AVN Training HartRAO 2018

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from G. Nicolson AVN 2017

Microwave Receivers

Overview

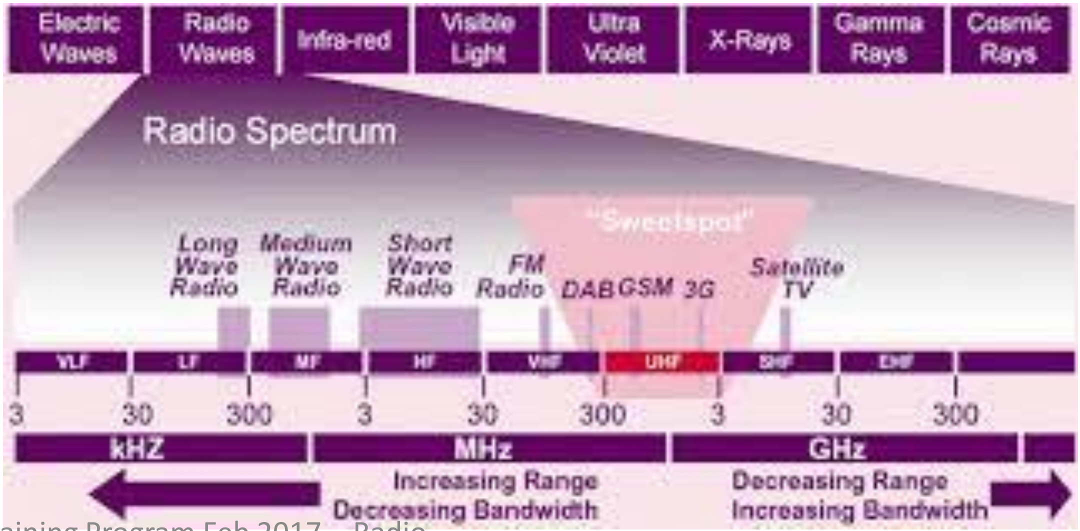
- Introduction to basic components used in microwave receivers.
- Performance characteristics of these components.
- Assembly of components into a complete microwave system.
- Measuring the performance of the system
- Improving the performance with cryogenic cooling

Definition of microwaves

This is not what we are talking about!

The Radio Spectrum

Microwaves are that part of the spectrum above 1000 MHz, i.e. above 1 GHz.



Low Noise amplifier – LNA

The radio Astronomy signal received by an antenna or radio telescope are extremely weak, so we need very sensitive equipment to detect and measure them.

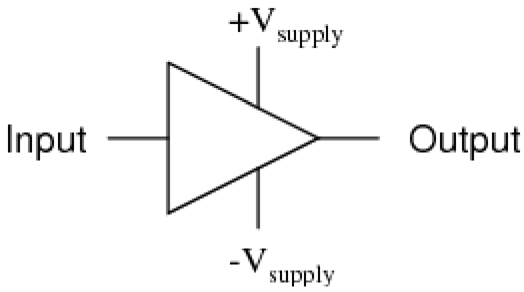
The signals also need to amplified many times so we need amplifiers with a very high gain.

The gain, **G**, of an amplifier is defined as the ratio of the output power. P_{out}, to the power fed to the input, P_{in}.

$$G = P_{out}/P_{in}$$

In the lecture on Antennas The concept of matching was discussed and applies to components in a receiver

General amplifier circuit symbol



Transfer of power

An important concept is that of maximum power transfer in any circuit.

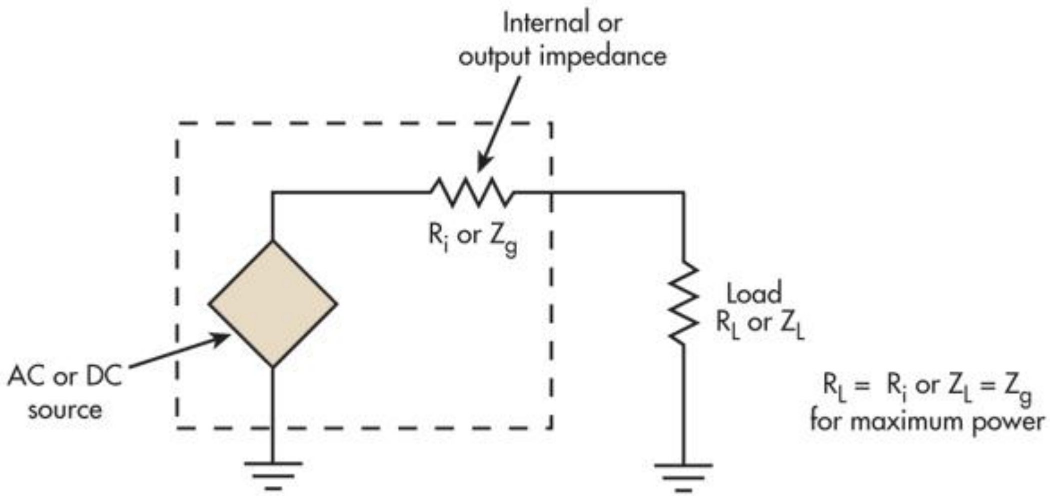
If one has a source of voltage, it always has an associated ***internal resistance or impedance***.

