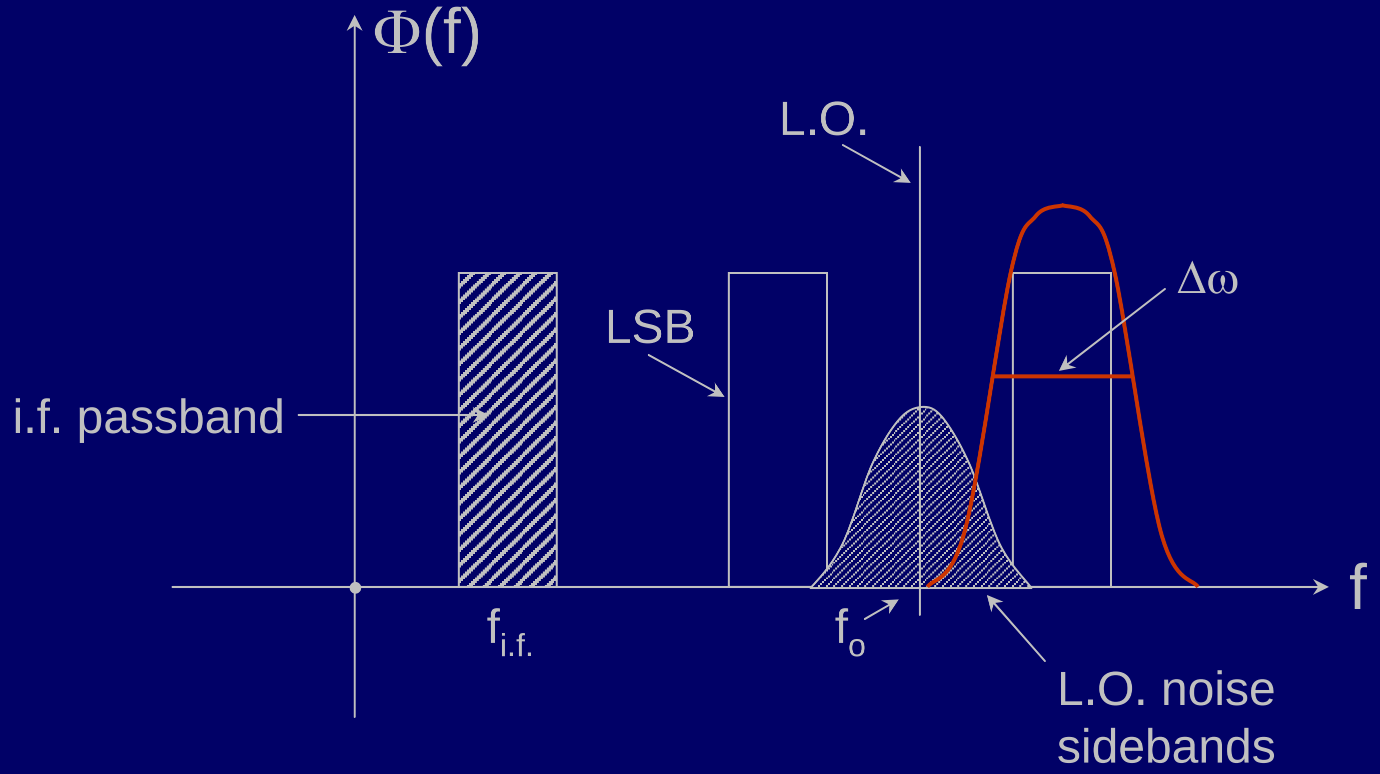
Noise Cancellation Methods

1. Filtering, down-conversion
2. Sideband cancellation
3. Balanced mixers
4. Reducing calibration noise

Noise Cancellation Methods

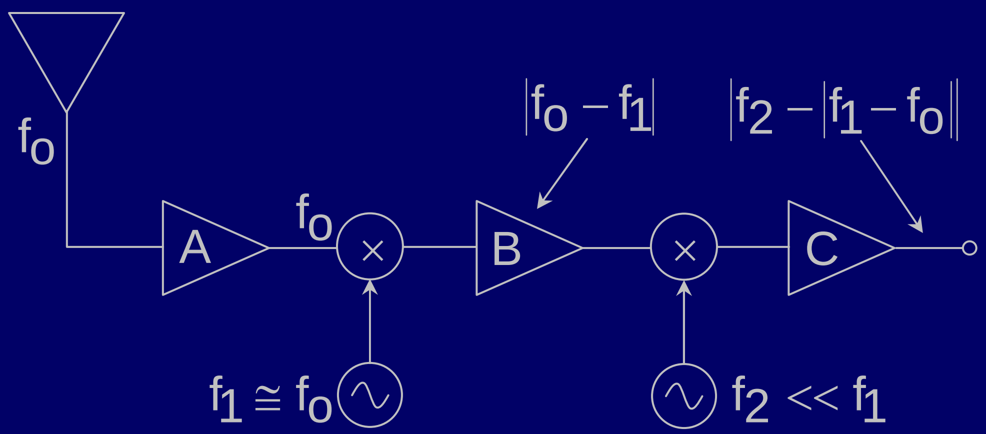
Example 1: canceling unwanted sidebands by filtering

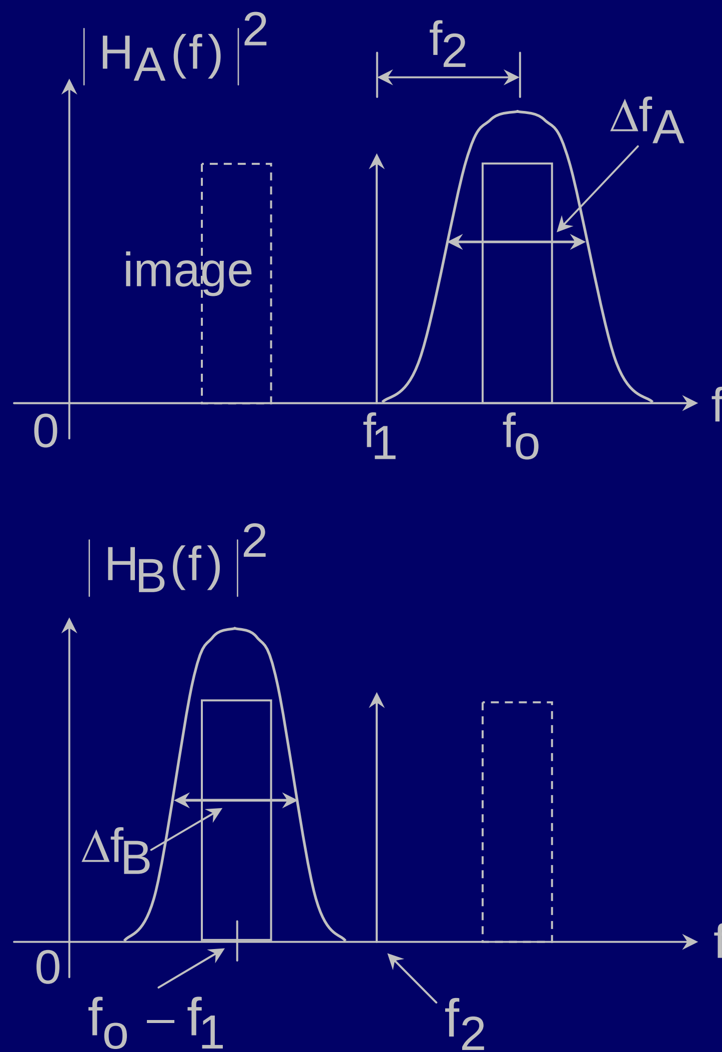
Want $Q \gg f_o / f_{i.f.}$ for filter where $Q \triangleq f_o / \Delta f$



