FINAL PROJECT

SDR BASED DUAL BAND EARTH STATION

FACULTAD DE INGENIERÍA - UNMDP

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URIZ, ALEJANDRO
ETCHEVERRY, JUAN ALBERTO

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INTRODUCTION

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BEGINNING OF THE PROJECT

WHAT IS A SDR?

SDR: Software Defined Radio

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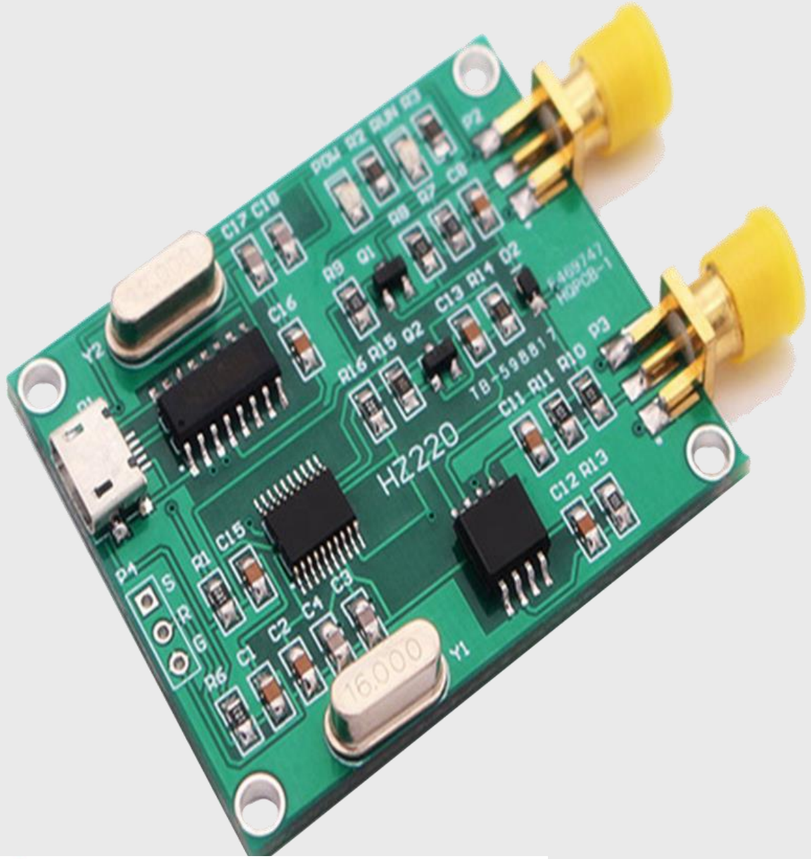
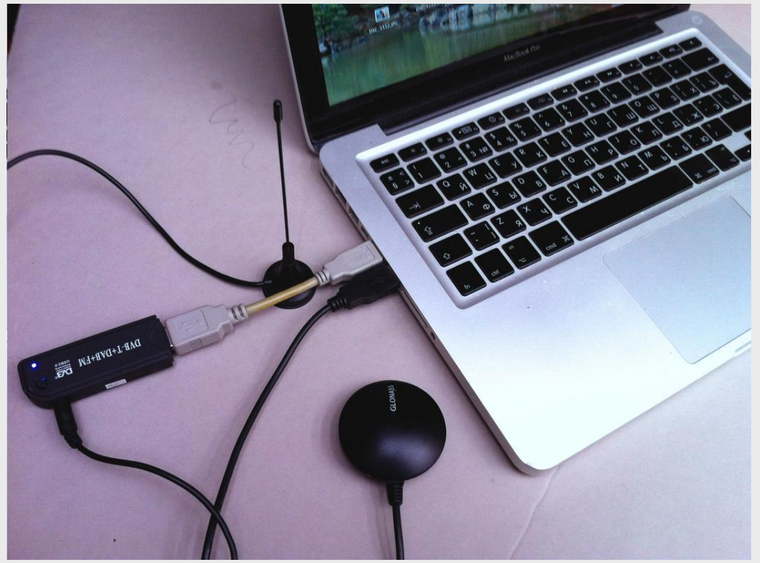
WHAT IS A SDR?

SDR: Software Defined Radio



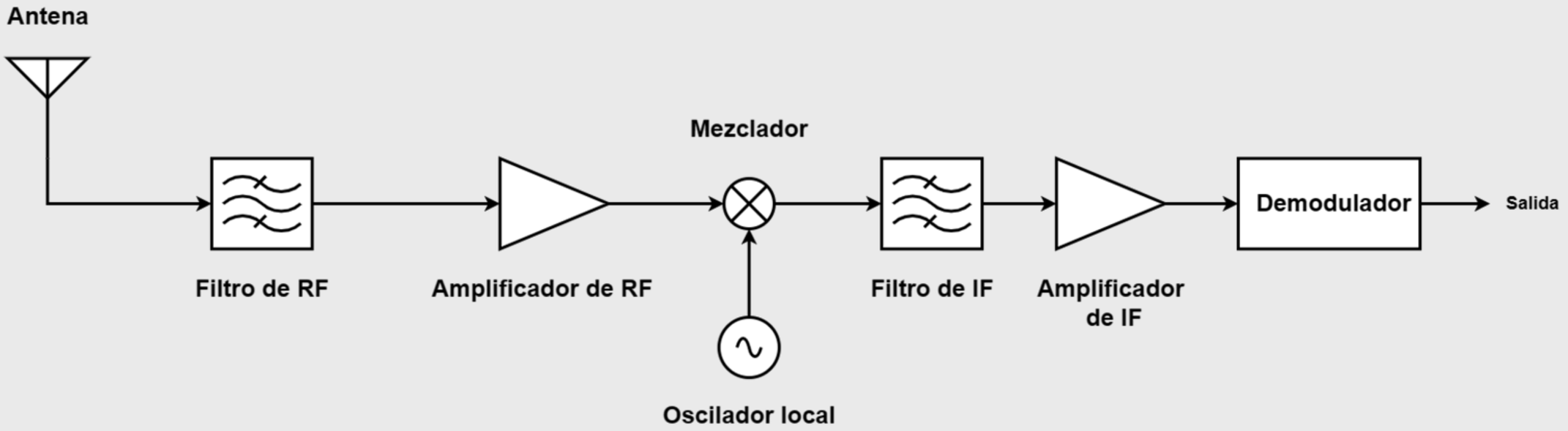


WHAT IS AN EARTH STATION?

Balcarce Earth Station

Las Cruces, New Mexico (NASA) Earth Station

WHAT IS AN EARTH STATION?



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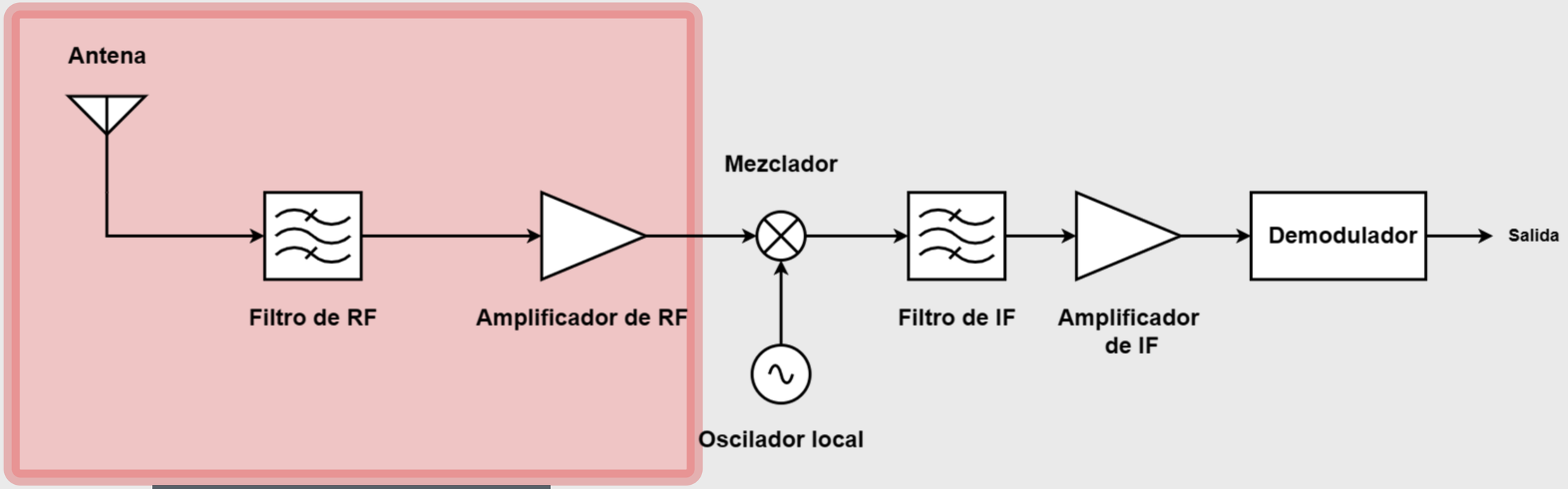

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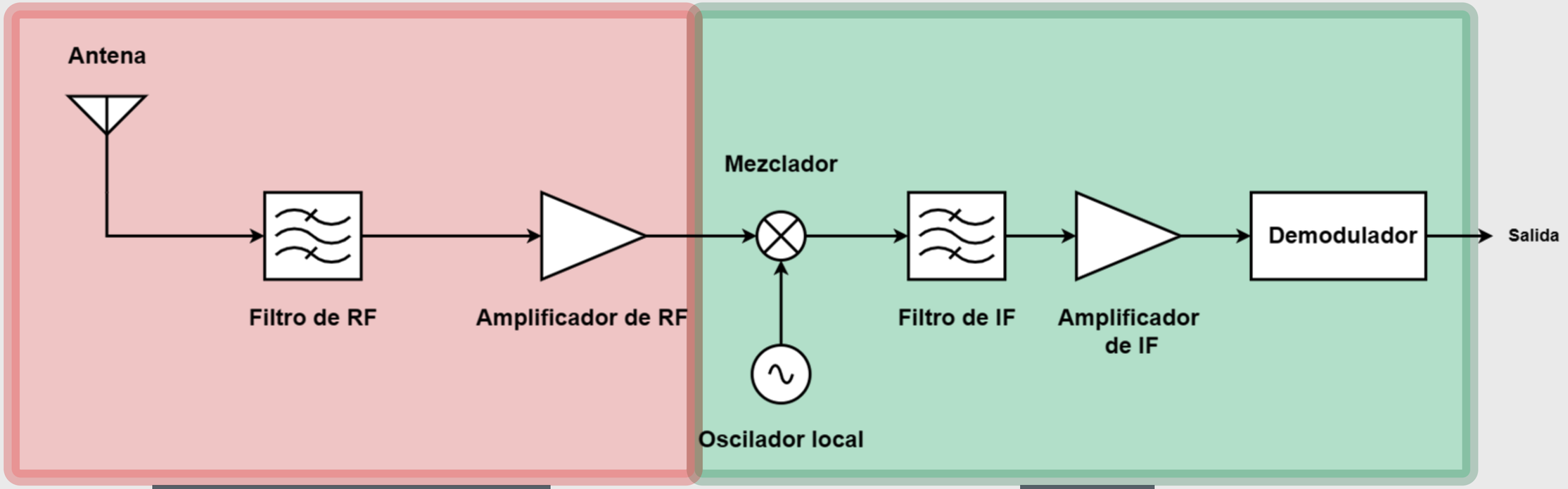

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SCOPE

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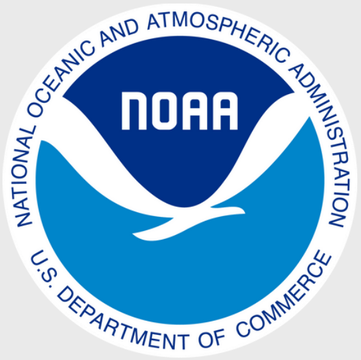
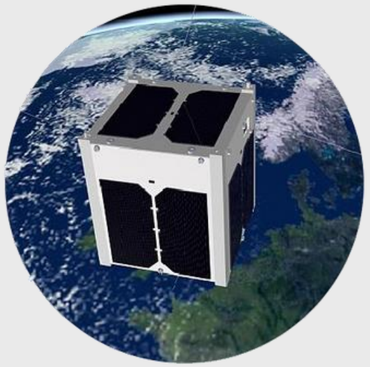
PROJECT SCOPE

- Dual band satellite data reception ground station.
- Deliverable:
    - VHF – UHF Antennas.
    - RF filter.
    - LNA (Low noise amplifier).
    - SDR board.
    - User interface for data visualization.

FEASIBILITY ANALYSIS

- Desk study: satellite link parameters, orbits
- Satellite link calculation
- 4 selected satellites: GOES-R, NOAA 19, AAUSAT 2, Bugsat 1

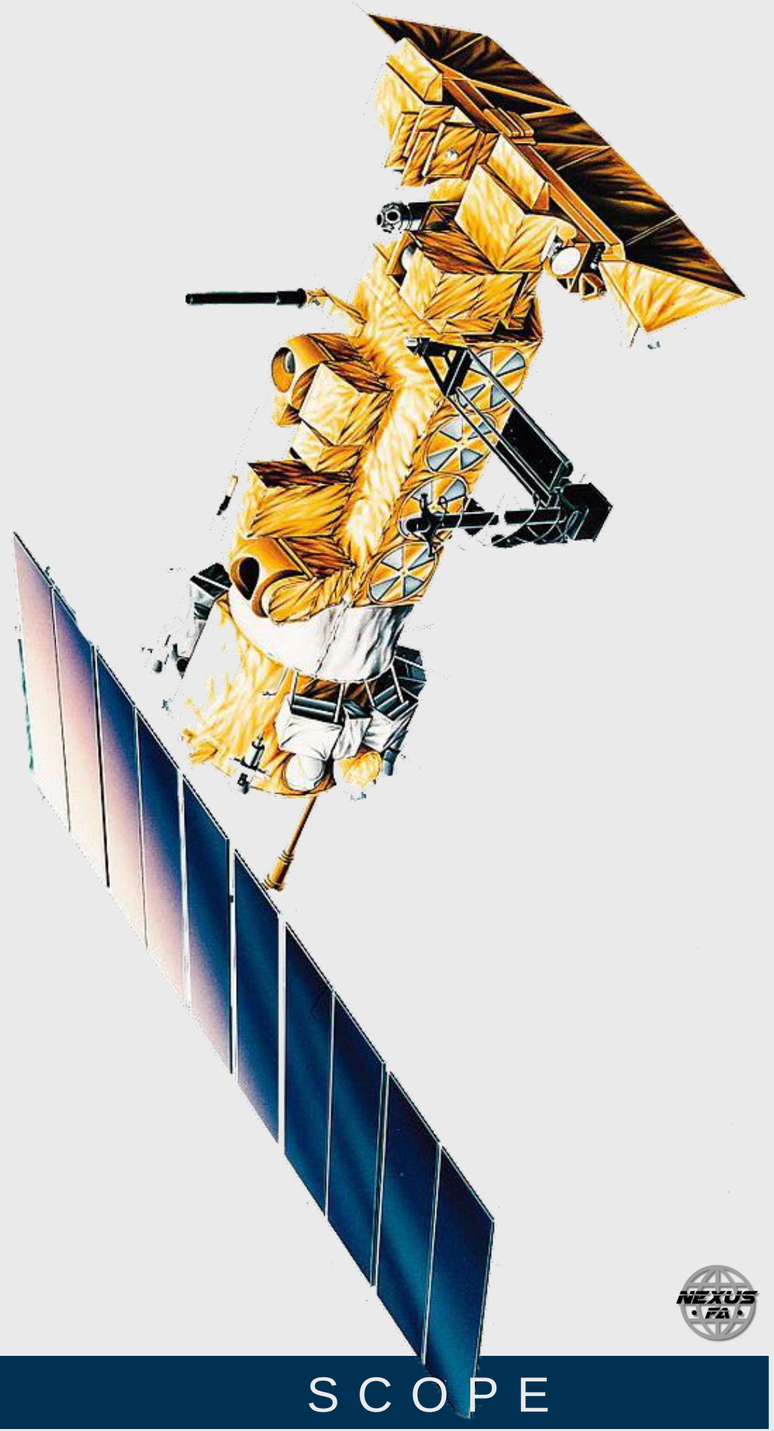




NOAA SATELLITES

NOAA 19

- Released in 2009.
- 4,2 meters high; 1,88 meters in diameter.
- Períod 102 minutes.
- Orbital height 850 km.
- Signals of interest at 137,1 MHz (APT) and 1698 MHz (HRPT).
- FM (analog) and BPSK (digital) modulation.



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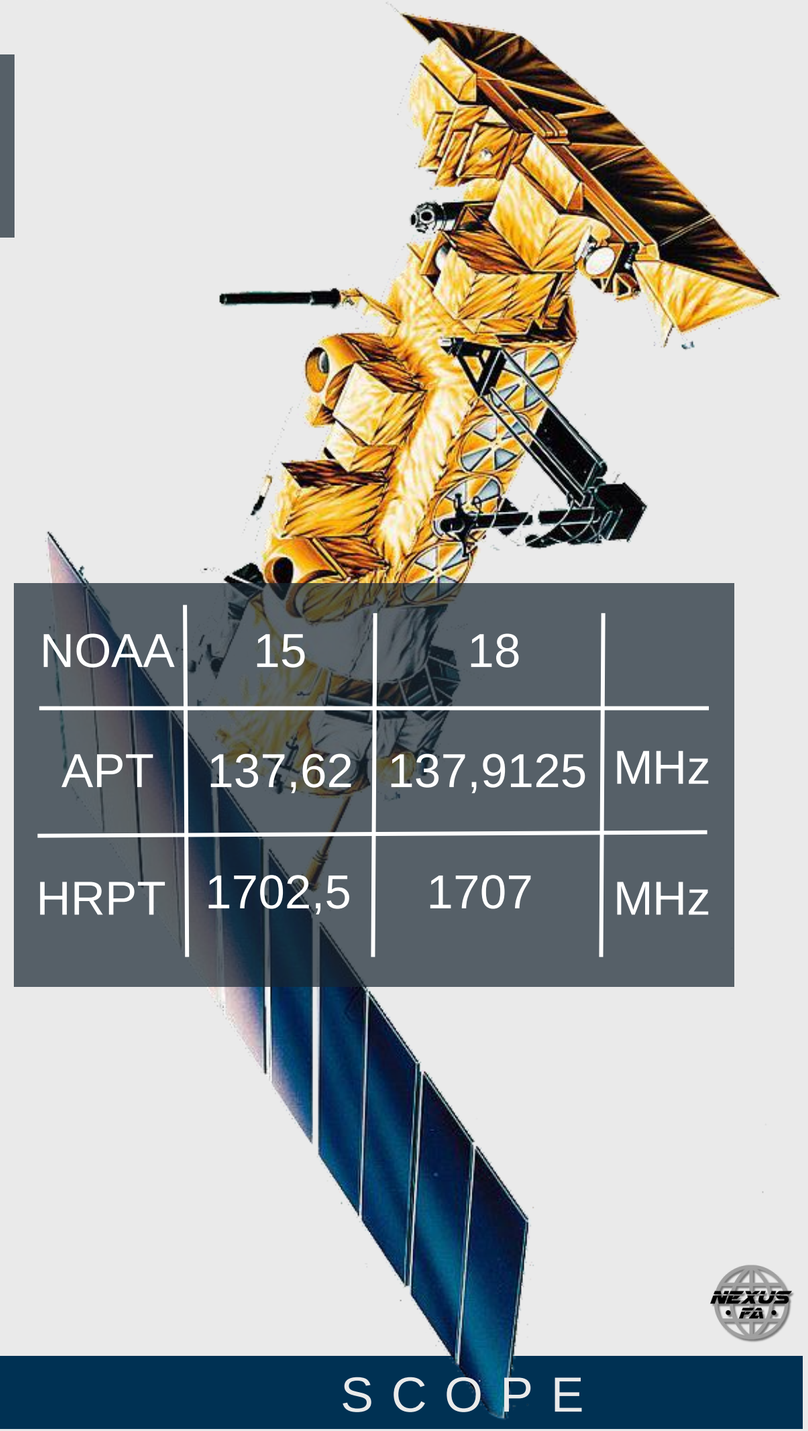
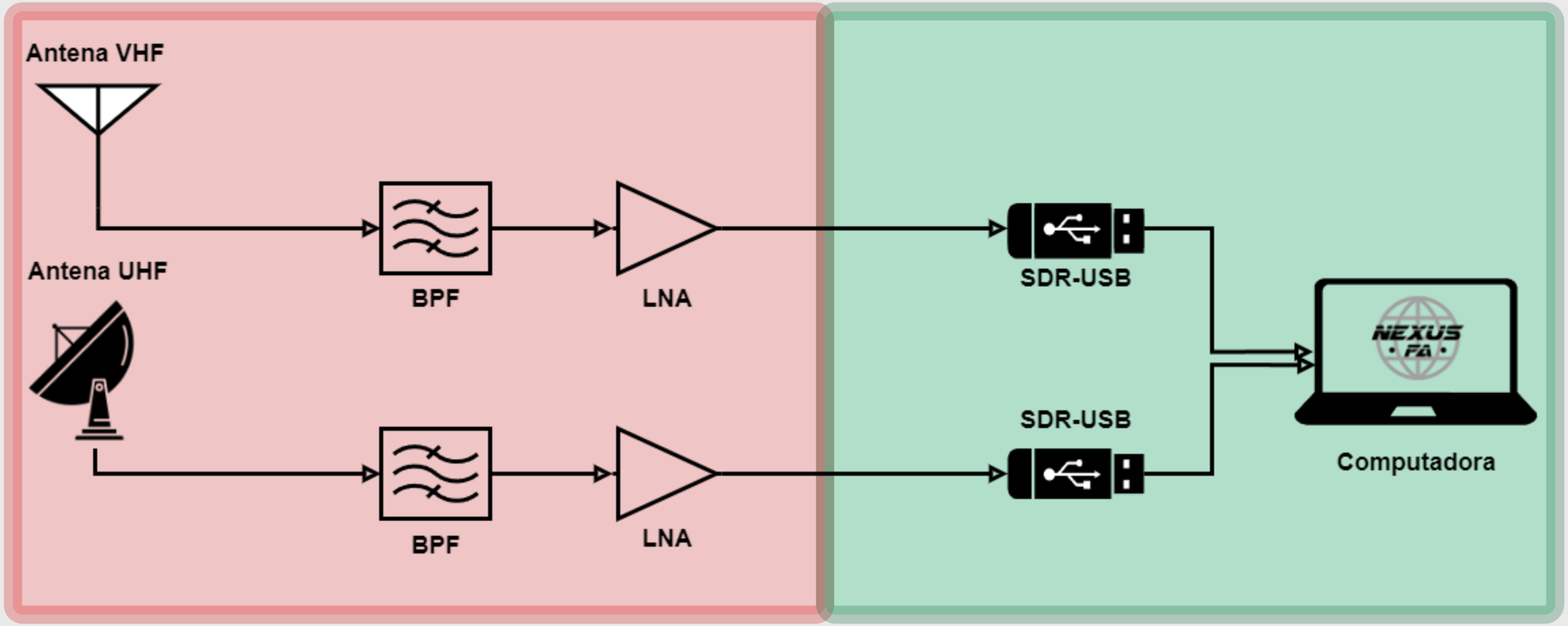