In order to transfer the ***maximum*** amount of power from the source, the resistance, or impedance, of the ***load*** must equal the ***internal resistance or impedance*** of the voltage source.

This is known as ***impedance matching.***

This implies equally to an antenna –which has its own ***characteristic impedance***.

Equally, an ampifier has a characteristic ***input impedance,*** which must the impedance of the antenna.



Optimising the match of an LNA

In order to optimise the matching of an LNA a devise known as a circulator is often used.

A circulator has three input ports, one of which is ***terminated*** with a matched resistance. A is the ***input*** and B the ***output.***

The circulator contains a magnetic material known as a ***ferrite.***

This constrains power to flow only in one direction (clockwise is shown here).

Any power reflected by the device under test because of ***"mismatch"*** is "circulated" to the resistor, which is ***matched,*** and absorbs this power.

The signal source sees a good match, even if the devise under test is mismatched.

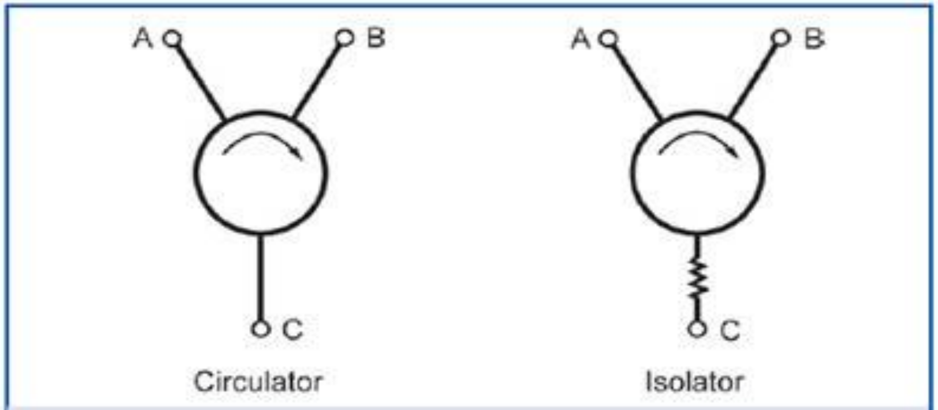


Figure 1

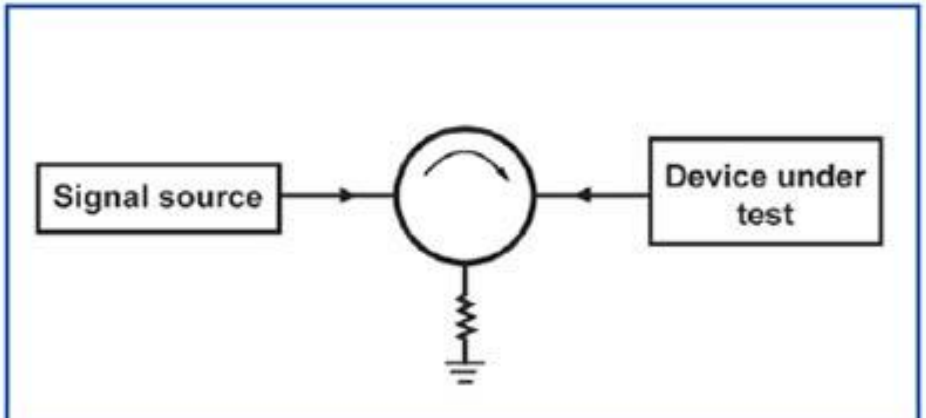


Figure 3

Typical components

Examples of circulators are shown at the top right.

A variety of amplifiers are shown at the right.

Some have coaxial connectors, and others, such as the large white units, have waveguide inputs.

Microwave amplifiers come in a range of gains (10 – 50 dB), operating frequencies, (from a few MHz up to 10s of GHz) and bandwidths (from 10-20% of the centre frequency, to amplifiers that cover 1-26 GHz).

Generally here has to be some compromise if very wide bandwidths are used.

Noise generated by microwave devices

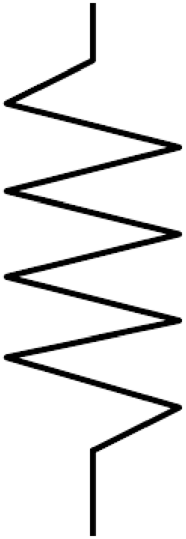
Any lossy microwave device generates thermal noise by virtue of random motion of electrons in that device.

