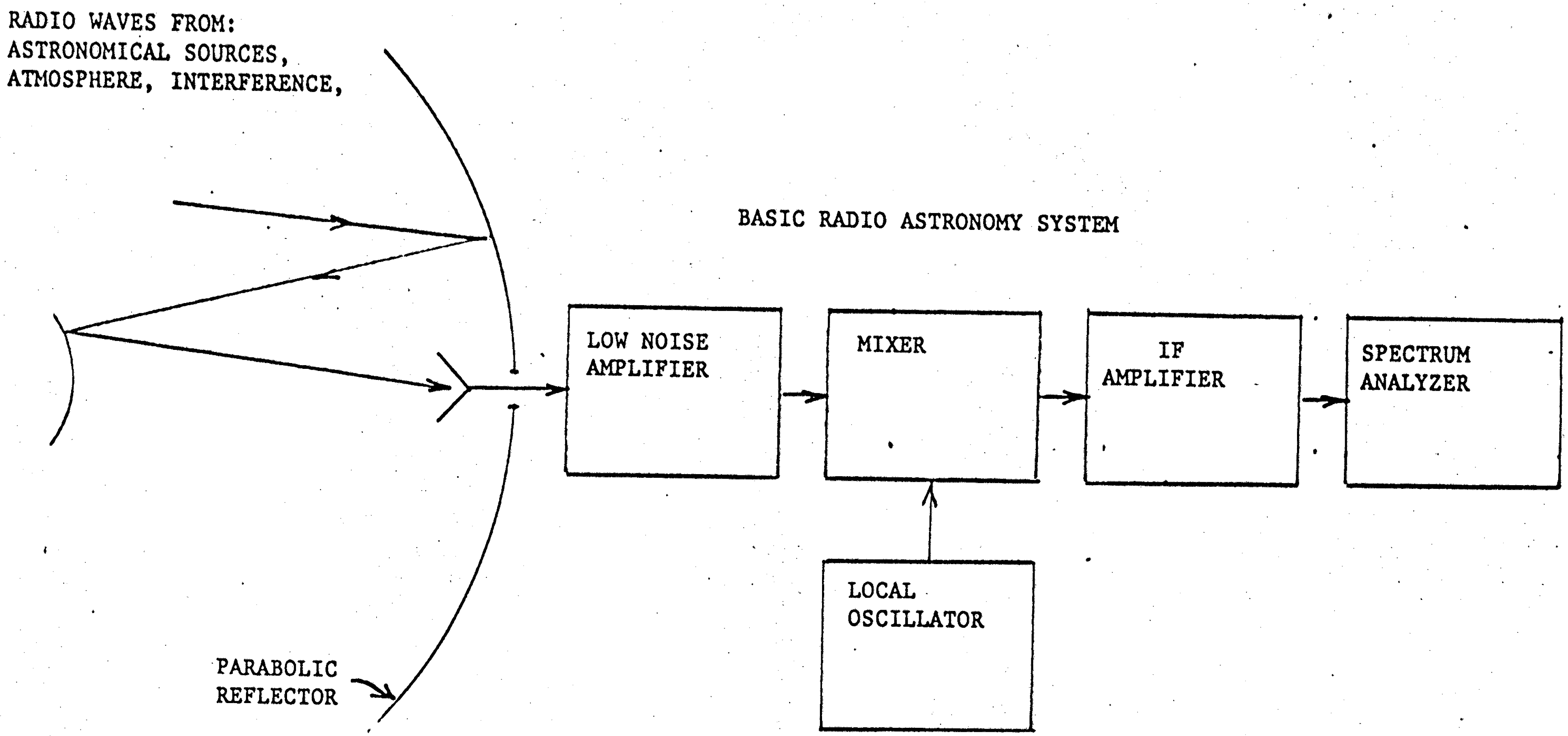
BASIC RADIO ASTRONOMY SYSTEM



PROBLEM AREAS

1) IN CM RANGE LOW-NOISE AMPLIFIERS LIMIT SENSITIVITY AND TEND TO BE UNRELIABLE.

2) IN MM-λ RANGE LOW-NOISE AMPLIFIERS DO NOT EXIST; EFFICIENT MIXERS MUST BE DEVELOPED.

3) MM-λ LOCAL OSCILLATORS ARE EXPENSIVE, UNRELIABLE AND DO NOT EXIST FOR SHORT MM-λ RANGES.

4) SPECTRUM ANALYZERS COVERING GHZ BANDWIDTHS WITH $\sim 10^4$ CHANNELS ARE NEEDED.

