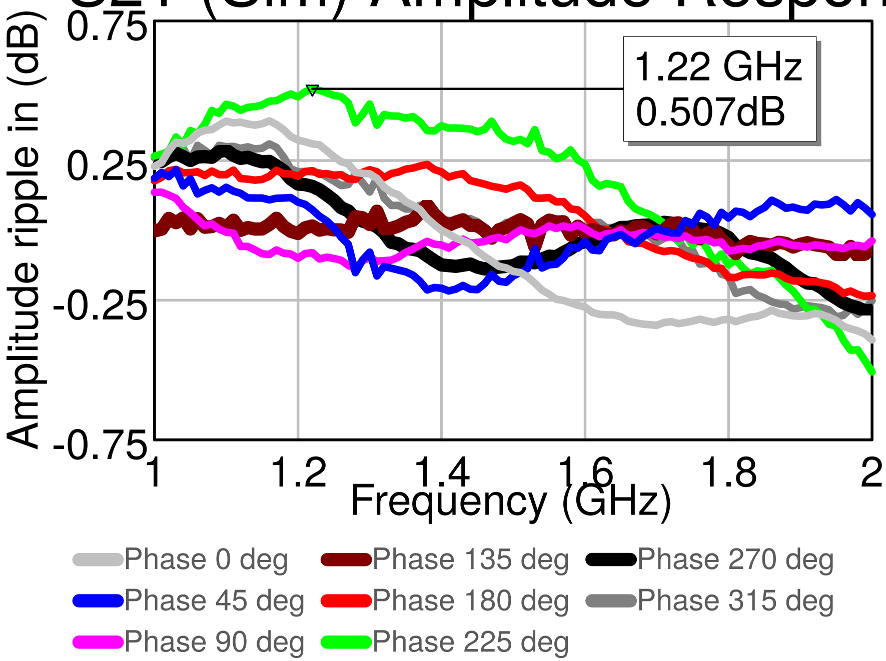
360° Variable Phase Shifter PHASE1

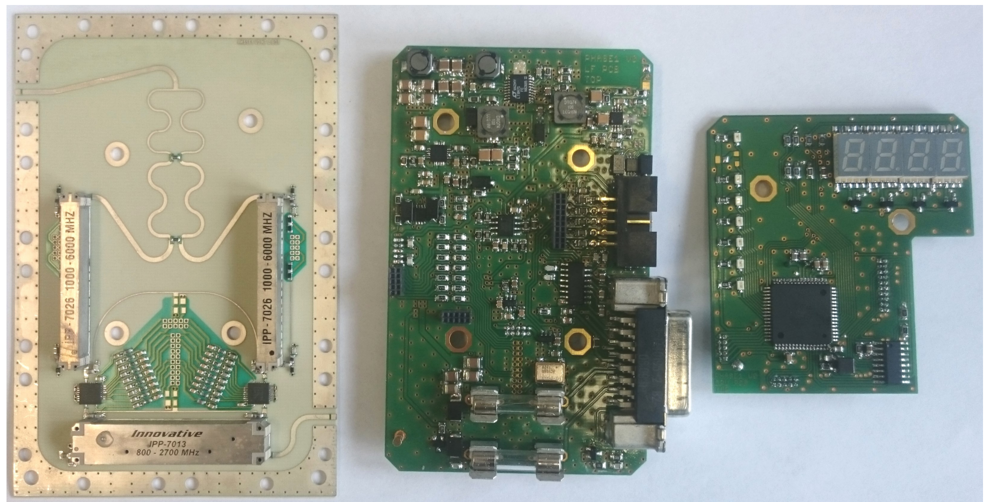
Based on an IQ vector modulator
Prototype in production.
Features:
- -Wide bandwidth 0.7...2.3GHz
- -Non-linear phase response of less than ±3.2deg
- -Amplitude ripple of less than ±0.55dB
- -Short electrical length <1.6ns
- -Phase resolution <2.5deg
- -Time resolution <100µs

