Radio Astronomy, Lecture 3

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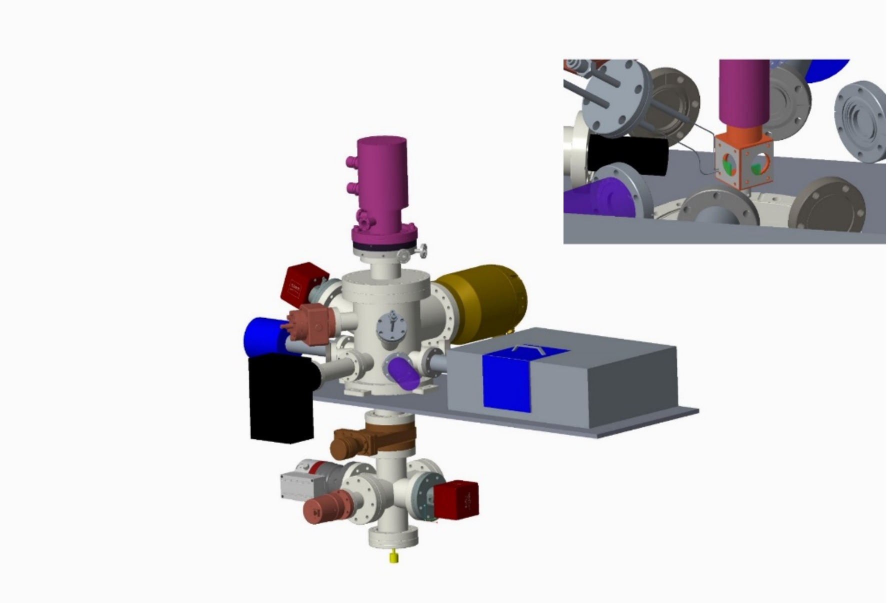
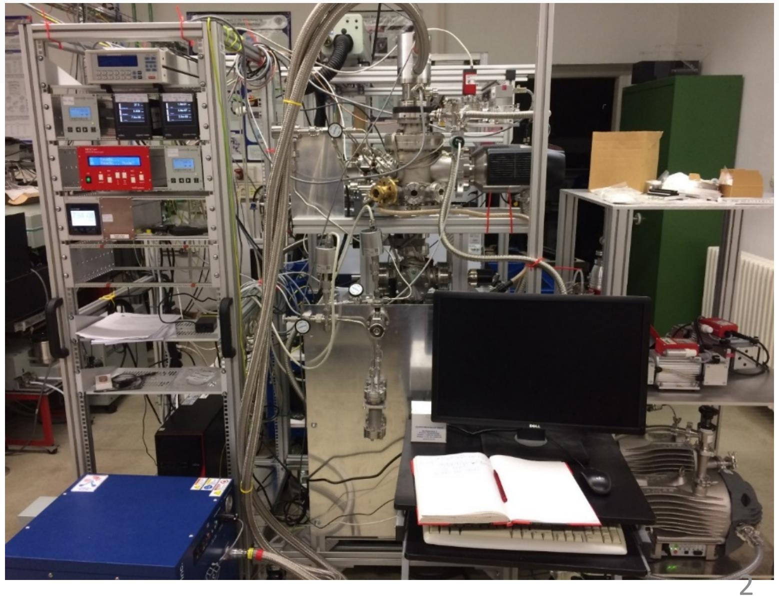
Laboratory Astrophysics Group

Laboratory Astrophysics





IRAM FILM

Today VL3 30.10.

Signal processing

Receiver Noise

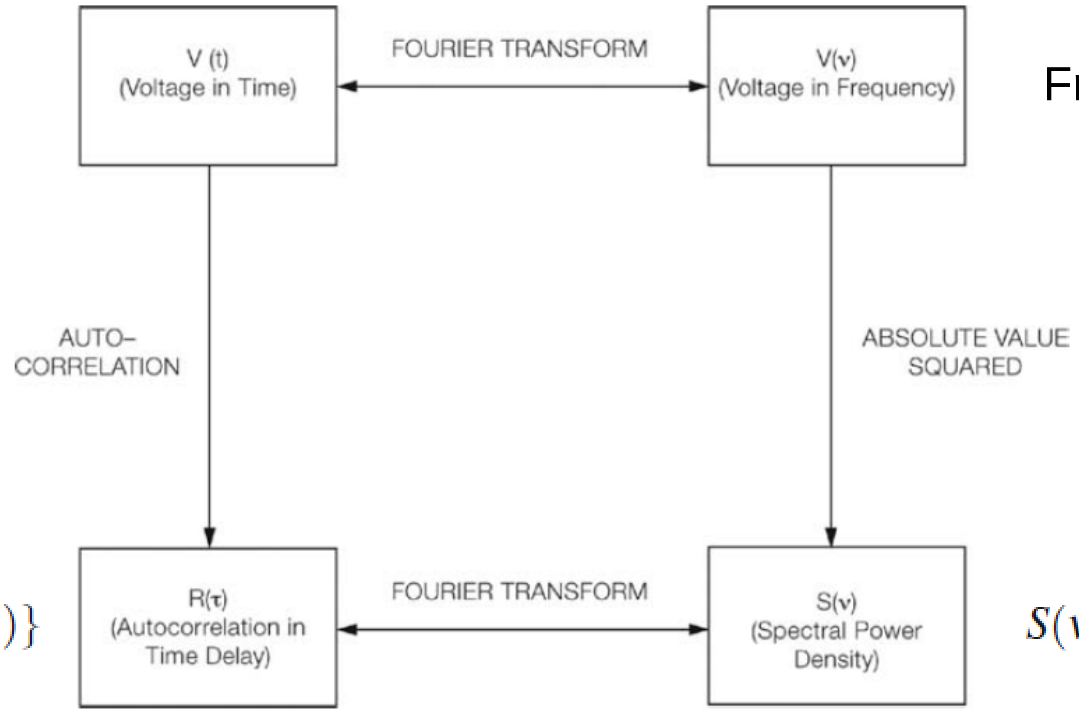
Bolometer

Heterodyne Receiver

Wiener-Khinchin Theorem

Time domain

Frequency domain



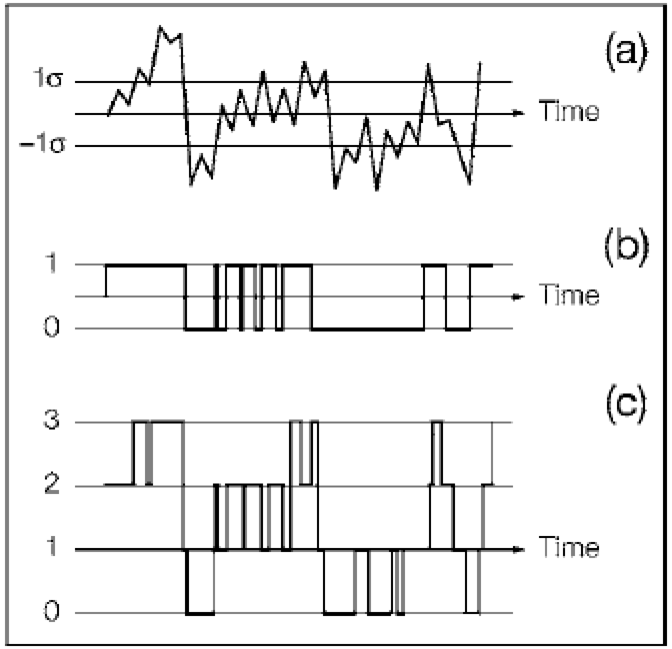
$$R_T(\tau) = E_T\left\{x(t-\tau)x(t)\right\}$$

$$S(\nu) = \lim_{T\to\infty} \frac{1}{T} E_T\left\{|X(\nu)|^2\right\}$$

Fig. 4.1 A sketch of the relation between the voltage input as a function of time, $V(t)$, and frequency, $V(\nu)$, with the autocorrelation function, ACF, $R(\tau)$, and corresponding power spectral density, PSD, $S(\nu)$. The two-headed arrows represent reversible processes

$$R(\tau) = \int_{-\infty}^{\infty} S(\nu)\,\mathrm{e}^{2\pi \mathrm{i}\nu\tau}\,\mathrm{d}\nu$$