LECTURE NOTES
S. WEINREB
6/18/80
LIBRARY

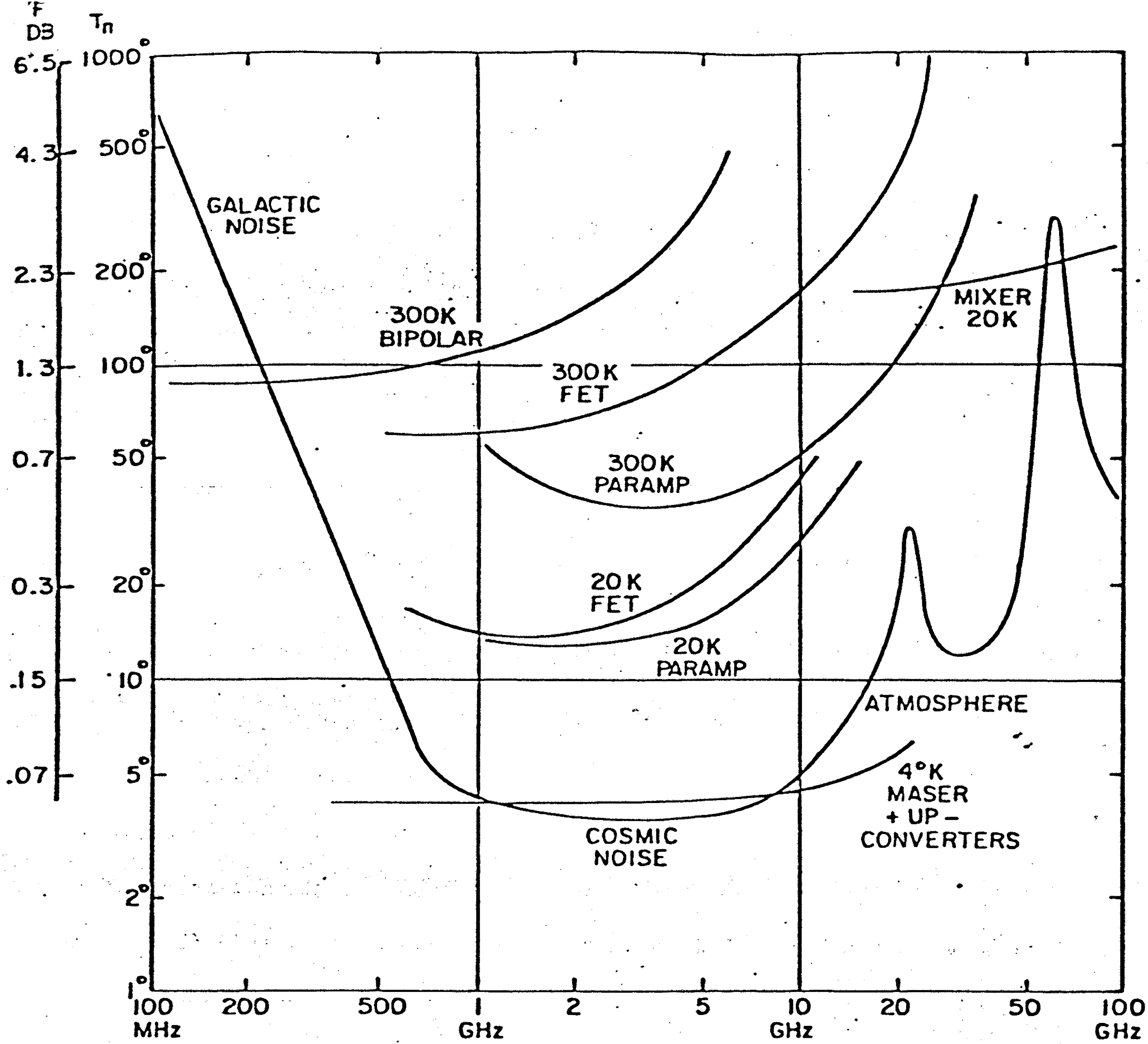