NOAA	15	18	
APT	137,62	137,9125	MHz
HRPT	1702,5	1707	MHz

GENERAL DIAGRAM

APT

HRPT



PROJECT MANAGEMENT

STAGES:

- Initial.
- #1 Study and training on the subject of work.
- #2 Feasibility analysis on the satellite link.
- #3 Study and implementation on SDR.
- #4 Analysis and design of the necessary hardware.
- #5 Implementation and testing.
- Final.

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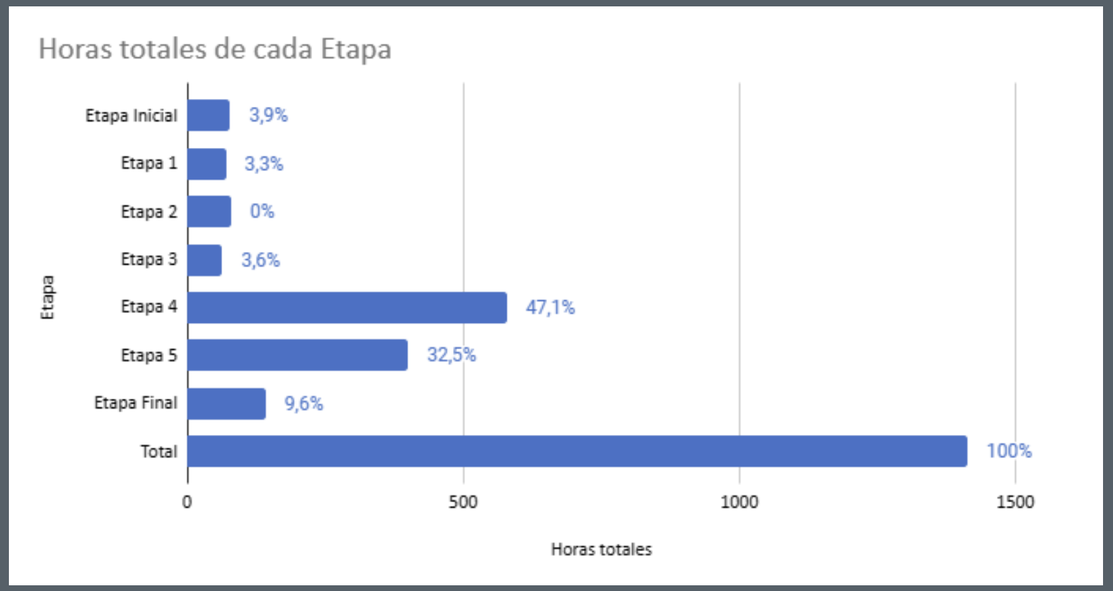
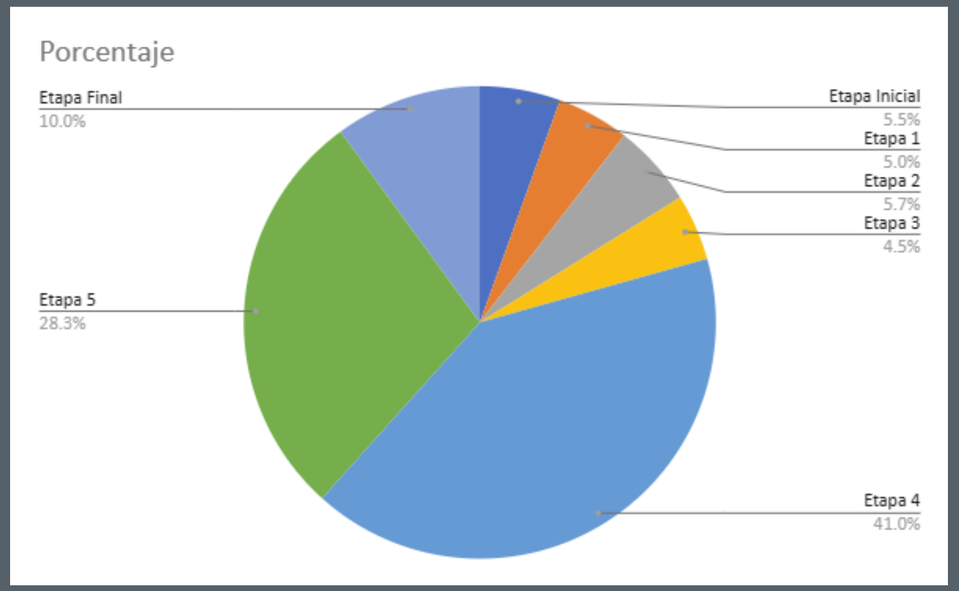
PROJECT MANAGEMENT

- Management and planning tools: Notion, Google Drive.
- Weekly meetings to report results with directors..
- Work in the Communications Laboratory.

PROJECT MANAGEMENT





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DEVELOPMENT

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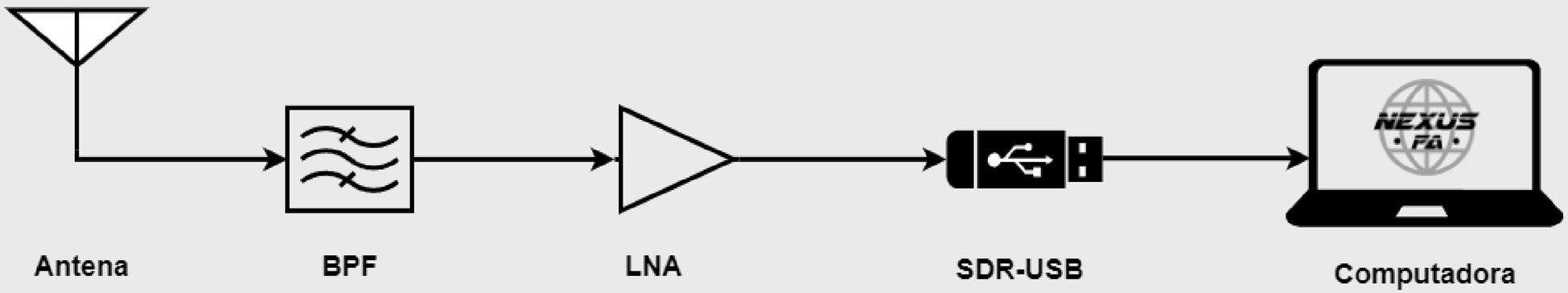
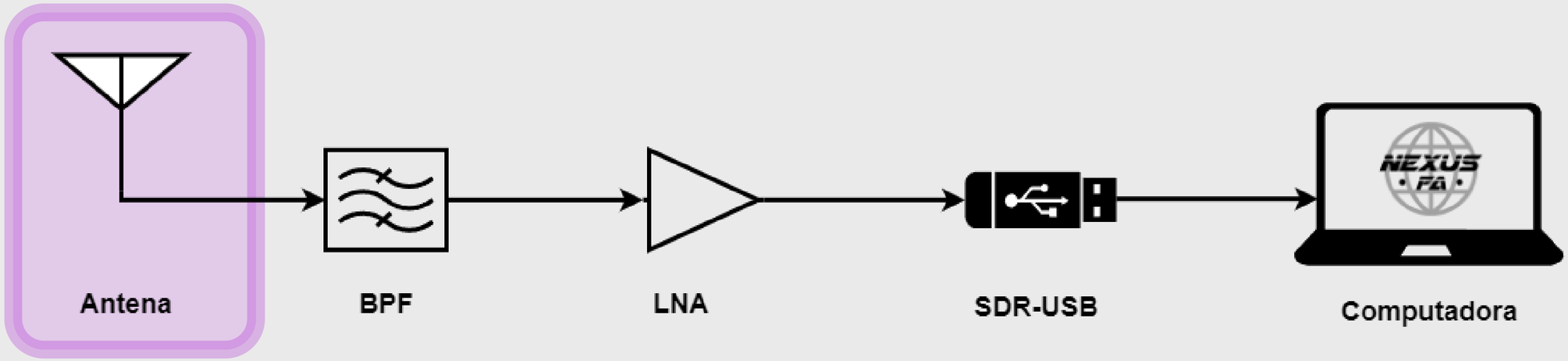
DESIGN AND IMPLEMENTATION

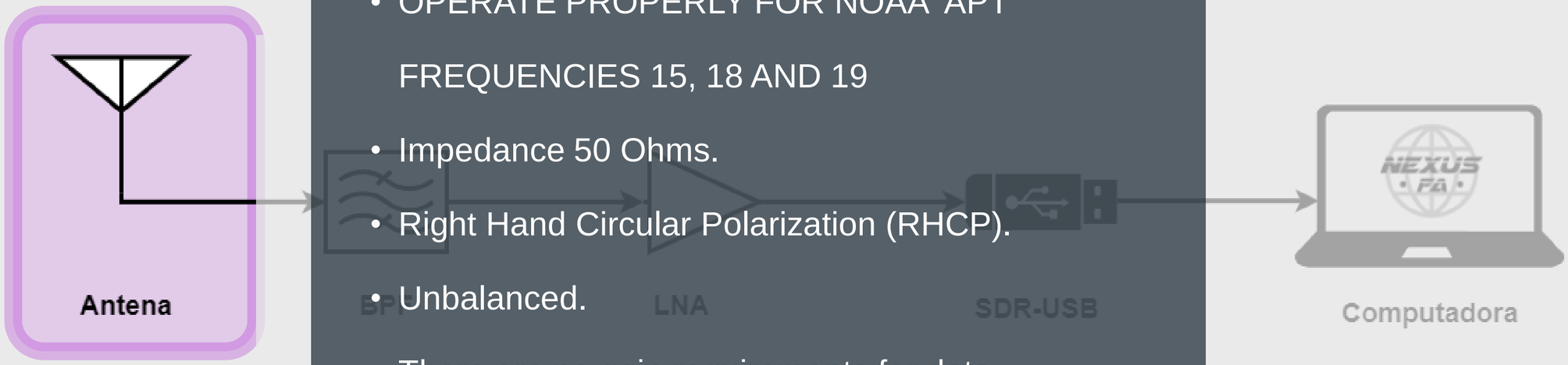


DESIGN AND IMPLEMENTATION



DESIGN AND IMPLEMENTATION

APT

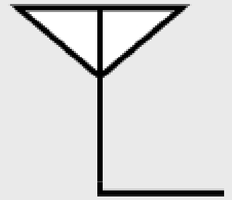


REQUIREMENTS:

- OPERATE PROPERLY FOR NOAA APT FREQUENCIES 15, 18 AND 19
- Impedance 50 Ohms.
- Right Hand Circular Polarization (RHCP).
- Unbalanced.
- There are no gain requirements for data acquisition.

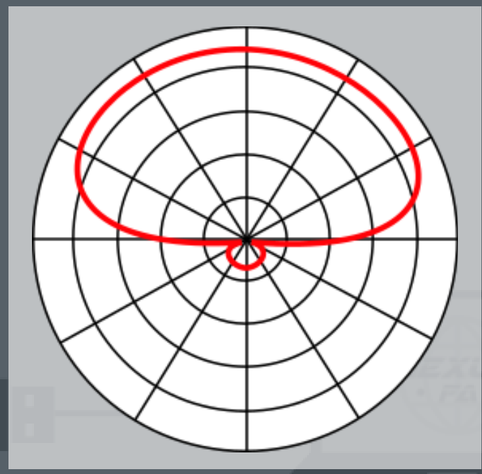
DESIGN AND IMPLEMENTATION

APT



CUADRIFILAR ANTENNA

- Lobe that illuminates the entire sky.
- Circular polarization throughout the main lobe.
- Tuning depends on the radius of the cylinders.
- Broadband.
- Balun requires .

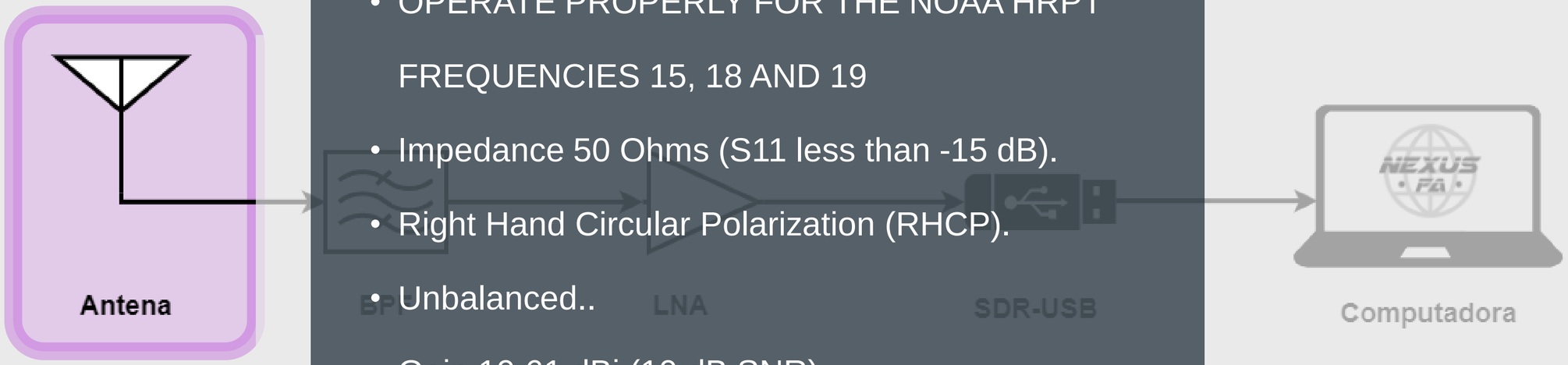


Antena

- S11 of -30 dB in 137,1 MHz.
- Test-validated lobe

DESIGN AND IMPLEMENTATION

HRPT



REQUIREMENTS :

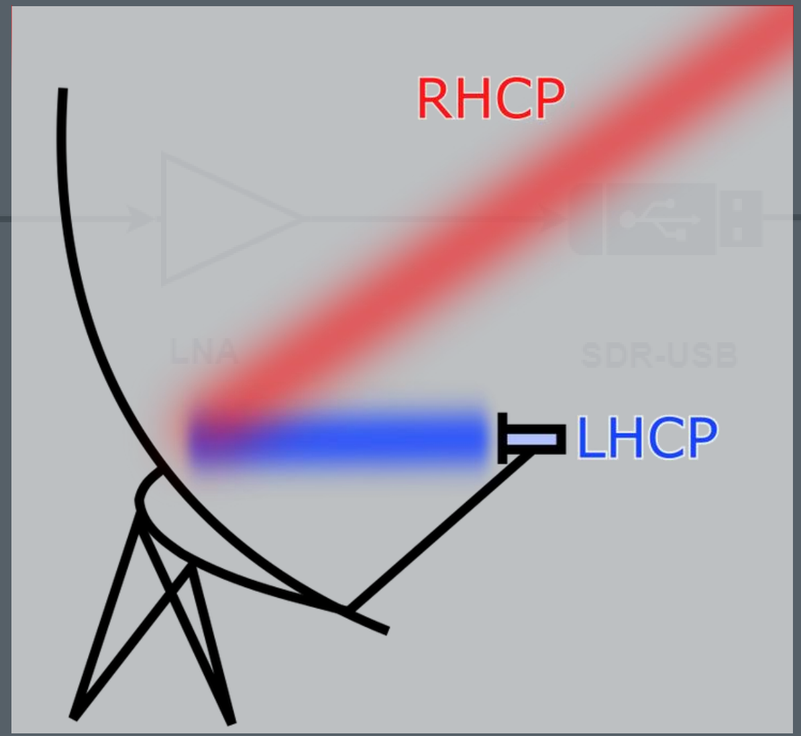
- OPERATE PROPERLY FOR THE NOAA HRPT FREQUENCIES 15, 18 AND 19
- Impedance 50 Ohms (S11 less than -15 dB).
- Right Hand Circular Polarization (RHCP).
- Unbalanced..
- Gain 19,61 dBi (10 dB SNR).
- Desirable: Maximize HPBW.

