PART II.

NFRAD DESIGN AND CONSTRUCTION [15]

Introductory Note

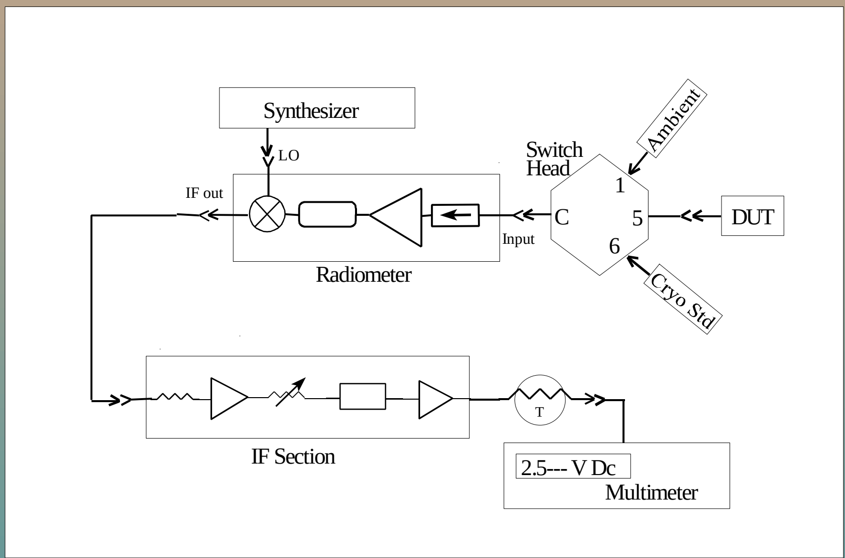
- System not simple to build or to operate.
- Not all features are needed by PSB.

Part II. Outline

- # System overview, major components
- # Important requirements and features
- # Switch head
- # Receiver
- # IF Section
- # Switching and interfaces
- # Electronics rack
- # Plumbing

System Overview

- # Block Diagram



Major Components

- Switch Head (and Table Top)
- Receiver
- IF Section
- Switching and Interfaces
- Rack of Support Electronics
- Software

Important Requirements and Features

- Designed to permit practical noise parameter measurements.
- Need speed, stability, repeatability.
- Byproduct: much less temperamental than old systems.
- Several “extra” features not needed for noise temperature measurements.

Speed:

- Electronic switching.
- Lookup tables for ' ’s and 0’s; measured on vector network analyzer. Old radiometers used built-in six-ports.
- Requires stability and repeatability of ' ’s and 0’s over months or years.
- Ten times as fast as old coaxial radiometers. Can calibrate about 10 to 15 frequencies in one day (DUT + check standard, 3 ports each).

Stability:

- Relevant time periods - several minutes to several hours.
- Radiometer gain and noise figure must be stable over a few hours so that can calibrate it with cryogenic standard & then use cryo standard for amplifier input. (Not needed for noise-*temperature* measurements.)
- Achieved by:
  - minimizing stress in receiver’s mechanical design
  - water plates for lossy elements
  - water plates for temperature-sensitive components (mixers and rf amplifiers).

Repeatability & long-term stability:

<Switches: average over many (50) readings.

<Connections: table top designed for good, repeatable connections.

<Other: long-term stability and repeatability from mechanical design of receiver and water plates for sensitive components.

Stability and repeatability results will be shown in testing section.

General system properties (8–12 GHz unit)

<Noise temperature . 450 K (at 8 GHz)

<Gain . 100 dB

<Sensitivity: Std. dev. of mean . 3 K

Switch Head (& table top)

Photos

Mechanical drawings in autocad files.

Stainless steel:
<Large thermal mass.
<Mechanical rigidity and stability.
<Rather hard to machine.

Water channels ° constant temperature for assembly:
<Constant environment for ambient standard.
<Switch & connectors at constant temp.