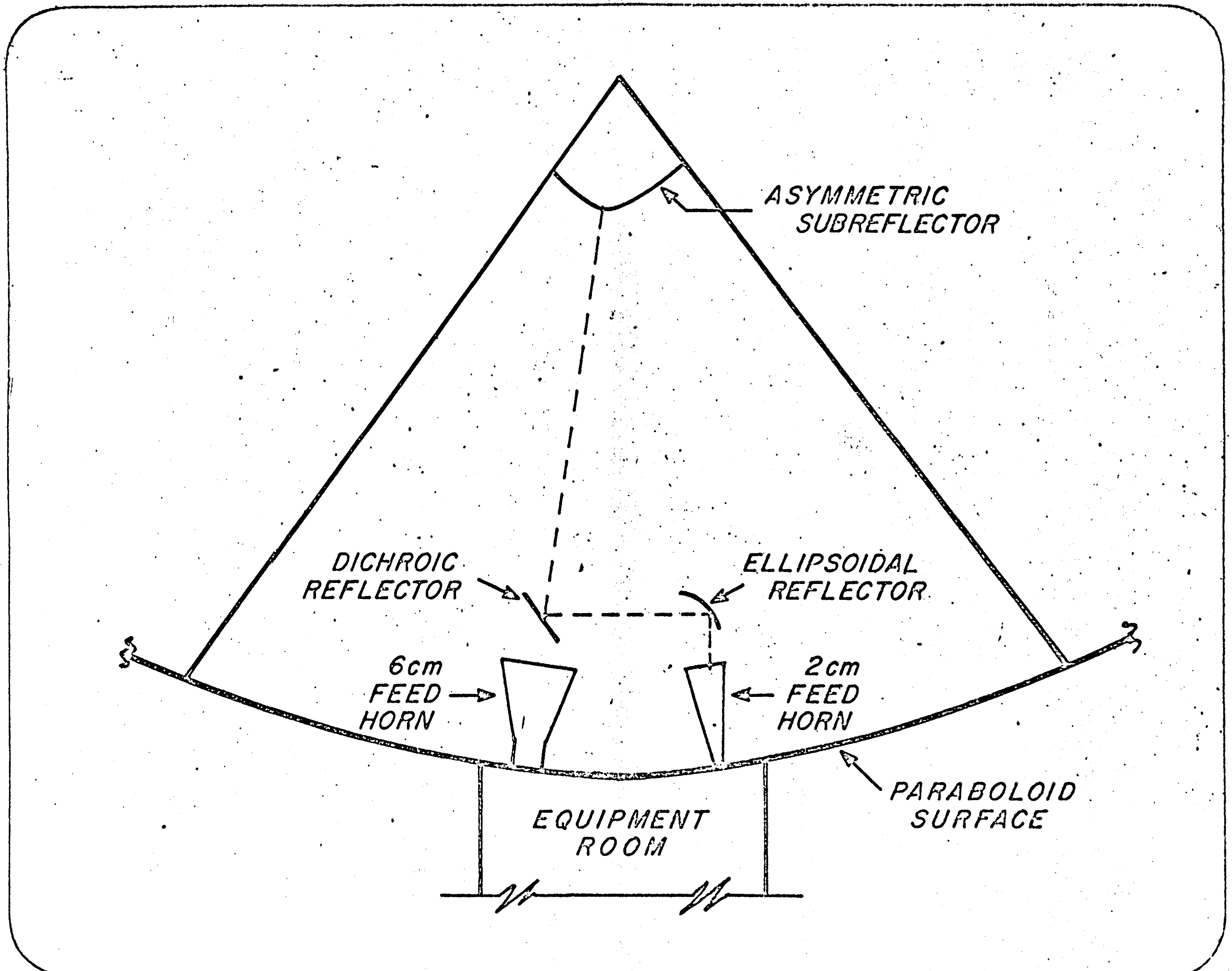
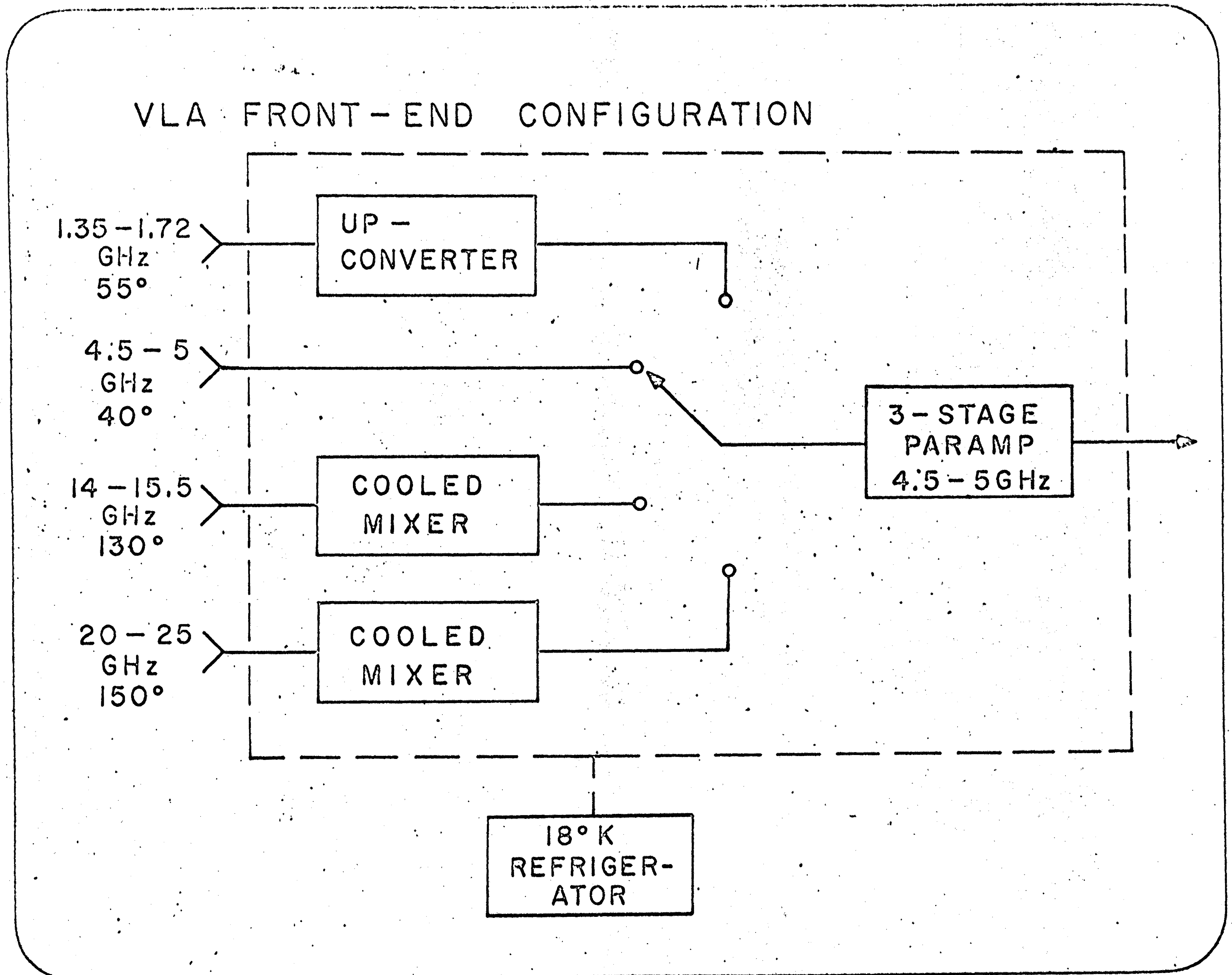