Noise Cancellation Methods

Example 2: dual-down conversion with lower Q





$$Q \cong f_1/\Delta f_A \cong f_2/\Delta f_B$$

Multiple conversion required when:

$$f_1/f_{i.f.} \gtrsim Q_{MAX}/3$$

$$\left(\text{e.g. triple conversion if } \frac{f_1}{f_{i.f.}} \gtrsim \left(\frac{Q}{3}\right)^2\right)$$

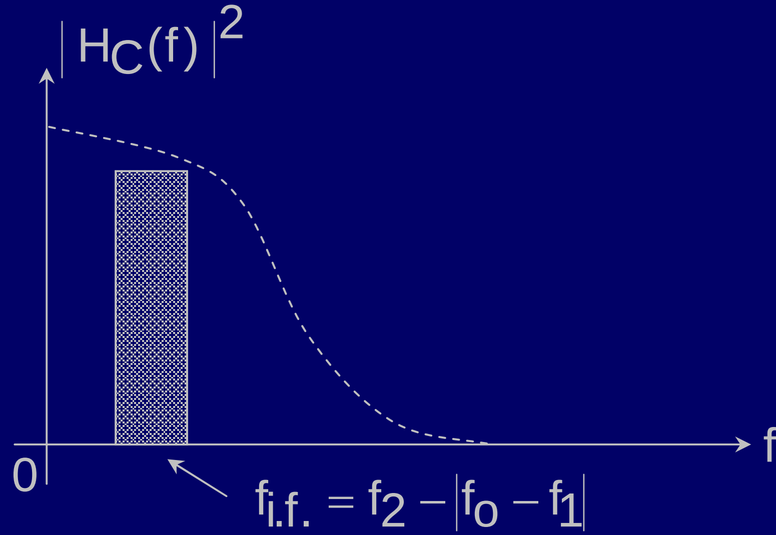
900-GHz Wireless Phone

$f_1/f_{i.f.} \gtrsim Q_{MAX}/3$

$\left(\text{e.g. triple conversion if } \frac{f_1}{f_{i.f.}} \gtrsim \left(\frac{Q}{3}\right)^2\right)$

Let $f_1 \cong 10^8$, $f_{i.f.} \cong 10^4$

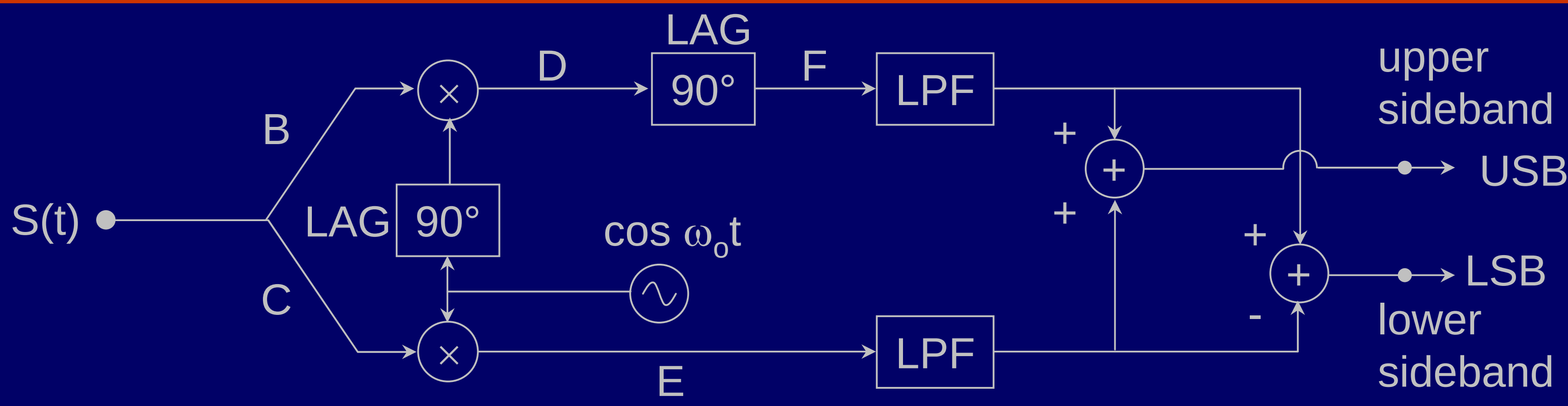
If Q = 100 (for RLC filter)



$$\frac{f_1}{f_{i.f.}} = 10^4 > \frac{100^2}{9},$$ Therefore we need triple conversion

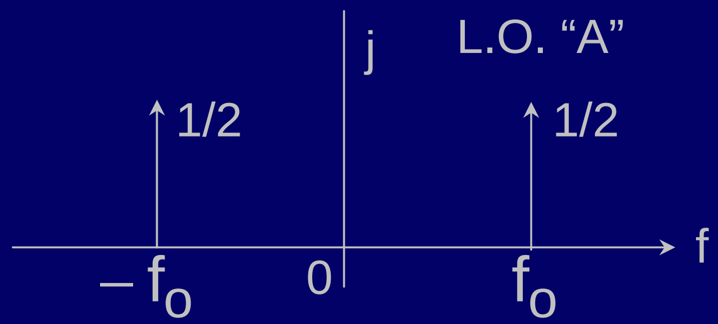
Surface Acoustic Wave (SAW) filters have $Q \cong 10^4$, and $Q \gtrsim 10^5$ for crystal filters, so double conversion works here with SAW filters $\left(10^4 > 10^4/3\right)$, and single conversion with crystal filters (for one 10-kHz channel) $\left(10^4 < 10^5/3\right)$

