THz Detectors

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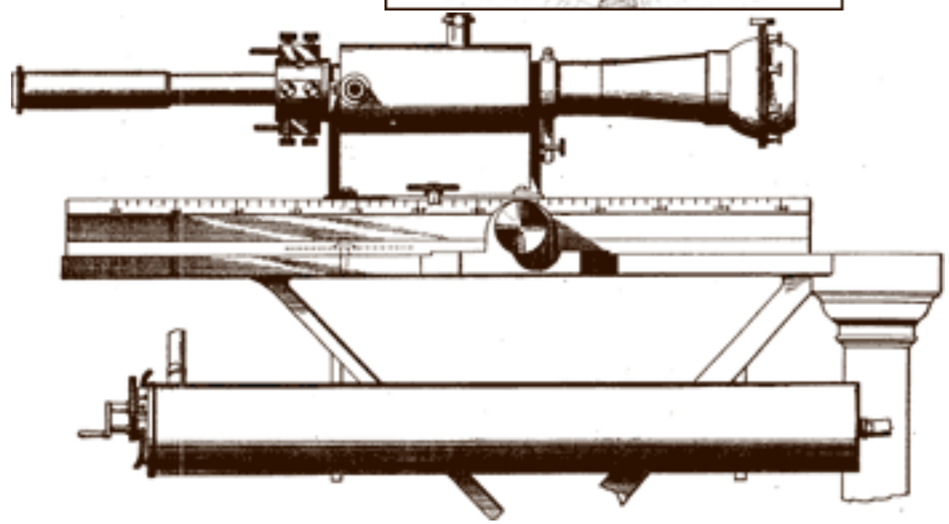
Overview

- Bolometers
- Pyroelectric detectors
- Diodes
- Golay Cell

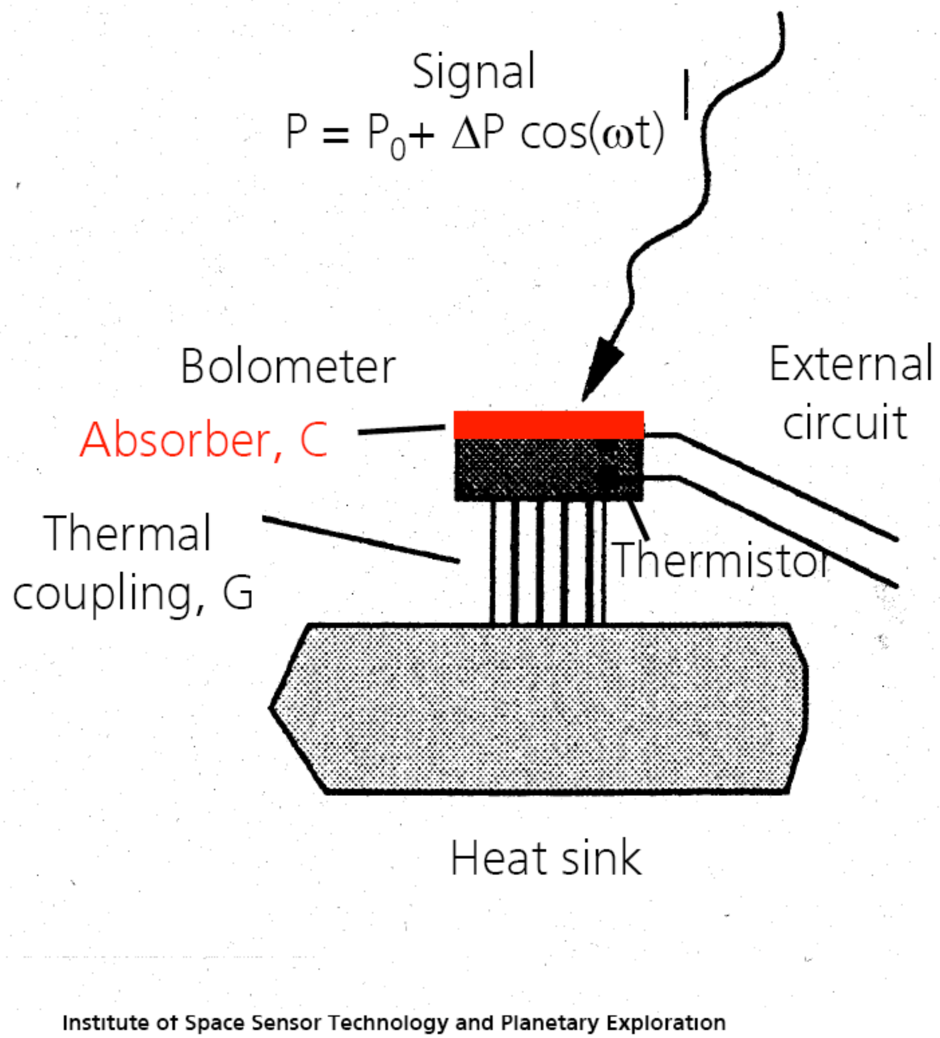
Bolometers

Bolometer: ORIGIN late 19th cent.: from Greek bolē 'ray of light' + **-meter**

In 1878 Samuel Pierpont Langley invented the bolometer, a radiant-heat detector that is sensitive to differences in temperature of one hundred-thousandth of a degree Celsius (0.00001 C) . Composed of two thin strips of metal, a Wheatstone bridge, a battery, and a galvanometer (an electrical current measuring device), this instrument enabled him to study solar irradiance (light rays from the sun) far into its infrared region and to measure the intensity of solar radiation at various wavelengths.



Bolometer principle



Heat transfer:

$$C\frac{dT}{dt} = P(t) - G\,(T-T_0)$$

C: heat capacity

G: heat conductivity

Temperature modulation:

$$\Delta T = \frac{\Delta P}{G\sqrt{1+\omega^2(C/G)^2}}$$

Responsivity:

$$R(\omega) = \frac{\Delta V}{\Delta P} \propto \frac{1}{G\sqrt{1+\omega^2(C/G)^2}}$$

$\omega << 1/\tau$: $R(\omega) \propto \frac{1}{G}$

$\omega >> 1/\tau$: $R(\omega) \propto \frac{1}{\omega C}$

$\tau = C/G$: bolometer time constant

Far-IR Silicon bolometer

- Spectral response: 2-3000 micron
- Operating temperature: 4.2-0.3 deg-K
- Responds only to AC signal within detector bandwidth (may need a chopper.)

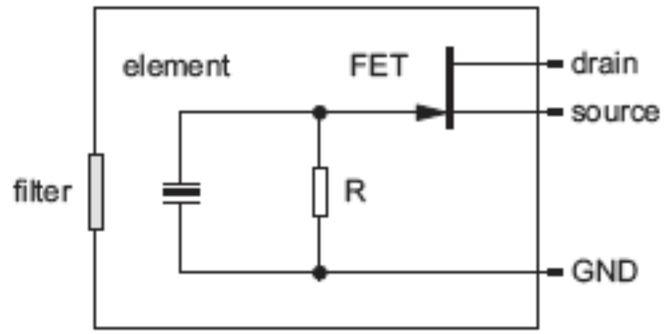
T_o (K)	4.2	1.2	0.3
G (w/K)	1×10^{-5}	1×10^{-7}	1×10^{-8}
F_o (Hz)	$> 8 \times 10^{2}$	$> 5 \times 10^{2}$	$> 1 \times 10^{3}$
NEP (w/Hz½)	1×10^{-13}	3×10^{-15}	2.4×10^{-16}

Table 1-2: Theoretical Performance of minimum area (A = 6.25 x 10-4 cm2) bare Si bolometers