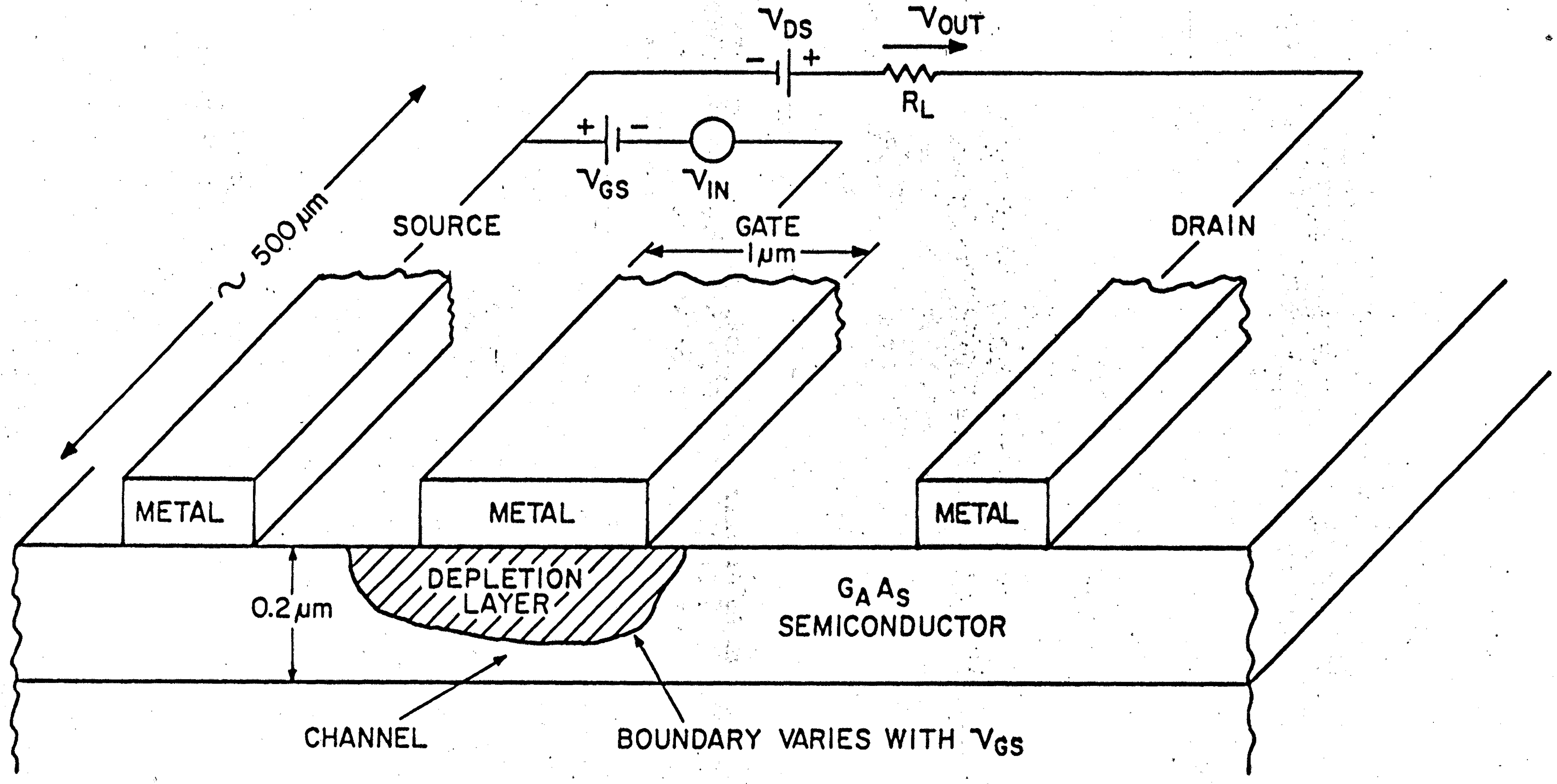
Fig. 1 – Noise figure, 10 log F, and noise temperature, $T_n = 290° (F-1)$, vs. frequency for various 1980 state-of-the-art low-noise devices. The 300°K bipolar transistor, FET, and paramp values are taken from manufacturers data sheets [1, 2, 3], the 20°K FET curve is from the data of this paper plus data of others [4, 5, 6] at 0.6, 1.4, and 12 GHz, respectively. The 20°K paramp, 4°K maser (including parametric up-converter at lower frequencies), and 20°K mixer results are from systems in use at National Radio Astronomy Observatory (NRAO). The natural noise limitations due to galactic noise, the cosmic background radiation, and atmospheric noise are for optimum conditions and are taken from [9] plus points at 22 GHz and 100 GHz measured at NRAO.