DESIGN AND IMPLEMENTATION

HRPT

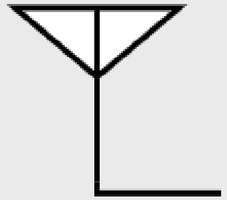
Antena

POLARIZATION BEHAVIOR IN DISH :

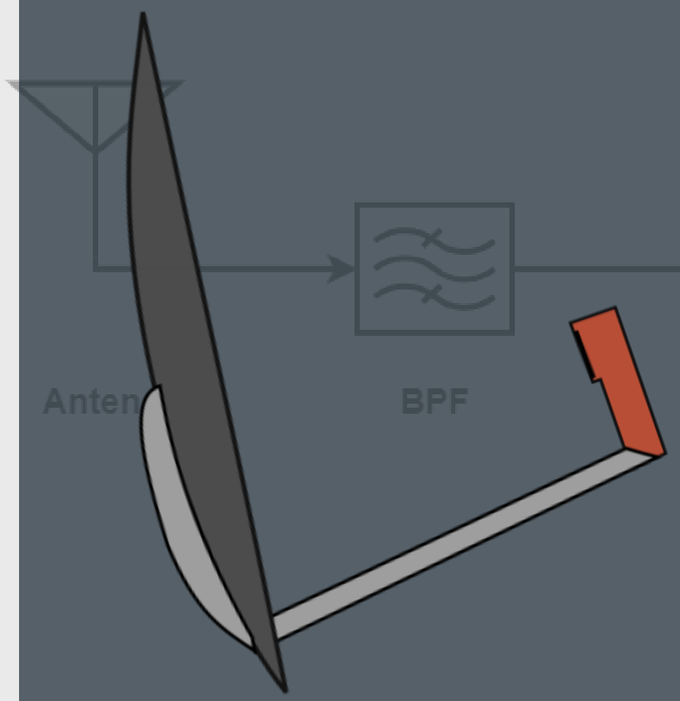


DESIGN AND IMPLEMENTATION

HRPT

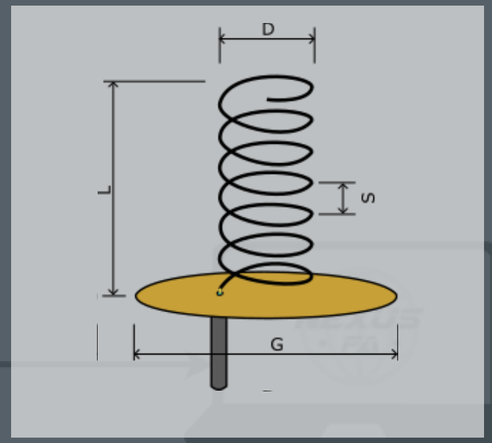


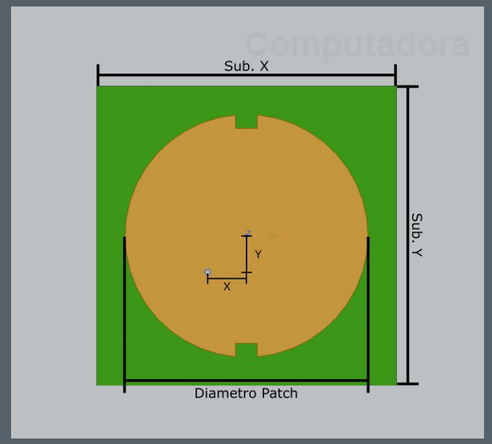
SATELLITE DISH WITH ILLUMINATOR



- HPBW 16°.
- Reverse Bias to Illuminator (LHCP)
- Theoretically 20.1 dBi.
- Highlighter Alternatives

Antena





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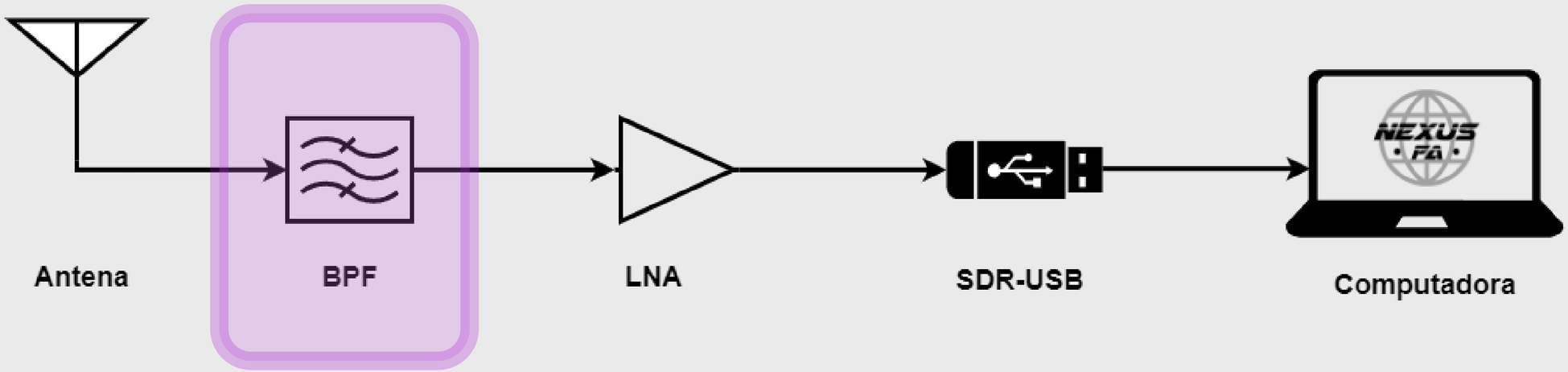
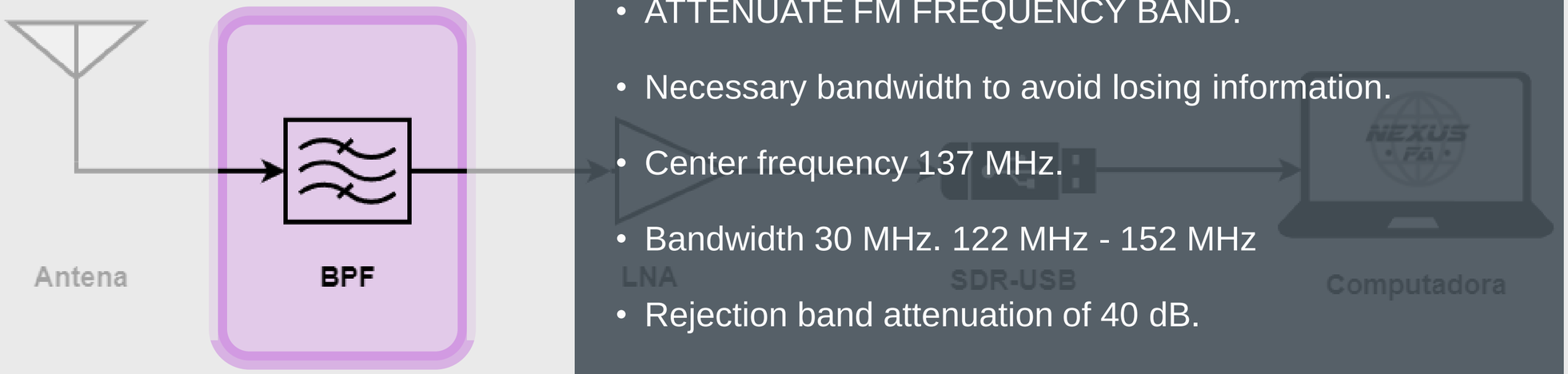


DESIGN AND IMPLEMENTATION

APT



REQUIREMENTS:

- ATTENUATE FM FREQUENCY BAND.
- Necessary bandwidth to avoid losing information.
- Center frequency 137 MHz.
- Bandwidth 30 MHz. 122 MHz - 152 MHz
- Rejection band attenuation of 40 dB.
- Passband insertion loss: < 0.5 dB.

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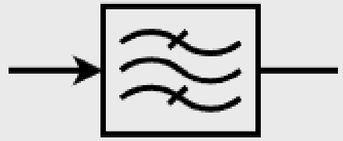
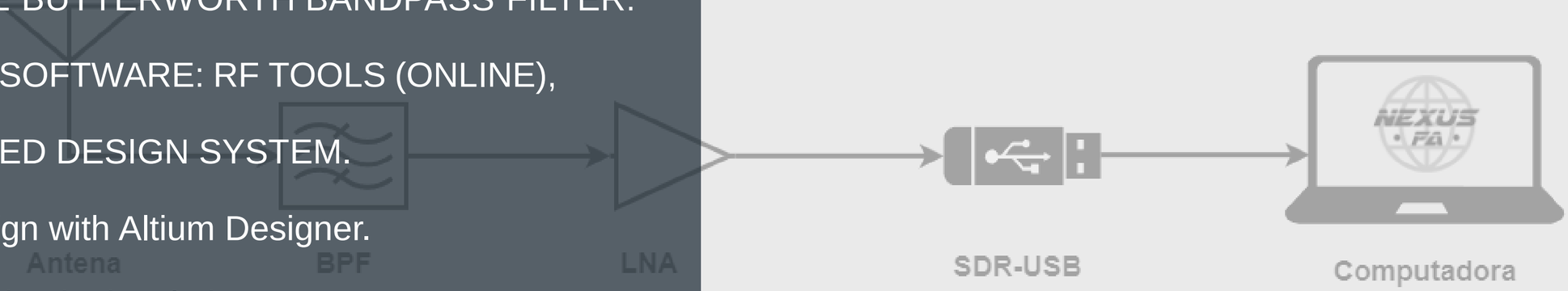
APT



BPF

LC-TYPE BUTTERWORTH BANDPASS FILTER:

- DESIGN SOFTWARE: RF TOOLS (ONLINE), ADVANCED DESIGN SYSTEM.
- PCB design with Altium Designer.
- Construction by insolation.



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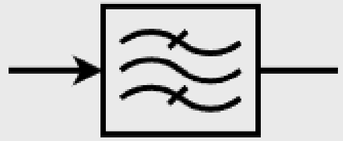

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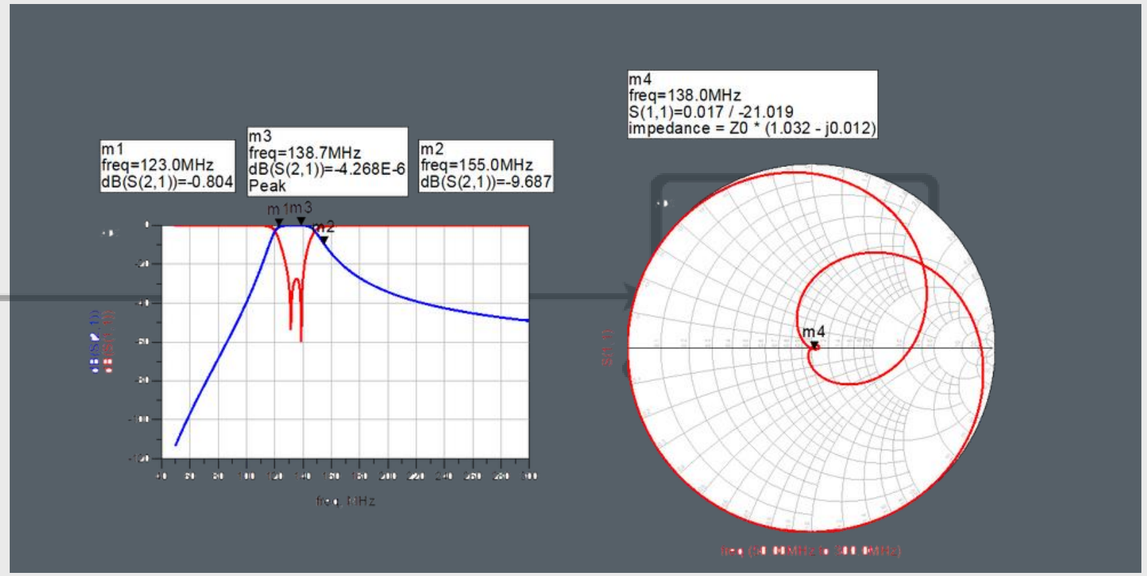

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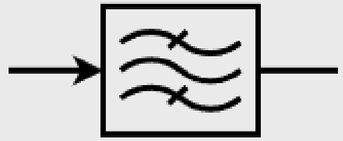

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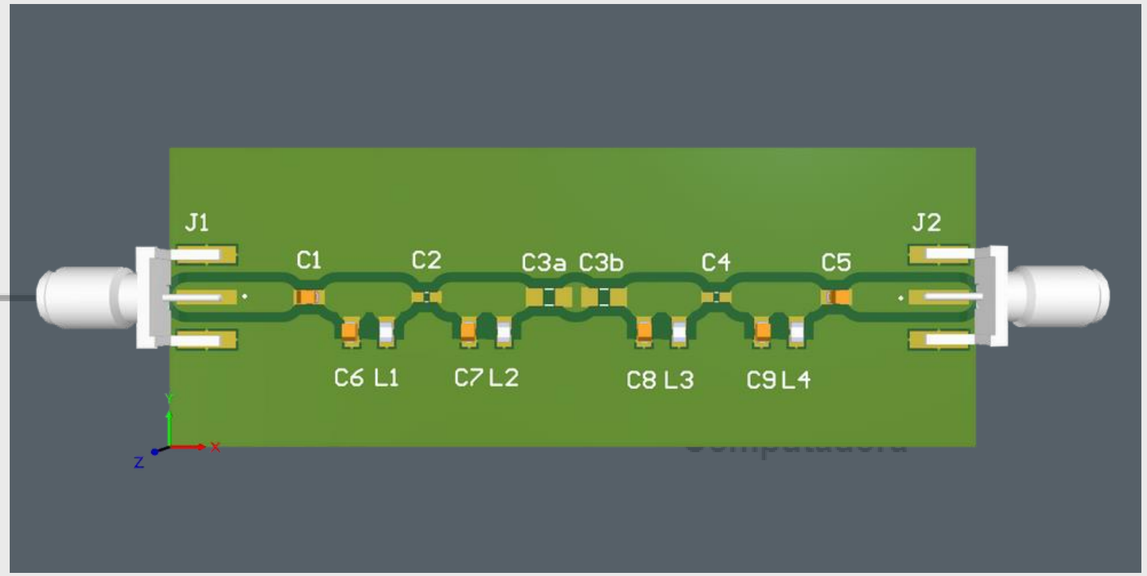

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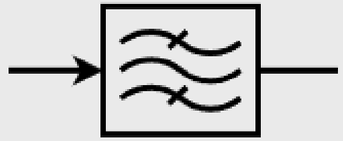

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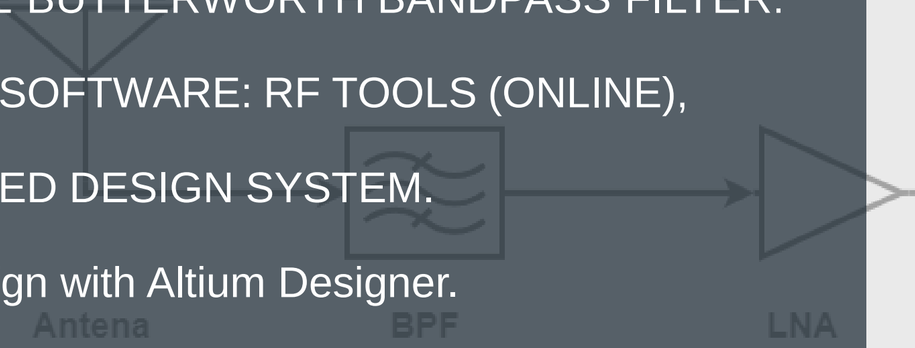

Componente	*Valor*	*Montaje*
C1, C5, C6, C7, C8, C9	47 pF	SMD 0805
C2, C4	12 pF	SMD 0603
C3a, C3b	15 pF	SMD 0603
L1, L2, L3, L4	22 nH	SMD 0603

DESIGN AND IMPLEMENTATION

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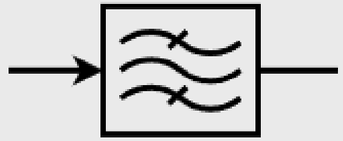
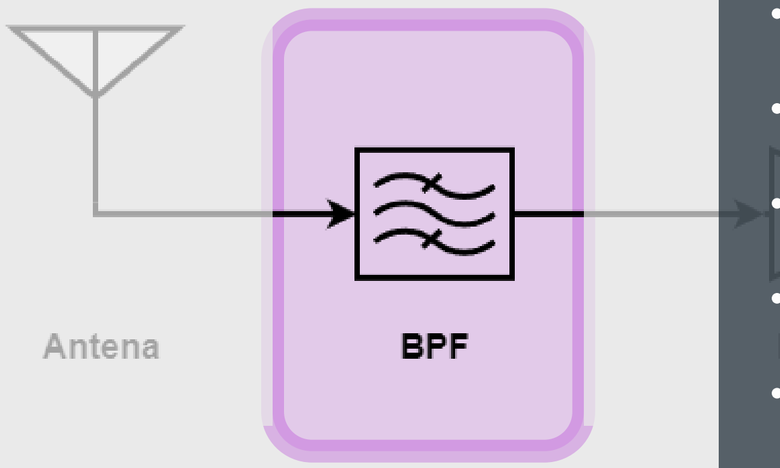


TESTS:

- INSTRUMENTS USED: SPECTRUM ANALYZER AND VNA.
- Resulting bandwidth: 117 MHz - 140 MHz.
- Passband attenuation: ~ 6 dB

DESIGN AND IMPLEMENTATION

HRPT

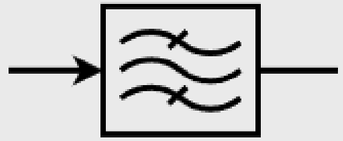


REQUIREMENTS:

- MITIGATE POSSIBLE INTERFERENCE.
- Necessary bandwidth to avoid losing information.
- Center frequency 1.7 GHz.
- Bandwidth 200 MHz. 1600 MHz-1800 MHz
- Rejection band attenuation of 40 dB.
- Passband insertion loss: < 0.5 dB.

DESIGN AND IMPLEMENTATION

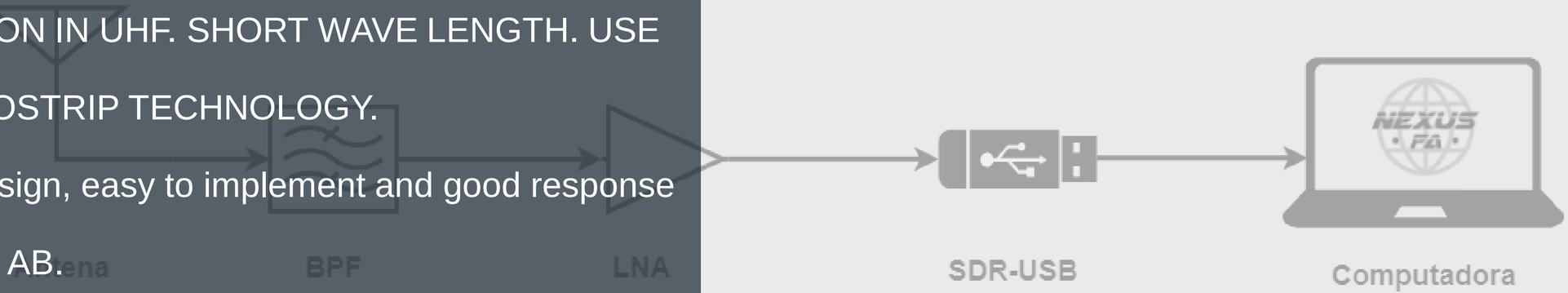
HRPT



BPF

COUPLED PARALLEL LINES FILTER:

- OPERATION IN UHF. SHORT WAVE LENGTH. USE OF MICROSTRIP TECHNOLOGY.
- Simple design, easy to implement and good response for narrow AB.
- Design software: Advanced Design System.
- Construction by insolation.