Example 3: Sideband Cancellation

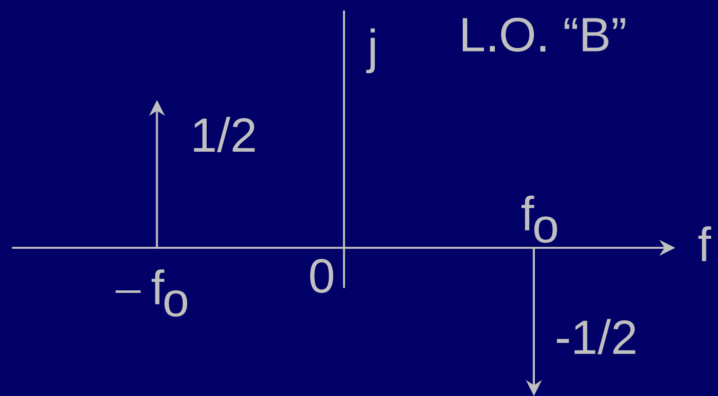


Recall:

$$\cos \omega_o t = \frac{e^{j\omega_o t} + e^{-j\omega_o t}}{2}$$

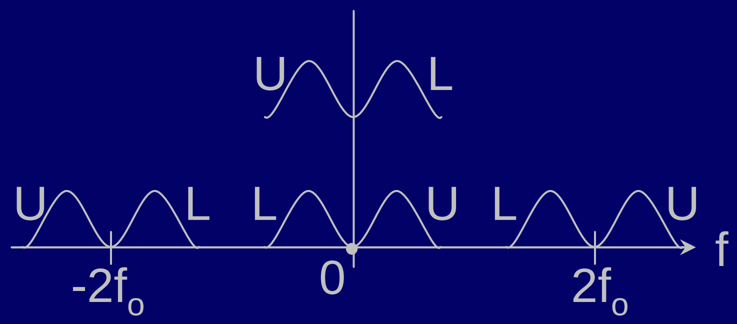


$$\sin \omega_o t = \frac{e^{j\omega_o t} - e^{-j\omega_o t}}{2j}$$

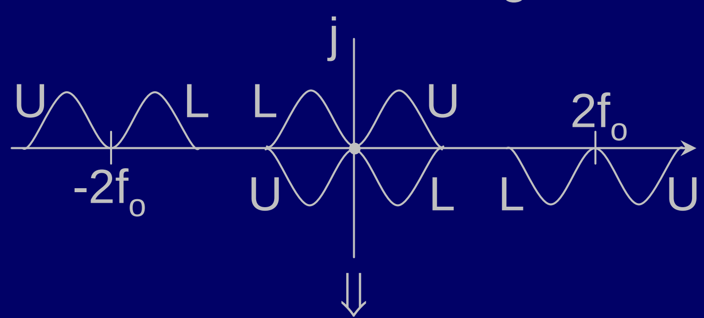


Example 3: Sideband Cancellation

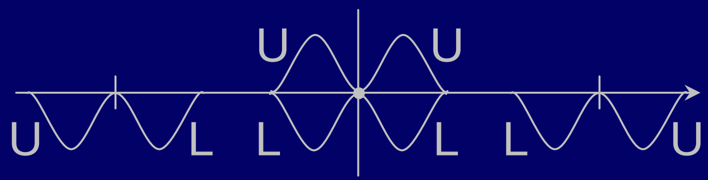
$$E = s(t)\cos\omega_o t$$

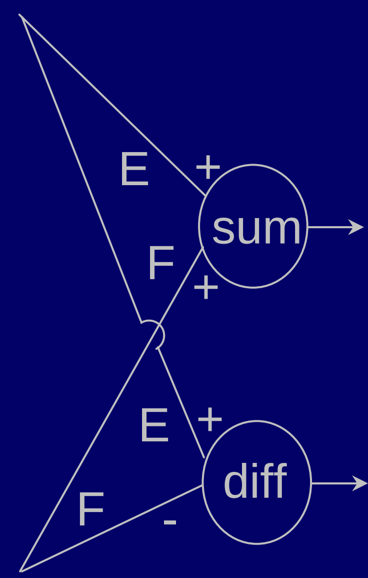


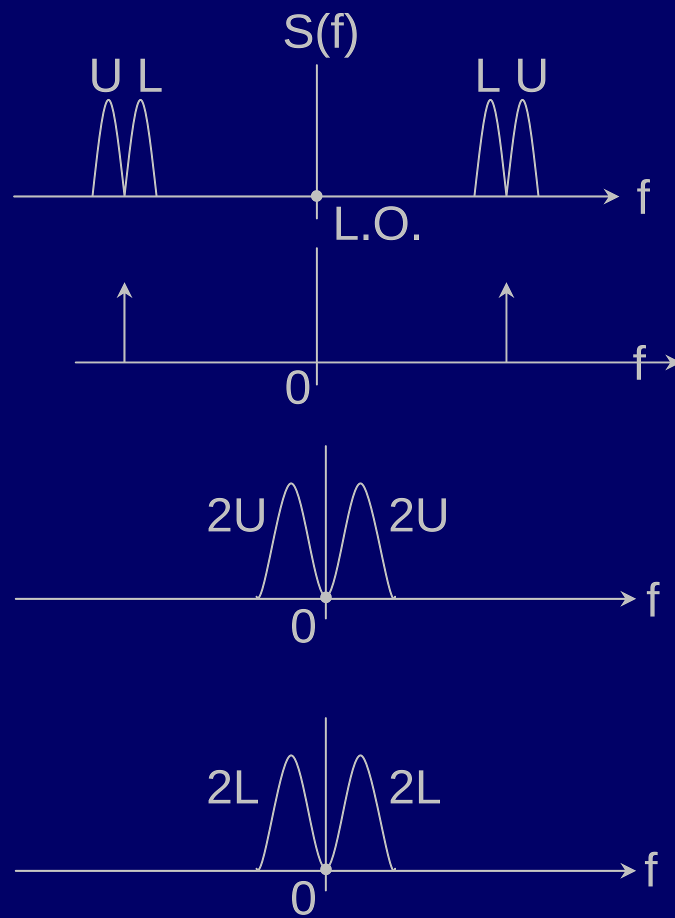
$$D = s(t)\sin\omega_o t$$



$$F(f) \Leftarrow \begin{cases} \times(-j) \text{ for } f > 0 \\ \times(j) \text{ for } f < 0 \text{ (as result of 90° delay)} \end{cases}$$