VLA FEED CONFIGURATION





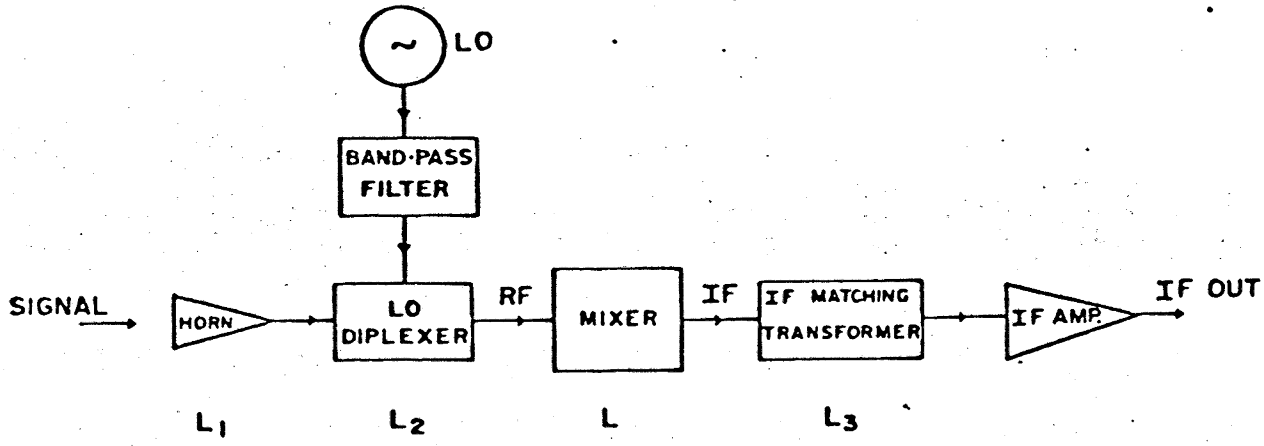
VLA FRONT-END CONFIGURATION
1.35-1.72 GHz 55°
4.5-5 GHz 40°
14-15.5 GHz 130°
20-25 GHz 150°
UP-CONVERTER
COOLED MIXER
COOLED MIXER
3-STAGE PARAMP 4.5-5GHz
18° K REFRIGERATOR