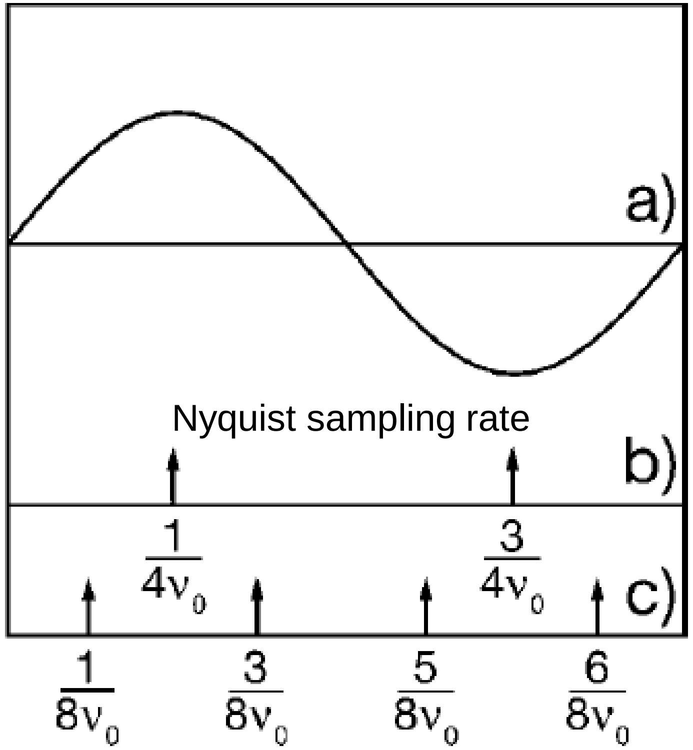
A/D convertion



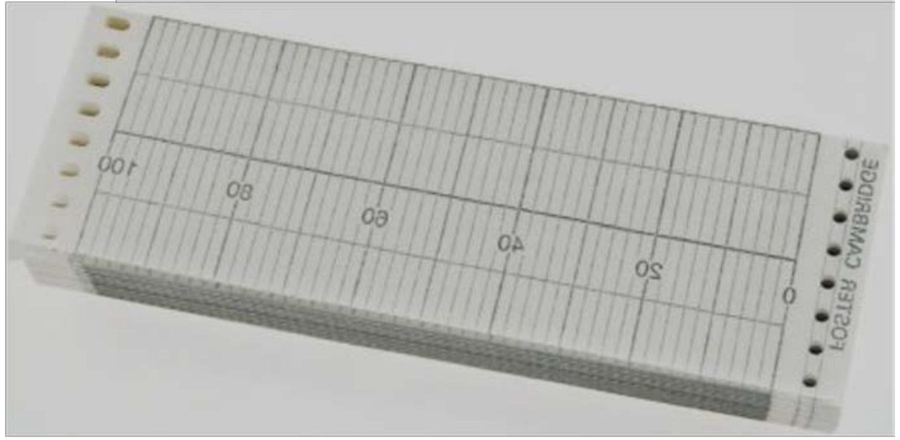
1 bit

2 bit

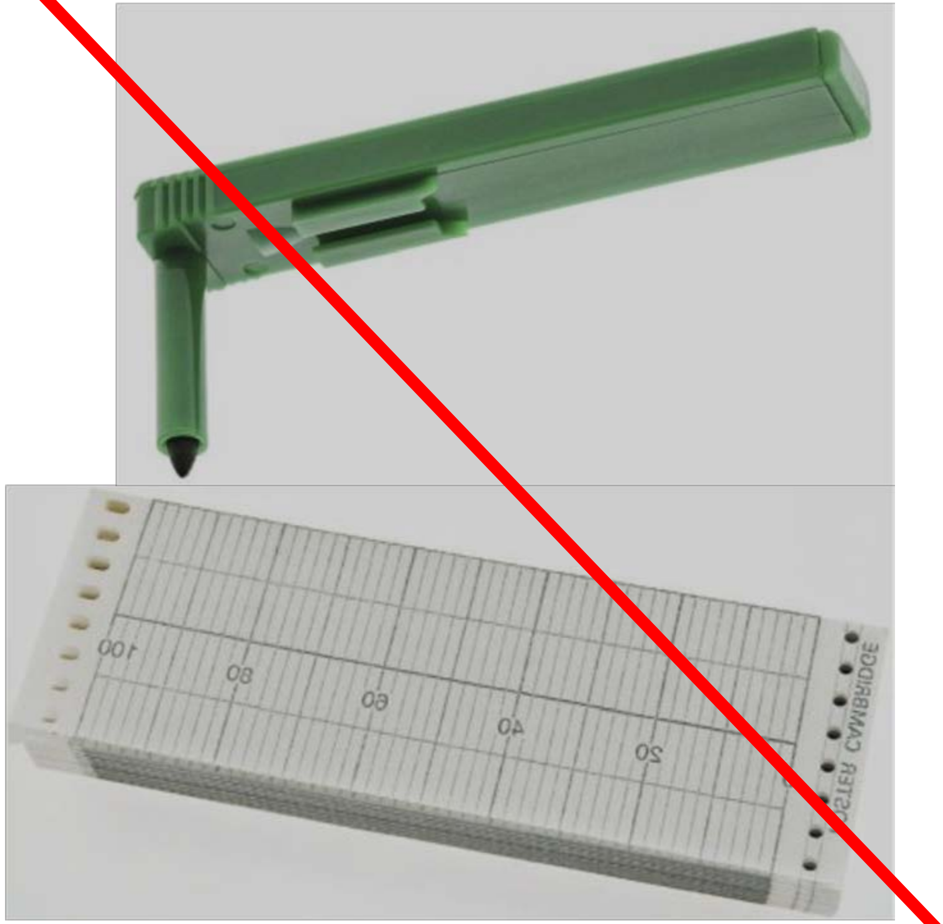
Sampling

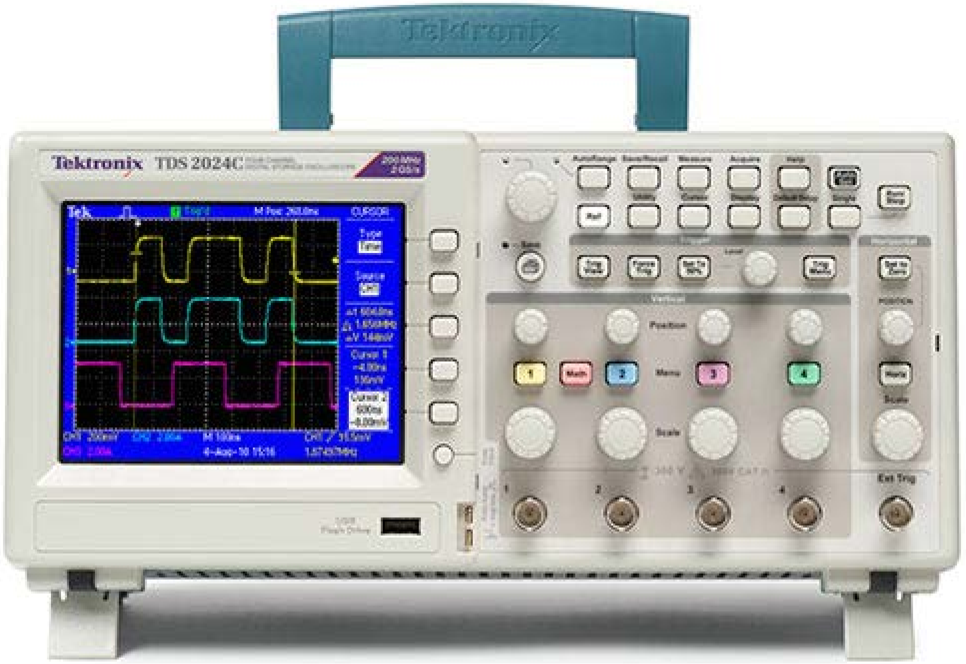


Nyquist sampling rate

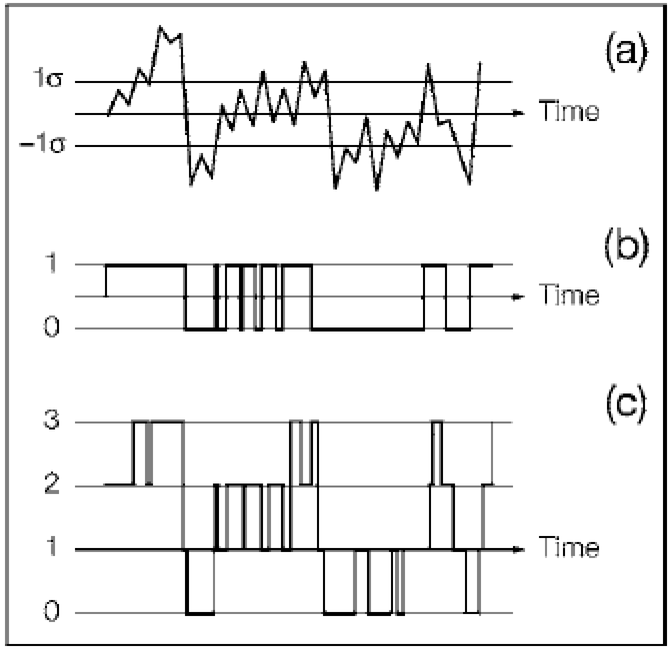


100
80
60
40