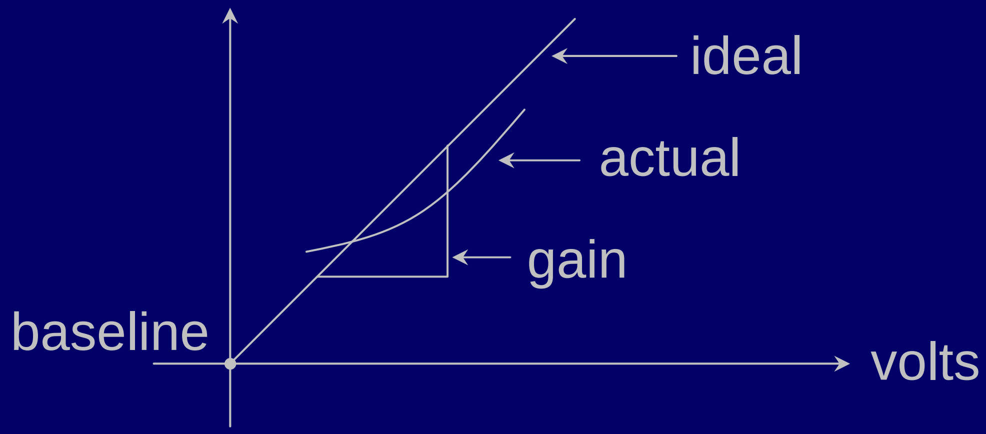




$$90° \pm \delta \Rightarrow \frac{B}{f_o} \lesssim 0.1$$

Note: Analog signals can be converted to digital at any point in these circuits

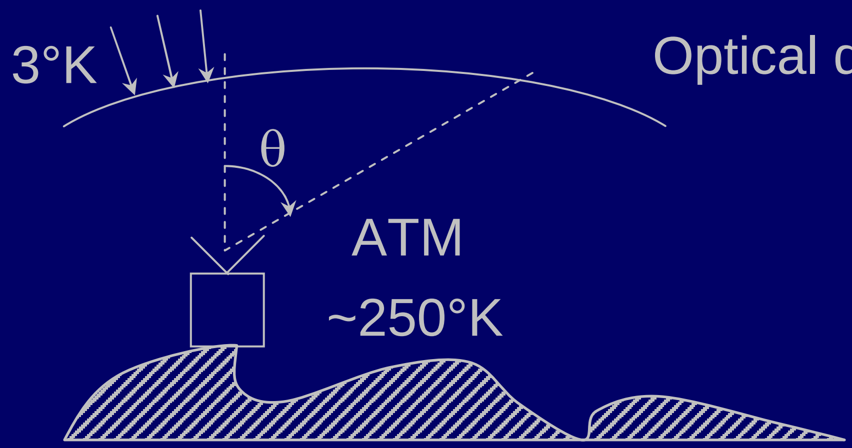
Example 4: Calibration



Calibrate:

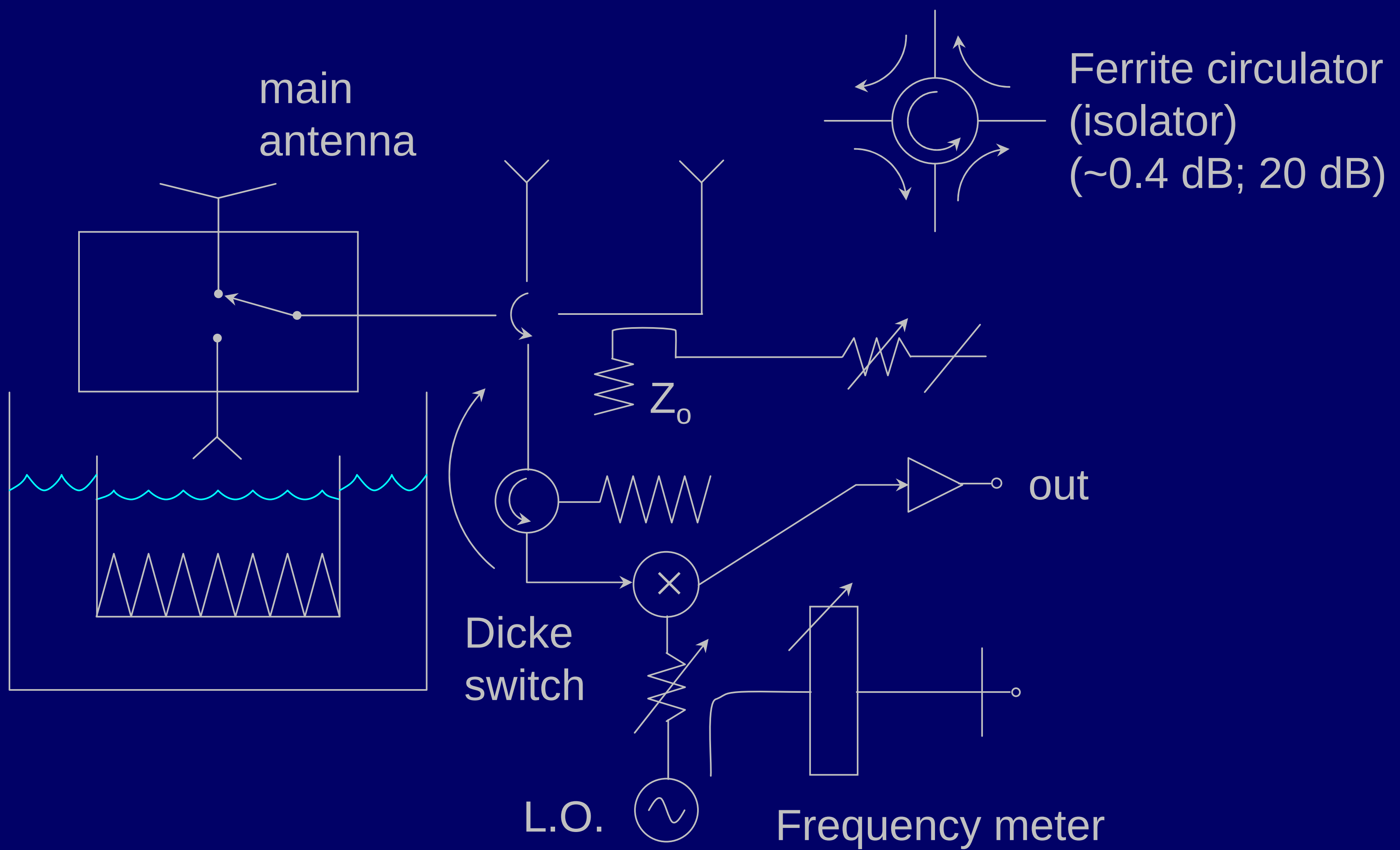
- gain
- baseline
- linearity

Example: cosmic background measurement



Optical depth $\tau \cong 0.01$ on 12,000-ft mountain

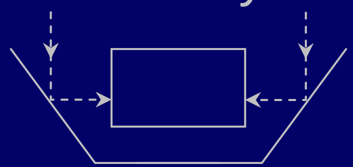
Example 4: Calibration



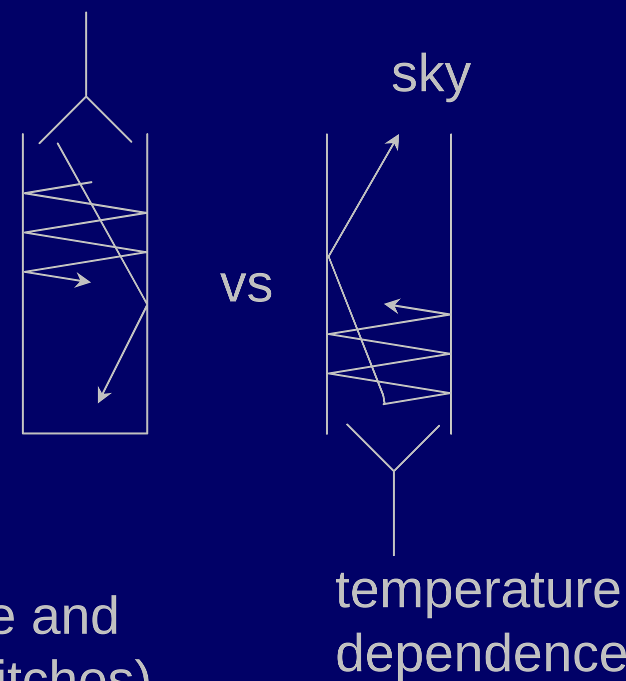
Example 4: Calibration

Issues:

1) switch assymetry



measure on sky



2) T_B of H_e load (~4°K)
(Note hf << kTT)

3) Liquid helium load VSWR

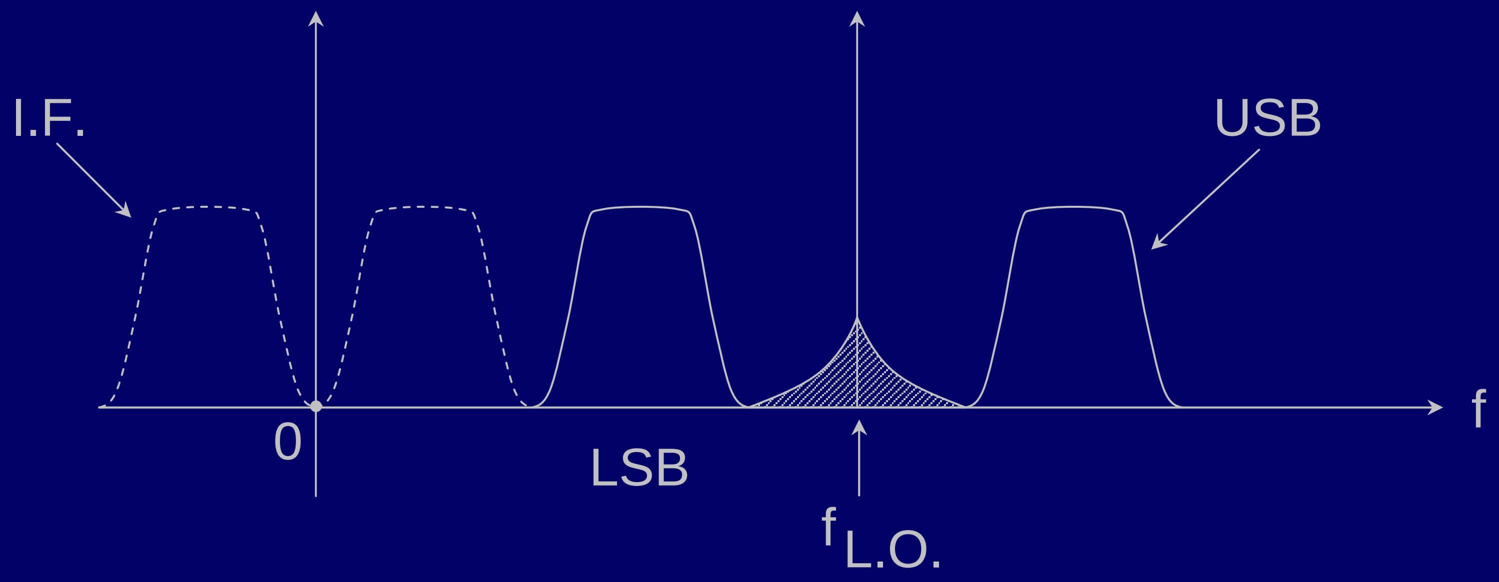
4) Isolator? (effects of LO and $2f_{LO}$ leakage and reflection from Dicke and calibration switches)

5) Atmospheric contribution

In general

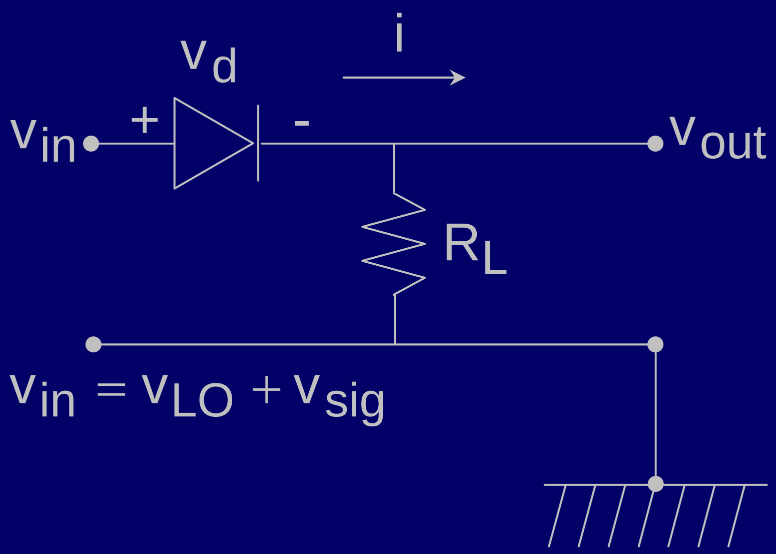
1) Design for calibration; seek symmetry and redundancy
2) Use lab calibration, internal calibration, sky calibration sources
3) Use antenna pattern ranges

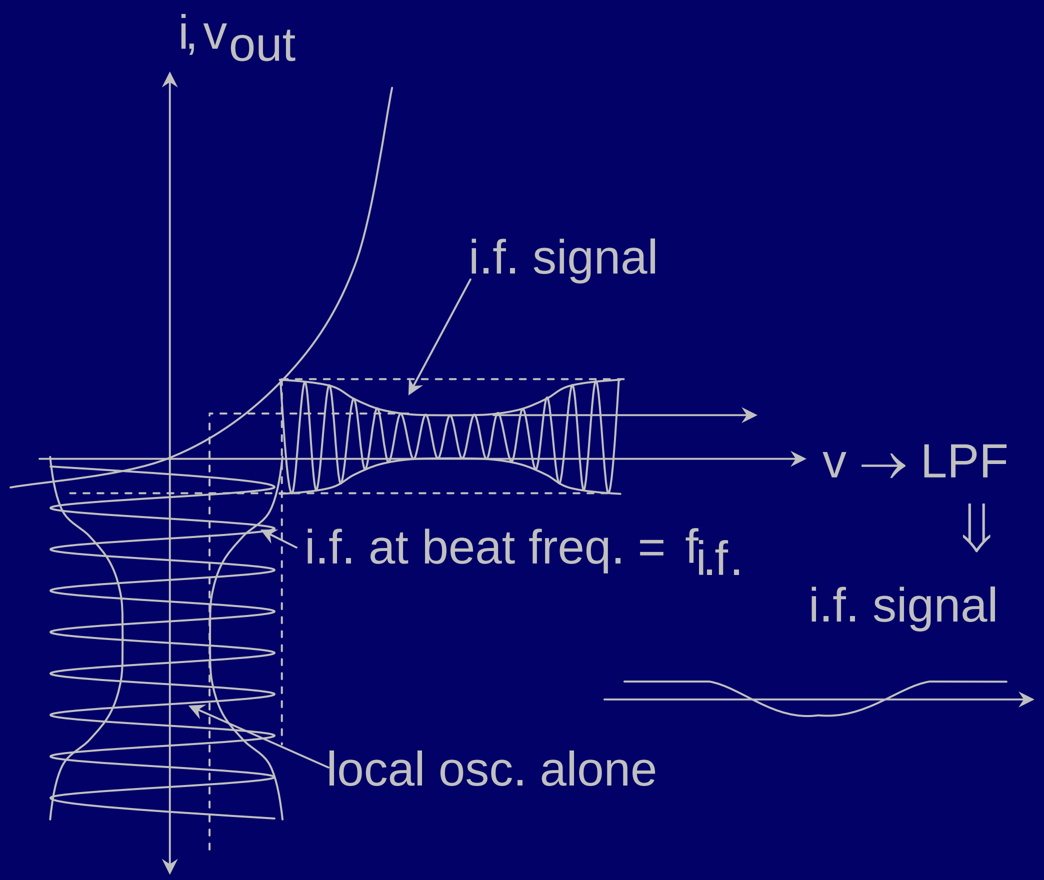
Example 5: Local Oscillator Noise Cancellation