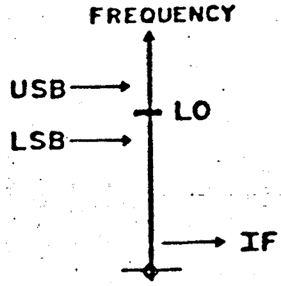


ISOMETRIC VIEW OF GASFET

TYPICAL HETERODYNE RECEIVER

MILLIMETER WAVE





DOUBLE-SIDEBAND RX : USB & LSB SIGNALS EQUALLY CONVERTED TO IF

SINGLE-SIDEBAND RX : ONLY ONE SIDEBAND CONVERTED TO IF

I-3

TYPICAL HETERODYNE RECEIVER

Main components

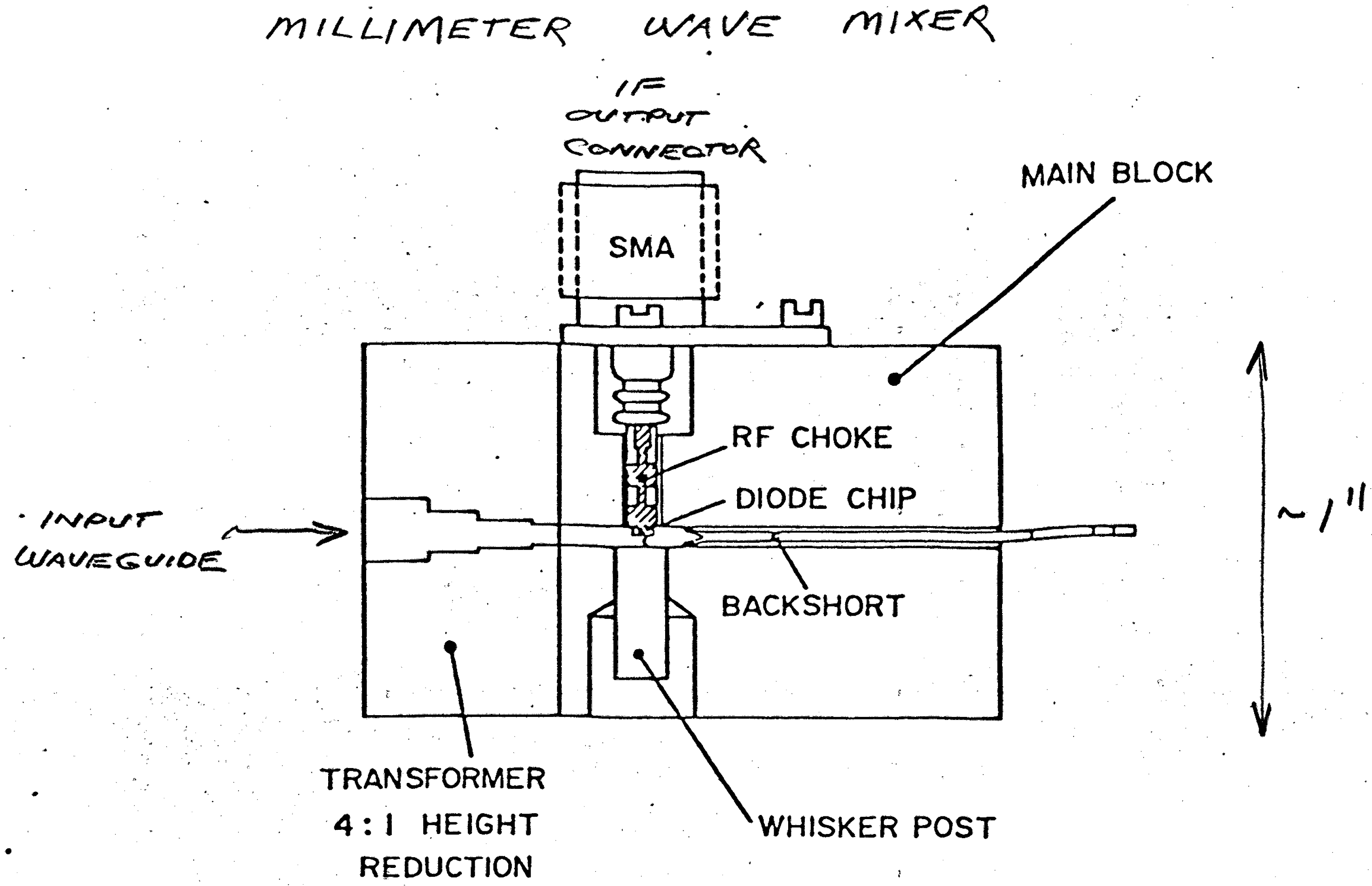
- feed horn: couples incoming signal energy into a single waveguide mode.
- LO diplexer: couples the LO power into the same waveguide as the signal.
- band-pass filter: removes noise generated at the signal frequency by the LO. This filter is often an integral part of the diplexer.
- mixer: uses a nonlinear device to generate an IF (beat frequency) at the difference between signal and LO frequencies.
- IF matching transformer: matches the mixer output to the input of the IF amplifier to ensure maximum power transfer.
- IF amplifier: amplifies the IF signal so that the noise of succeeding stages is negligible.