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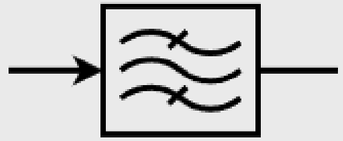

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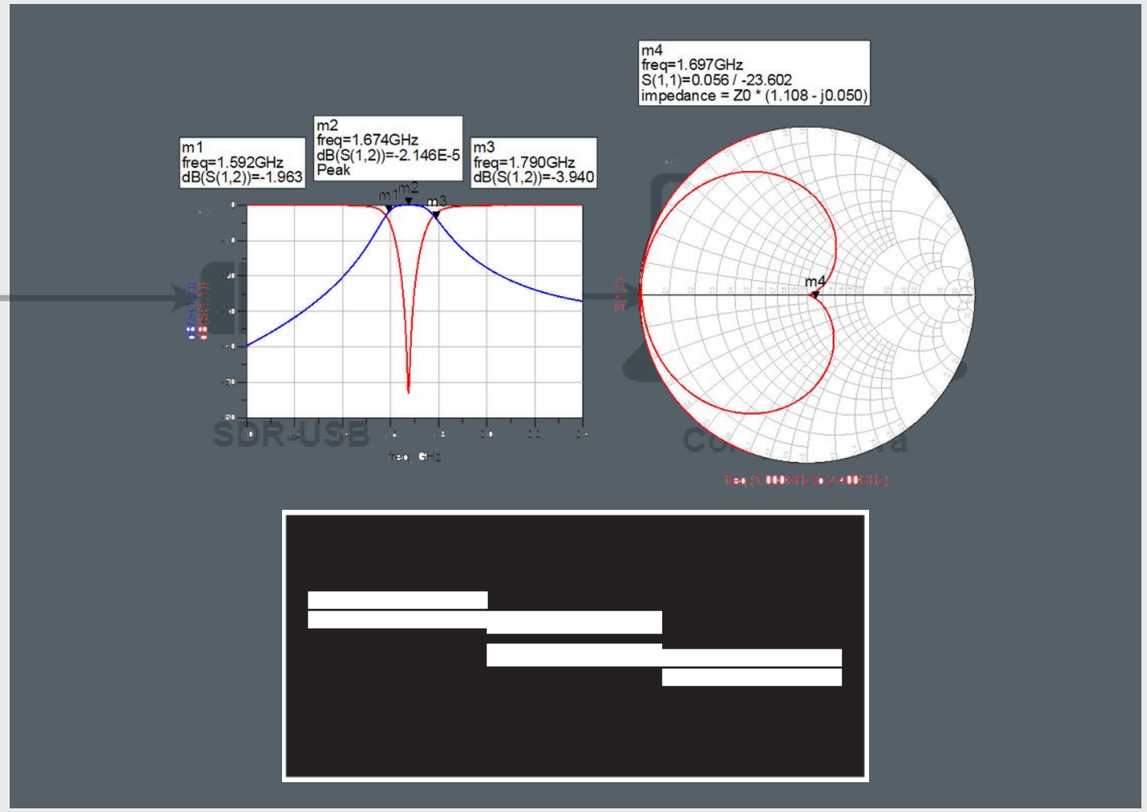

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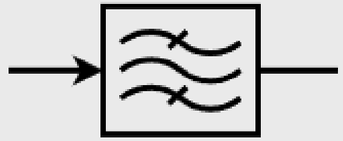
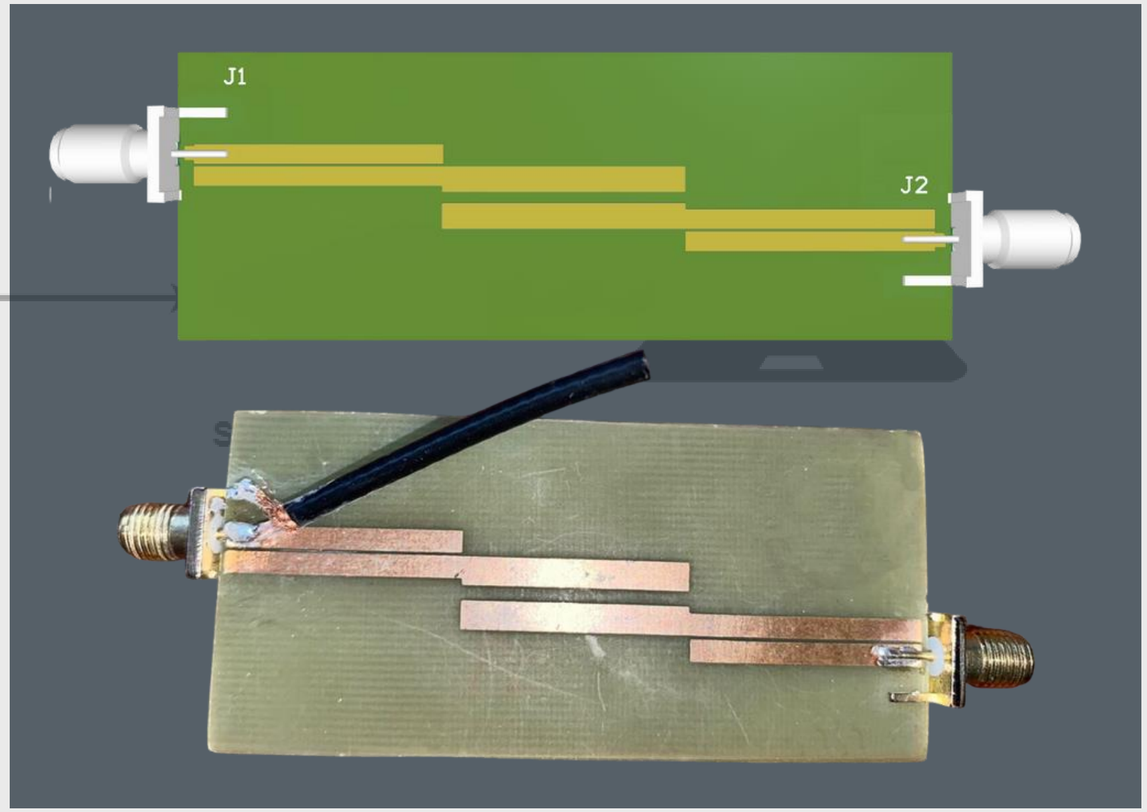


BPF

TESTS:

- INSTRUMENTS USED: SPECTRUM ANALYZER AND VNA.
- Resulting bandwidth: 1567 MHz-1744 MHz.
- Passband attenuation: ~ 5 dB.
- Simple plug adaptation.



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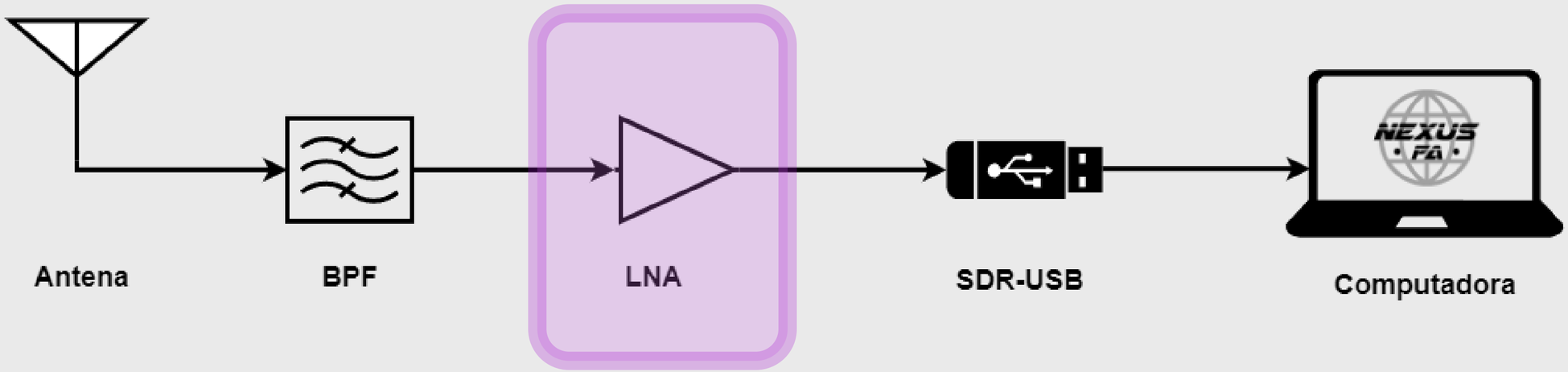
DESIGN AND IMPLEMENTATION



DESIGN AND IMPLEMENTATION

HRPT

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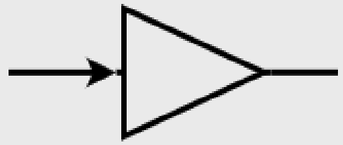
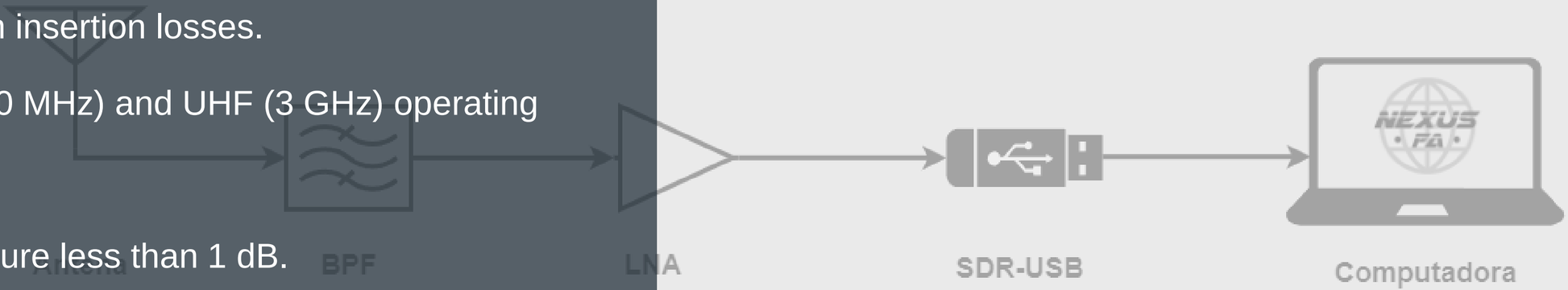


LNA

REQUIREMENTS:

- LINEAR BEHAVIOR IN THE WORK AREA.
- Minimum insertion losses.
- VHF (300 MHz) and UHF (3 GHz) operating range.
- Noise figure less than 1 dB.



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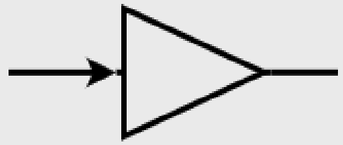
DESIGN AND IMPLEMENTATION

HRPT

APT



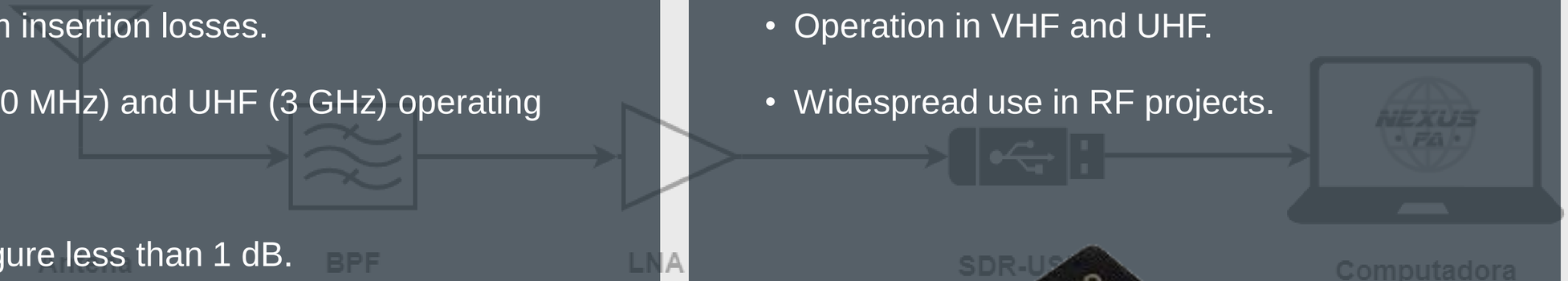
LNA

REQUIREMENTS:

- LINEAR BEHAVIOR IN THE WORK AREA.
- Minimum insertion losses.
- VHF (300 MHz) and UHF (3 GHz) operating range.
- Noise figure less than 1 dB.

SPF-5189Z:

- INTEGRATED MMIC.
- Operation in VHF and UHF.
- Widespread use in RF projects.



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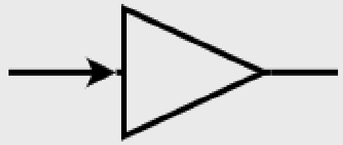
HRPT

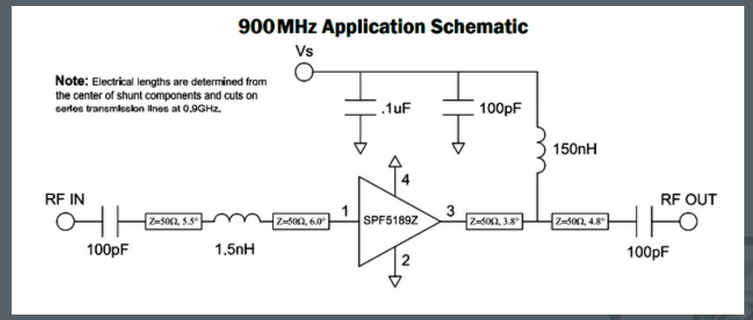
APT

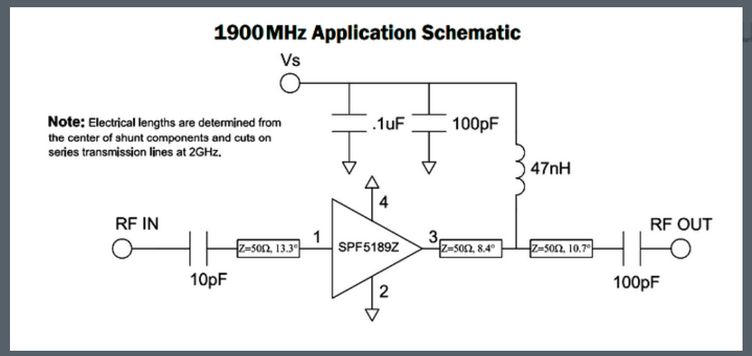


LNA

DESIGN:

- MANUFACTURER PROVIDES 2 CONFIGURATIONS.
- PCB with Altium Designer.
- Construction: By CNC milling machine and printed circuit thermal transfer method.
- Power range: 3V-5V
- Power supply implemented: 3 V - double AA type batteries.

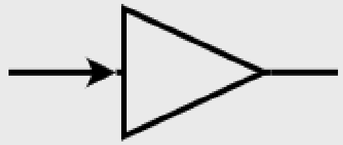




DESIGN AND IMPLEMENTATION

HRPT

APT



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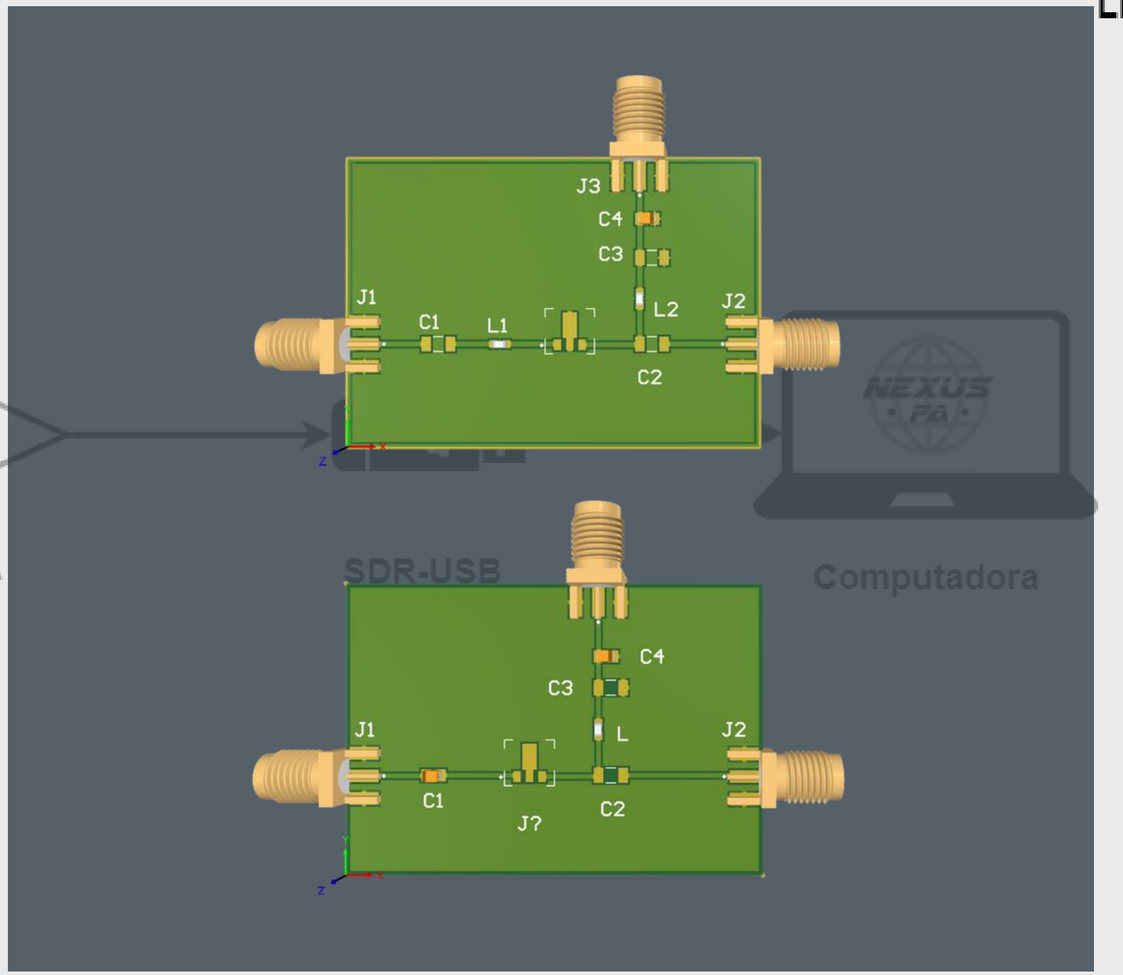
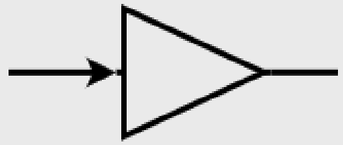


DESIGN AND IMPLEMENTATION

HRPT

APT



LNA

TESTS:

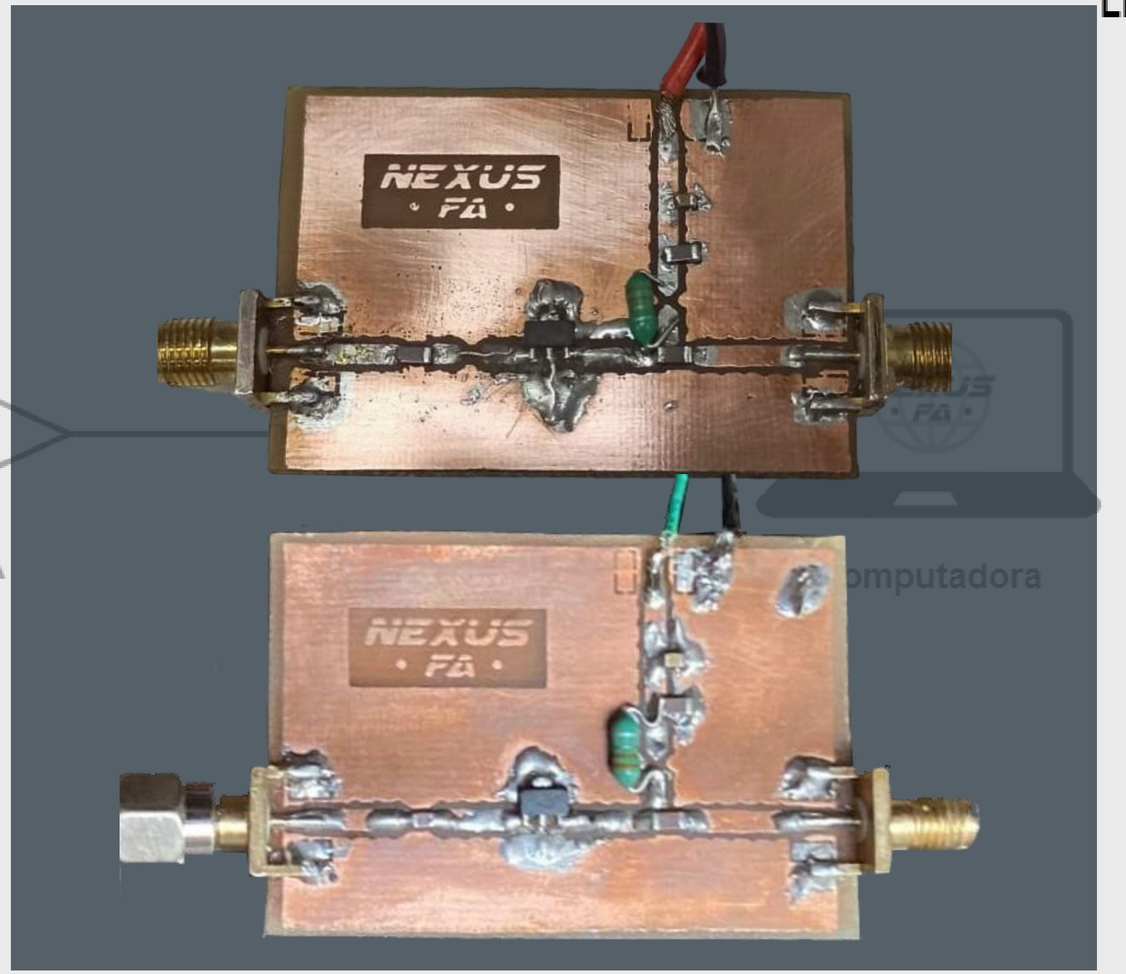
- INSTRUMENTS USED: SPECTRUM ANALYZER AND VNA.