Consider a simple resistor with a resistance **R**.

If the resistor is at a temperature **T** (degrees K, where zero temperature is -273.16 C)

Then, theory shows that over a bandwidth **B (=f2 – f1)** a mean squared thermal voltage is available at its terminals equal to:

$$\langle v \rangle^2 = 4kTBR$$



Noise generated by microwave Amplifiers

If the resistor at a temperature **T** is connected to a low noise amplifier with a matched input impedance equal to **R** and a bandwidth **B**, then a power equal to

$$Pr_{in} = kTB \text{ Watts}$$

will be transferred to the input of the amplifier.

k is Boltzmann's constant

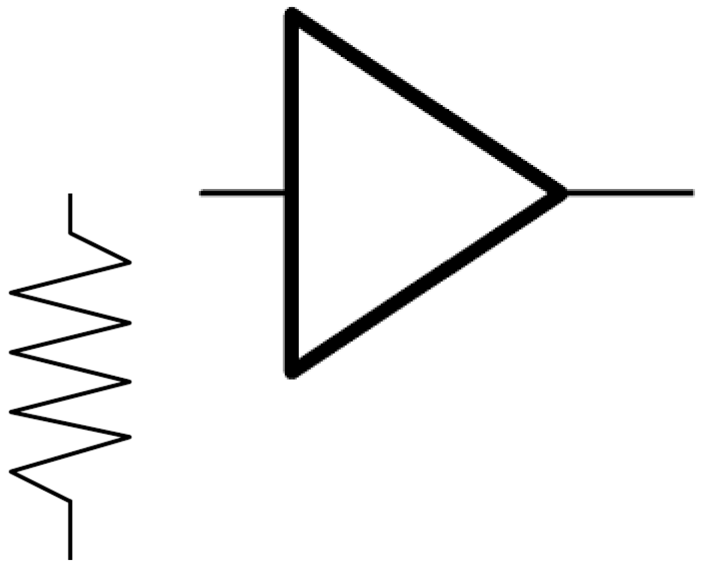
For **$B=10^9$ (1 GHz)**

$$Pr_{in} = 1.38 \times 10^{-23} \times 300 \times 10^9$$

$$= 4.14 \times 10^{-14} \text{ watts.}$$

Even after amplification by a typical gain, **$G = 10^4$** P_lna_{out} will be minute.

$$P\_lna_{out} = 4.14 \times 10^{-10} \text{ Watts.}$$



Definition of noise temperature for a low noise amplifier, T_lna

But low noise amplifiers will also generate noise .....

A low noise amplifier also generates noise. In order to quantify this imagine that the temperature of the resistor is zero K, so that it does not generate any noise at all, and that the noise output power measured is **P_lna_{out}.**

Then, if we refer this power back to the input, we get

$$P\_lna_{in} = P\text{-}lna\_{out}/G$$

This can be equated to and equivalent thermal noise power

$$P\_lna_{in} = k(T_{lna})B$$

T_{lna} is defined as the **Noise Temperature** of the amplifier.

Measuring the Noise Temperature of LNAs

In order to measure the noise temperature of a LNA we require a stable and accurate reference source of noise over a given, and preferably very wide bandwidth.

A simple noise source is a matched resistor, normally called a load, at a constant temperature.

It can either be heated to a temperature above room temperature, often 100 C is used, (boiling point of water) for a ***Hot Load.***

Or a load can be immersed in liquid nitrogen, which boils at a constant temperature of 77 K to ,provide a ***Cold Load.***

MAURY MICROWAVE
CORPORATION

Model MT7027J
December 2011

WAVEGUIDE CRYOGENIC TERMINATION (COLD LOAD)

WR10 – 75.0 TO 110.0 GHZ

Features

- *Accurate Noise Temperature At Specified Calibration Frequencies*
- *Low VSWR Across The Full Frequency Range*
- *Liquid Nitrogen Cooled*
- *Metrology Grade Calibration For Solid State Noise Generators*
- *Low Noise Figure/Temperature Measurements*

Model MT7027J with power supply and foam-lined wood carrying case.

Calibrating the noise temperature of a LNA with a Hot-Cold load.

Two loads are used – a ***Hot (373)***and a ***Cold (77 K)*** load connected in turn to the input of the amplifier.