Pyroelectric Detectors

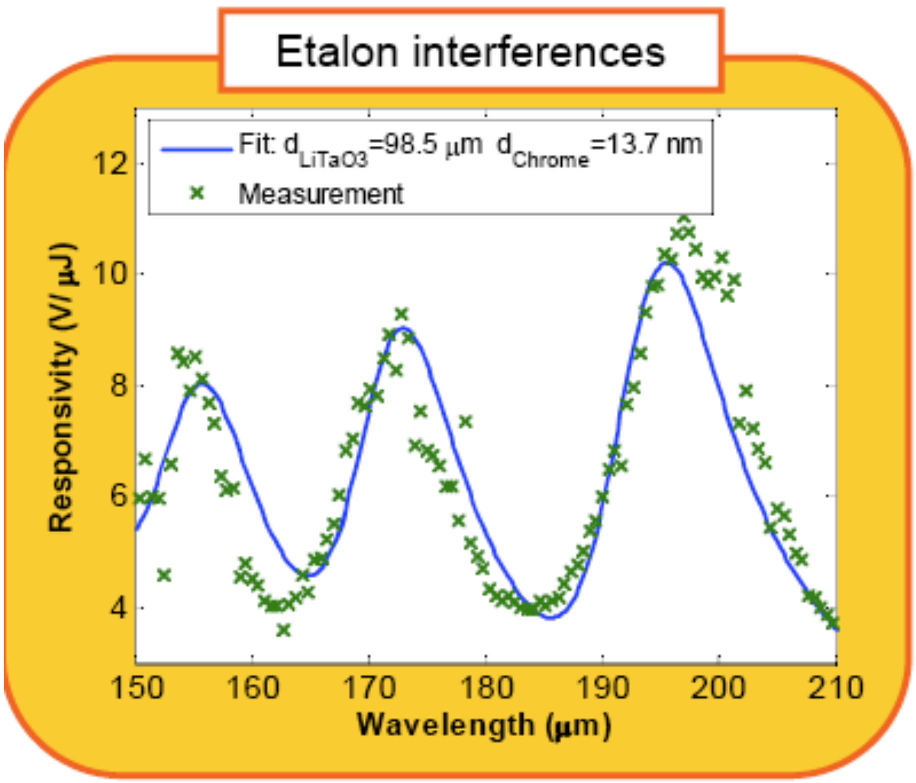
•Ferroelectric materials such as TGS or Lithium Tantalate, exhibit a large spontaneous electrical polarisation which has varies with temperature.
•Observed as an electrical signal if electrodes are placed on opposite faces of a thin slice of the material to form a capacitor.
•Creates a voltage across the capacitor for a high external impedance
•Only sensitive to AC signals (I.e. time-varying)
•Room temperature operature
•Small detector area can give fast thermal response time. (<1 microsec)

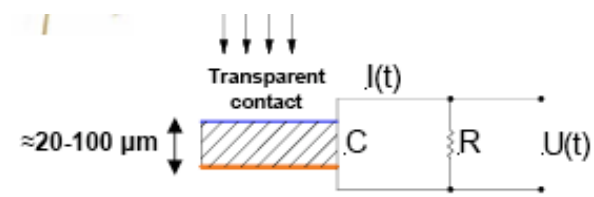
NEP (W/Hz1/2, BW-1Hz) =1.1 x 10-9
Responsivity (V/W)=3.7 x 105

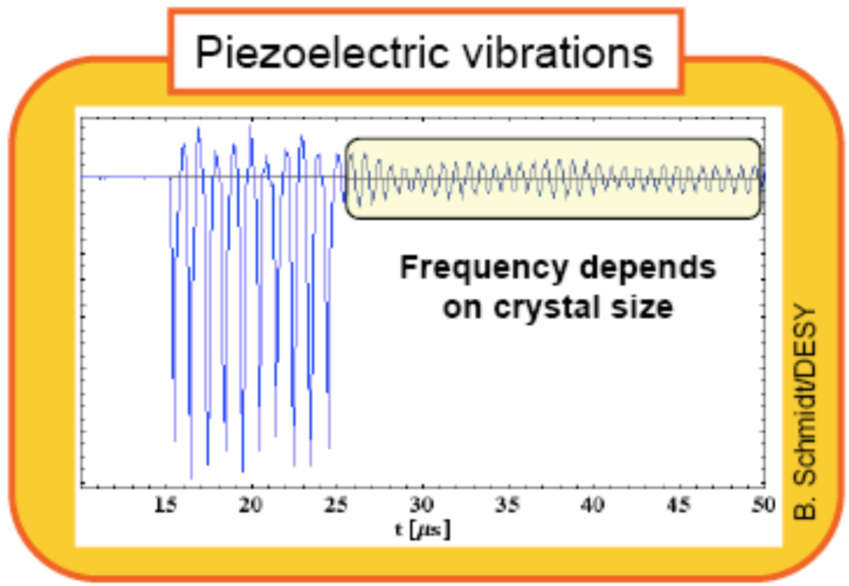


Pyroelectric Detectors

- Pyroelectric effect sensitive only to heat (not wavelength)
- Wavelength selection made with window material
- Sensitive to piezoelectric noise (vibrations=noise signal)