20
0
FOSTER CAMBRIDGE


100
80
60
40
20
CAMBRIDGE


Tektronix
Tektronix TDS 2024C

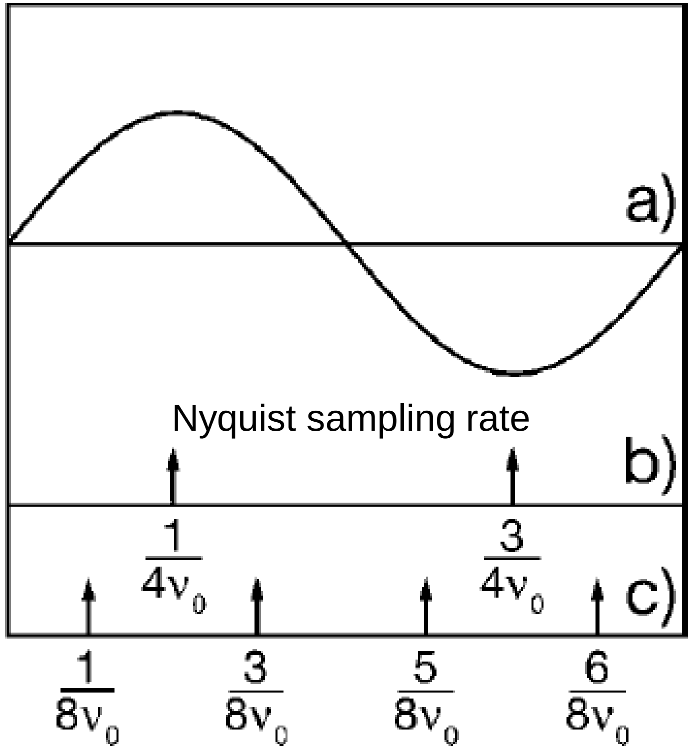
A/D convertion



1 bit

2 bit

Sampling



Nyquist sampling rate

Filters:

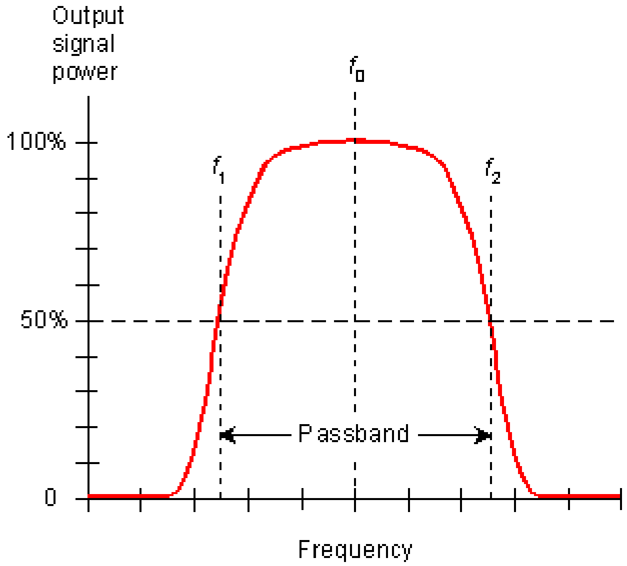
Band pass filter, $v_{min} < v < v_{max}$