Ambient Standard:
<One port of switch through hole in copper tube cap.
<50 S coaxial load connected to port.
<Short section of tube over load and cap.
<Second cap, with hole; thermistor & thermal paste through hole.

Other:

<Water ports: accept “quickconnects.”

<Slot at bottom of assembly is access hole for wrench for bottom connector.

Details:

<Gaskets: 1/160 neoprene.

<Switch: HP 87106B (DC – 20 GHz) SP6T.

<Connectors

@ Precision 7 mm, SMA inside: from Midwest Microwave (Saline, MI).

@ SMA: J. Smith & Assoc. (Colorado Springs, CO).

Details (cont’d)

<Semirigid cable: from Richardson Electronics (Woodland Hills, CA).

<Ambient standard load: INMET, model TS 260M.

<Thermistors: 5 kS, from Thermometrics (Edison, NJ), calibrated at Ball Aerospace (Boulder, CO).

Table Top:

<Photo

<Stainless steel plate set in 1¾0 (44 mm) laminated maple.

<Hole for switch assembly.

<Slot for WR-90/GPC-7 adapter for WR-90 cryogenic standard.

<Holes in stainless steel plate are for mounting purposes, if needed.

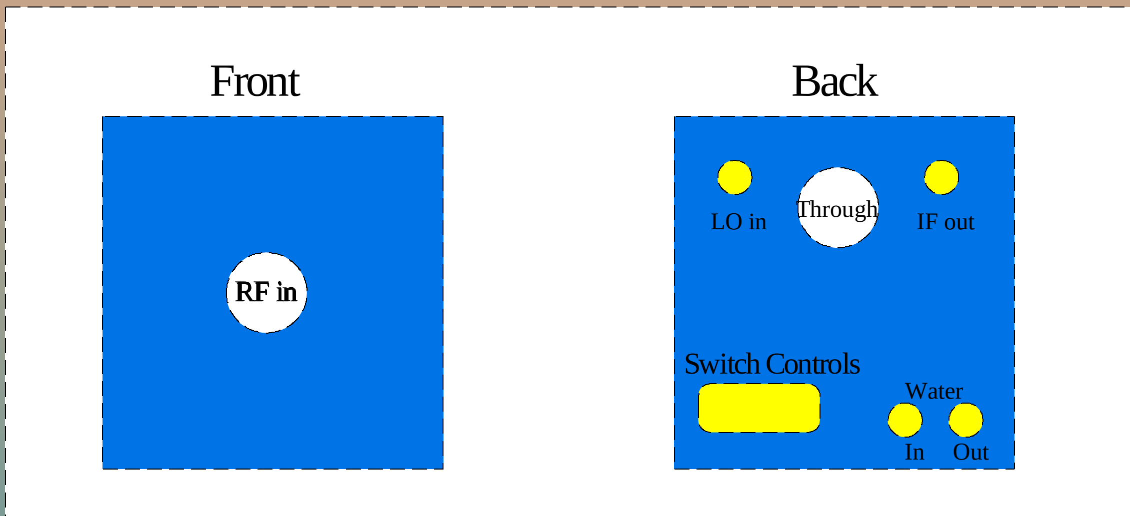
<Mechanically stable, rigid.

Receiver(s)

Total of 5 separate units: 1 – 2, 2 – 4, 4 – 8, 8 – 12, 12 – 18 GHz.

Mechanical drawings in autocad files.