The output power is measured with a ***Power Meter or a microwave radiometer using a square law detector***

Hot Load connected:

$P\_out_{hot} = k(T_{hot}+T_{lna})BG$

Similarly:

$P\_out_{cold} = k(T_{cold}+T_{lna})BG$

Dividing these two equations we get

(P_out_hot) / (P_out_cold) = Y, where Y is called the "Y-factor". Then:

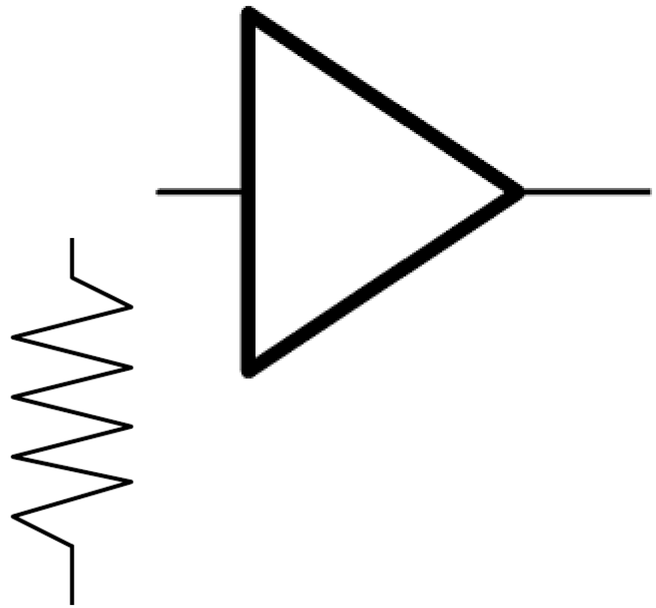
$Y = (k(T\_hot+T\_lna)BG)/(k(T\_cold+T\_lna)BG)$

Cancelling out common terms , k, B and G

$Y = (T_{hot}+T_{lna})/(T_{cold}+T_{lna})$

And solving for Tlna

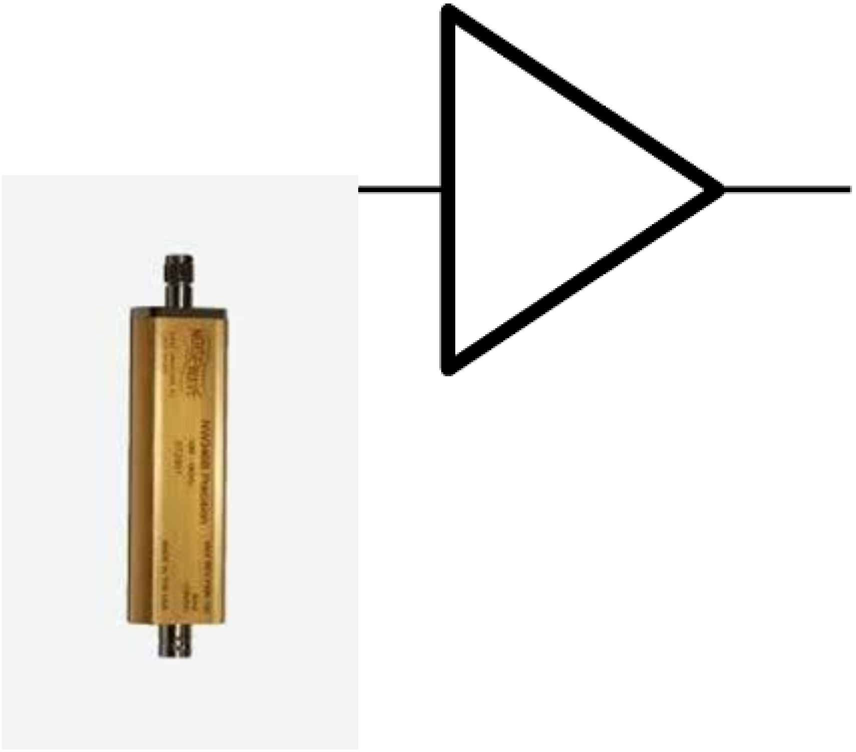
$T_{lna} = (T_{hot} - YT_{cold})/(Y-1)$



Alternative method using a calibrated microwave noise diode

A microwave noise diode is a device that generates a highly constant level of radio noise when a voltage is applied. They generally cover 10 MHz to 18 GHz.

They are calibrated by the manufacturer. When they are off the generate noise equivalent to room temperature, T_0 . When turned on they generate a calibrated noise T_{nd}.



In this case the maths is similar to before and:

$T_{lna} = (T_{nd} - YT_0)/(Y-1)$

Either method can be used, and we will do a lab experiment using both methods.

Additional equipment needed to construct a microwave receiver.

As mentioned earlier, even the noise coming from the output of an amplifier is at an extremely low level,
So further amplification is required.

Rather than add additional microwave amplifiers, the out put is converted to a lower ***Intermediate Frequency*** using a device known as a mixer.

The local oscillator generates a single frequency that is a certain amount lower than the input signal.