Band stop filter, $v_{min} < v < v_{max}$ eliminated

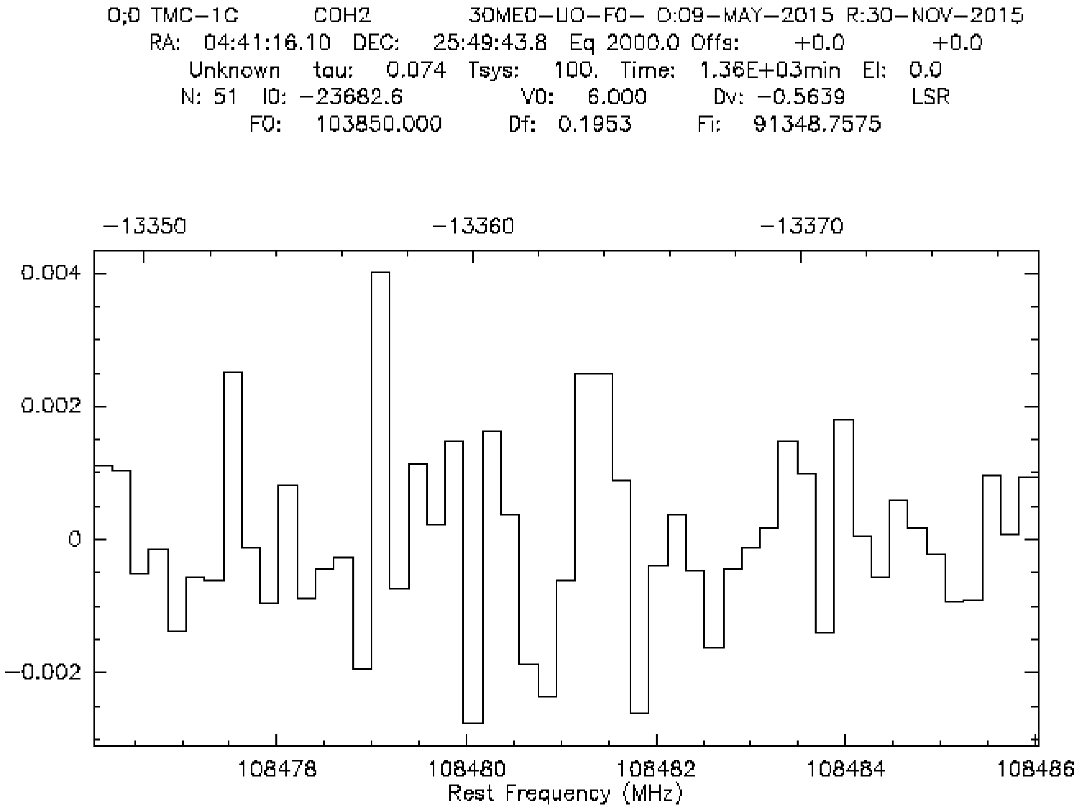
Low pass filter, $v < v_{max}$

High pass filter, $v > v_{max}$

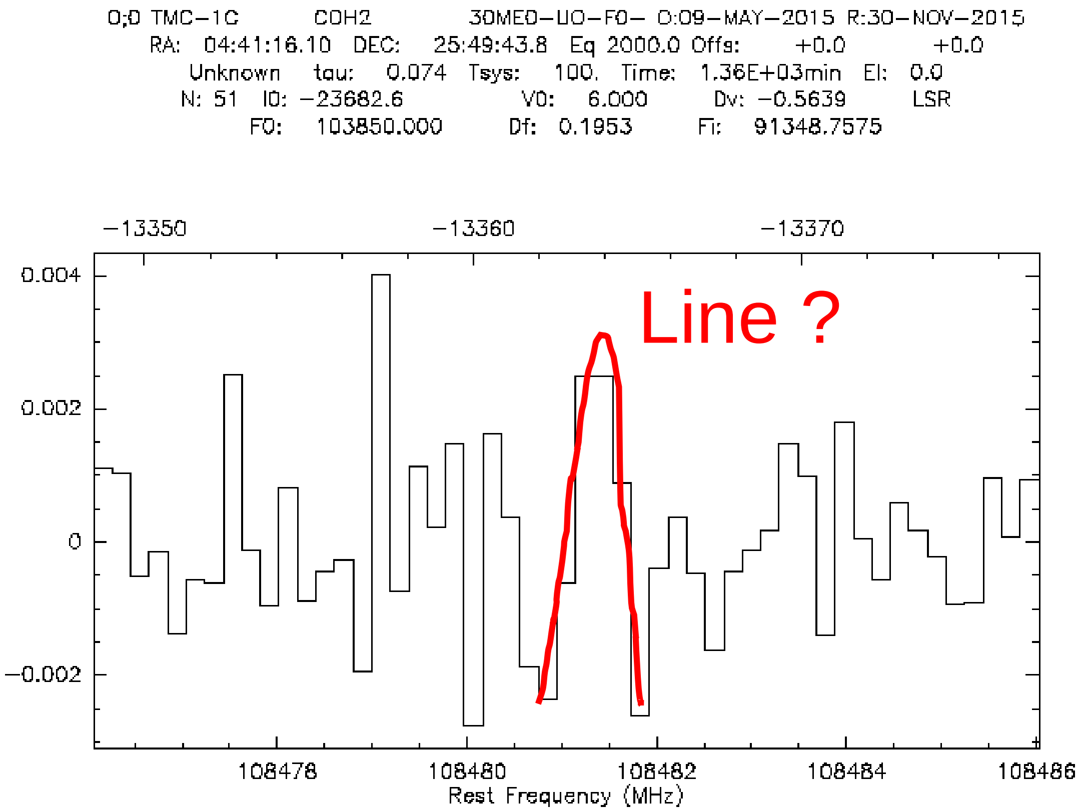
All pass filter, phase change



Noise

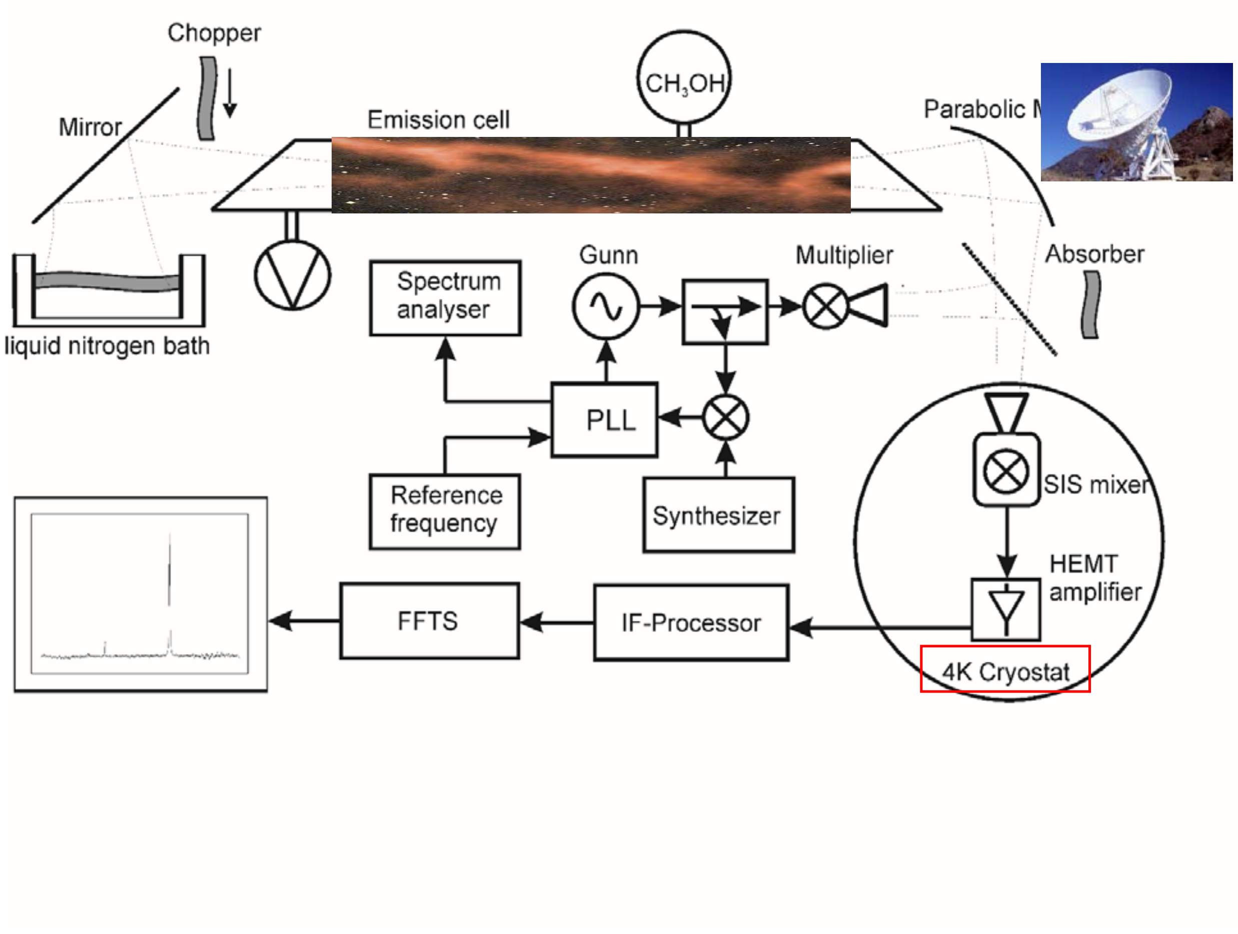

0;0 TMC-1C COH2 30ME0-U0-F0- O:09-MAY-2015 R:30-NOV-2015
RA: 04:41:16.10 DEC: 25:49:43.8 Eq 2000.0 Offs: +0.0 +0.0
Unknown tau: 0.074 Tsys: 100. Time: 1.36E+03min El: 0.0
N: 51 I0: −23682.6 V0: 6.000 Dv: −0.5639 LSR
F0: 103850.000 Df: 0.1953 Fi: 91348.7575
−13350
−13360
−13370
0.004
0.002
0
−0.002
108478
108480
108482
108484
108486
Rest Frequency (MHz)