Photos



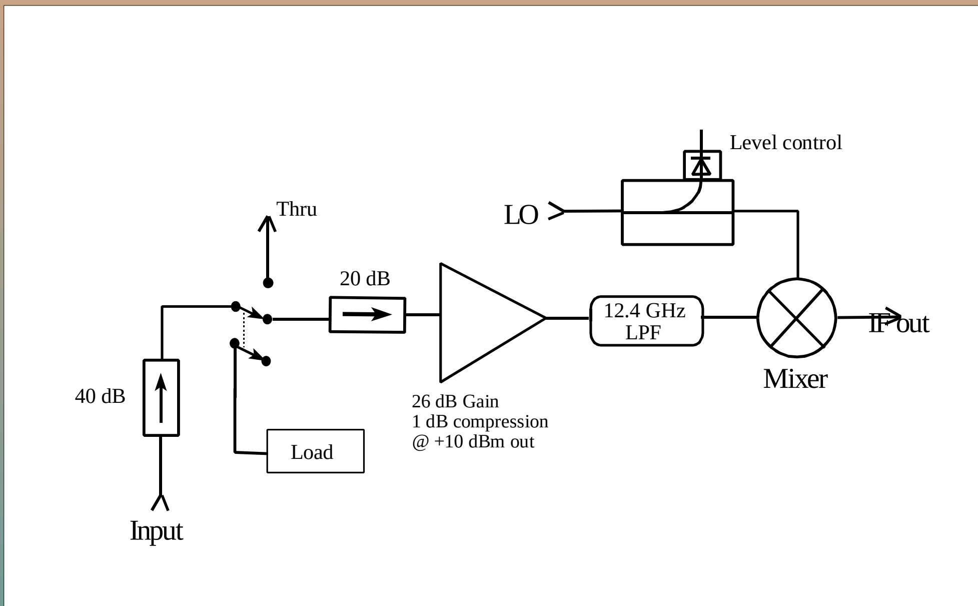
Materials:

- <Box: milled from block of aluminum, anodized.
- <Water plates: brass.
- <Tubing: copper or brass.
- <Semirigid cables (as above)

Mechanical:

- <Designed to minimize stresses and subsequent relaxation over time.
- <Everything mounted to box, then box to base plate.
- <Leveling feet for alignment & good connections.

RF Section Diagram



Circuit elements:

< Isolators: remove dependence of receiver properties on input impedance.

< Through port: enables two-port measurement of S-parameters to a common point beyond the first isolator.

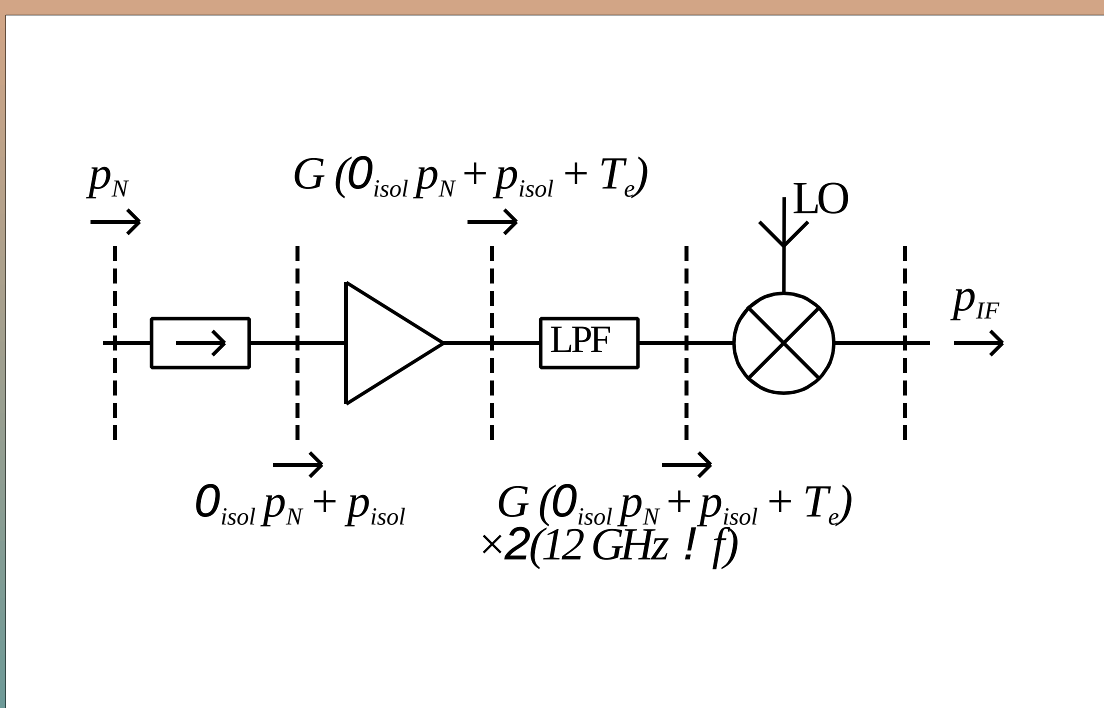
< Load: provides an ambient source for comparison to ambient standard or possible use in noise-parameter measurements.