1) use quiet L.O.'s
2) filter the L.O's
3) use high $f_{i.f.}$
4) cancellation (balanced mixers)

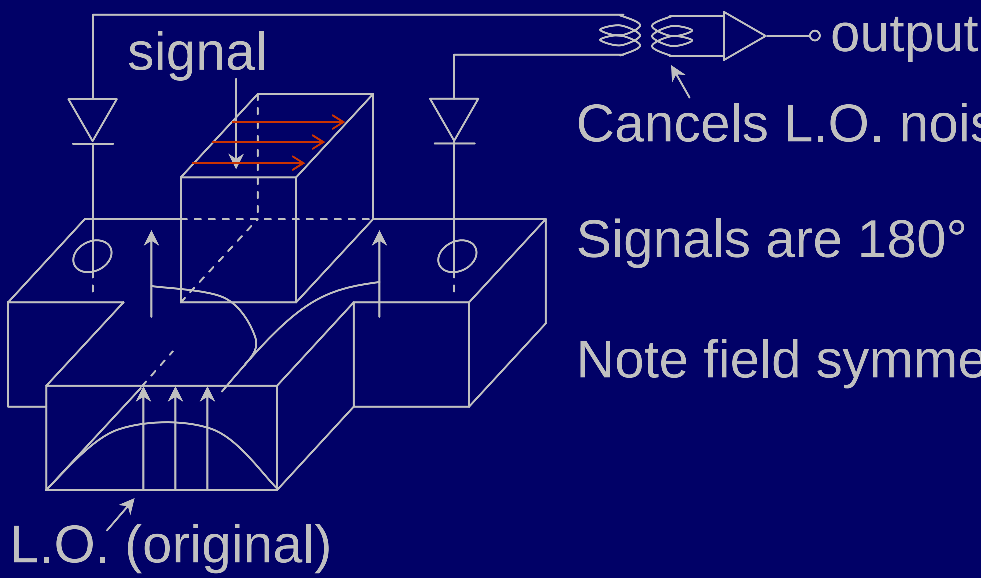
Example 6: Balanced Mixers





LO and r.f. signal add, so v_{in} produces i.f. component in v_{out}

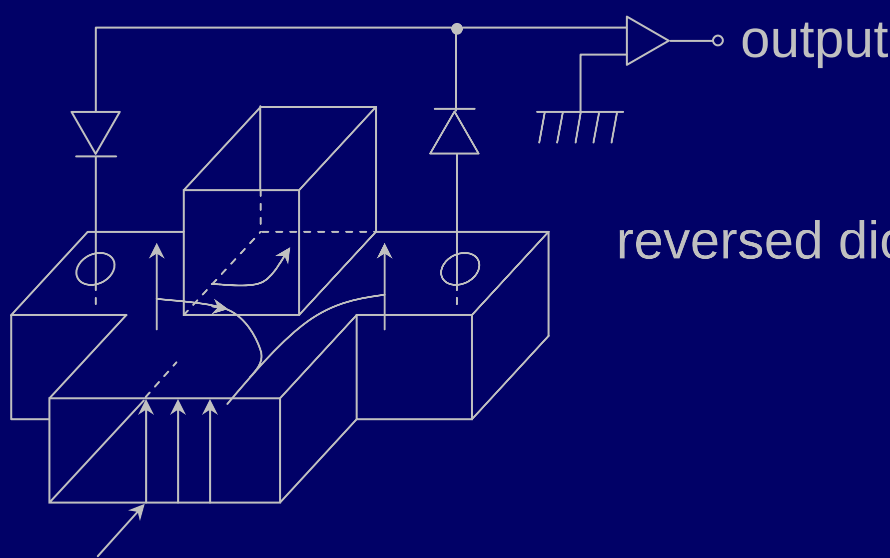
Example 6: Balanced Mixers



Cancels L.O. noise, which is identical at both diodes

Signals are 180° out of phase, add

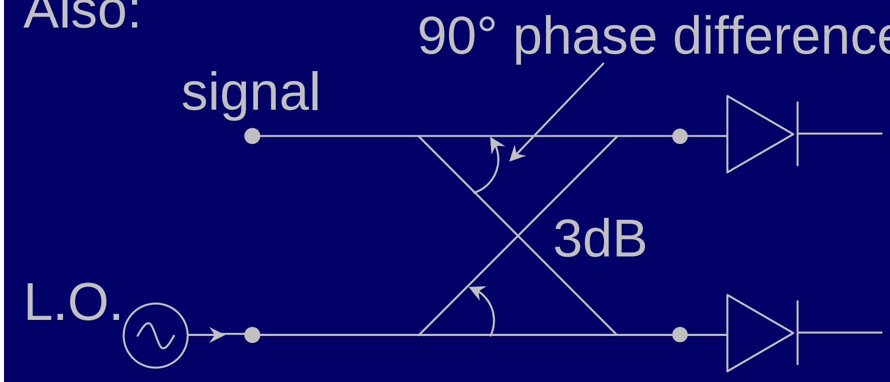
Note field symmetries: at i.f. [even] × [odd] = [odd]



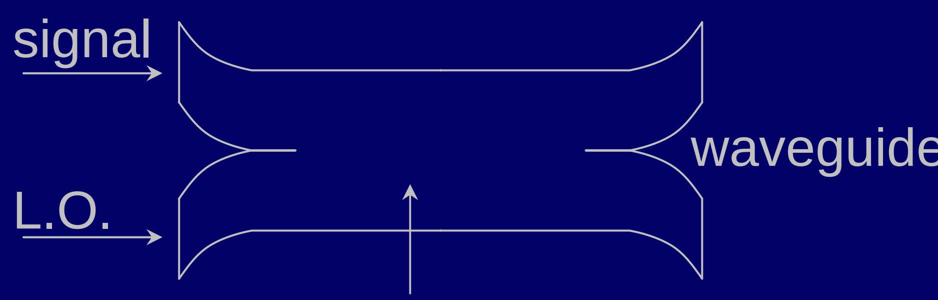
reversed diodes cancel L.O. noise upon addition