Each component has some loss at the signal frequency.

The sensitivity of the receiver is limited only by its own internally generated noise:

- LO noise not removed by the band-pass filter,
- shot and thermal noise in the mixer diode,
- noise in the IF amplifier,
- thermal noise in each lossy element.

A mixer receiver may respond to only one sideband, or to both upper and lower sidebands (signal and image) - hence single sideband (SSB) and double sideband (DSB) receivers.

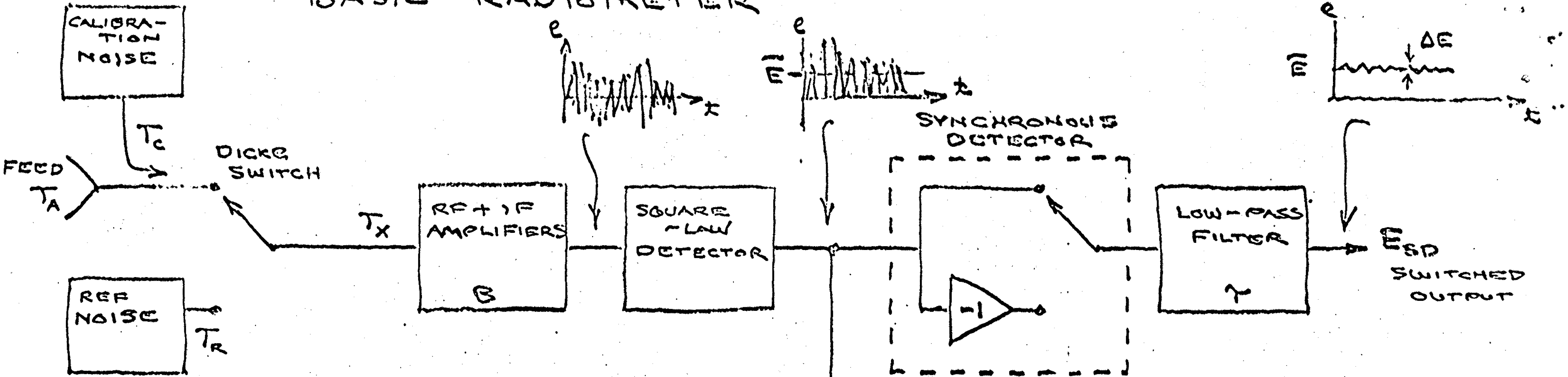


The disadvantages of the wafer mount are largely overcome in the block type of mount. [Ref. 4-8]. By using a coaxial or microstrip RF choke, the mount can be used over full waveguide bands. A small coaxial dumbel type of choke (alternate high and low Z_0 quarter-wave sections) can be supported in a low ϵ dielectric material. A printed circuit microstrip choke can be fabricated on fused quartz and expoxied in place. Care should be taken to ensure that the choke structure is small enough not to support higher-order modes within the intended RF band.

The stepped waveguide transformer can be fabricated by electroforming, as can the main block.

A disadvantage of the block type of mount as shown is the difficulty of seeing the diode while the whisker is being pushed into contact with it. It is also somewhat difficult to mount the choke and diode inside a solid block-type mount.