< Amplifier: low-noise, sets system noise figure, amplifies input noise.

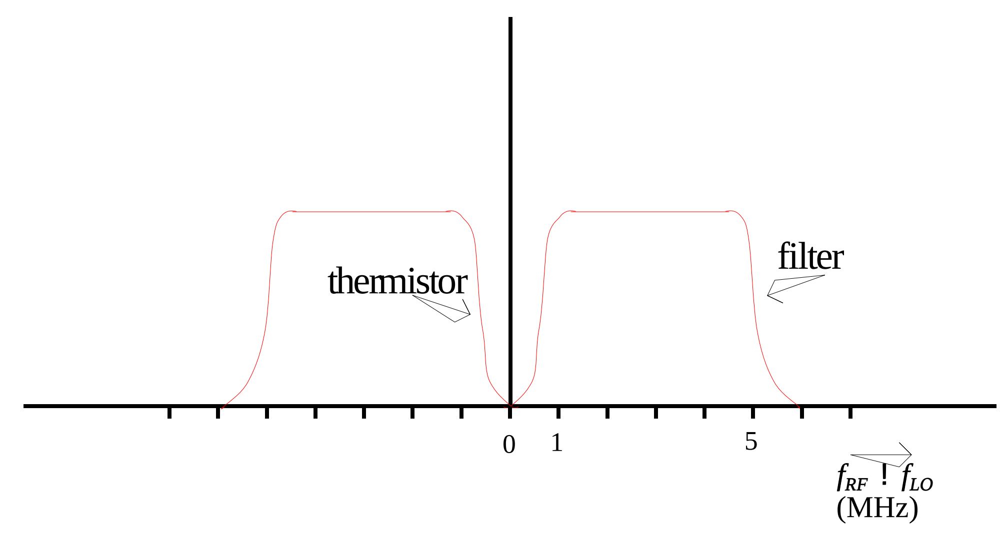
Circuit elements (cont'd):

- LPF: removes higher frequency components to prevent them from being downconverted.
- ALC: maintains constant LO input to mixer; located in receiver box to eliminate any effect of cable variation.
- Wiring to 15-pin connector shown on separate sheet, in notebook.
- Parts lists given on separate sheets, in notebook.

Circuit behavior:



System response (in principle)



Mixer Considerations:

< Don't know detailed design of mixer. For basic analysis, consider simple diode mixer.

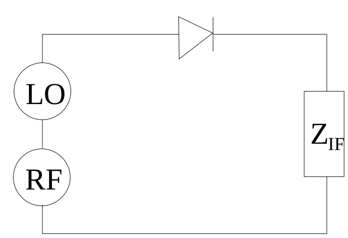


Fig. 1 Basic configuration for simple diode mixer.

$$v_d = v_{LO} + v_{RF} - v_{IF}$$

Basic Mixer Analysis [16]

Follow (roughly) treatment by Collin (Foundations for Microwave Eng.)