Example 6: Balanced Mixers

Also:

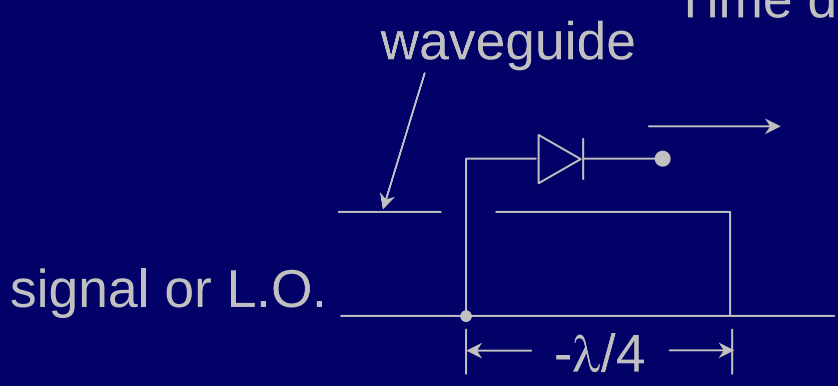


3-dB hybrid

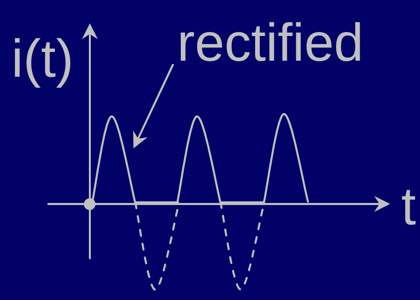


3-dB sidewall coupling

Another balanced mixer

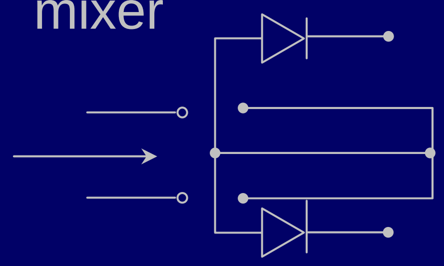


Time domain:



or

double balanced mixer

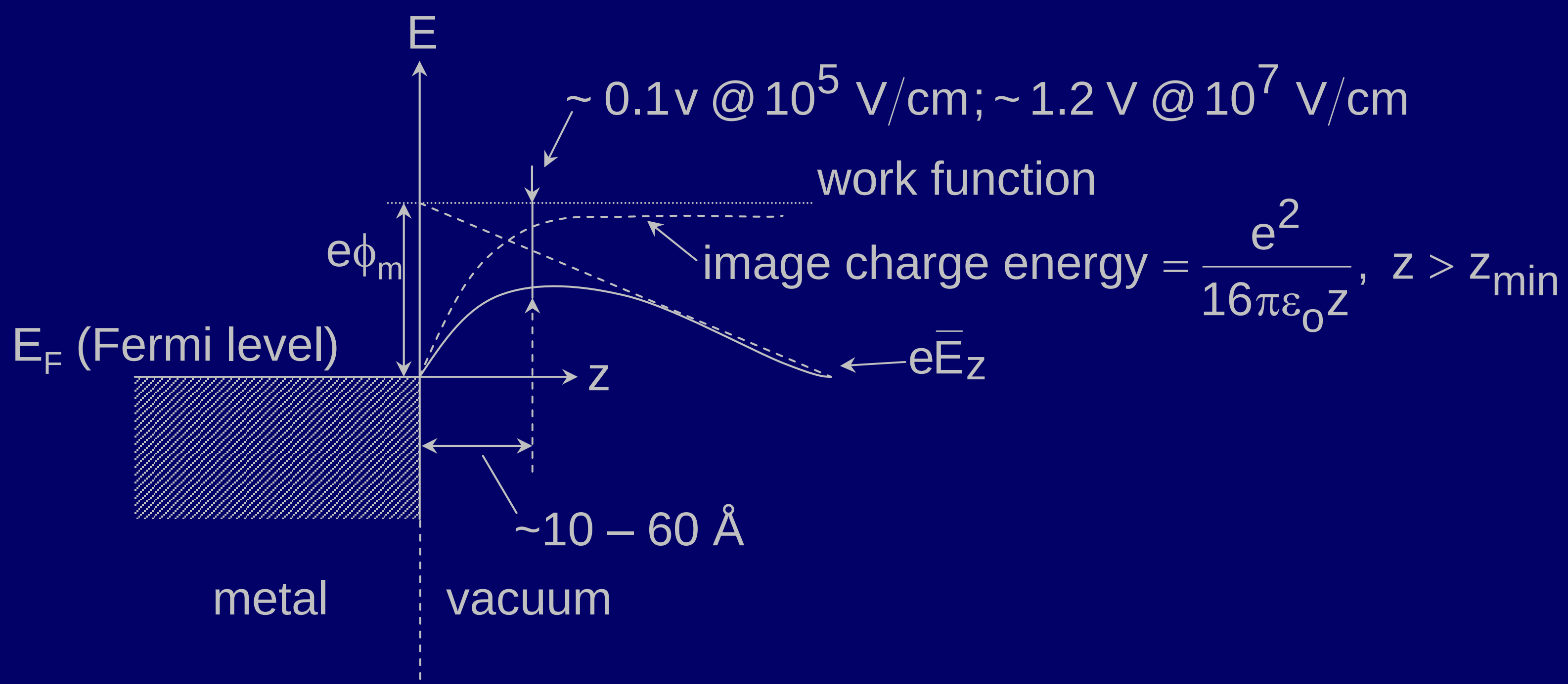


Optical detection

Classification of detectors:

Before:	$hf << kT$	Rayleigh-Jeans radio limit
Now:	$hf >> kT$	Optical limit (photon counting)
Next:	$hf \cong kT$	Infrared

Photoelectric effect



z_{min} is ~1 angstrom when electron "sea" vanishes; yields $e\phi_m$

ϕ_m = 1.95 (cesium), 2.1 (rubidium), 2.3 (lithium) volts
$\cong$ 4 – 5 volts, most common metals

Photoelectric effect

ϕ_m = 1.95 (cesium), 2.1 (rubidium), 2.3 (lithium) volts
$\cong$ 4 – 5 volts, most common metals