The mixer operates by multiplying the input signal and the output signal together which results in an output equal to the difference between the two frequencies, i.e.

$$F_{out} = F_{in} - F_{lo}$$

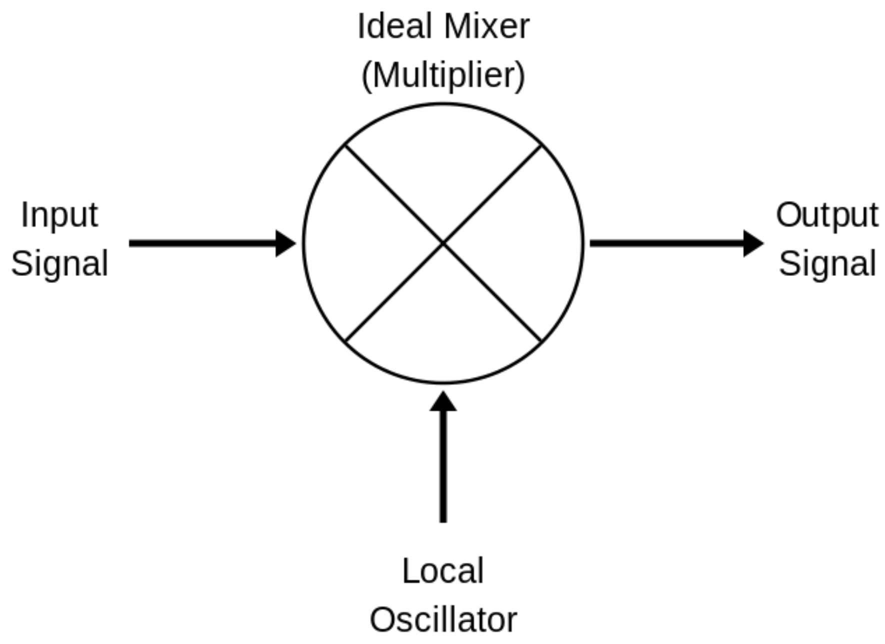
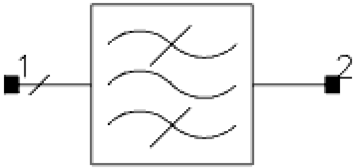


Image bands in mixers

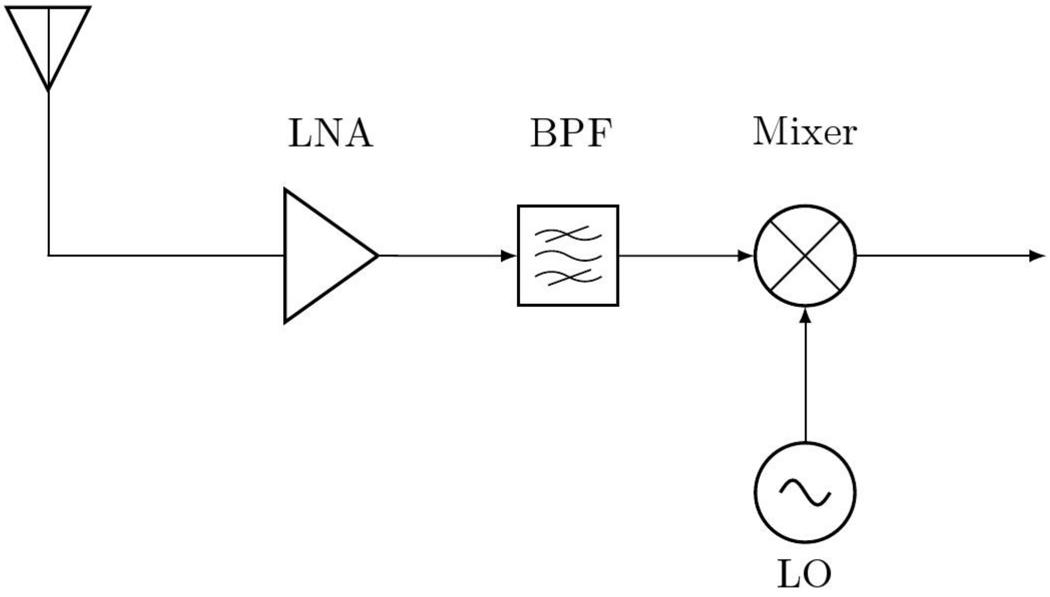


The mixer can convert signals that are both above and below the Local Oscillator frequency.

Frequencies above the LO are generally regarded as ***Signal Frequencies,*** and those below as unwanted ***Image Frequencies.***

In order to eliminate them, a ***Microwave Bandpass Filter (BPF)*** is used.   See the top symbol for such a filter.