Assuming the voltage across the diode is small relative to the diode voltage scale, expand diode current in a power series in the voltage:

$$i_d = I_0 + a_1 v_d + a_2 v_d^2 + a_3 v_d^3 + \ldots$$

Or expand

$$i_d = I_s (e^{\alpha v_d} - 1) .$$

Substitute $v_d = v_{LO} + v_{RF} - v_{IF}$ into first equation to get

$$i_d \approx I_0 + a_1(v_{LO} + v_{RF} - v_{IF}) + a_2(v_{LO}^2 + v_{RF}^2 + v_{IF}^2 + 2 v_{LO} v_{RF} - 2 v_{RF} v_{IF} - 2 v_{LO} v_{IF}) .$$

The only terms on the right hand side that have ω_{IF} components are v_{IF} and $v_{LO} v_{RF}$, which has an IF component of ½$V_{LO} V_{RF}$. (Upper-case V's and I's indicate magnitudes of time dependent *v*'s and *I*'s.)

Thus, if we restrict our attention to ω_{IF} and use $i_d = v_d / Z_{IF}$, we have

$$V_{IF} = -a_1 V_{IF} + a_2 Z_{IF} V_{LO} V_{RF}$$

or

$$V_{IF} = \frac{a_2 Z_{IF} V_{LO} V_{RF}}{1 + a_1} .$$

So

$$P_{IF} \sim Const \times P_{LO} P_{RF} \sim Const \times G(p_N + p_{isol} + T_e)$$

or

$$P_{IF} \sim G_{system}(p_N + T_{system}) .$$

<Use double balanced mixer to reduce harmonic mixing (will check in tests).

<Effect of LO noise: can show that it just changes G_{system} and T_{system}.

<Effect of imperfect LO/RF isolation

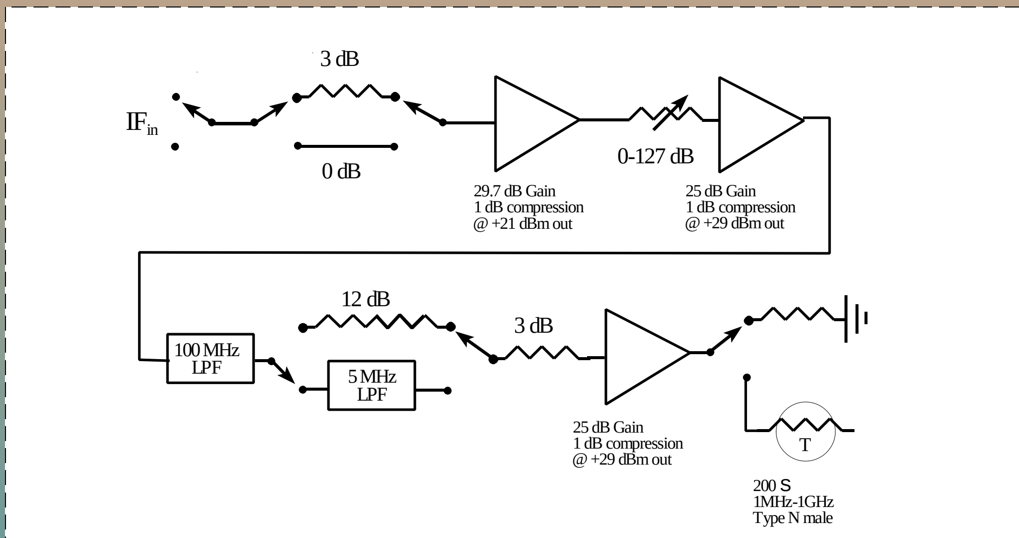
If some leakage of the LO into the RF channel, and it gets reflected back into the RF input of the mixer, then v_{RF} 6 v_{RF} + " v_{LO} , where " is the product of the leakage and the reflection coefficient looking into the RF channel from the mixer.

This results in several new terms in equation for i_d , but the only one which has an T$_{IF}$ component is $2a_2$" $v_{LO}\, v_{RF}$. This just results in a factor of (1+") on the right hand side of eq (9),

$$V_{IF} \;\;'\;\; (1\,\%\,")\frac{a_2 Z_{IF} V_{LO} V_{RF}}{1\,\%\,a_1}.$$

For reasonable good LO/RF isolation (20 dB?) and a not too large reflection coefficient (0.1 or less), this is not a worry. The key point was that the " v_{LO}^2 term does not contain any T$_{IF}$ component, unless of course T$_{IF}$ = 0.