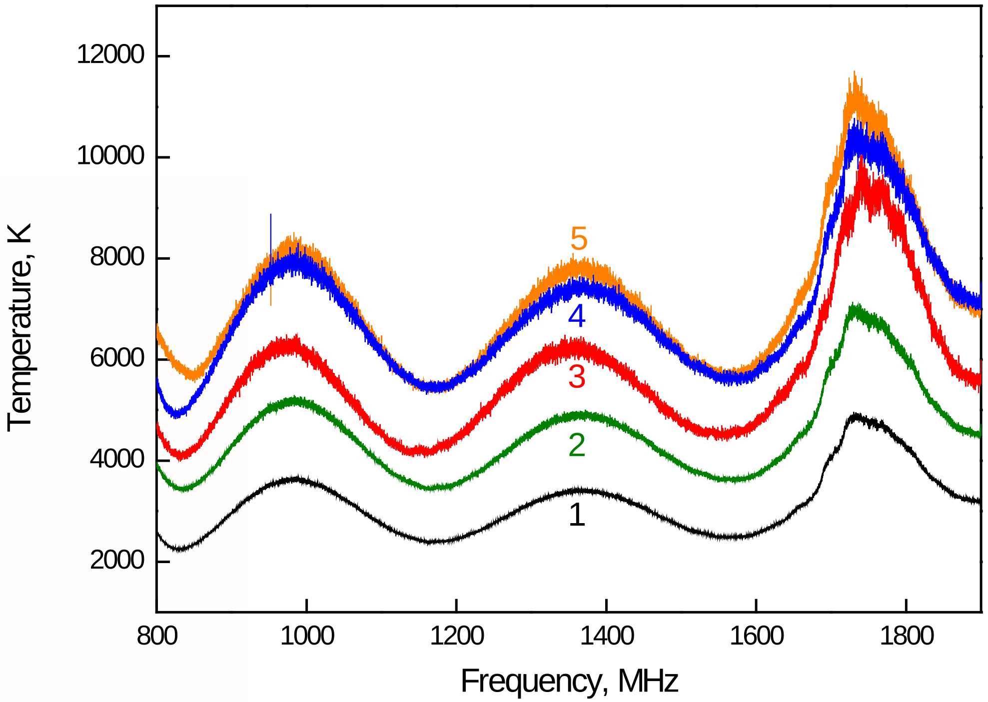
Noise



```
0;0 TMC-1C        COH2          30MED-UO-F0-  O:09-MAY-2015  R:30-NOV-2015
   RA:  04:41:16.10  DEC:    25:49:43.8  Eq 2000.0 Offs:      +0.0          +0.0
      Unknown     tau:    0.074  Tsys:    100.  Time:  1.36E+03min  El:  0.0
     N: 51   I0: -23682.6           V0:    6.000        Dv: -0.5639      LSR
          F0:    103850.000       Df:  0.1953       Fi:   91348.7575
```

Line ?





Receiver $\boldsymbol{T_{rec}}$ and system $\boldsymbol{T_{sys}}$ noise temperatures at the LO frequency of 804 GHz:

1) T_{rec} 2) T_{sys} including the emission cell without windows

3) T_{sys} including the evacuated cell and HDPE windows

4) T_{sys} including the evacuated cell and Teflon windows

5) T_{sys} including the cell and Teflon windows, the cell is filled with 1 bar of air

Radiometer formula:

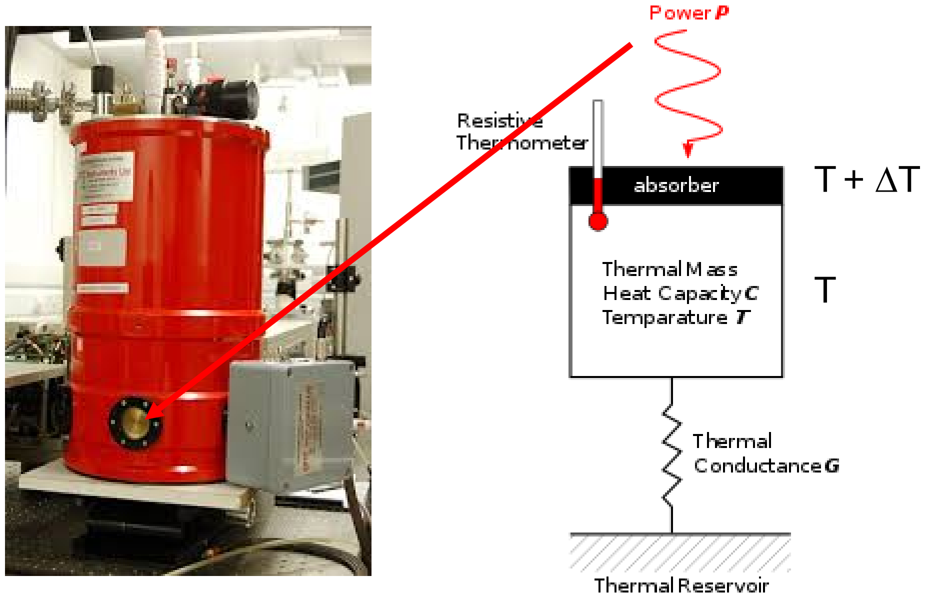
$$\frac{\Delta T}{T_{\rm sys}} = \frac{1}{\sqrt{\Delta \nu \, \tau}}$$

Receiver stability

$$\frac{\Delta T_{\rm RMS}}{T_{\rm R}} = \frac{\Delta G}{G}$$

ΔT – root mean square (RMS) noise, Δv – bandwidth, τ – integration time, G – gain

Bolometer



Cooled down to K

Energy balance equation:

$$\mathscr{C}\frac{\mathrm{d}\Delta T}{\mathrm{d}t}+\mathscr{G}\cdot\Delta T=P$$

Capacity (C = ΔQ/ΔT) Conductance (G = 1/*R*) Power absorbed

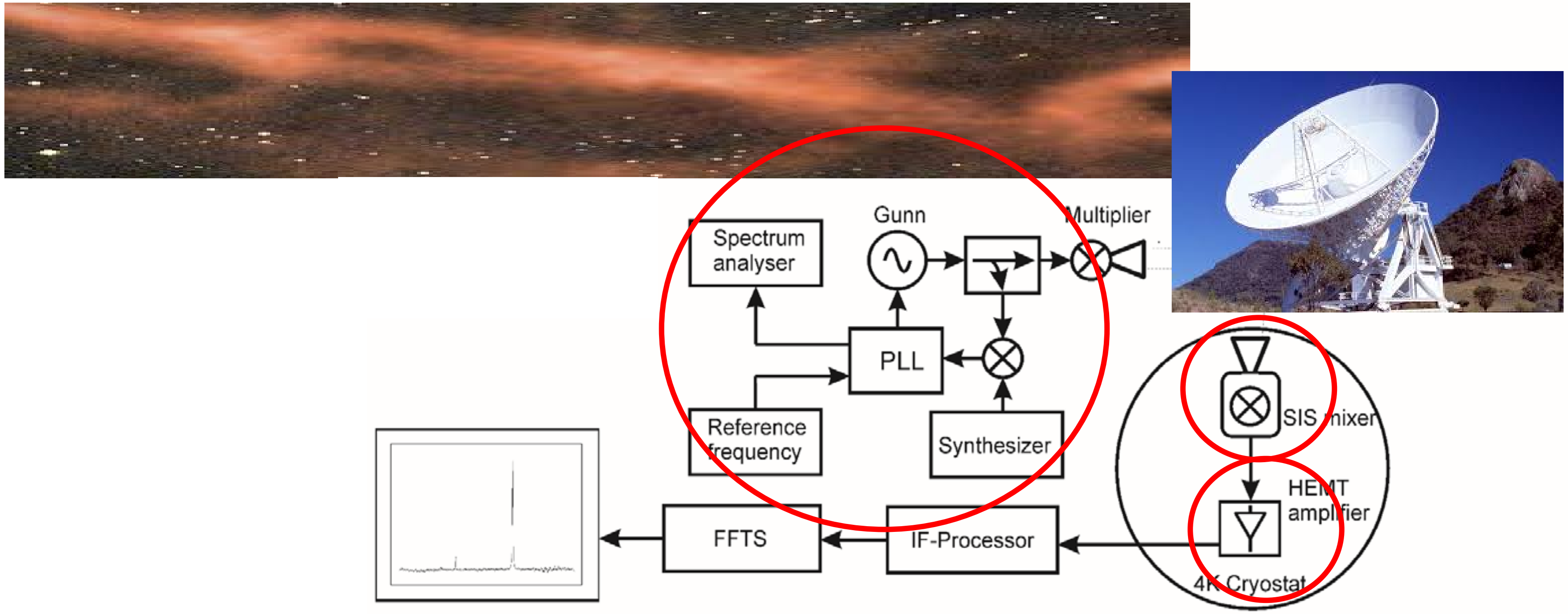
$$\Delta T=\frac{P}{\mathscr{G}}\mathrm{e}^{-t/\tau}\qquad\tau=\mathscr{C}/\mathscr{G}$$