ϕ_m sensitive to surface contamination and microstructure: local $\bar{E}$

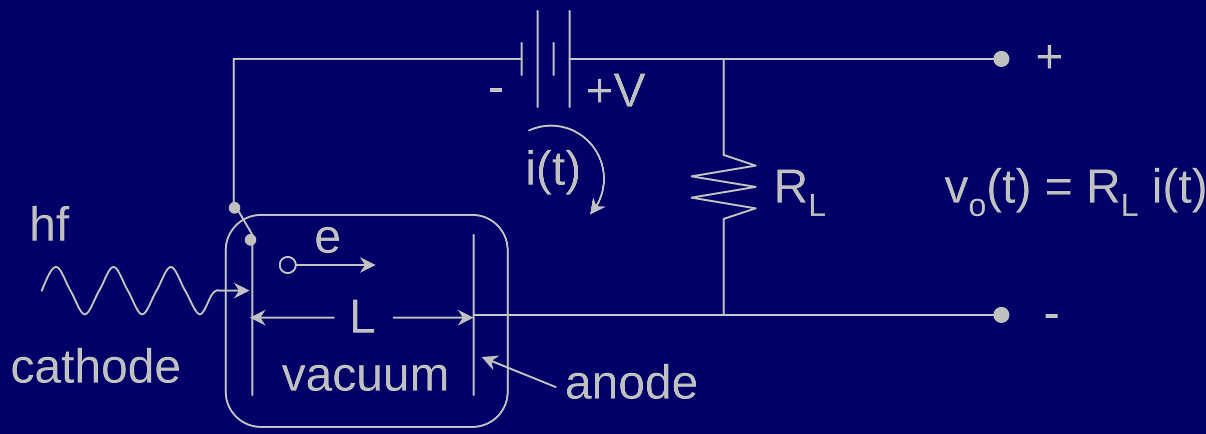
$$hf \gtrsim \phi_m e \Rightarrow \text{emission } [1\,\text{e.v.} = e \text{ Joules}]$$

$$\lambda_{c.o.} = c/f_{c.o.} = \frac{hc}{e\phi_m} \cong 0.6 - 0.7\ \mu\text{m for cesium}$$

Tunneling is important for short leaps and high E_z

(Microstructure, etc $\tilde{\Rightarrow}$ 1 μm cutoff wavelength)

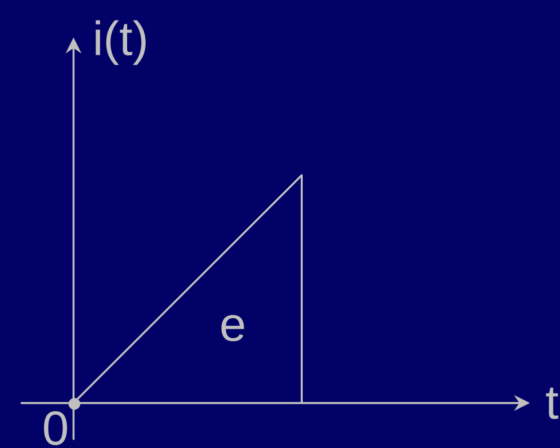
Phototubes



quantum efficiency $\eta \lesssim 30\%$ for G_e, S_i

$$i(t) = e\,v_{el}/L = e\,at/L \cong e^2\,Vt/m_eL^2$$

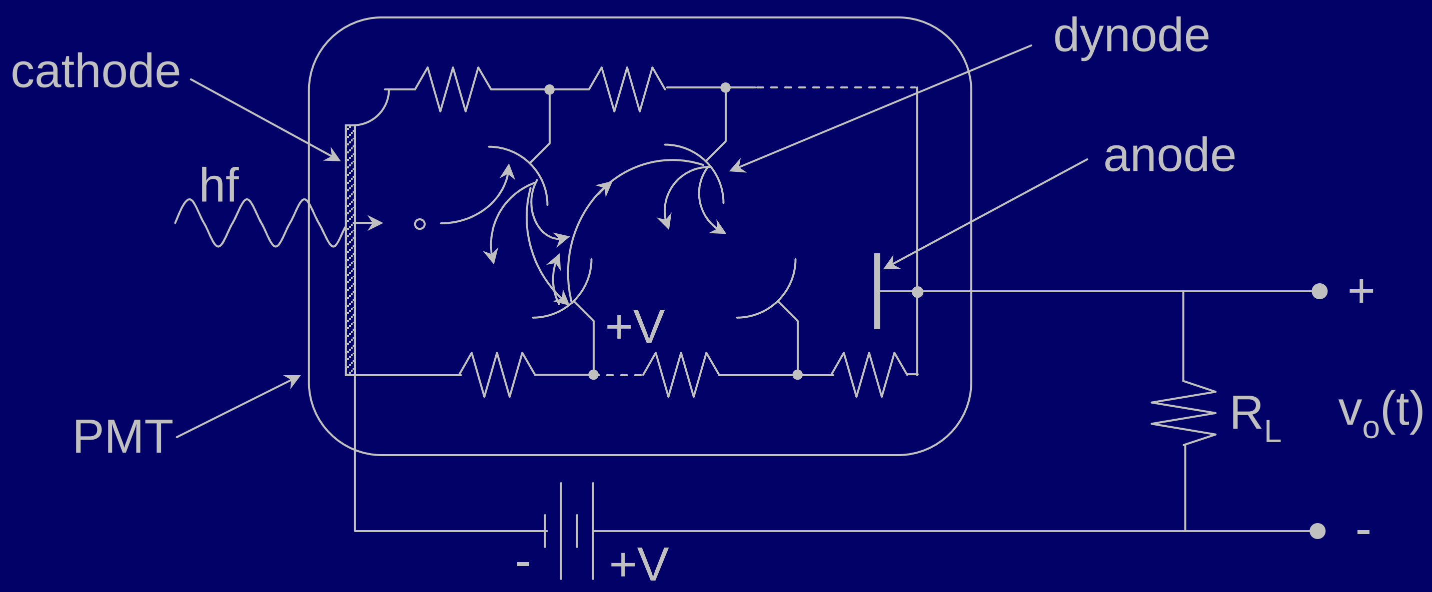
$$a = dv/dt = f/m_e = eV/m_e\,L$$



Problem:

single electron voltage spikes are lost in R_L Johnson noise.

Photomultiplier Tubes (PMT's)



7 – 13 dynodes typical, $G \cong 10^4 - 10^7$

With $10^4 - 10^7$ electrons per detected photon, Johnson noise from R_L becomes negligible.

Photomultiplier Tubes (PMT's)

7 – 13 dynodes typical, $G \cong 10^4 - 10^7$

With $10^4 - 10^7$ electrons per detected photon,
Johnson noise from R_L becomes negligible.

Number of electrons emitted per dynode hit
$\cong (V_1/\phi_m) \bullet Q \approx 4$, say [impact efficiency $Q < 1$]
(V_1 = electron kinetic energy)

Dark current from cosmic rays, thermal, etc.
(note: smaller pulses from dynodes permit rejection)
(Thermal: 1 e.v. $\approx 10^4$K; so modest cooling helps)

Dark count $n_D \gtrsim 1000$ sec^{-1} typically
Counting rate ~10 MHz – 1 GHz + or more