S21 (Sim) Phase Response

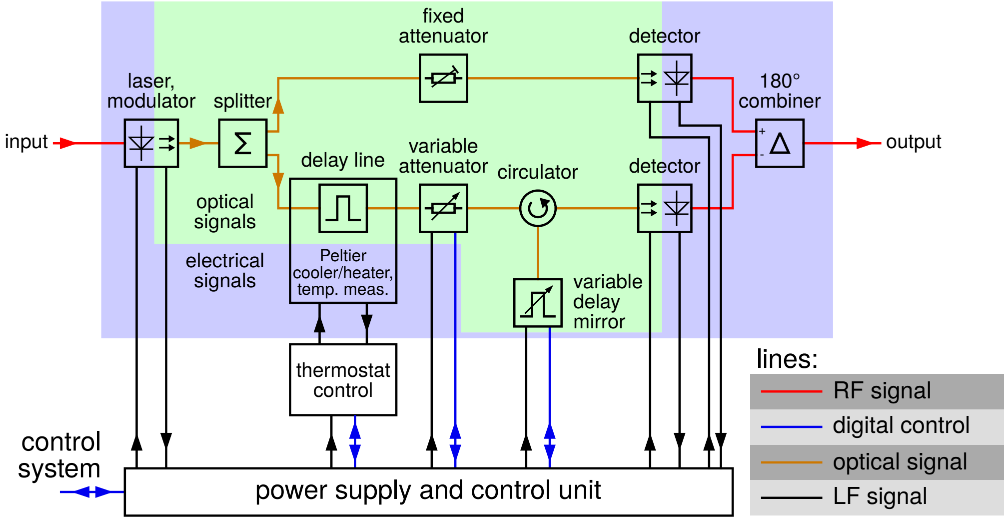


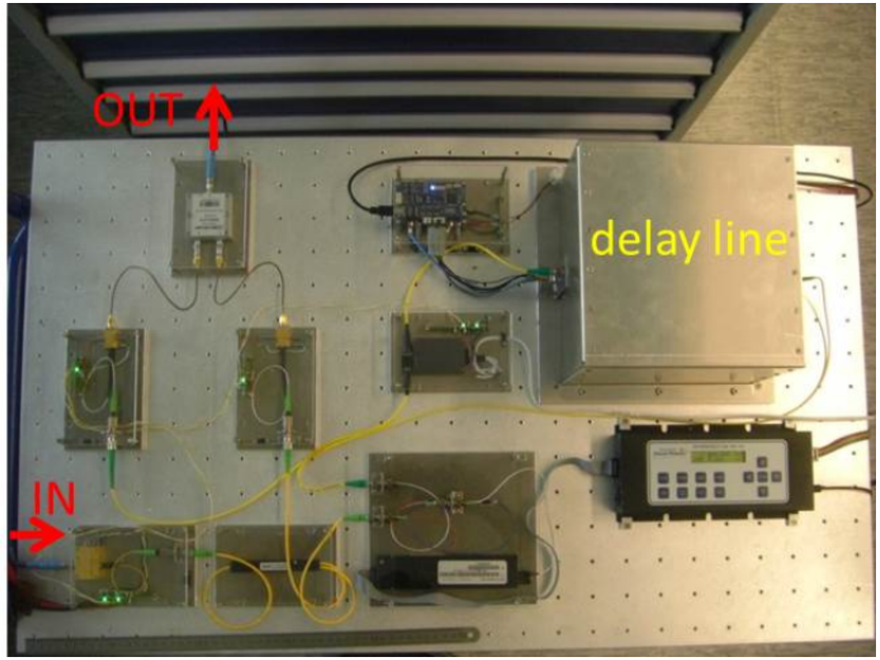
S21 (Sim) Amplitude Response

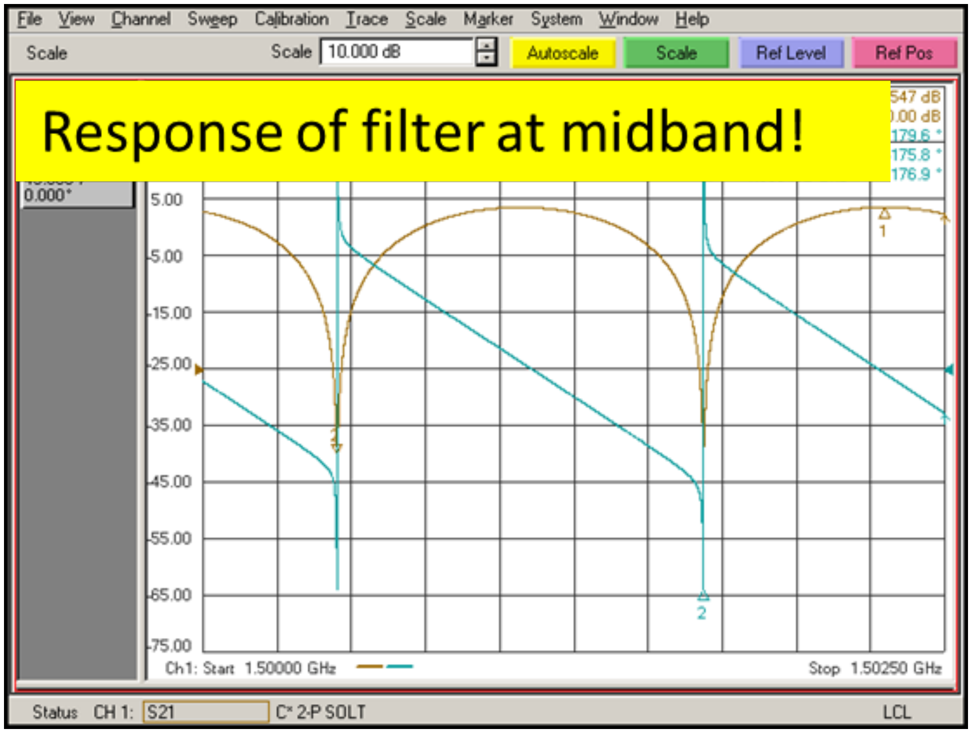




Optical notch filters







2 CR notch filter with optical delay line (pbar v=0.97c, RIBs v=0.83c)
+1 for AD@CERN
-Operartion wavelength 1550nm
-electrical length (propagation delay) of short branch t_0 =3.5ns
-Delay T = exactly the nominal revolutuin period of the beam to be cooled

-Transfer function (ideal correlation notch filter):

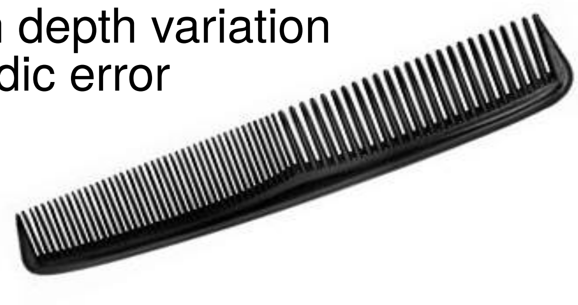
$$S_{21,ideal} = \frac{S_0}{2}(1 - e^{j\omega T}) = -j\,|S_0|\sin\left(\frac{\omega T}{2}\right)e^{j\omega\left(t_0 + \frac{T}{2}\right)}$$