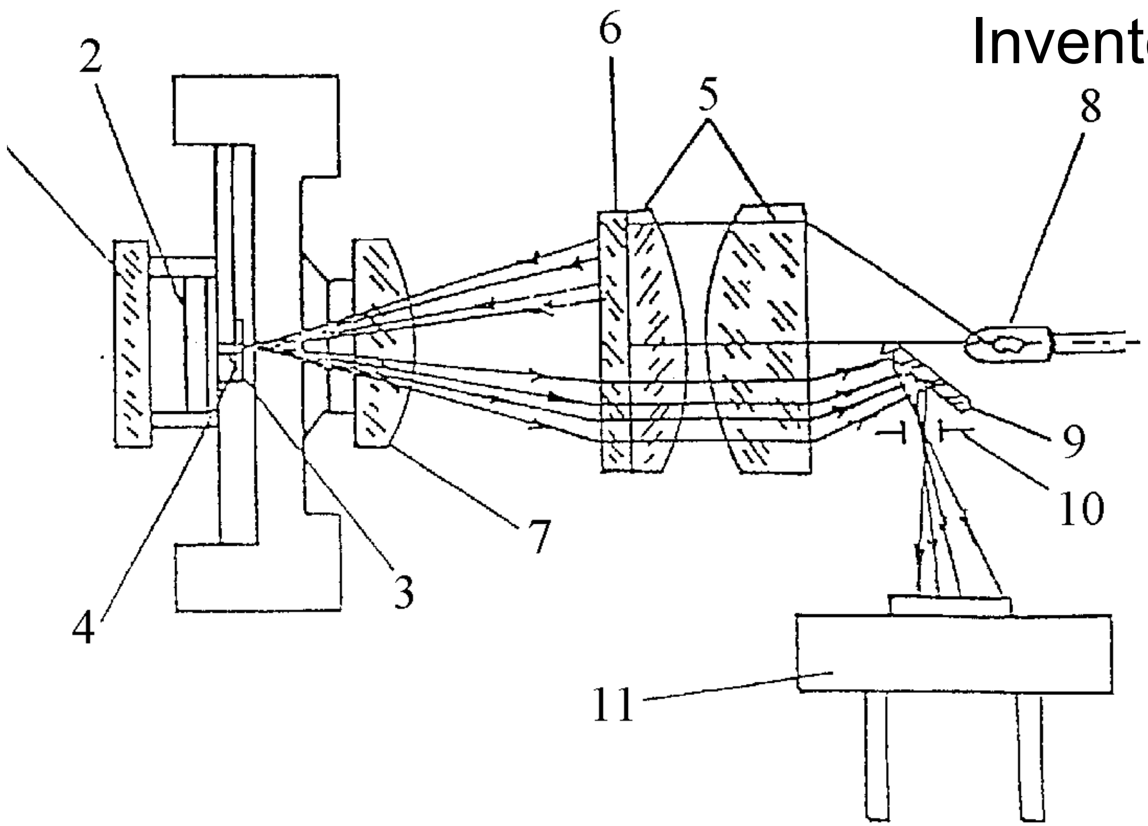




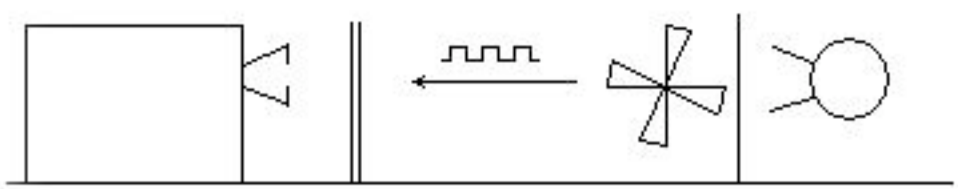


Golay Cell

Invented by M.J.E.Golay in 1947



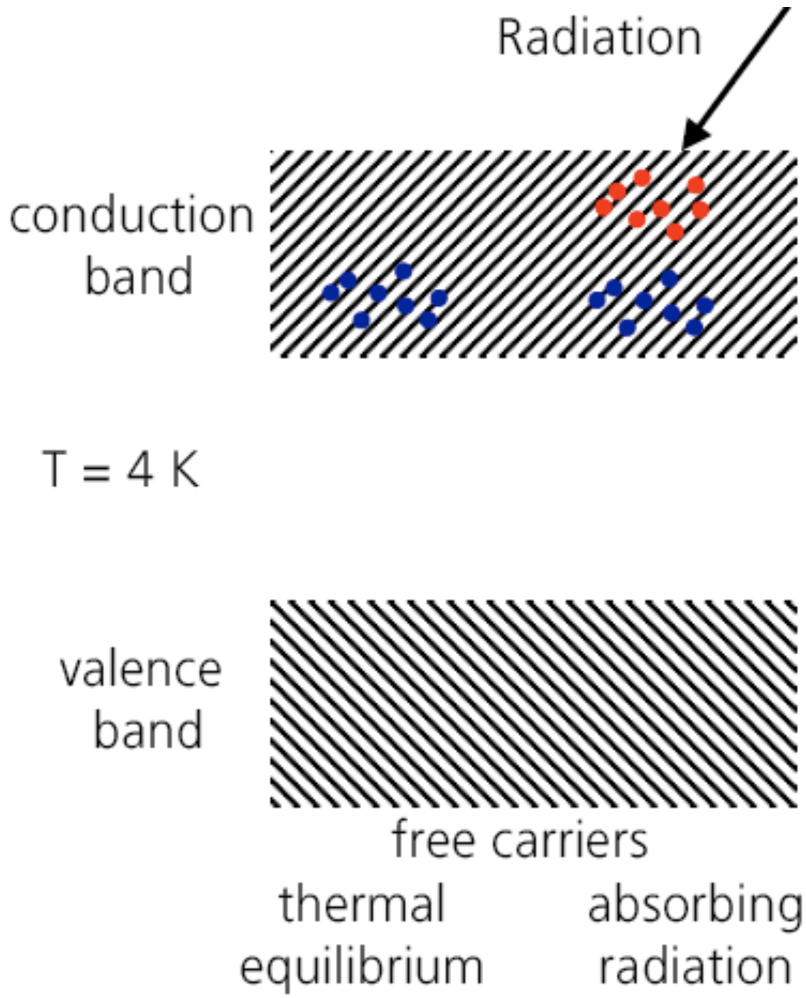
A modulated signal (1) is incident upon the semi-transparent film (2). This heats the gas in the chamber and distorts the membrane forming the wall of the chamber. An LED (8) sends a signal onto the mirrored back surface of the chamber containing the absorbing membrane. The modulated signal appears as a modulated optical signal.



Golay Cell

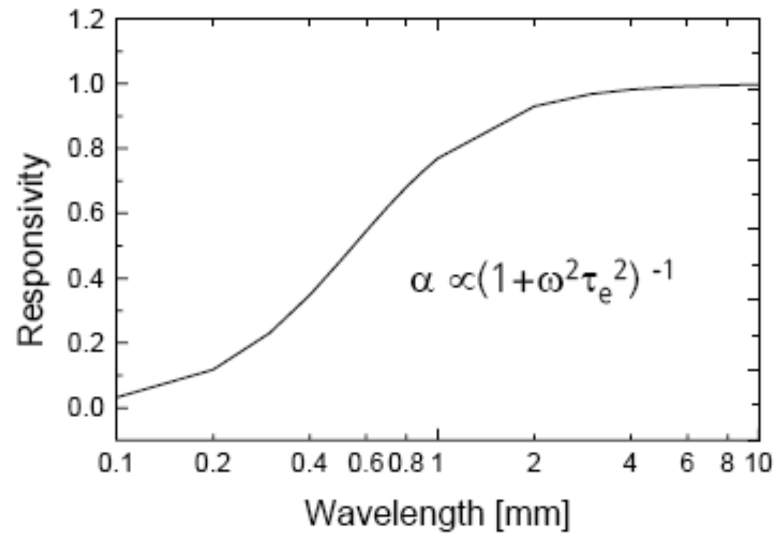
- Operating temperature = 300K
- Wavelength range (polyethylene window) = 20 to 1000μm
- Optical responsivity at 15Hz ≥ 100 kV/W
- Optical NEP at 15Hz : < 100 pWatt.Hz-1/2
- Speed (-3 dB) = 25Hz
- Detector weight = 1kg
- Detector dimensions l=140mm, w=65mm, h=90mm
- Connecting lead length ≅1m

Indium Antimonide (InSb) Detectors



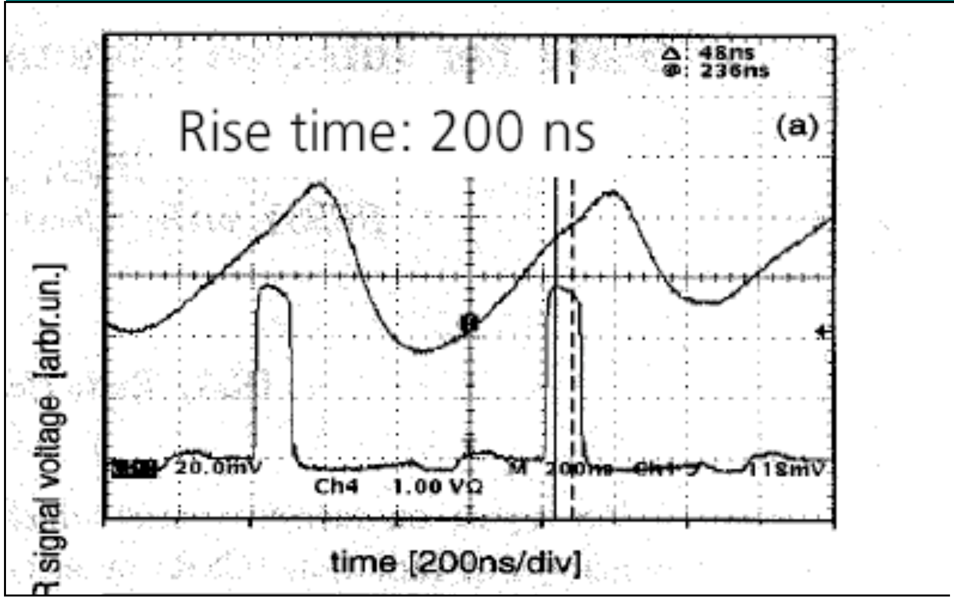
Detection mechanism:

Absorption of radiation by free electrons



Response time: ≈ 200 nsec (≈ 1.5 MHz)

InSb with CSR signals



Rise time: ≈200 nsec

Decay time: > 400 nsec

Resolution of single bunches within a train of bunches is not possible.