Modulation

$$\Delta T=\frac{P_0\,\mathrm{e}^{2\pi\mathrm{i}\nu t}}{\mathscr{G}(1+2\pi\mathrm{i}\nu\tau)}$$

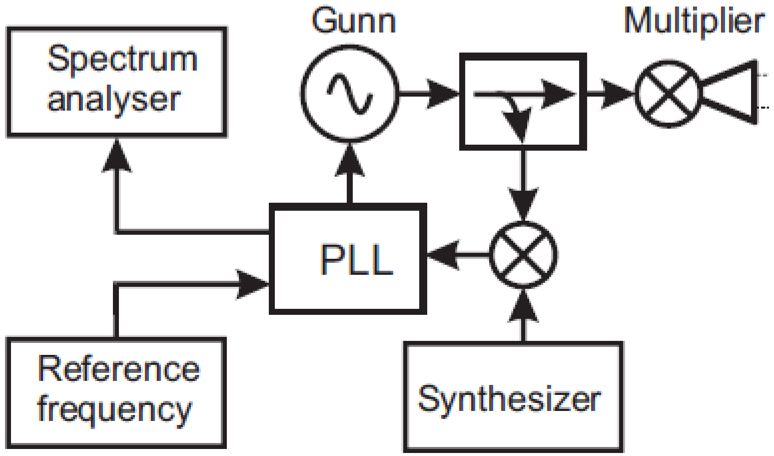
$$|\Delta T|=\frac{P_0}{\mathscr{G}\sqrt{1+(2\pi\nu\tau)^2}}$$

Heterodyne receiver



Heterodyne receiver

Local oscillator (LO)



Heterodyne receiver

Mixer

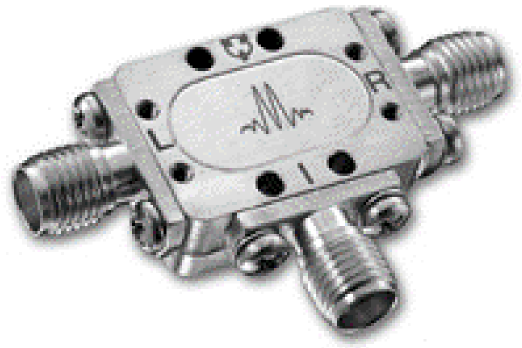
Heterodyne receiver

Mixer

$$I = \alpha\,[E\sin(2\pi\nu_{\rm S}t+\delta_{\rm S})+V\sin(2\pi\nu_{\rm LO}t+\delta_{\rm LO})]^2$$

Signal

LO



$$
\begin{aligned}
I = {} & \tfrac{1}{2}\alpha\,(E^2+V^2) && \text{(DC component)}\\
& -\tfrac{1}{2}\alpha E^2\sin(4\pi\nu_{\rm S}t+2\delta_{\rm S}+\tfrac{\pi}{2}) && \text{(2nd harmonic of signal)}\\
& -\tfrac{1}{2}\alpha V^2\sin(4\pi\nu_{\rm LO}t+2\delta_{\rm LO}+\tfrac{\pi}{2}) && \text{(2nd harmonic of LO)}\\
& \boxed{+\alpha VE\sin[2\pi(\nu_{\rm S}-\nu_{\rm LO})t+(\delta_{\rm S}-\delta_{\rm LO}+\tfrac{\pi}{2})] \quad \text{(difference frequency)}}\\
& -\alpha VE\sin[2\pi(\nu_{\rm S}+\nu_{\rm LO})t+(\delta_{\rm S}+\delta_{\rm LO}+\tfrac{\pi}{2})] && \text{(sum frequency).}
\end{aligned}
$$