APT:

- Gain: 15,7 dB
- Noise figure: 0,8 dB

HRPT:

- Gain: ~ 10 dB
- Noise figure: 0,8 dB



DESIGN AND IMPLEMENTATION

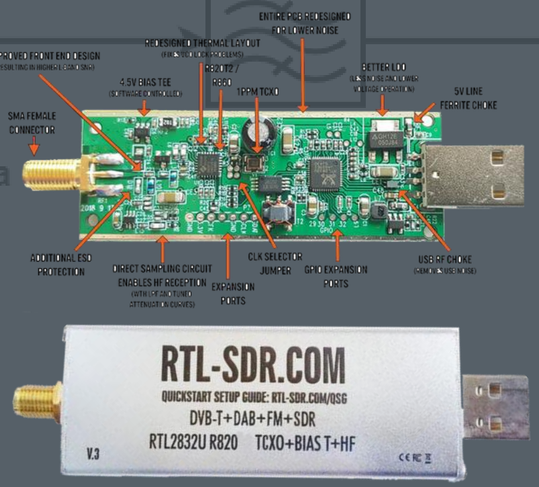
HRPT

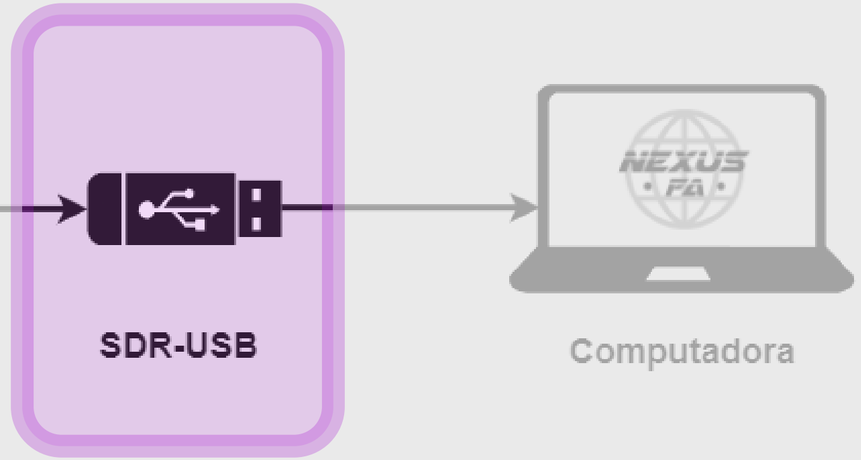
APT

SDR-USB

RTL-SDR:

- FREQUENCY RANGE: 24-1766 MHZ.
- Sampling frequency: 2.56 MHz.
- ADC resolution: 8 bits.





DESIGN AND IMPLEMENTATION

HRPT

APT

SDR-USB

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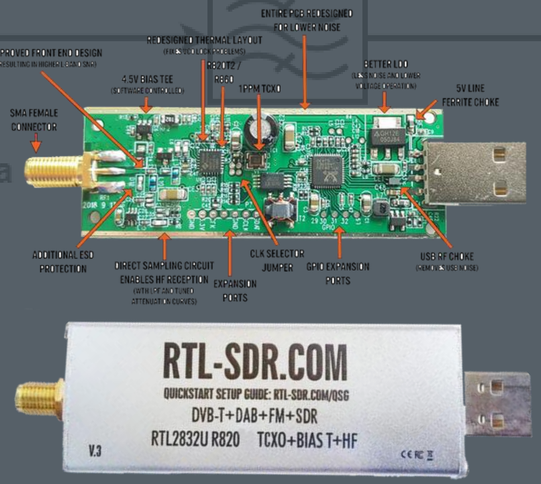
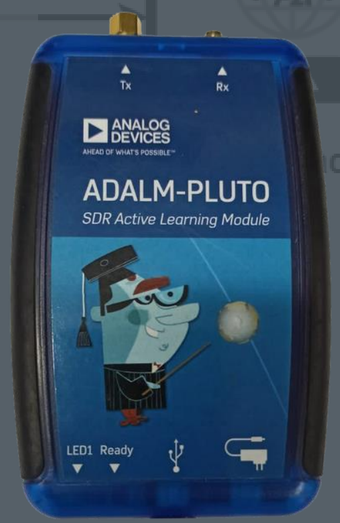


137,1 MHz

ADALM-PLUTO:

- FREQUENCY RANGE: 325-3800 MHZ.
- Sampling frequency: 61,44 MHz
- ADC resolution: 12 bits.



1,7 GHz

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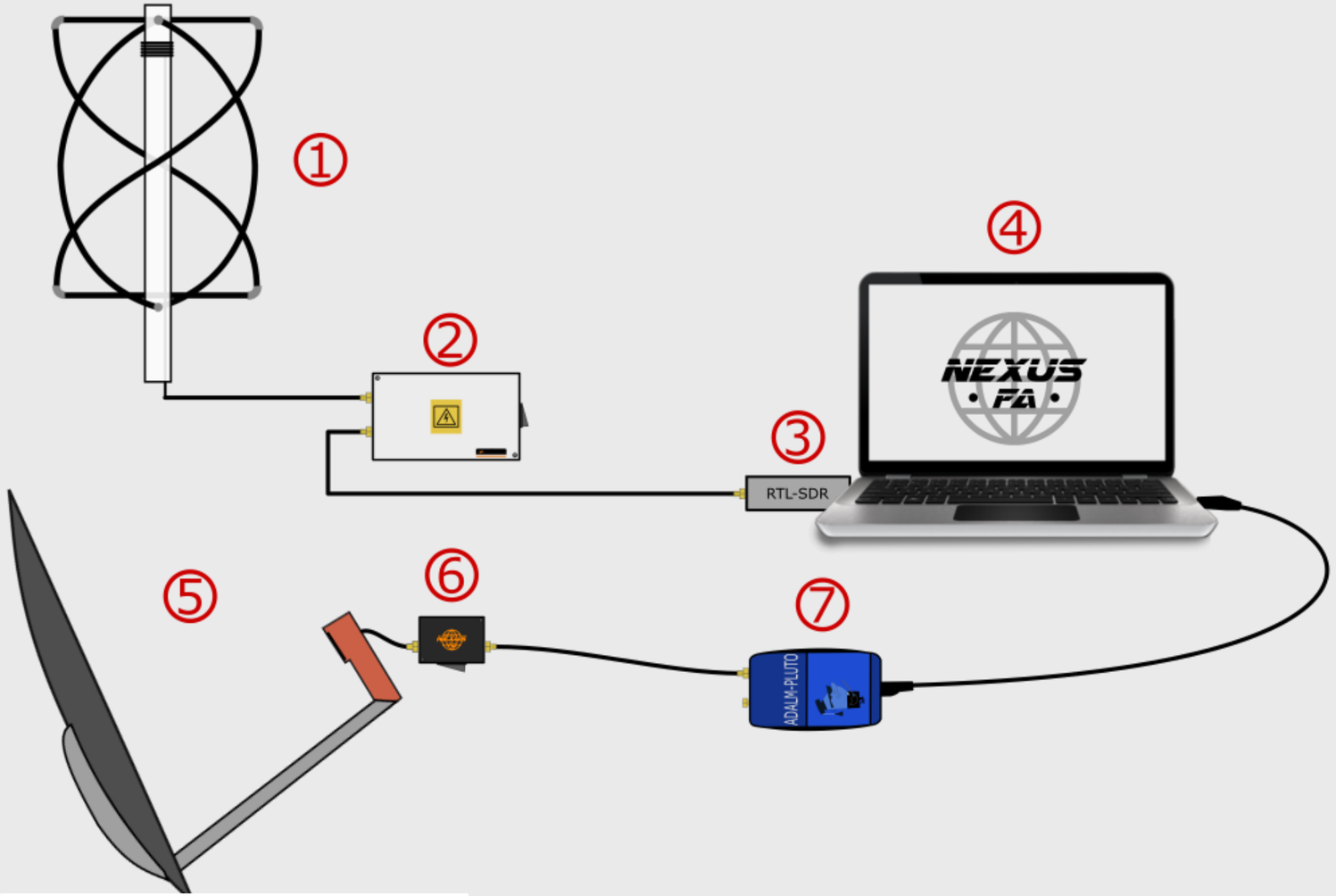
DESIGN AND IMPLEMENTATION



- Cuadrifilar antenna.
- BPF + LNA.
- RTL-SDR.
- Computer.
- Satellite dish with illuminator.
- LNA.
- ADALM-PLUTO.

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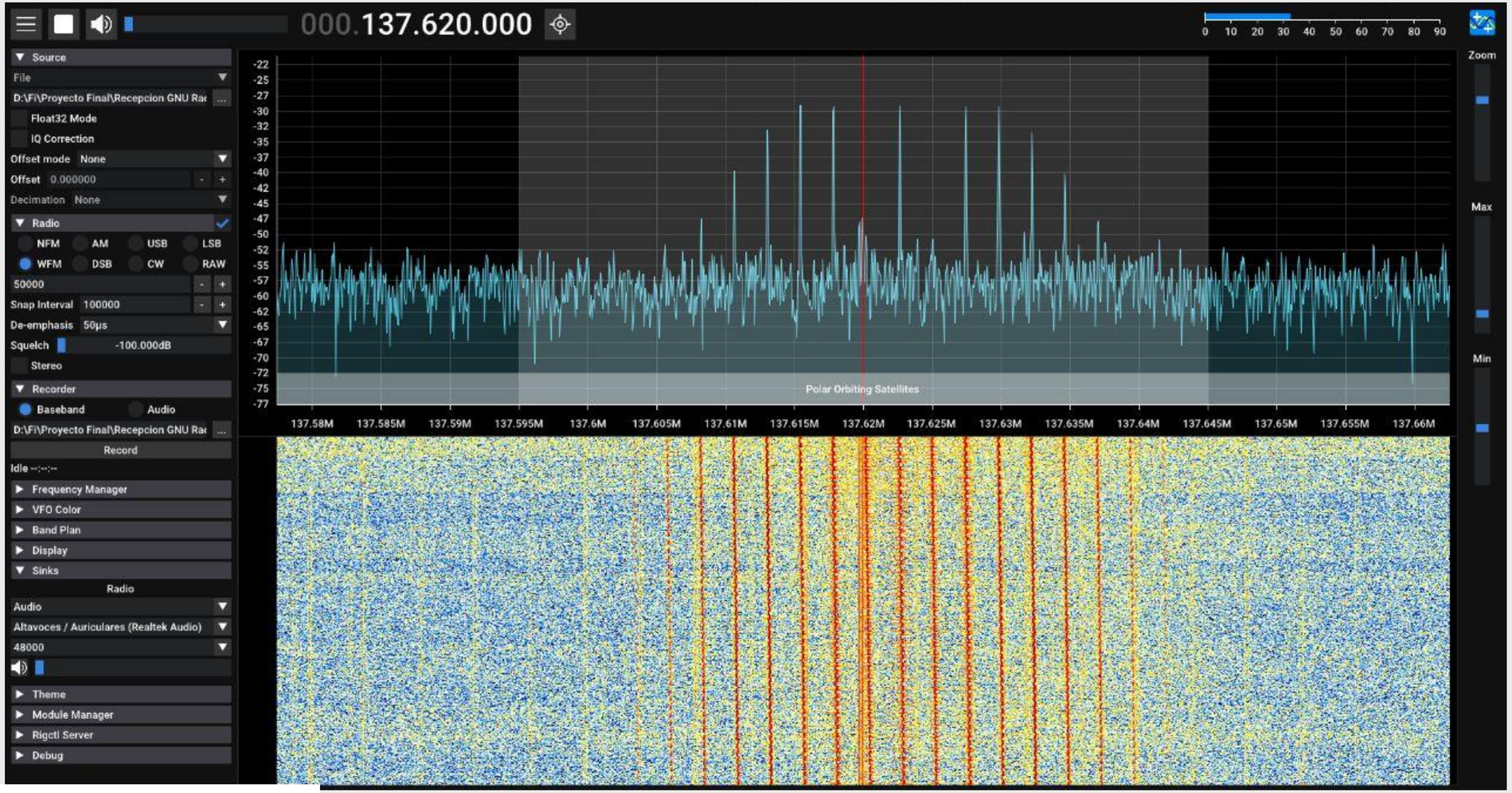
VALIDATION TESTS

VALIDATION TESTS

APT



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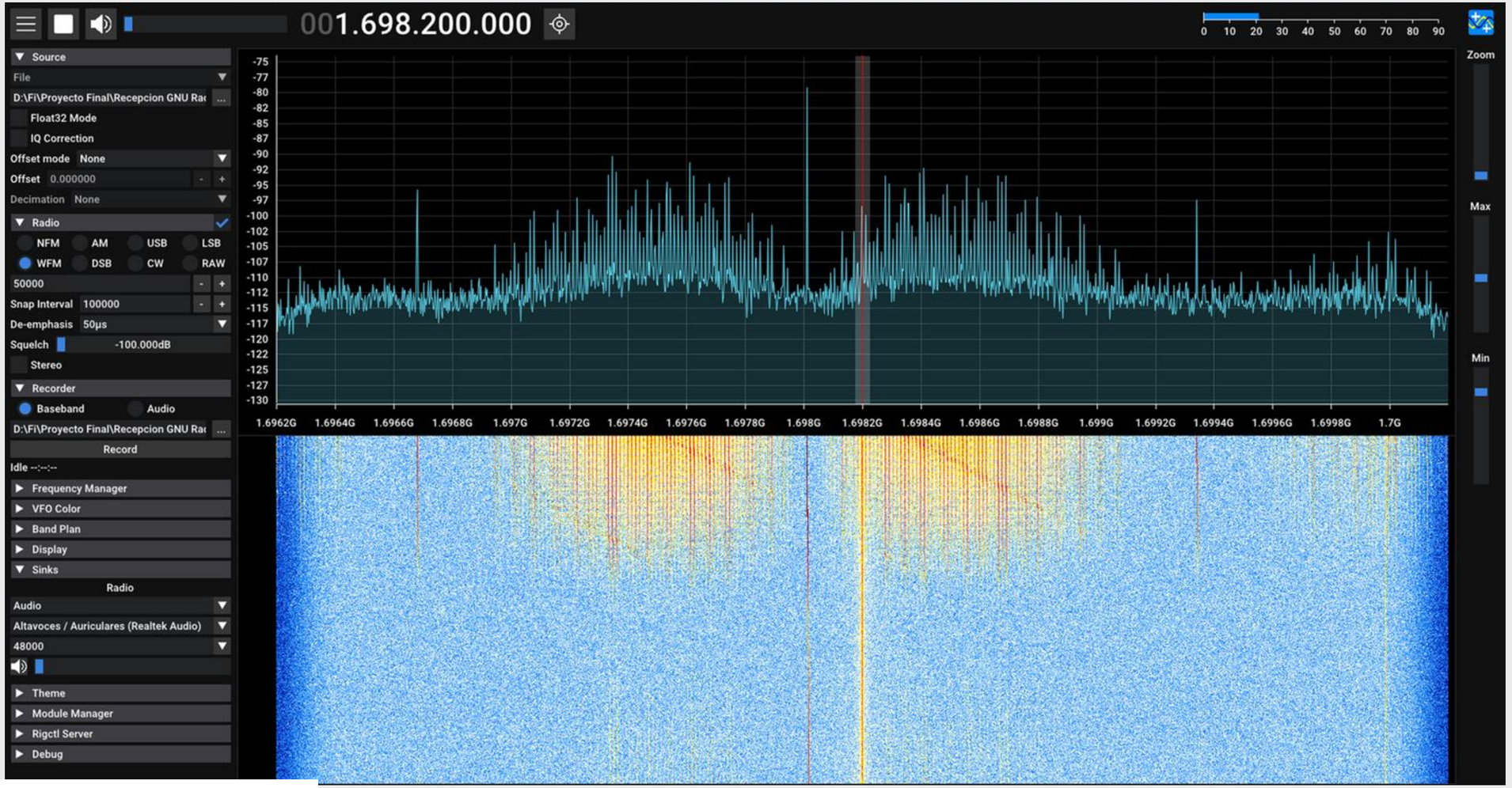
VALIDATION TESTS

HRPT



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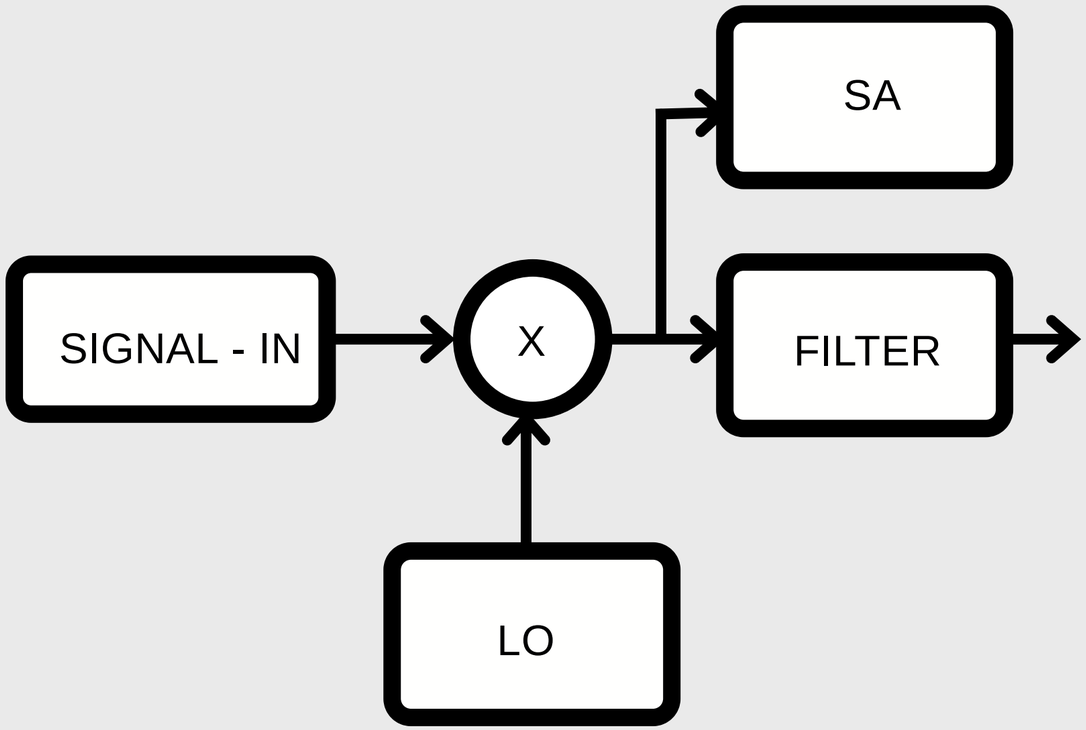
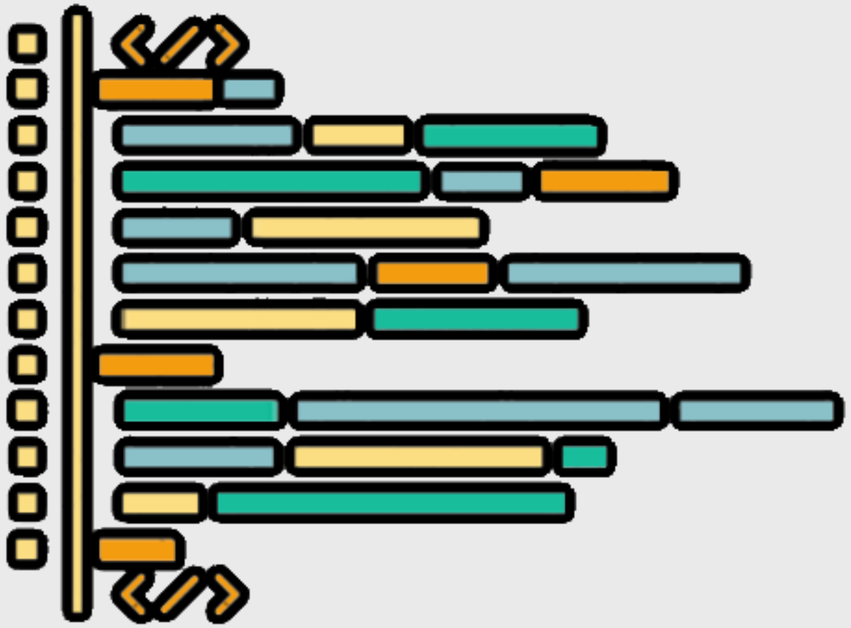
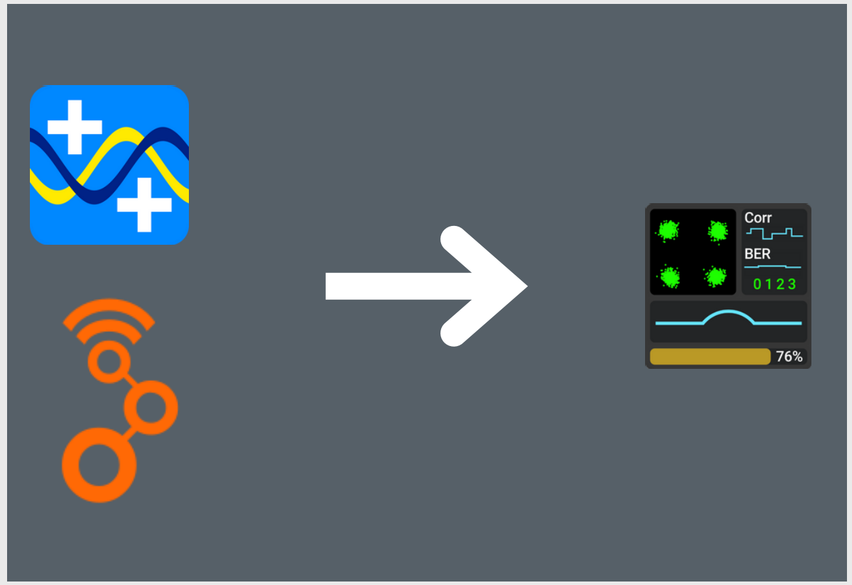
GNU RADIO