Slicing signal

Burst

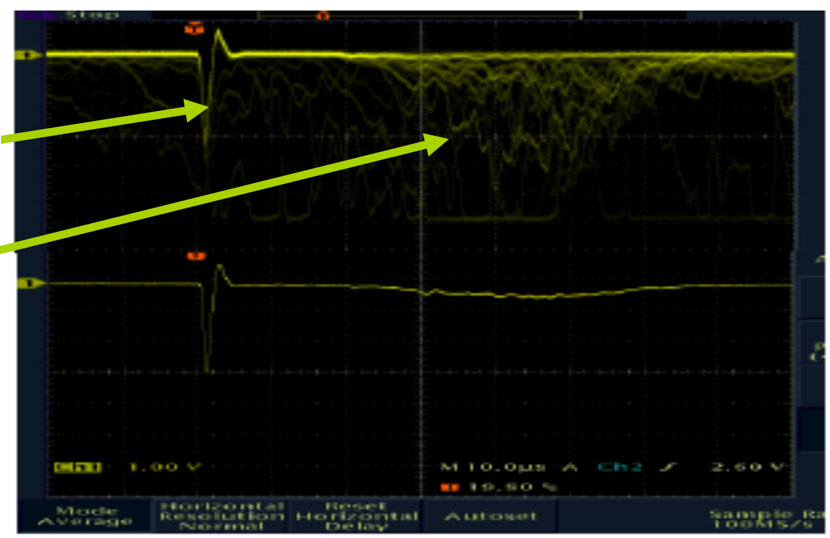
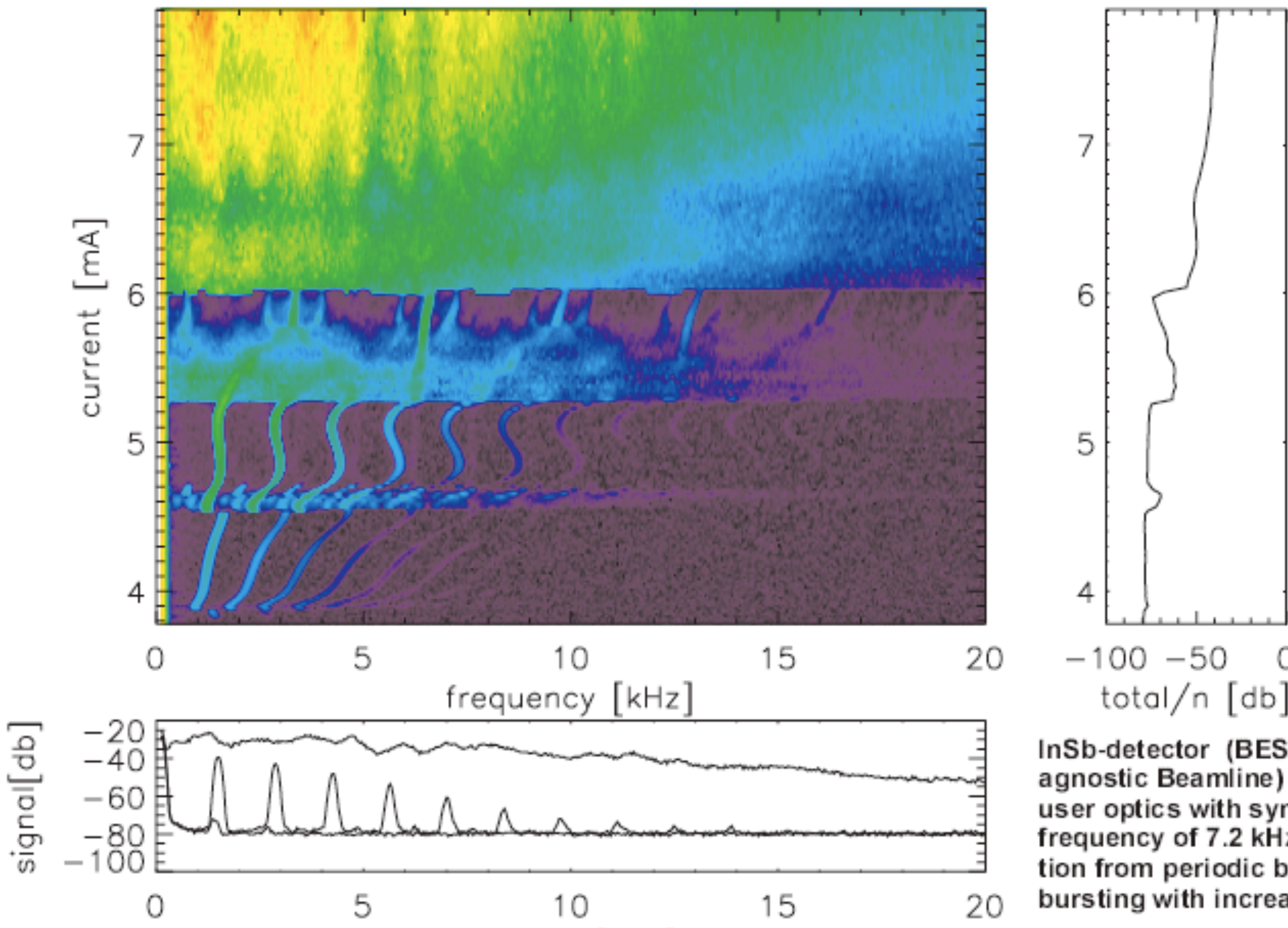


Figure 7: Scope tracks of the seeded burst signal at the fast detector. Scales: 10 μs/div and 1V/div

Fast detectors allow observation of turn-by-turn dynamics

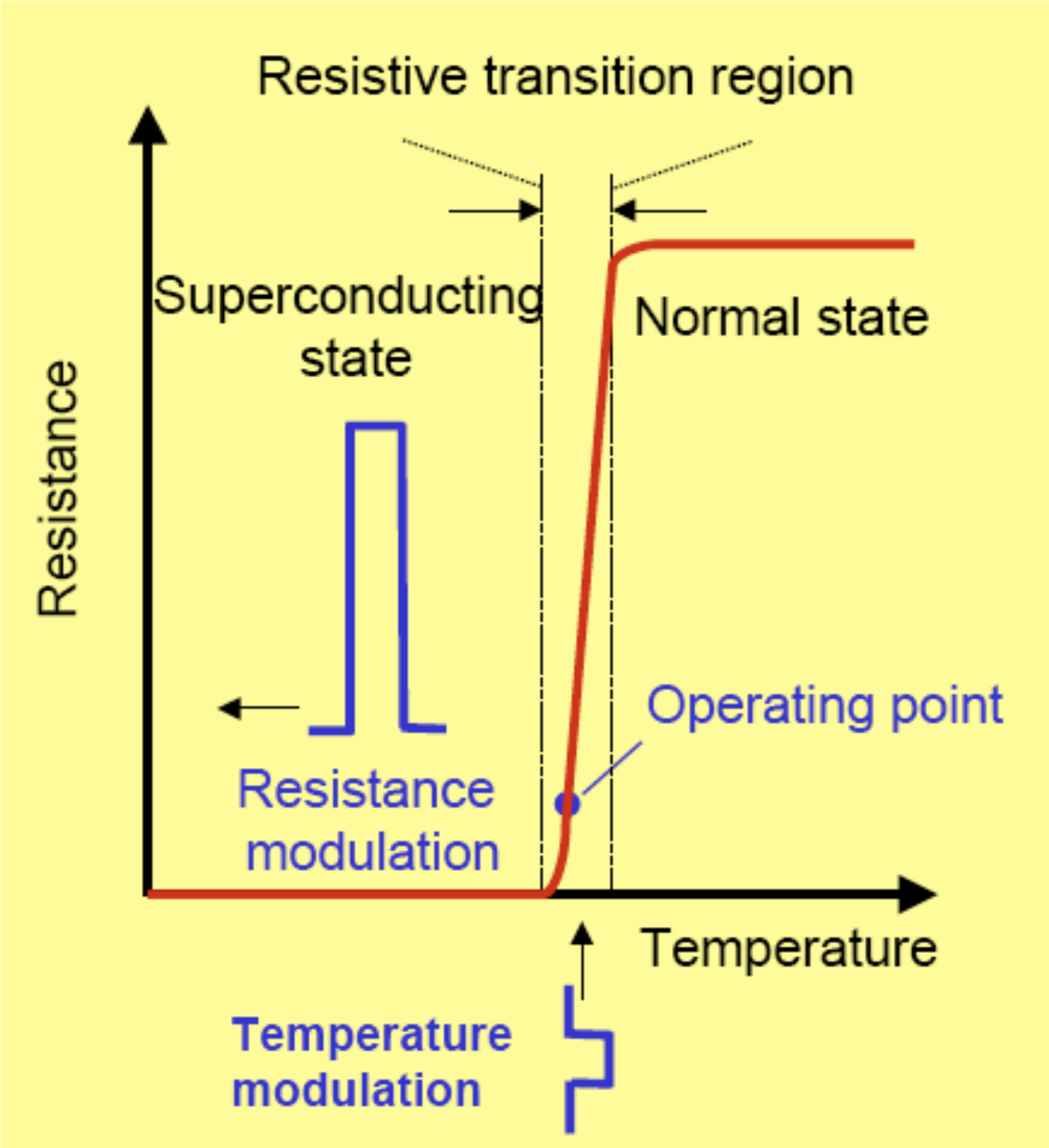
Frequency domain response

detecting electron beam instabilities and thresholds. Transition of periodic to chaotic bursting in single bunch mode