Heterodyne receiver

SIS (superconducting-insulating-supercondacting) Mixer

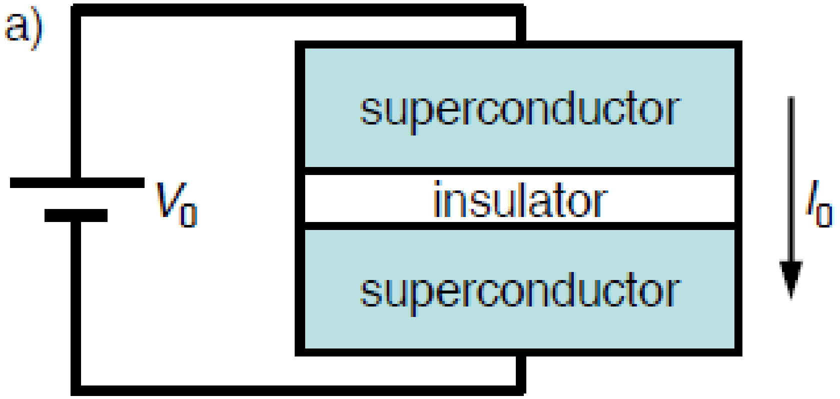
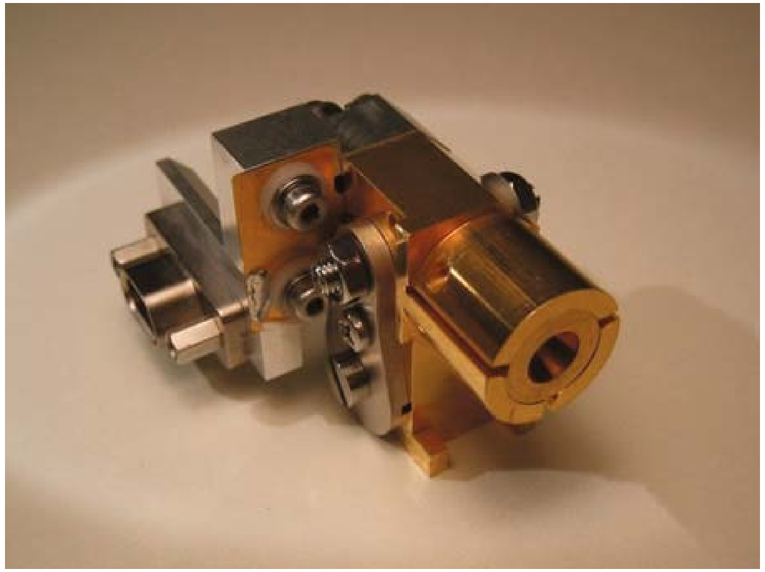
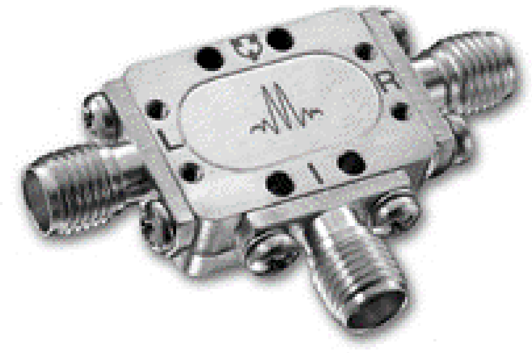
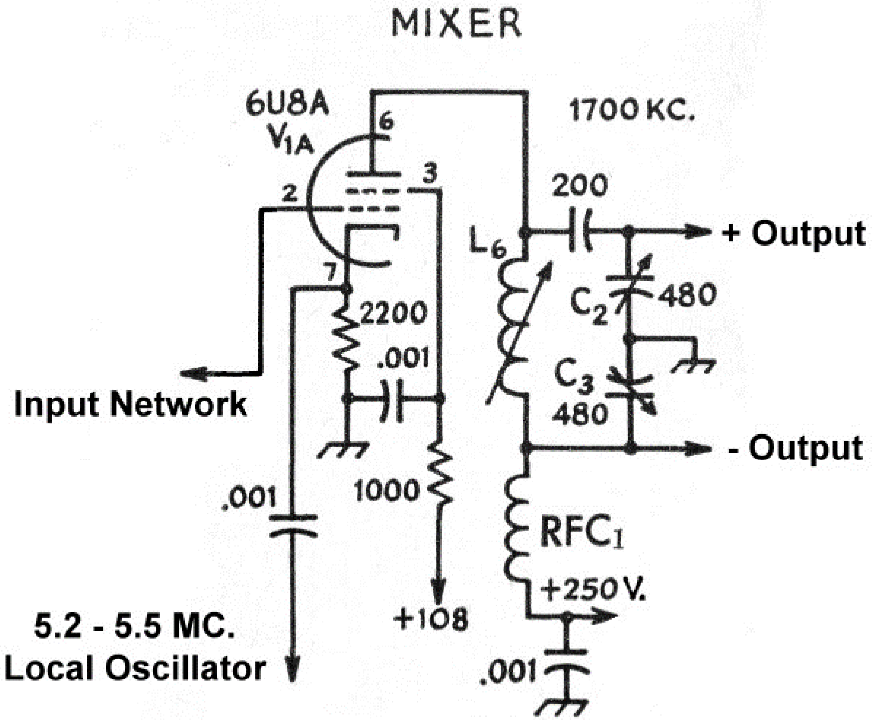


Fig. 2.2: *Basic concept of a SIS-junction.* **a)** *Two superconductive electrodes (≈100 nm thickness) are divided by a thin insulating barrier (≈2-5 nm thickness).*



Heterodyne receiver





Heterodyne receiver

Hot electron bolometer (HEB) Mixer

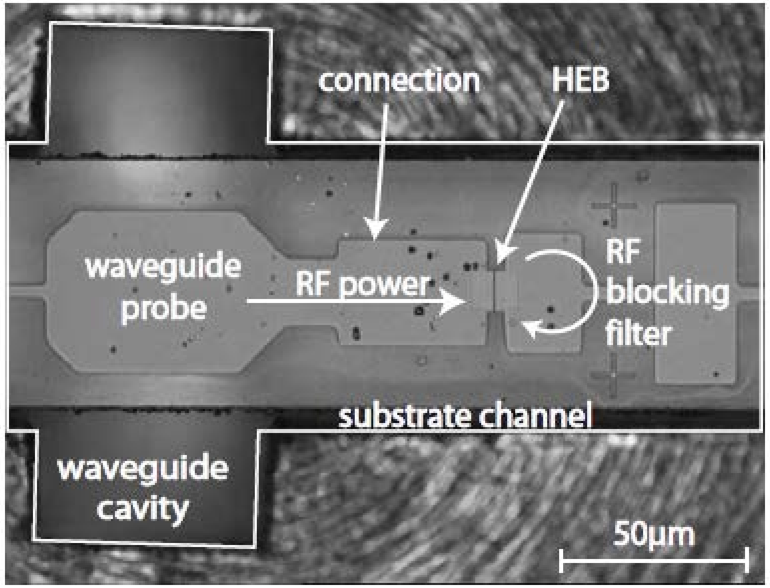
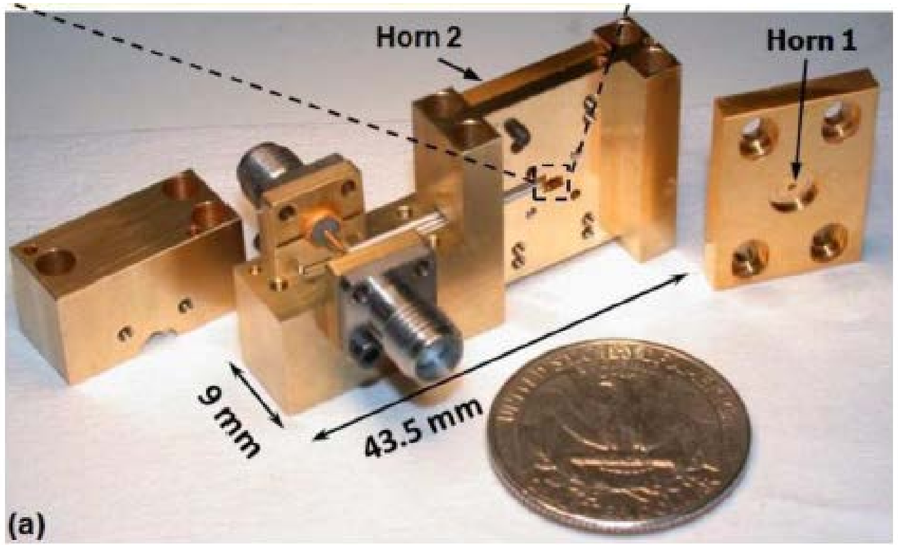
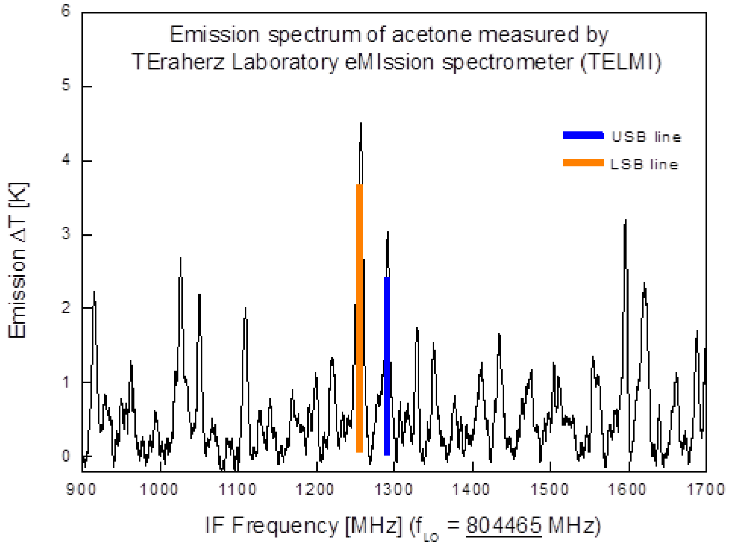
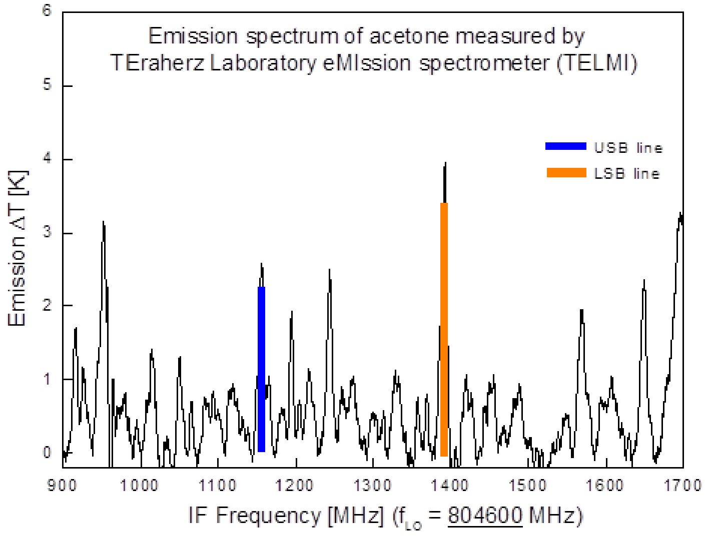