BASIC RADIOMETER



$T_A \sim .01$ to $10°K$

$T_X \sim 100$ to $1000°K$

$T_C \sim 10°K$

$T_R \sim T_A$

$\to E_S$, E_C, AND E_R } TOTAL POWER OUTPUT, $\bar{E}$

WE WISH TO MEASURE T_A

BASIC INPUT-OUTPUT RELATION $\longrightarrow$ (AVERAGE DETECTOR OUTPUT VOLTAGE, $\bar{E}$) = ($\overbrace{k\ B\ G'}^{=G}$) × (TOTAL INPUT NOISE TEMPERATURE)

k = 1.38×10^{-23}; B = NOISE BANDWIDTH; G' = TOTAL POWER GAIN

SWITCH UP, CAL OFF $\longrightarrow$ $\bar{E}_S = G(T_X + T_A)$ SIGNAL VOLTAGE

SWITCH UP CAL ON $\longrightarrow$ $\sim \bar{E}_C = G(T_X + T_A + T_C)$ CALIBRATION VOLTAGE

SWITCH DOWN CAL OFF OR ON $\longrightarrow$ $\bar{E}_R = G(T_X + T_R)$ REFERENCE VOLTAGE

3 EQUATIONS, 3 UNKNOWNS (T_A, G, T_X)

SENSITIVITY LIMITATIONS

(1)

$$\frac{\text{rms}}{\text{mean}} = \frac{\Delta E}{\bar{E}} = \frac{\Delta T_A}{T_x + T_A} = \frac{1}{\sqrt{B\tau}}$$

LIMIT DUE TO STATISTICAL FLUCTUATIONS OF NOISE

(B: NOISE BANDWIDTH; τ: INTEGRATION TIME)

(2)

$$\frac{\Delta G}{G} \sim 1\%$$

LIMIT DUE TO RECEIVER GAIN STABILITY

MODIFICATIONS TO BASIC RECEIVER

(1) DICKE SWITCHING – SYNCHRONOUS DETECTION

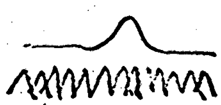
$$\bar{E}_{SD} = E_S - E_R = G(T_A - T_R)$$

(2) COMPUTER SYNCHRONOUS DETECTION

$$T_A = \frac{\bar{E}_S - \bar{E}_R}{\bar{E}_C - \bar{E}_S} \cdot T_C + T_R$$

(3) MULTICHANNEL LINE RECEIVER

– COMB FILTERS AND MULTIPLE DETECTORS



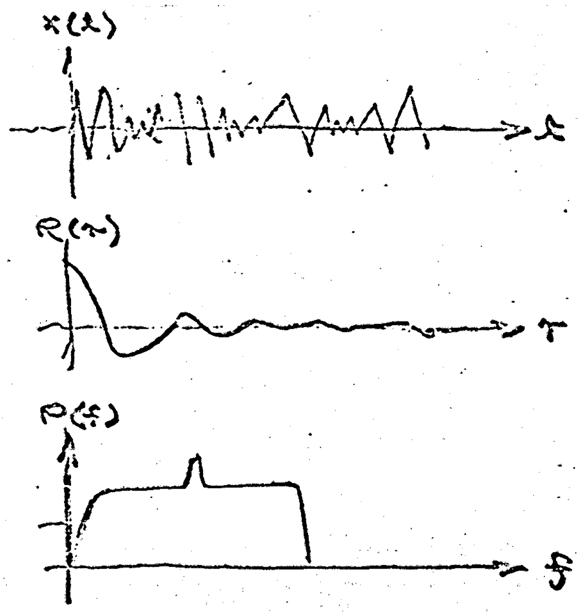
← SPECTRAL LINE

← COMB FILTER BANK

AUTOCORRELATION RECEIVERS

$$T(f) = \int_{-\infty}^{\infty} R(\tau)\cos 2\pi f\tau \, d\tau$$ { TEMPERATURE SPECTRUM T(f) AS FOURIER TRANSFORM OF AUTOCORRELATION FCN, R(τ)

$$R(\tau) = \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} x(t)\,x(t+\tau)\,dt$$ { DEFINITION OF R(τ) IN TERMS OF SIGNAL TIME FUNCTION, x(t).



MODIFICATIONS TO THEORY

MODIFICATION	EFFECT
τ CANNOT $\to \infty$	FREQUENCY RESOLUTION $B \sim \frac{1}{\tau_{MAX}}$
T CANNOT $\to \infty$	STATISTICAL FLUCTUATION $\frac{\Delta T}{T} = \frac{1}{\sqrt{BT}} \sim \sqrt{\frac{\tau_{MAX}}{T}}$
$R(\tau)$ IS SAMPLED IN STEPS OF $\Delta\tau$	$f_{MAX} = \frac{1}{2\Delta\tau}$
$x(t)$ IS SAMPLED IN STEPS OF Δt	NO EFFECT IF $f_{MAX} = \frac{1}{2\Delta t}$
$x(t)$ IS QUANTIZED IN N BITS	$\frac{\Delta T}{T}$ SLIGHTLY INCREASED