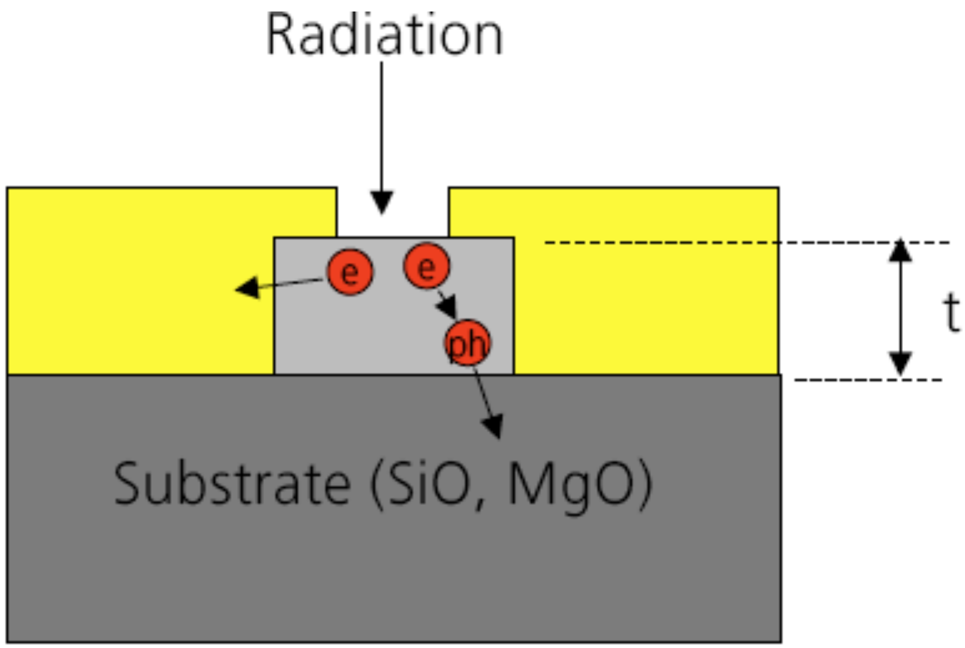
InSb-detector (BESSY, at Diagnostic Beamline) normal user optics with synchrotron frequency of 7.2 kHz. Transition from periodic bursting to bursting with increasing current

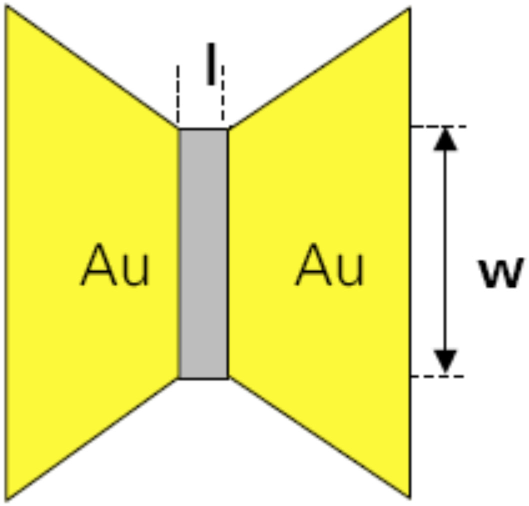
Superconducting Hot Electron Bolometer



Detector operates at superconducting transition region. Small temperature modulation gives large resistance modulation.

HEB dimensions





Time scales (NbN):

$\tau_{e\text{-}e} \approx 2$ ps

$\tau_{e\text{-}ph} \approx 15$ ps

$\tau_{esc} \approx 25\text{-}50$ ps (3.5 nm film)

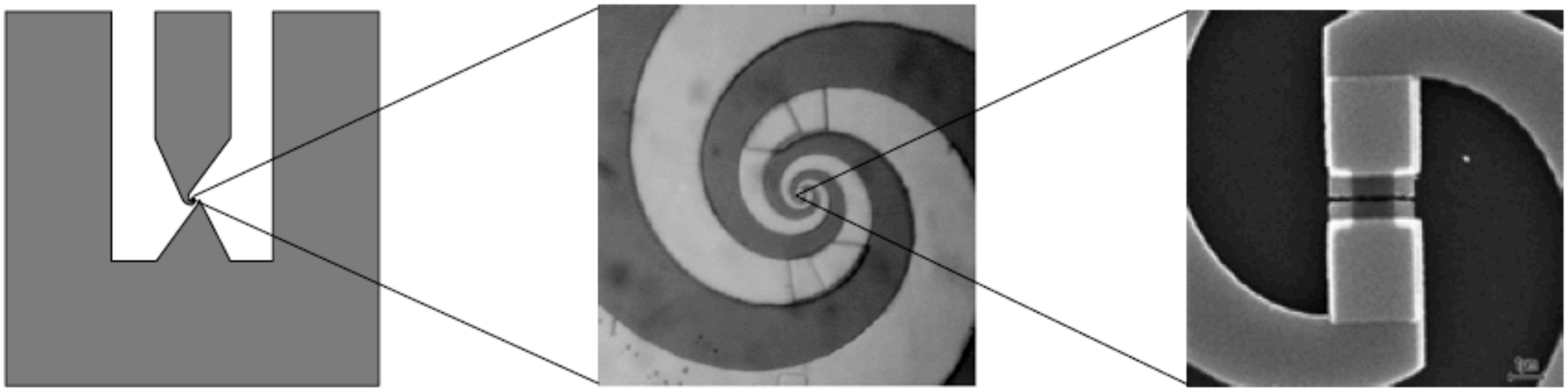
Dimensions:

l: 0.2 - 1.0 μm

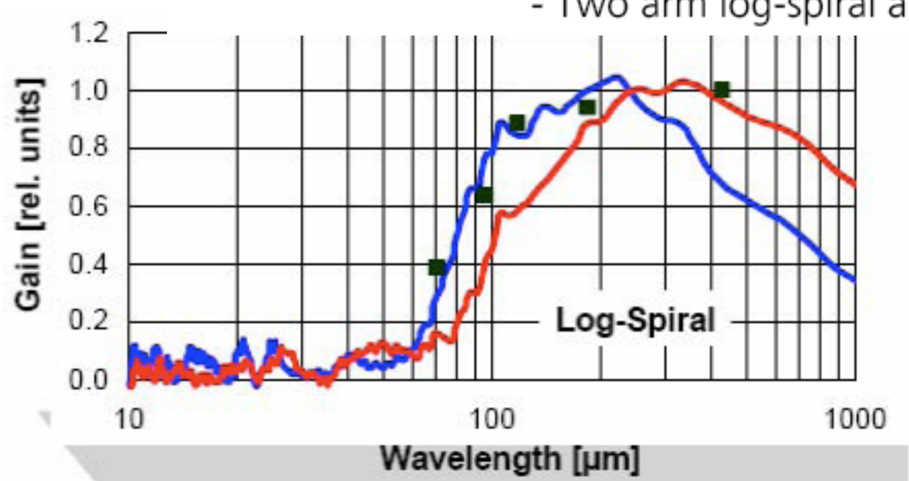
w: 1 - 4 μm

t: 3.5 nm

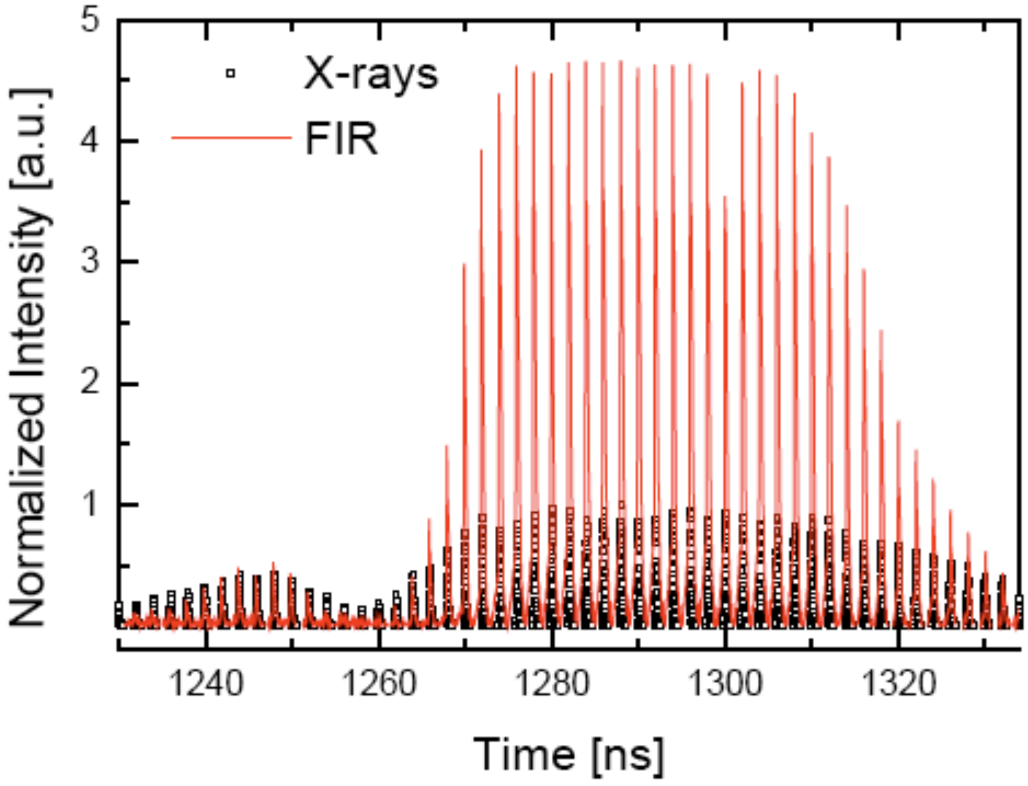
HEB Antenna and mixer

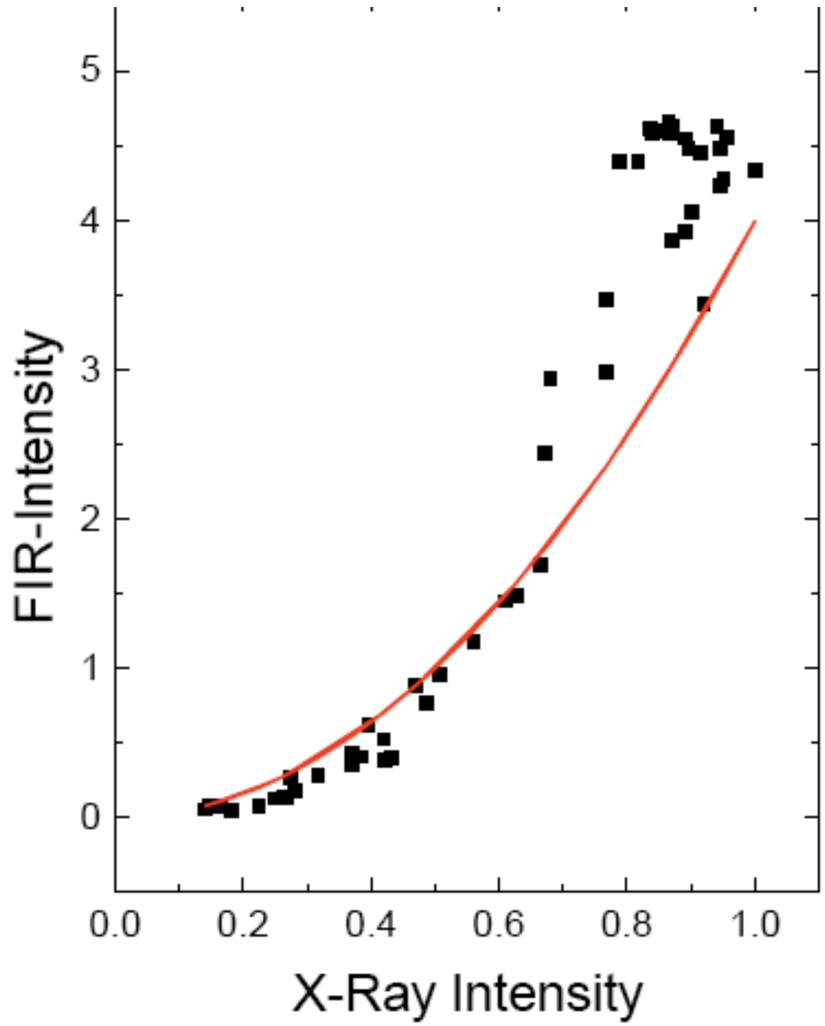


- NbN film: 3.5 nm thick (dc reactive magnetron sputtering)
- Transition temperature: 9 K, width: ≈ 0.5 K
- Si substrate: > 10 kΩ cm
- Two arm log-spiral antenna terminated by 50 Ω coplanar line

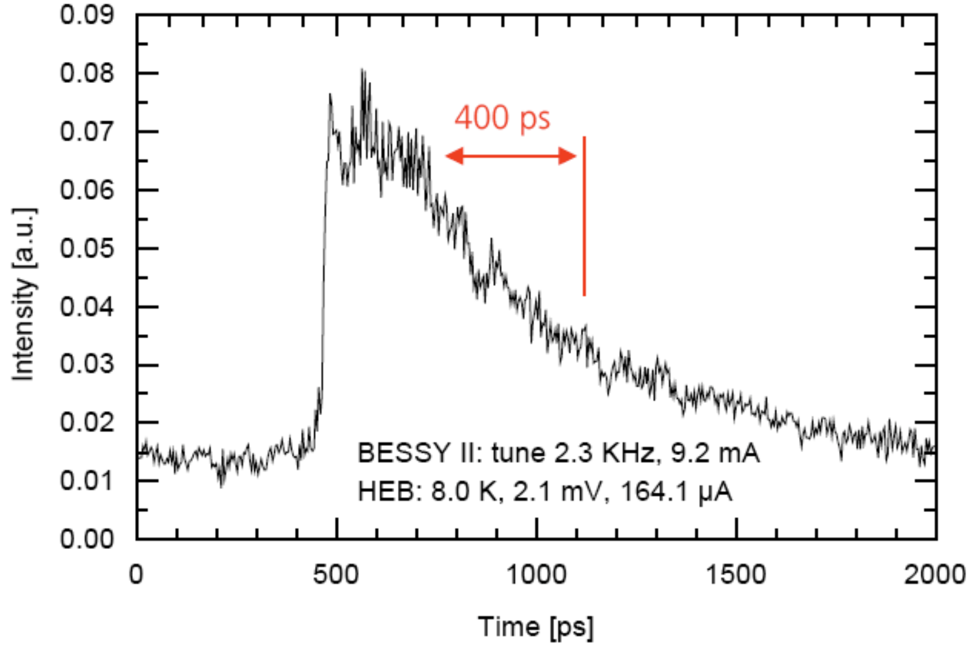


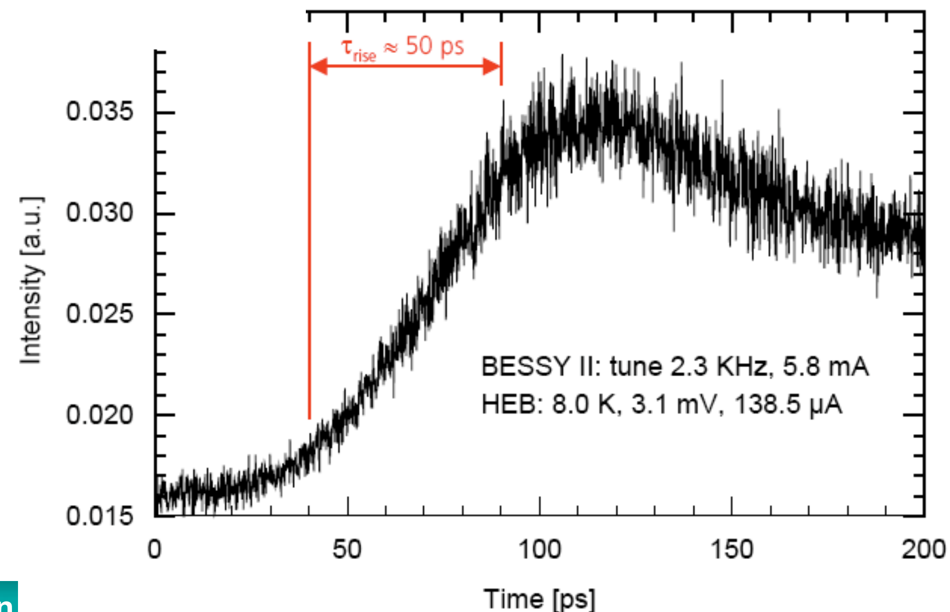
Bessy Beam signals





HEB Response time





Measurement:

$\tau_{rise} \approx 50$ ps

Detector:

$\tau_{e\text{-}e} \approx 2$ ps

$\tau_{e\text{-}ph} \approx 25$ ps

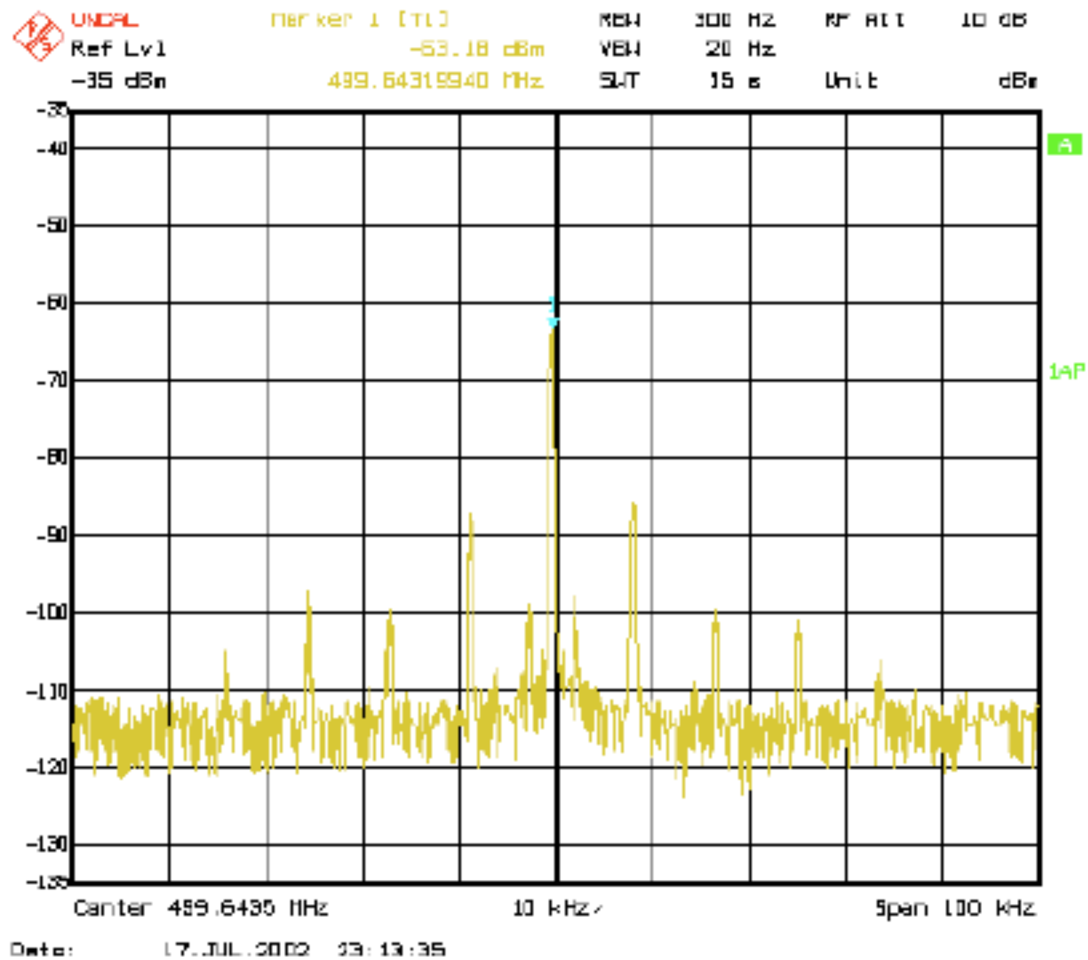
$\tau_{electr} \approx 35$ ps

Electron bunch:

$\tau_{FWHW} \approx 10$ ps

Frequency response

500 MHz component of HEB signal.
Indicates sufficient resolution for 2 nsec bunch spacing.
Sensitive to multibunch dynamics affecting CSR signal.



Diode Detectors

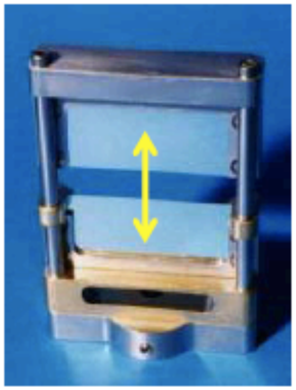
Virginia Diodes, Inc., Cha

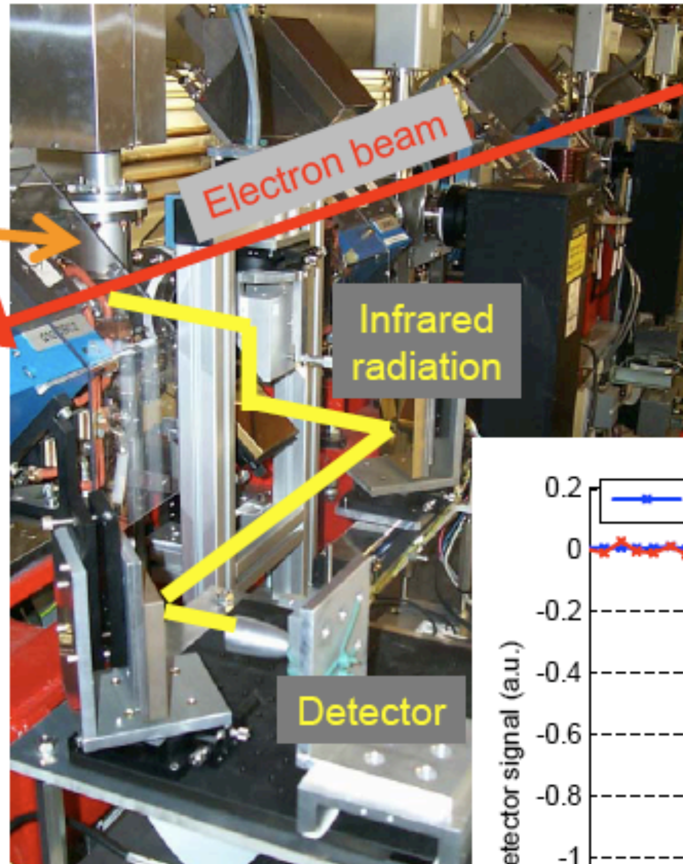
Model Number	DXP-06
Frequency band and range (GHz)	D 110-170
Video voltage (mV at -20 dB input) (typ)	5
Video sensitivity (mV/mW) (min into 1 MΩ)	150
Flatness (dB) (typ)	±3.0
TSS at 1 kHz (bw 40 Hz, dBm) (typ) *1	-40
Video bandwidth (MHz) (typ) *2	10
Operating RF input power (dBm, CW max)	+16
Absolute max rating (dBm)	+20