Fig. 1.10: *Left: Microscope picture of a 1.9 THz waveguide cavity and substrate channel carrying a silicon nitride membrane with an HEB mixer and integrated waveguide circuit.*

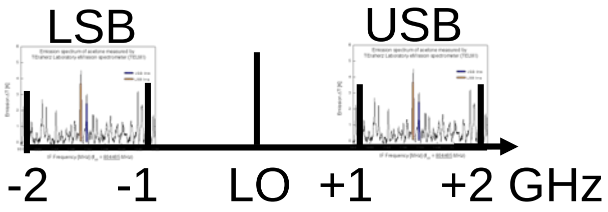


Side band problem





f(LO) – f   or   f – f(LO)



USB: f = f(LO) + f(IF)
f(IF) = f - f(LO)

LSB: f = f(LO) - f(IF)
f(IF) = f(LO) - f

Side band problem

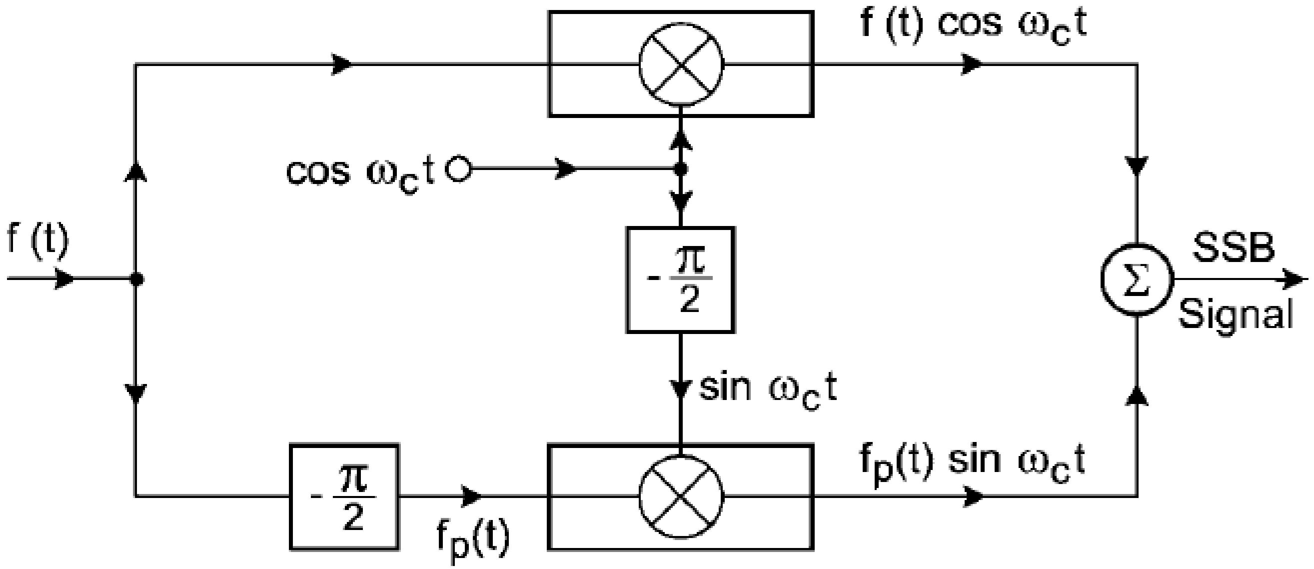


Fig. 5.6 A sketch of the single sideband mixer (SSB). The input signal, $f(t)$, is divided into two equal parts. There are two identical mixers located in an *upper* and *lower* branch of the sketch. The LO frequency from a central source, ω_c, is shifted in phase by $\pi/2$ from the input to the output of the mixer in the *lower part* of the sketch. In the *lower* branch, the phase of the input signal is also shifted by $\pi/2$. After mixing the signals are added to produce the single sideband output

Heterodyne receiver

Amplifier, High Electron Mobility Transistor (HEMT)

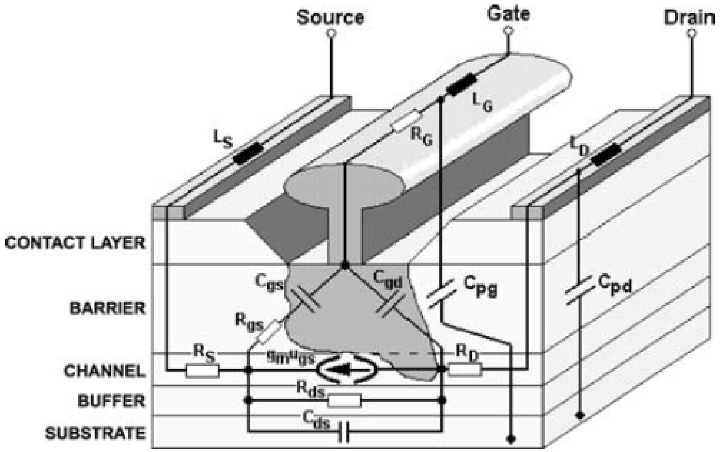
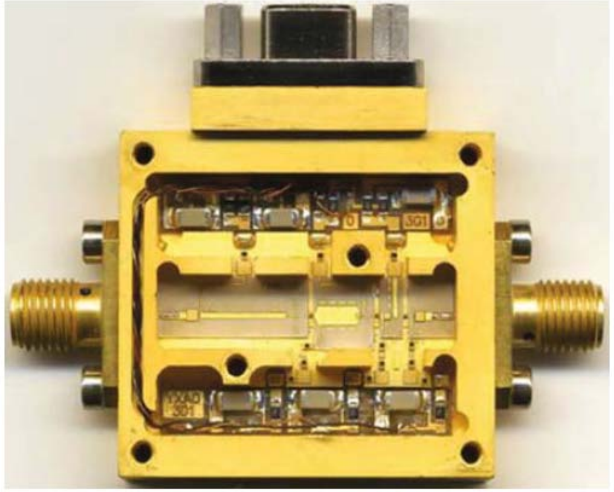


Fig. 5.8 This figure shows a HEMT amplifier. As with FETs, the current flow from Source to Drain, around the Gate. The electric field from the Gate is shown as a darker, irregular region, has a large effect on the current flow from Source to Drain. Thus, this amplifies the signal placed on the Gate. Because of the potentials in the interface layers, the electrons can flow from Source to Drain only in a very thin layer. This is shown enclosed in semicircles; this part of the HEMT provides the gain. The quantity g_m is the transconductance, and u_{gs} is the velocity from gate to source. The product of these is the gain of the amplifier. The quantities labelled "L_s, L_D, etc." represent inductances internal to the HEMT; the "R"s are internal resistances, and "C"s are internal capacitances



Beauty in Radio Astronomy