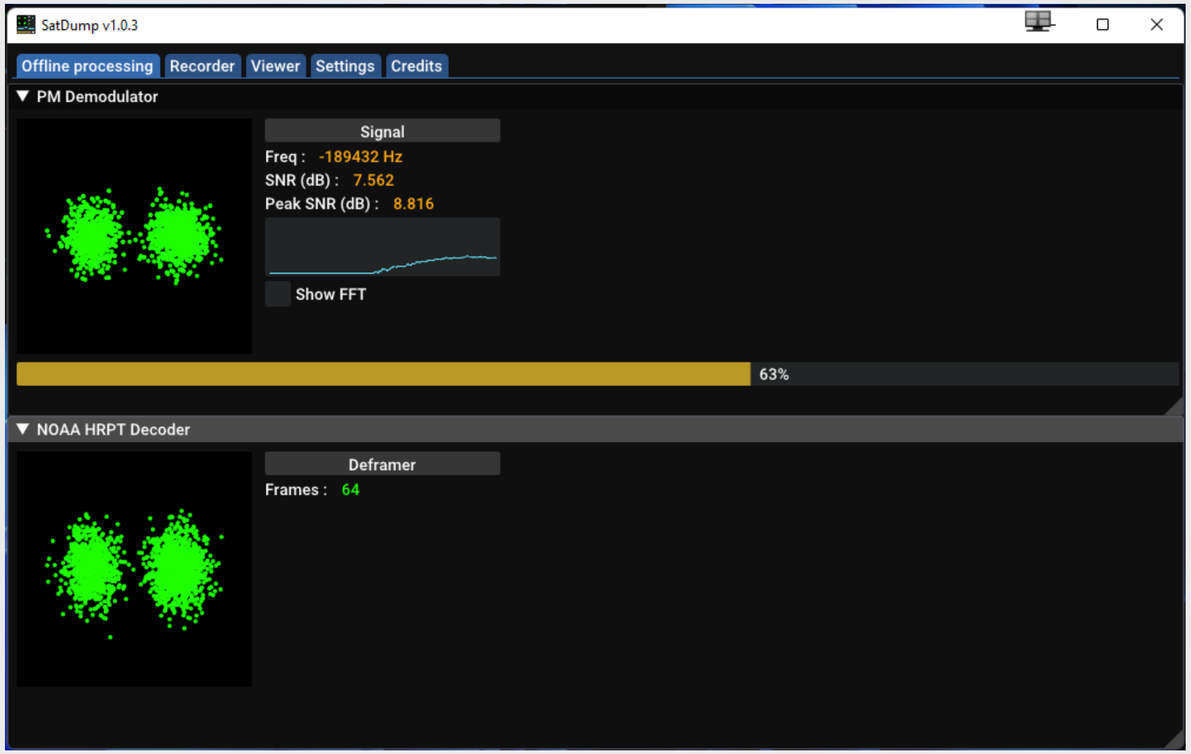




SATDUMP

Software for satellite data decoding.





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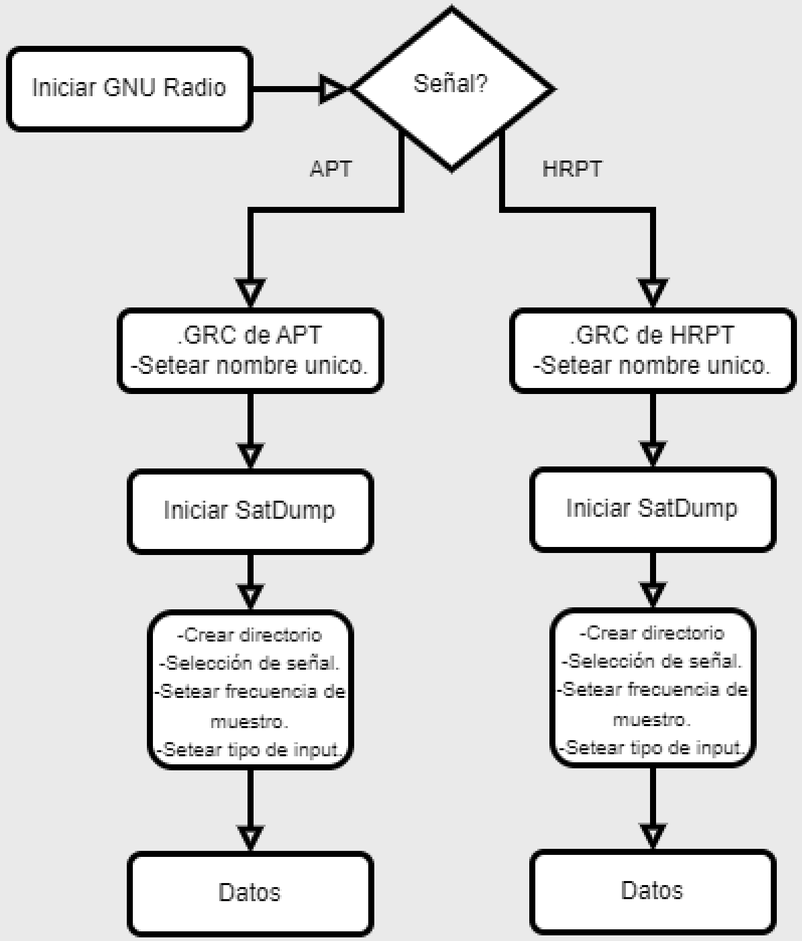
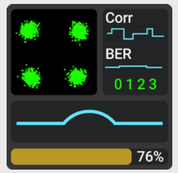
IU - NEXUS FA



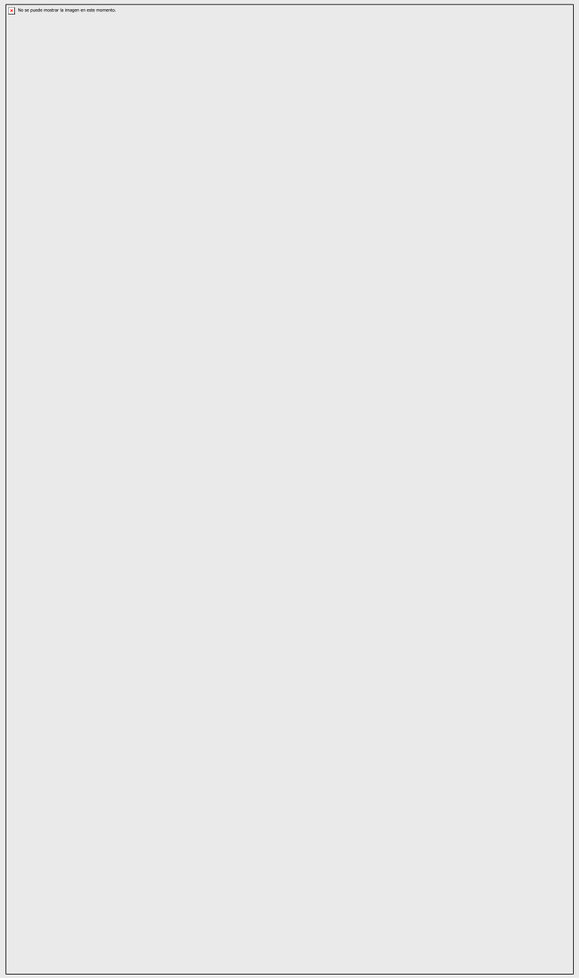
GNU Radio
THE FREE & OPEN SOFTWARE RADIO ECOSYSTEM

.grc → .py

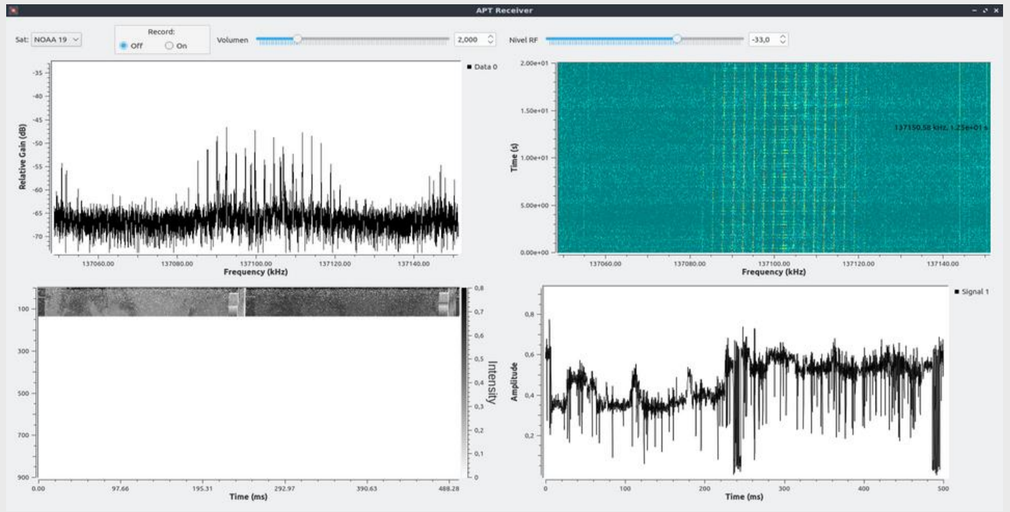


SatDump →

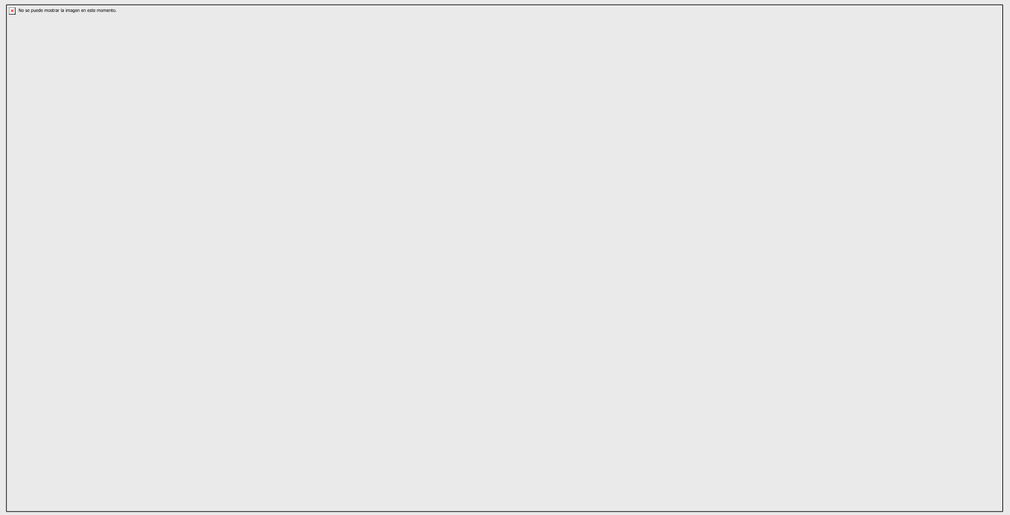
IU - NEXUS FA



APT
(137,1 MHz)



HRPT
(1,7 GHz)



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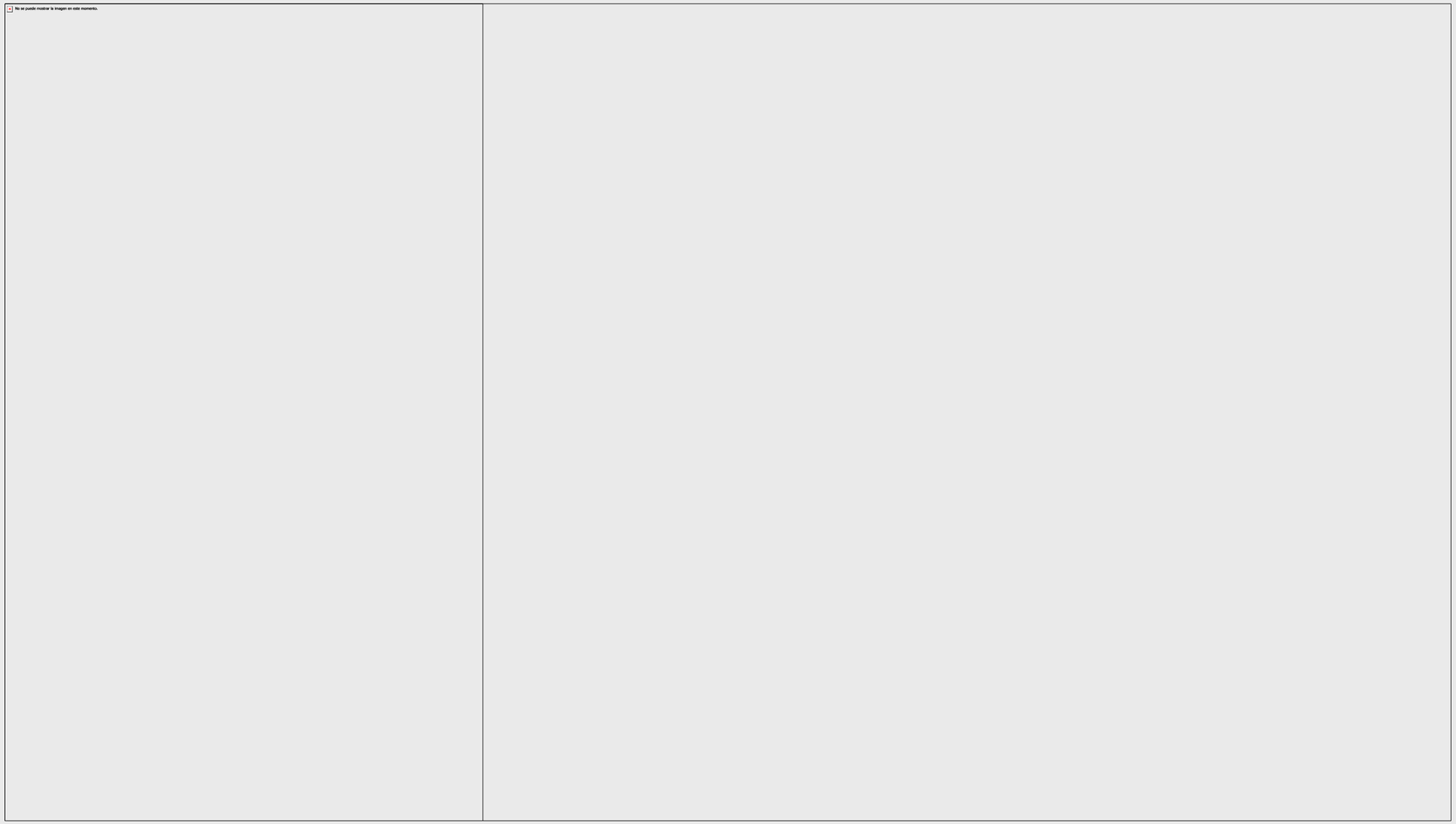
IU - NEXUS FA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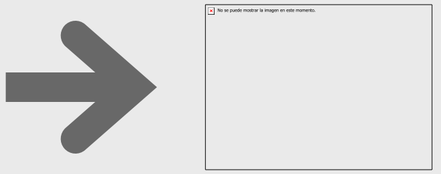
No se puede mostrar la imagen en este momento.