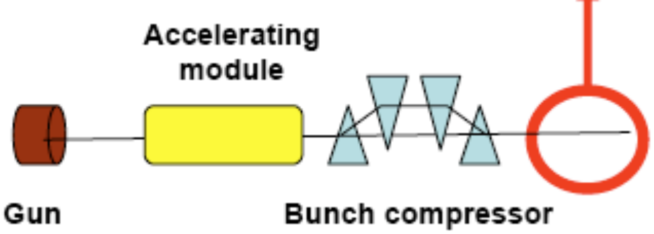
Band	WR-	(GHz)	Comment
L	650	1.1-1.7	Long wave
R	430	1.7-2.6	
S	284	2.6-3.95	Short wave
H (G)	187	3.95-5.85	
C	137	5.85-8.2	Comprise between S and X
W (H)	112	7.05-10	
X	90	8.2-12.4	Used in WWII for fire control, **X** for cross as in cross-hair.
K_u	62	12.4-18	Kurz-under
K	42	18-26.5	Kurz (German word for short)
K_a	28	26.5-40	Kurz-above
Q	22	33-50	VDI: WR22x2 is a frequency doubler to 32-55 GHz.
U	19	40-60	VDI: D55v2 covers ~ 47-58 GHz.
V	15	50-75	VDI: WR15x2 is a frequency doubler to 50-75 GHz.
E	12	60-90	VDI: WR12x2b is a frequency doubler to 60-90 GHz.
W	10	75-110	VDI: WR10x2c, D90, D100
F	8	90-140	VDI: WR8x3 is a frequency tripler to 90-140 GHz.
D	6.5	110-170	VDI: WR6.5SHM is a subharmonic mixer to 110-170 GHz.
G	5.1	140-220	VDI: WR5.1DD, WR5.1ZBD, WR5.1x2, WR5.1x3, D200…
	4.3	170-260	VDI: WR4.3x2, WR4.3x3, WR4.3x6, WR4.3SHM, D240
	3.4	220-325	VDI: WR3.4x2, WR3.4x3, WR3.4SHM, WR3.4ZBD
	2.8	265-400	VDI band: WR2.8x2, WR2.8x3, WR2.8DD, WR2.8HM…
	2.2	330-500	VDI band: WR2.2x2, WR2.2x3, WR2.2x5, D400, T438…
	1.9	400-600	VDI band: WR1.9x2, WR1.9x3, WR1.9x5, D480
	1.5	500-750	VDI band: WR1.5ZBD (zero bias detector)
	1.2	600-900	VDI band: WR1.2x3, WR1.2x5, WR1.2SHM, T738
	1.0	750-1000	VDI band: WR1.0x3
	0.65	1100-1700	VDI band: WR0.65x3, WR0.65x5

FLASH Bunch compression monitor

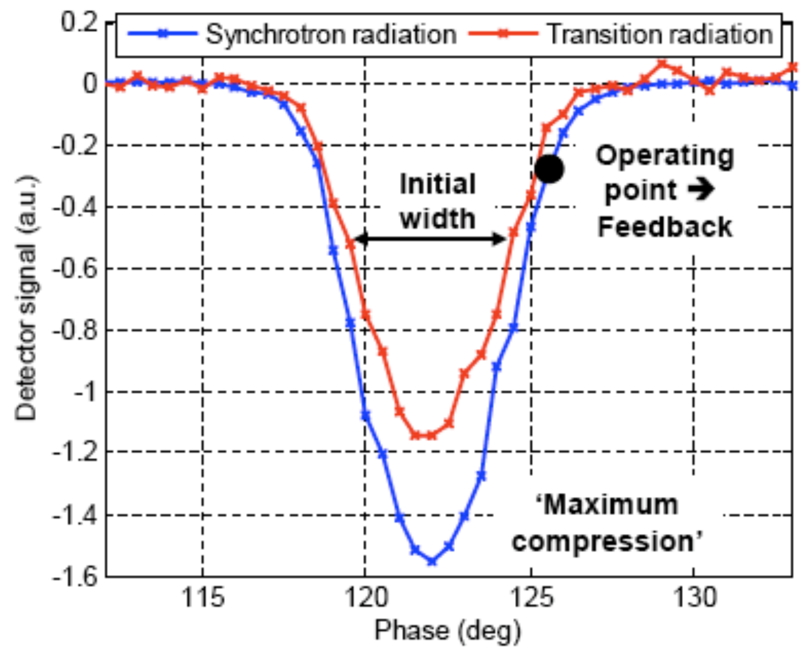
Transition/Diffraction Radiator



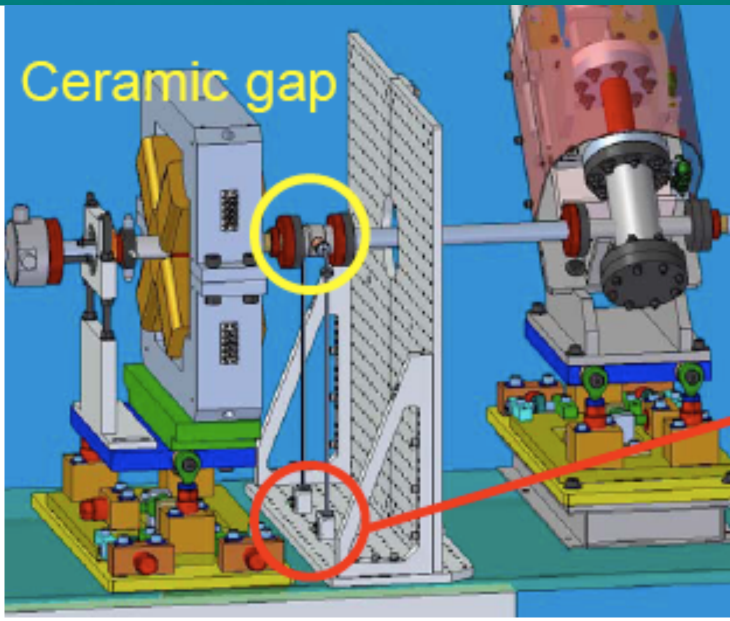


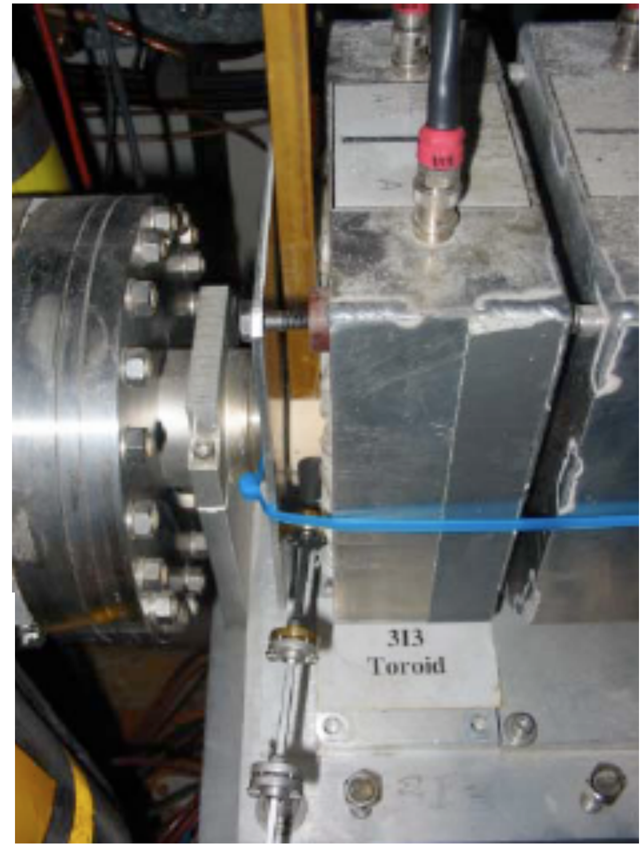


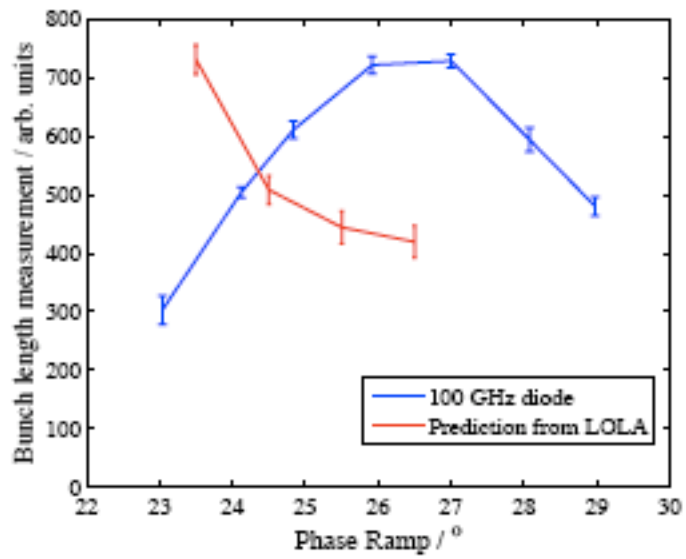
Phase/compression scan



SLAC bunch shape monitor







Wire Grid Polarizers