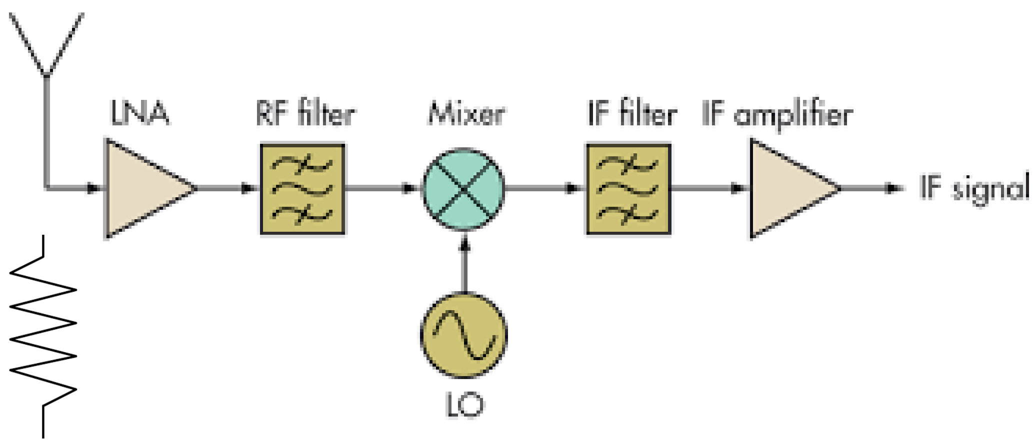
This allows only the desired band of frequencies to be fed to the mixer, eliminating the ***image band.***



In the diagram The LNA is connected to a feed and only signals that pass through the BPF are mixed down to intermediate frequencies.

A complete receiver system is shown below.

When being calibrated, the antenna would be replaced by a hot/cold load and measurements made on a power meter or a square law detector, a device that gives an output voltage proportional to power.



Improving noise temperatures

Noise temperatures of amplifiers can be significantly improved by cooling them to very low temperatures.

By cooling from room temperature , say 22 C (295 K) to 10-20 K, improvement factors of 10-20 can be achieved.

Most modern radio astronomy receivers are cooled in vacuum enclosures by closed cycle helium refrigerators that employ the Gifford-MacMahon two-stage cooling cycle.

The cooler on the right is an example of one of those used at HartRAO. The motor (top) drives a piston (right) which moves up and down in a cylinder (lower left). Helium gas is compressed then expanded , cooling in the process. The tip (second stage cools to 10-20 K, and the copper band to 30-50 K, depending on the thermal load.

Some examples of cryogenic receivers used at HartRAO

This shows the final assembly of the HartRAO 18 cm receiver.

The driving motor for the cooler is at the bottom and amplifiers can just be seen in middle section below the polished copper Ortogonal Mode Transducer (OMT).

The amplifiers will be enclosed in a polished copper radiation shield to protect them from heat absorption.

Everything is sealed in a vacuum Dewar to prevent gaseous heat transfer from the very cold parts.

Inssallation of 18 cm receiver on HartRAO 26 m telescope

The reciever is being installed in the white box at the base of the 18 cm feed.