FINAL PROJECT

FINAL TESTS

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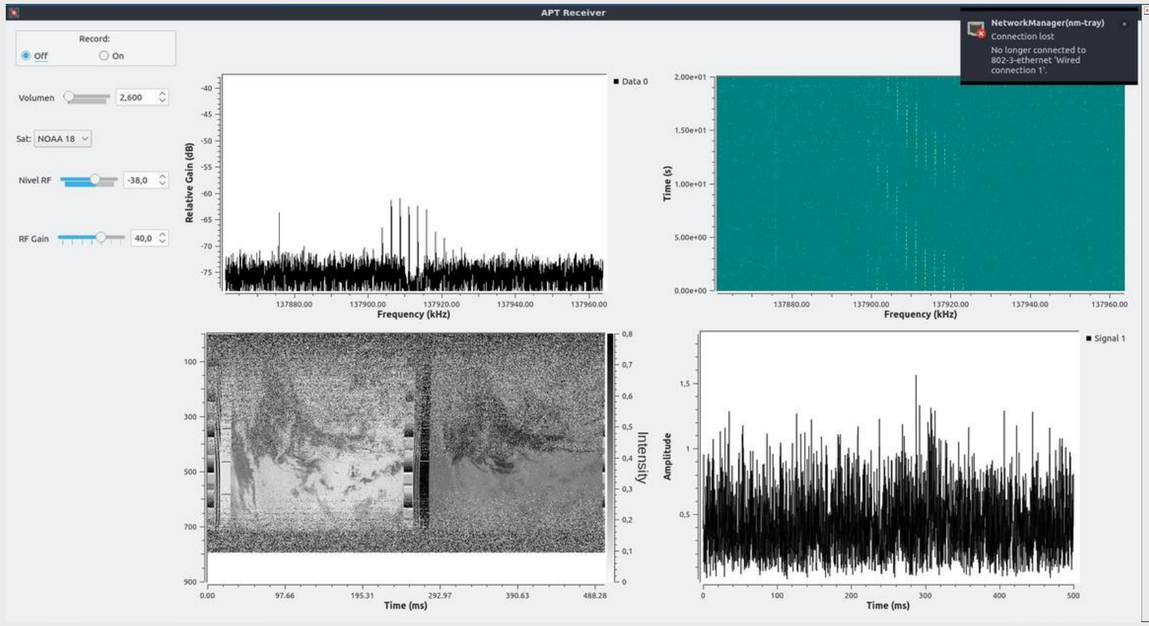
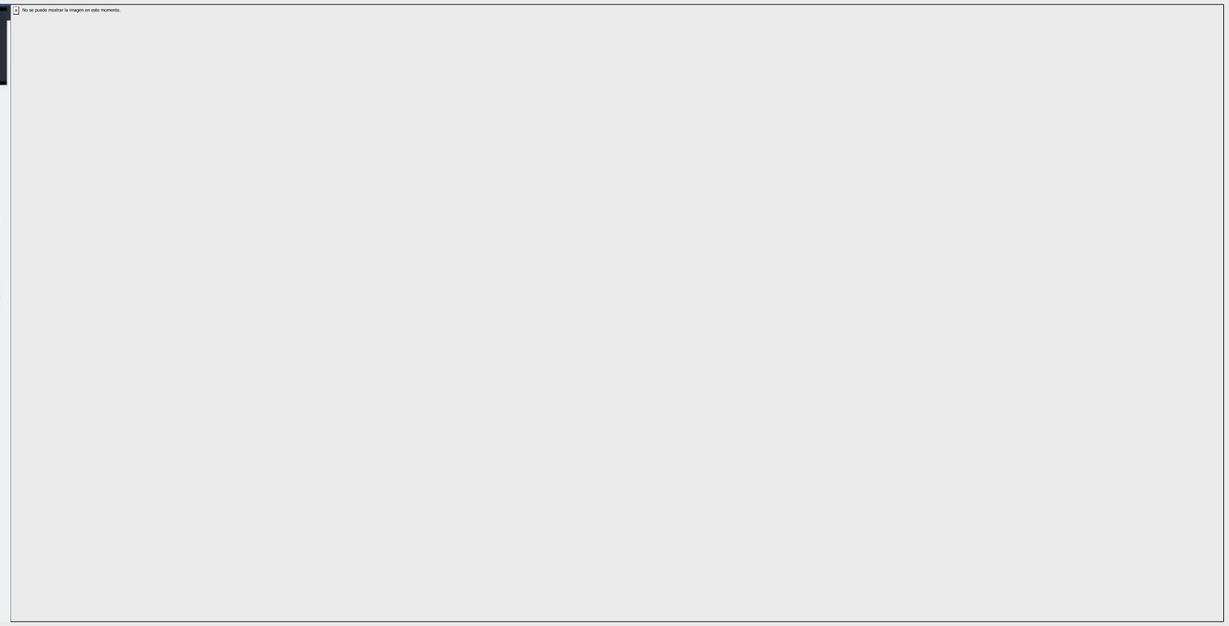
of the European Union

FINAL RECEPTION

APT
(137,1 MHz)

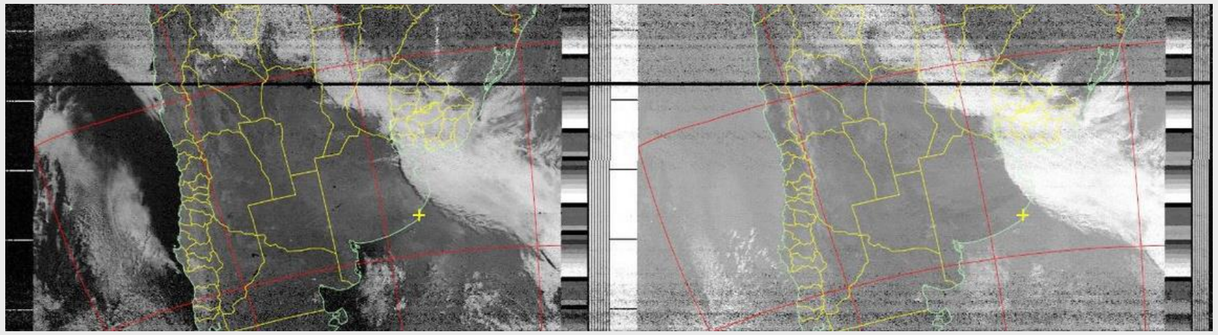
HRPT
(1,7 GHz)

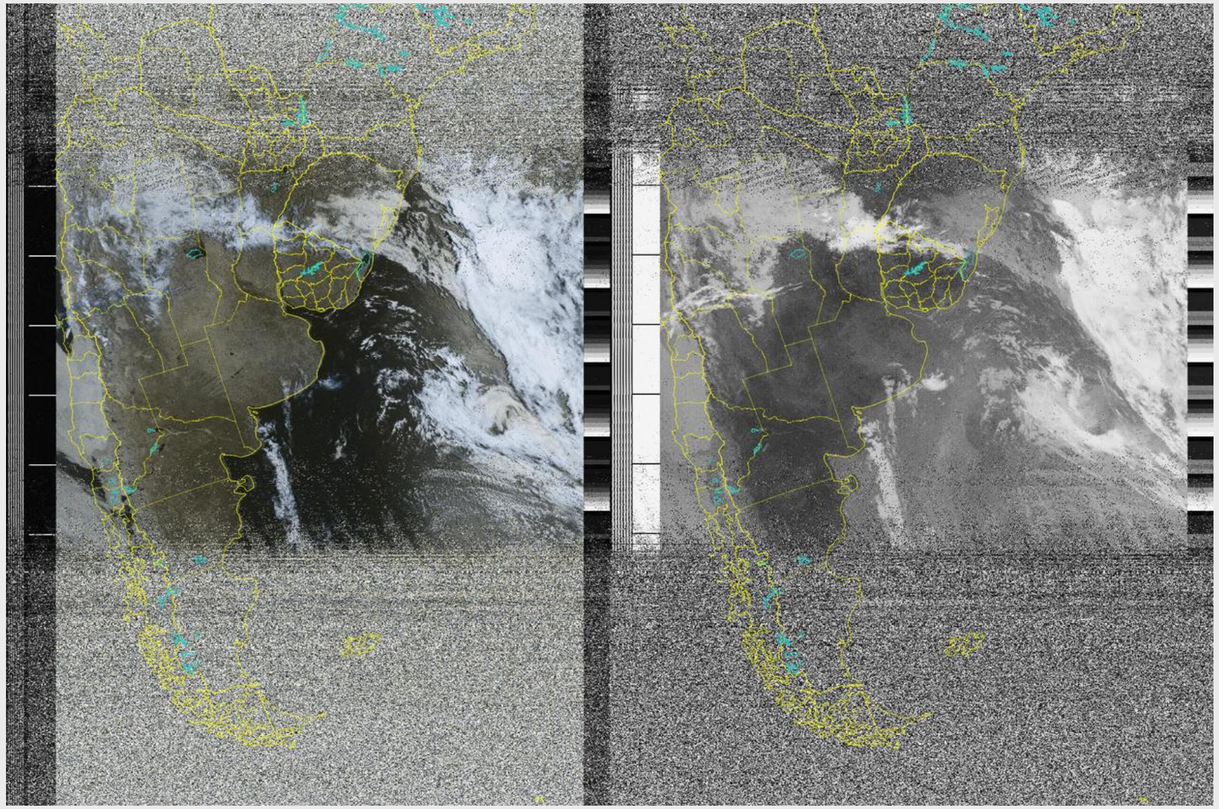




FINAL RECEPTION

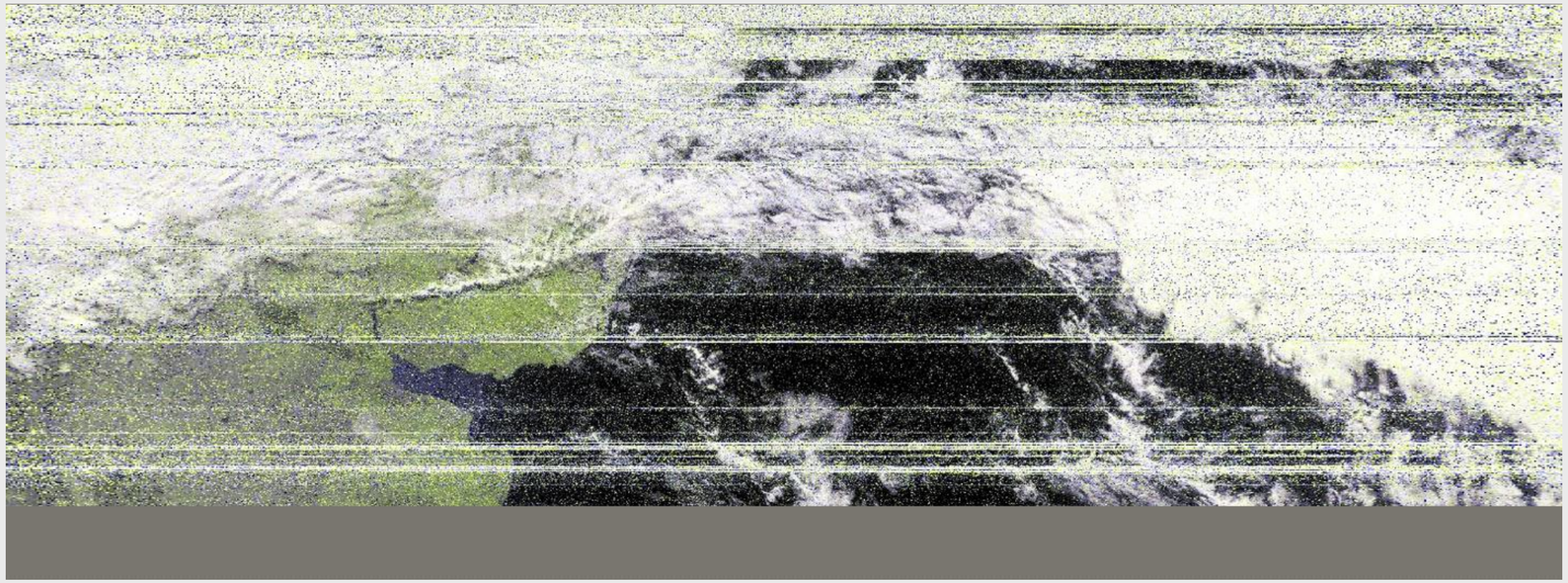
APT





FINAL RECEPTION

HRPT



No se puede mostrar la imagen en este momento.

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ADDITIONAL ACTIVITIES

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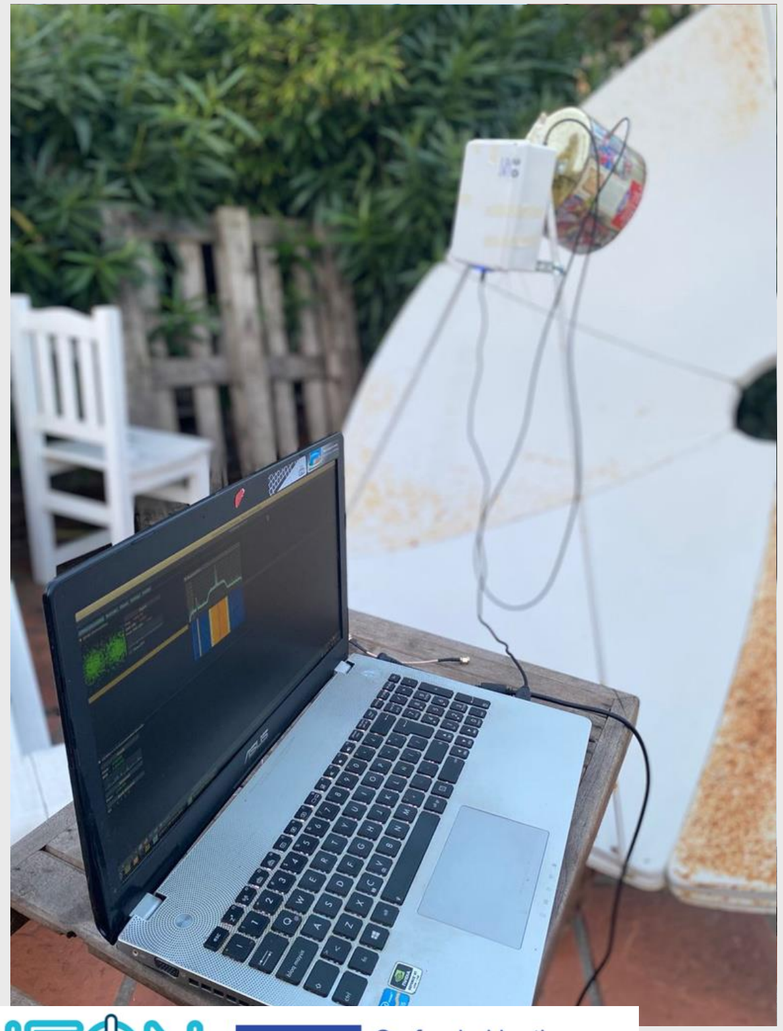
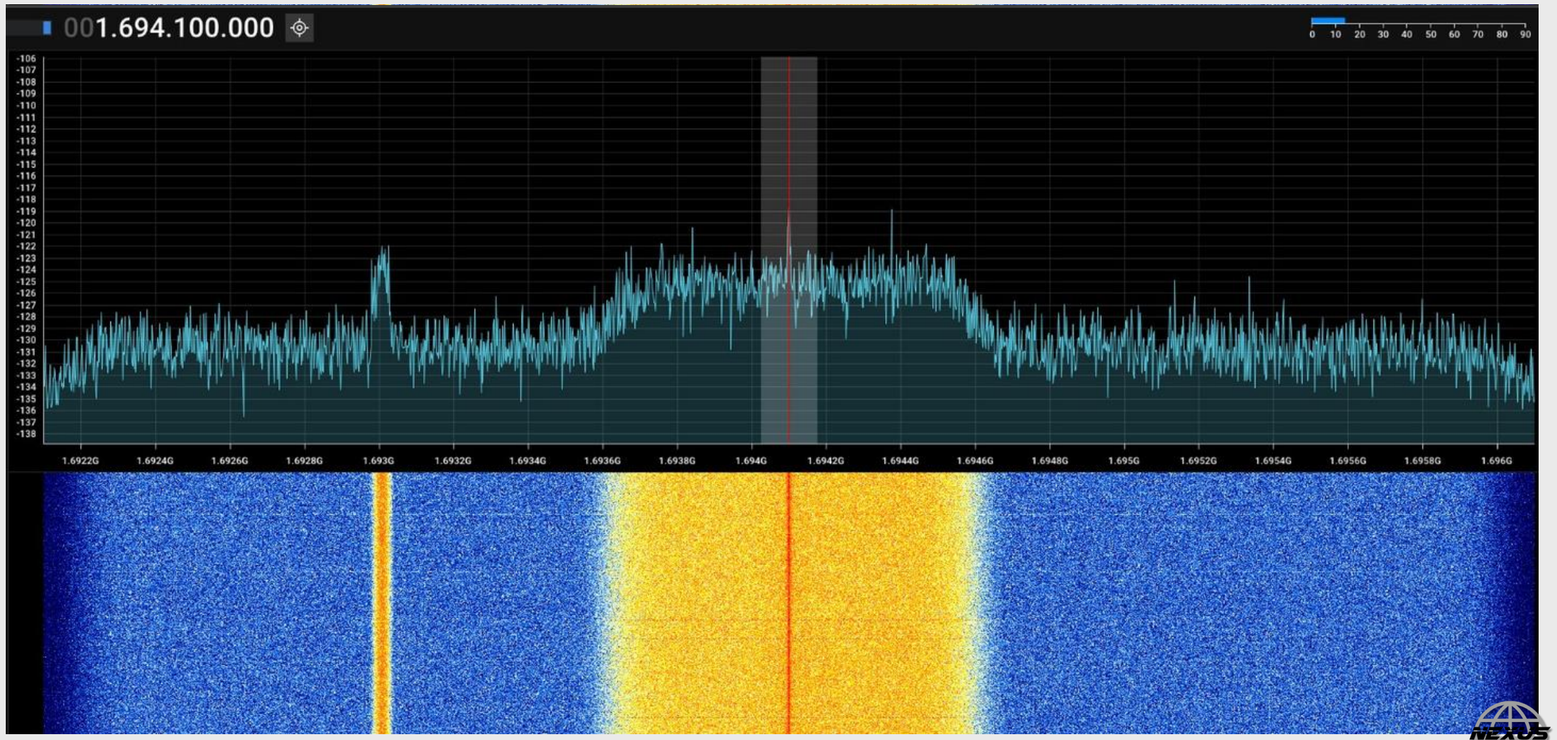
GOES-R RECEPTION



- Geostationary.
- Linear polarization.
- 1,6941 GHz (HRIT).
- Hardware.tests



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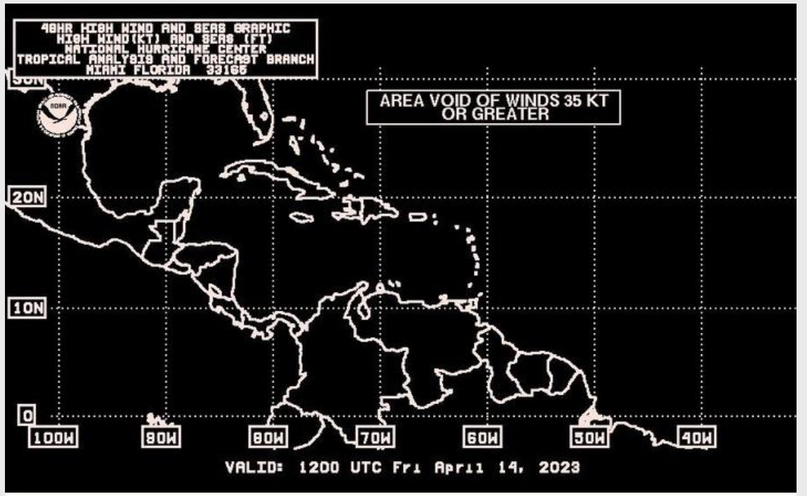
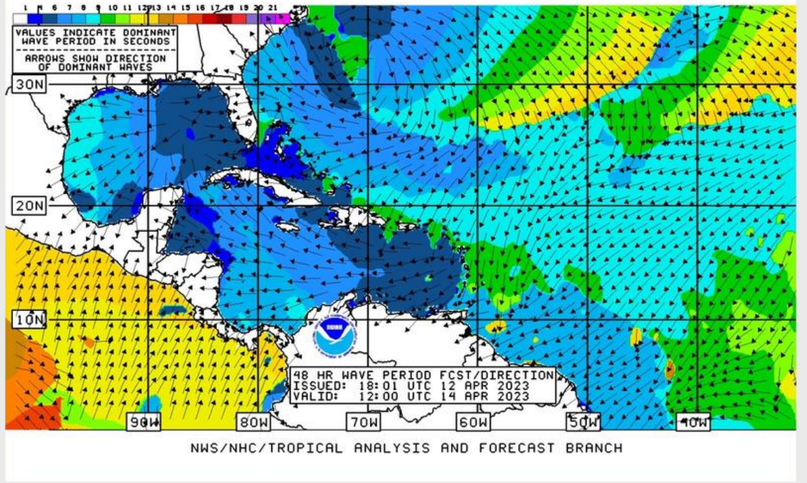
GOES-R RECEPTION





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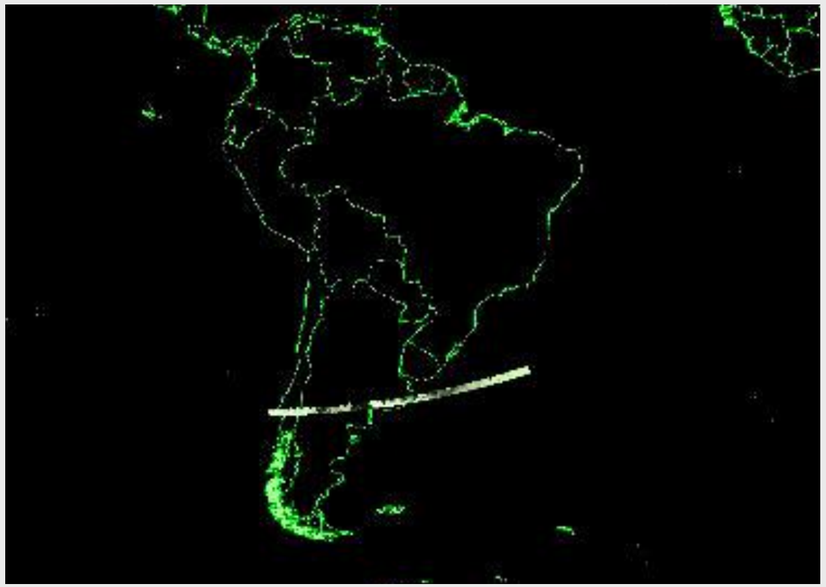
NOAA 19 RECEPTION



FINAL PROJECT

CONCLUSIONS

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CONCLUSIONS OF THE FINAL PROJECT

- Implementation of an earth station for reception of two NOAA satellite bands based on SDR.
- SNR = 40 dB for APT and SNR = 7 dB for HRPT.
- Major portion of time receiving. Hand tracking.
- Better performance in open field.
- Isolated tests, integration, on RF hardware.
- Nexus FA user interface implementation.