$$S_0 = |S_0|\,e^{j\omega t_0}$$

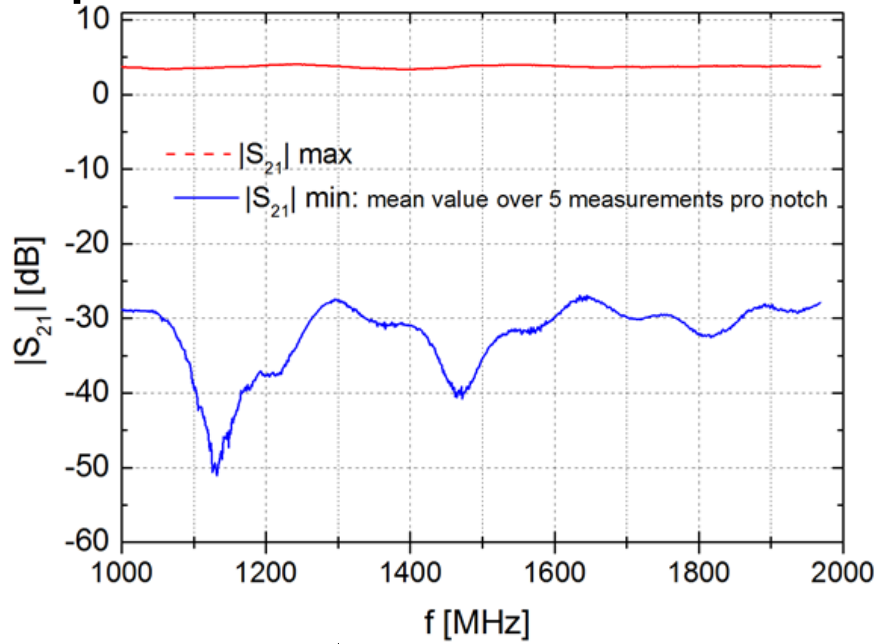
Optical notch filters

Notch (comb) filters are specified by two main parameters:

→notch depth variation
→periodic error



Notch depth < -30dB in the band 1...2Ghz as specified!



Periodicity error:

linear fit to the measured position of the notches (transmission minima)

fn = f(n) = f_0 • n + b = (1.234832 MHz) • n - 36 kHz

f_0 = mean notch distance:
with this filter setting a beam will be cooled to this revolution frequency

36kHz =mean periodicity error

$$\Delta f[\mathrm{Hz}] = \frac{f_n - n f_0}{n} \qquad \alpha[\mathrm{ppm}] = \frac{\Delta f}{f_0}$$

α ≲ 32ppm in 1...2GHz