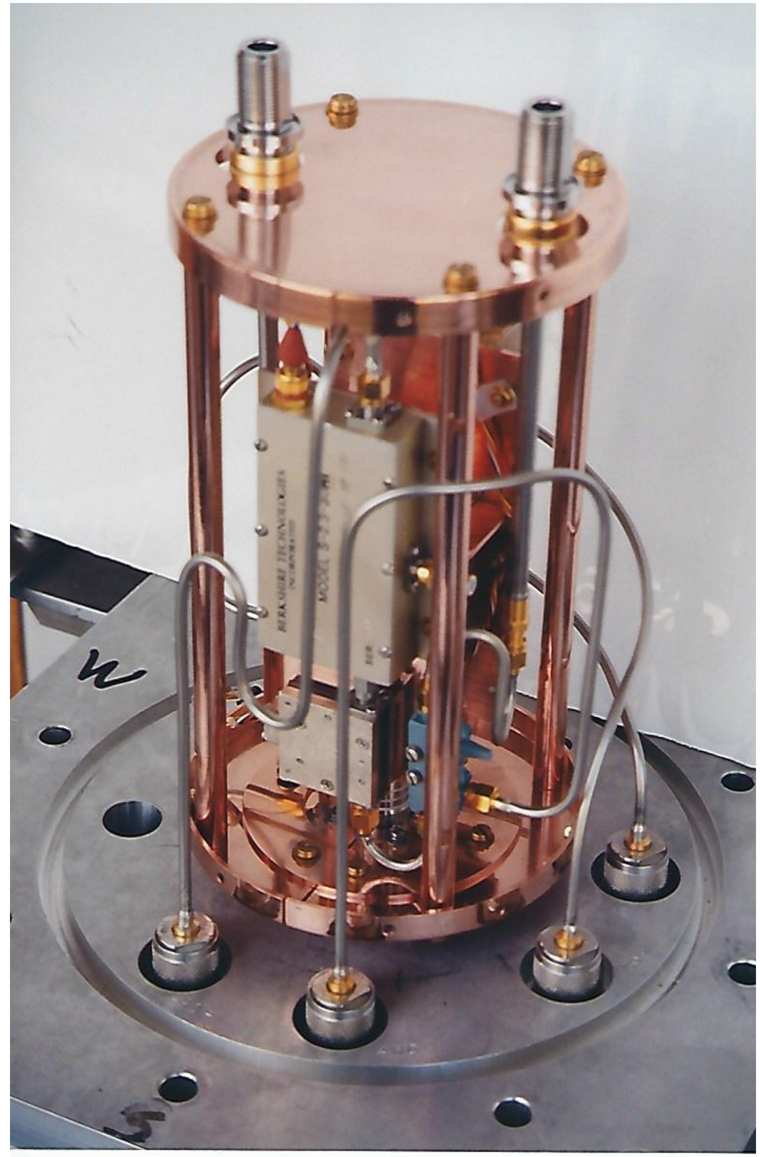
13 cm cryogenic receiver system

Input connectors at the top

Small grey unit is a circulator, the larger unit the amplifier.

The small blue item is a directional coupler which couples noise from a calibration noise diode into the receiver.

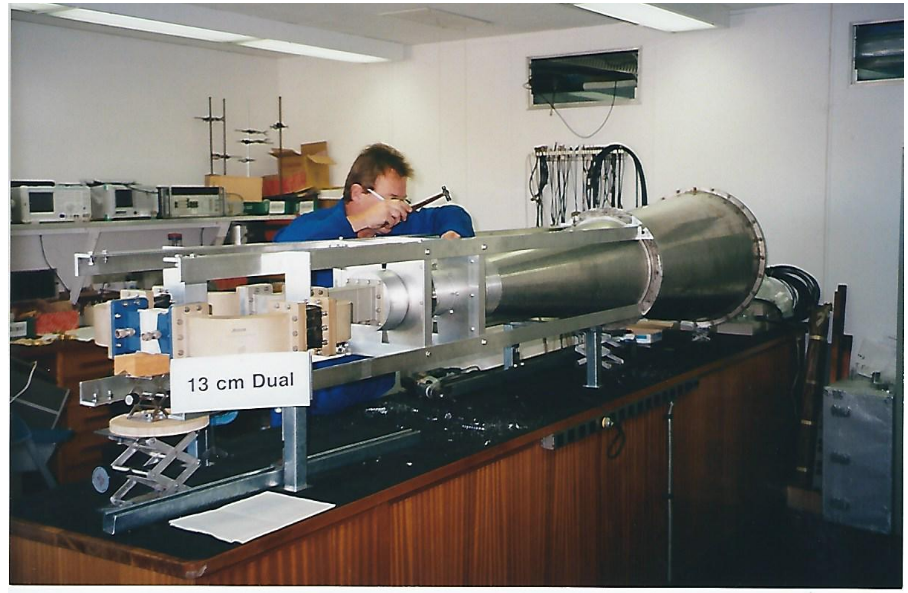
The output cables are at the bottom.



13 cm system

Top shows the final assembly of the 13 cm feed in the microwave laboratory.