IF Section



Parts

- First switch: HP 8762 C
- Other switches (5): HP 8765 B
- IF Amp #1: ANZAC AM-110
- IF Amps #2 & 3: Mini-Circuits ZHL-32A
- 100 MHz LPF: Trilithic 6IM100-3-KK
- 5 MHz LPF: Trilithic6IM5-3-KK
- Thermistor mount: HP 478A option H55
- Attenuators: anything decent.

IF Design:

- First switch allows connection to two different radiometers.
- 3 dB attenuator switched in & out in IF linearity checks.
- 127 dB variable attenuator used in linearity checks and to set IF sensitivity & prevent saturation.
- The two LPF’s set the bandwidth, either 100 MHz or 5 Mhz.

IF Design (cont’d):

- Final switch shown allows “on” and “off” readings of power meter.
- Thermistor mount 1 MHz – 1 GHz, notch at DC.
- Thermistor read by NIST Type-4 power meter [17]. Commercial version available from Arbiter.
- All (except Type-4 power meter) mounted on water plate. (Water plate drawings in notebook.)

Electronics Rack

HP 3458A Multimeter

HP 8673B Synthesizer (2–26 GHz); Fluke 6062A (100 kHz–2.1 GHz) or "equivalent" (must have external ALC feature)

Switching/Routing box (not really needed)

HP 3488A Switch/Control Unit

HP 3488A Switch/Control Unit

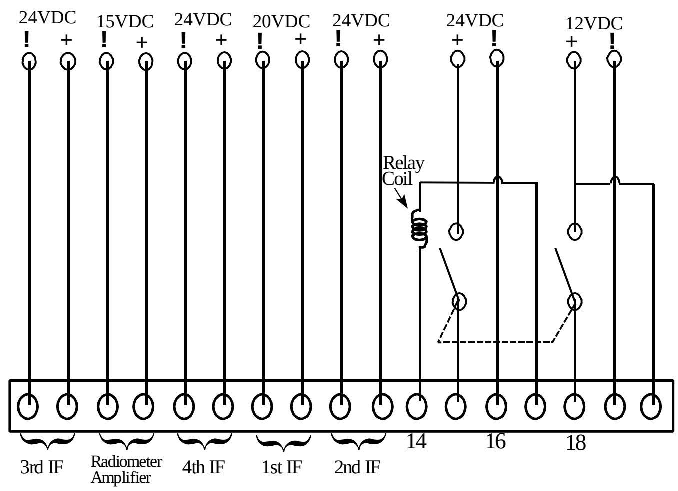
Power supply box (all Lambda Electronics):

- <3 LDS-X-15 (15 V), #2, 6, 7
- <3 LCS-A-02 (0-18 V), #1, 8, 9
- <1 LDS-X-20 (20 V), # 3
- <1 LRS-52-24 (24 V), #5
- <1 LDS-X-24 (24 V), #4 (not needed)

IF Box

Power supply box:

<Details on separate sheet.



<Details on separate sheet.

<Grounds (-) for IF amps go to IF water plate. Ground for radiometer amp goes to radiometer.

Switching & Interfaces

Interfaces & documentation not yet in final form.
Switch/Control cards: shown on separate diagrams.
Radiometer: ribbon cable to external board, details on separate sheet.
Front-end switch: to switch/control unit 1, card 3 (via external board).

Power supply box: shown on separate sheet.

External board will be eliminated by ribbon cable & connector(s) on front panel.

Bus: HPIB used throughout system.

Plumbing

- Water bath: NESLAB RTE-220 (± 0.01 K) with external computer control optition
- 1 ° 6 manifold (with valves).
  - Receiver
  - Switch head
  - Cryogenic standard
  - IF section
  - Two extra

- Tygon tubing, about 8.5 mm & 6.3 mm i.d.