Bottom shows the completed 13 cm receiver with its power supplies and compressor

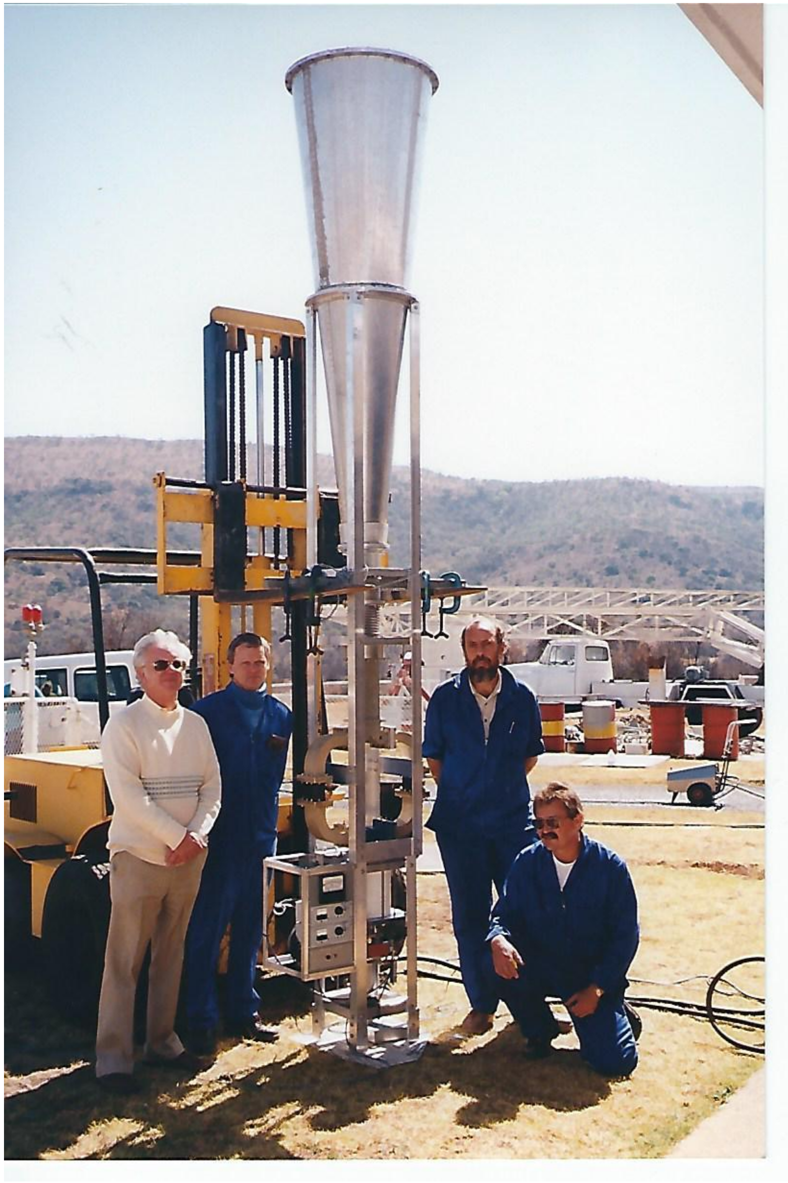


Competed system with feed

Completed system with proud project team.

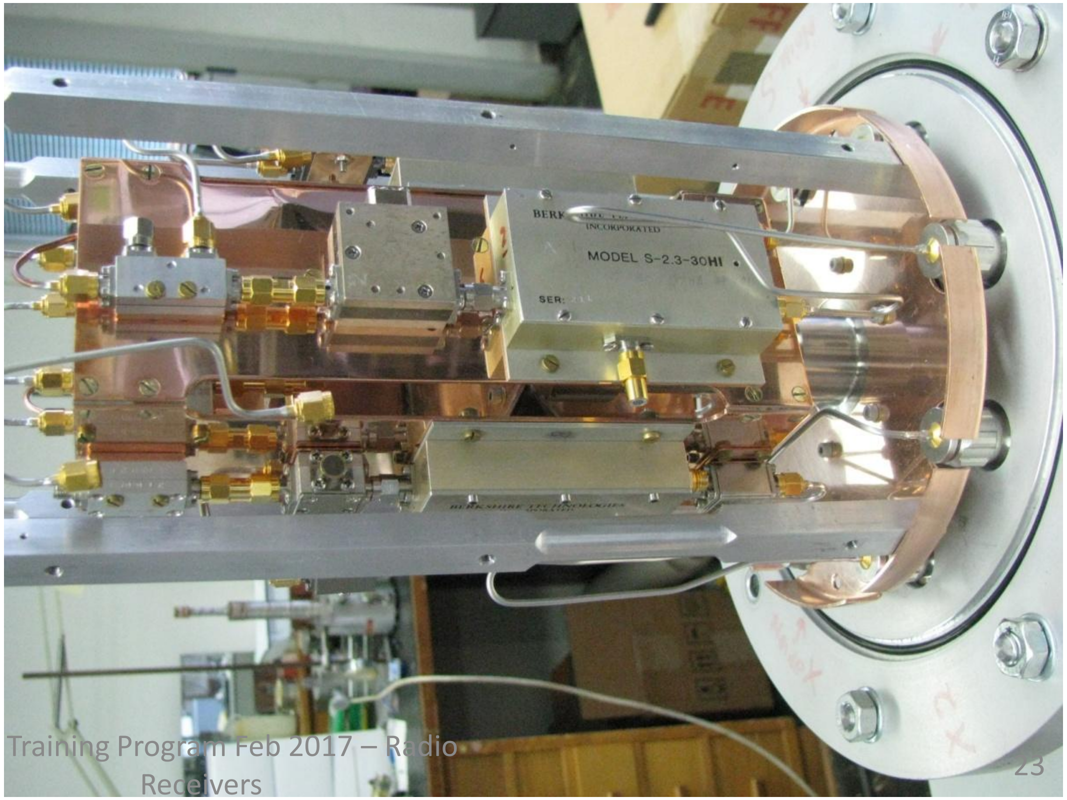
Ready for final testing on the ground before installation on the telescope.

This feed is mounted inside the Cassegrain Cone.



S/X-Band receiver for the 15m telescope

Pieter looks on as Jacques assembles the new dual S/X-Band receiver for the 15m geodetic VLBI antenna.



Close up view of one of the four amplifiers.

This is the most complex system built at HartRAO

Thank you!