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CONCLUSIONS OF THE PROJECT MANAGEMENT

- Efficiency of the time invested.
- Final Work Seminar: Planning and management tools.
- Notion, Google Drive, documentation, blog.
- Extraordinary academic activities.
- NEON project scholarship. Stay at DIEC-UNS.
- NOAA satellite orbit.
- Improve test log.

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ACQUIRED KNOWLEDGE

- Satellite link parameters.
- GNU Radio and SDR.
- RF: techniques, criteria and methodologies for design.
- RF simulation software: ADS, Ansys, CST Studio.
- PCB Design: Altium Designer. PCB manufacturing methods.
- 3D modeling and printing.
- Python: Tkinter for IU design. SDR programming.
- Field testing experience.

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THANK YOU SO MUCH!

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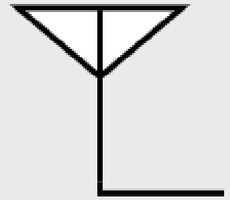
FUTURE IMPROVEMENTS

- Rotor for 1,7 GHz antenna.
- Remote earth station. Through Raspberry PI. Web server.
- Implementation finish for exterior.
- Data post-processing: Weather activity or remote sensing.
- Assign a team to each work area.
- Several sections improve aspects for a more professional finish.

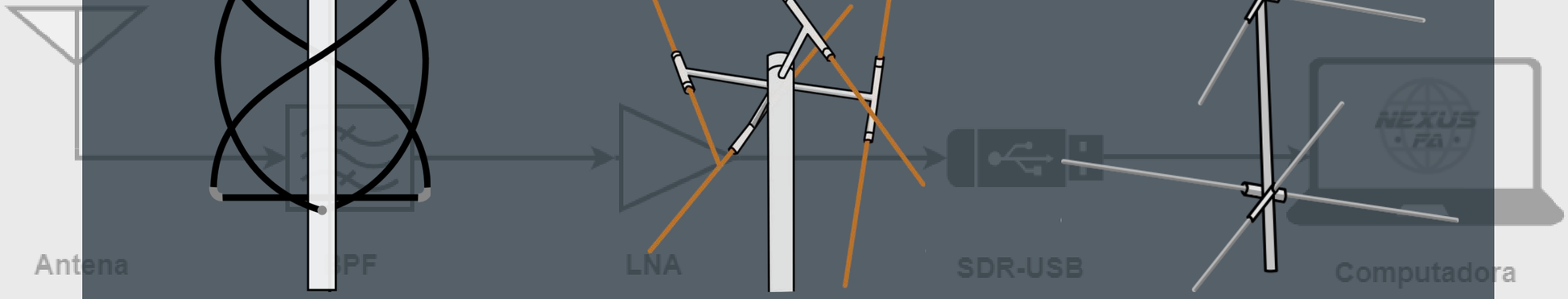
DESIGN AND IMPLEMENTATION

APT

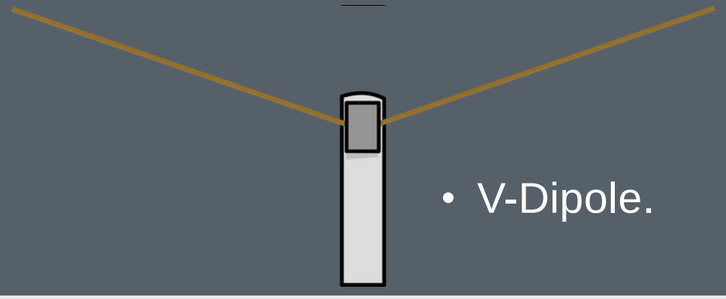


Antena

ALTERNATIVES:



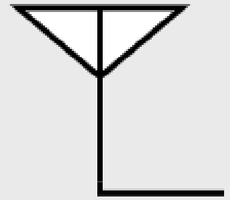
- Cuadrifilar antenna.
- Double cross antenna.
- Turnstile antenna.



- V-Dipole.

DESIGN AND IMPLEMENTATION

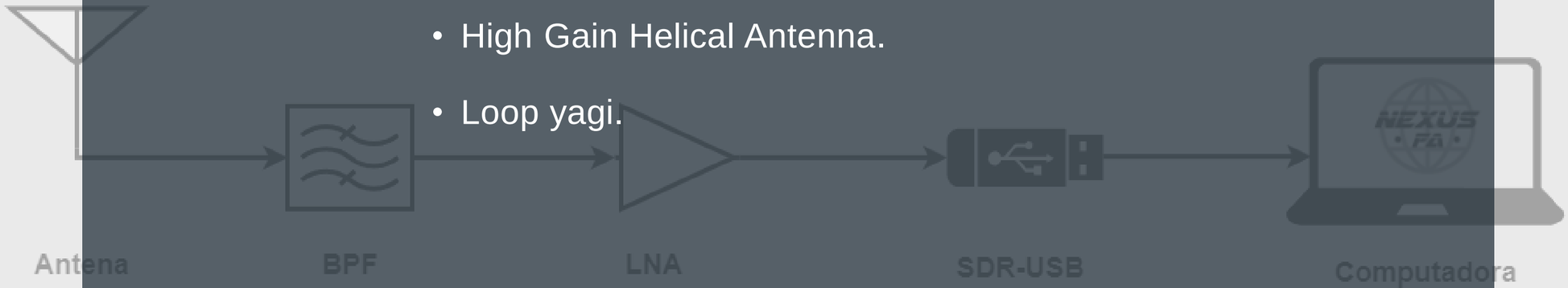
HRPT



Antena

ALTERNATIVES:

- DISH WITH ILLUMINATOR.
- High Gain Helical Antenna.
- Loop yagi.



DESIGN AND IMPLEMENTATION

HRPT

APT

SDR-USB

RTL-SDR:

Basic Information

- **Bandwidth:** Up to 2.4 MHz stable.
- **ADC:** RTL2832U 8-bits
- **Frequency Range:** 500 kHz – 1766 MHz (500 kHz – 24 MHz in direct sampling mode)
- **Typical Input Impedance:** 50 Ohms
- **Typical Current Draw:** 270 – 280 mA

Datasheet: https://www.rtl-sdr.com/wp-content/uploads/2018/02/RTL-SDR-Blog-V3-Datasheet.pdf

DESIGN AND IMPLEMENTATION

HRPT

APT

SDR-USB

ADALM-PLUTO

ADALM-PLUTO Detailed Specifications

Features List:

- ADI AD9363, RF Agile Transceiver:
  - 1 Transmit, 1 Receive channel (with separate tuning frequencies)
  - Tuning range: 325 MHz - 3.8 GHz
    - 2.4 Hz LO step size
  - Tunable channel bandwidth: 200 kHz - 20 MHz
  - Integrated 12-bit DACs (Tx) and ADCs (Rx)
  - Variable output data rates: 61.44 MSPS - 65.1 kSPS
  - Modulation Accuracy (EVM): ≤−40 dB (typical, not measured on every unit)
  - Internal I/Q correction and calibration
  - Tx to Rx Isolation:
  - Tx Specifications
    - Maximum Output Power:
  - Rx Specifications
    - Min sensitivity:
    - RX gain control: 0 to +74.5dB (800 MHz)
      - Manual Modes
      - Slow Attack
      - Fast Attack
    - Received Signal Strength Indicator: 100 dB (±2 dB)

Computadora

Datasheet: https://wiki.analog.com/university/tools/pluto/devs/specs

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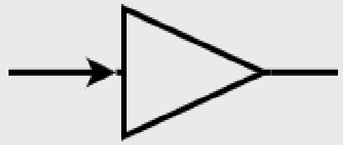
DESIGN AND IMPLEMENTATION

HRPT

APT

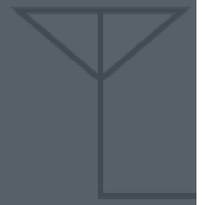


LNA

SPF-5189Z:

Absolute Maximum Ratings

Parameter	Rating	Unit
Max Device Current (I_D)	120	mA
Max Device Voltage (V_D)	5.5	V
Max RF Input Power	27	dBm
Max Dissipated Power	660	mW
Max Junction Temperature (T_J)	150	°C
Operating Temperature Range (T_L)	-40 to + 85	°C
Max Storage Temperature	-65 to +150	°C
ESD Rating - Human Body Model (HBM)	Class 1B	
Moisture Sensitivity Level (MSL)	MSL 2	



Antena

Computadora

Datasheet: https://ar.mouser.com/datasheet/2/412/RFMDS04436_1-2564742.pdf

DESIGN AND IMPLEMENTATION

HRPT

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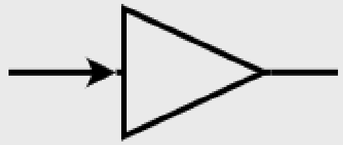


LNA

SPF-5189Z:

Typical RF Performance - Application Circuit Data with V_D=5V, I_D=90mA

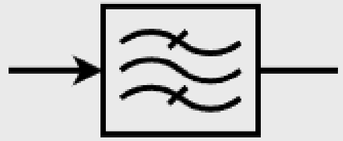
Parameter	Unit	0.8 GHz	0.9 GHz	1.0 GHz	1.7 GHz	1.8 GHz	1.9 GHz	2.0 GHz	2.1 GHz	2.2 GHz
Small Signal Gain	dB	19.6	18.7	17.9	13.8	13.5	12.9	12.7	12.2	11.9
Noise Figure	dB	0.52	0.55	0.79	0.75	0.81	0.83	0.90	0.91	0.98
Output IP3	dBm	38.4	38.5	39.0	39.2	39.5	39.5	39.8	39.8	39.9
Output P1dB	dBm	22.3	22.4	22.5	22.6	22.6	22.7	22.7	22.7	22.7
Input Return Loss	dB	17.1	17.5	17.5	17.5	17.5	18.5	18.5	18.5	18.0
Output Return Loss	dB	16.0	16.0	15.5	14.0	14.0	14.5	15.0	15.5	16.0
Reverse Isolation	dB	24.5	24.0	23.0	18.5	18.5	18.0	18.0	17.5	17.0

Test Conditions: V_D=5V, I_{DQ}=90mA, OIP_3 Tone Spacing=1MHz, P_{OUT} per tone=0dBm, T_L=25°C, Z_S=Z_L=50Ω

Datasheet: https://ar.mouser.com/datasheet/2/412/RFMDS04436_1-2564742.pdf

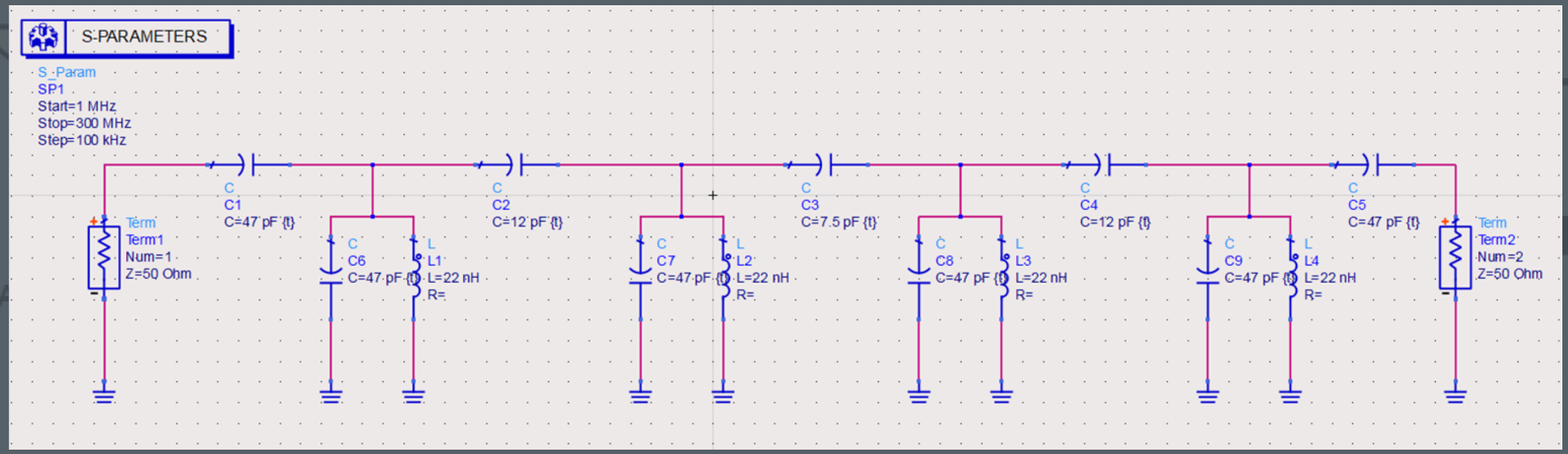
DESIGN AND IMPLEMENTATION

APT



BPF

LC-type Butterworth bandpass filter:



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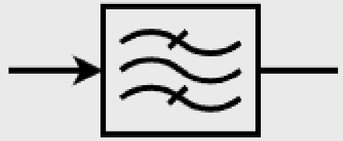
DESIGN AND IMPLEMENTATION

APT



BPF

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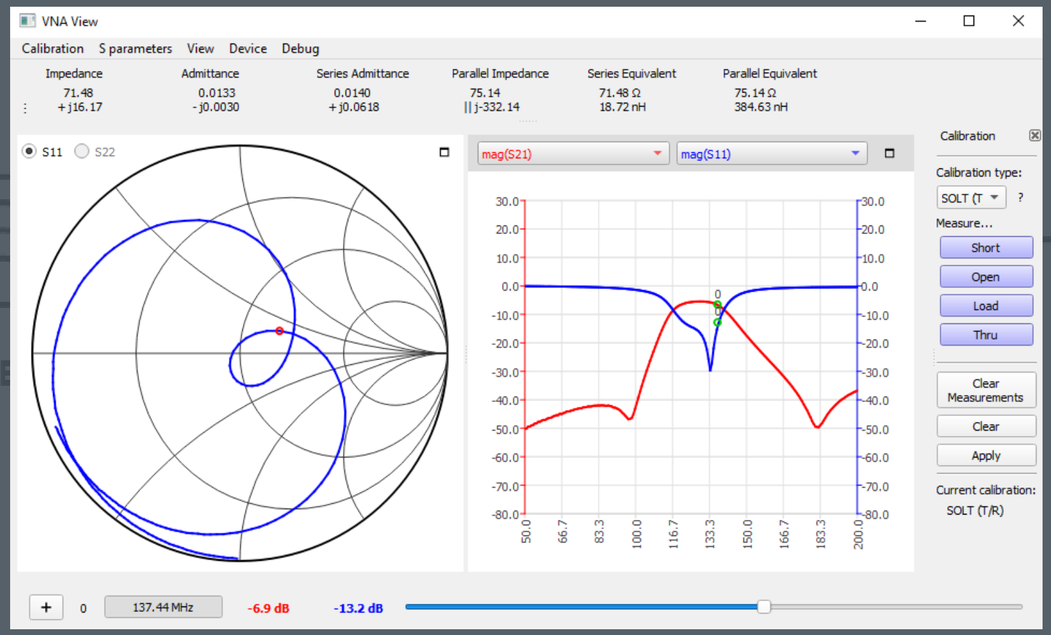
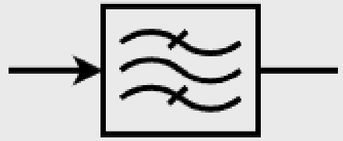


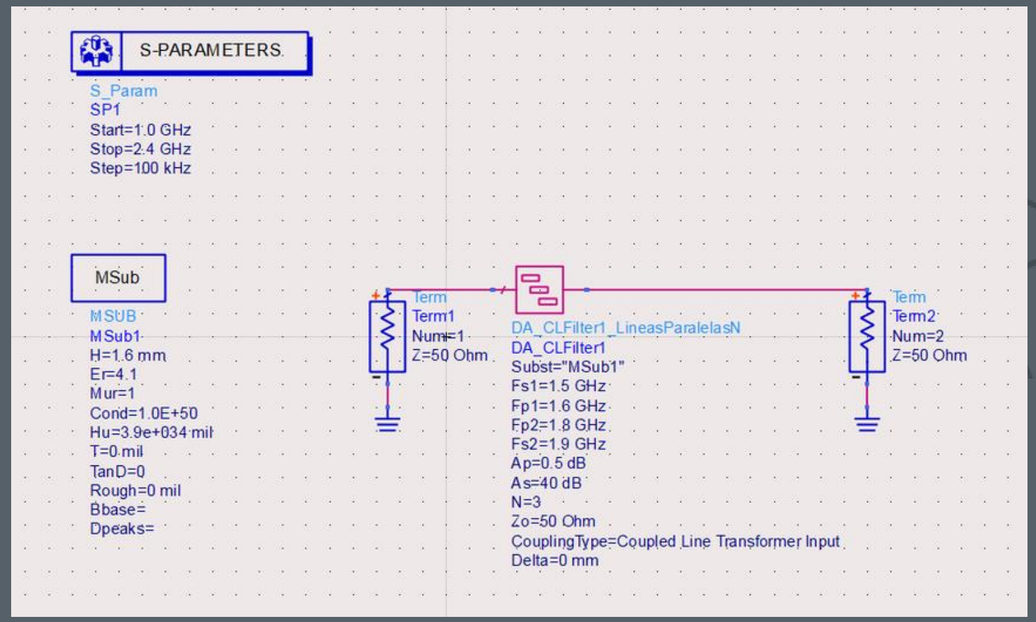
DESIGN AND IMPLEMENTATION

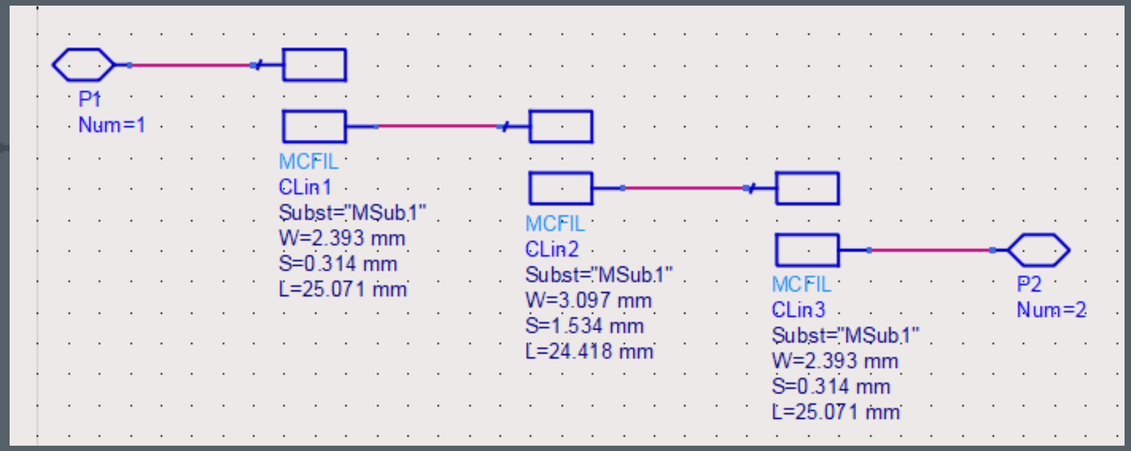
APT



BPF

Band Pass Filter Coupled Parallel Lines:





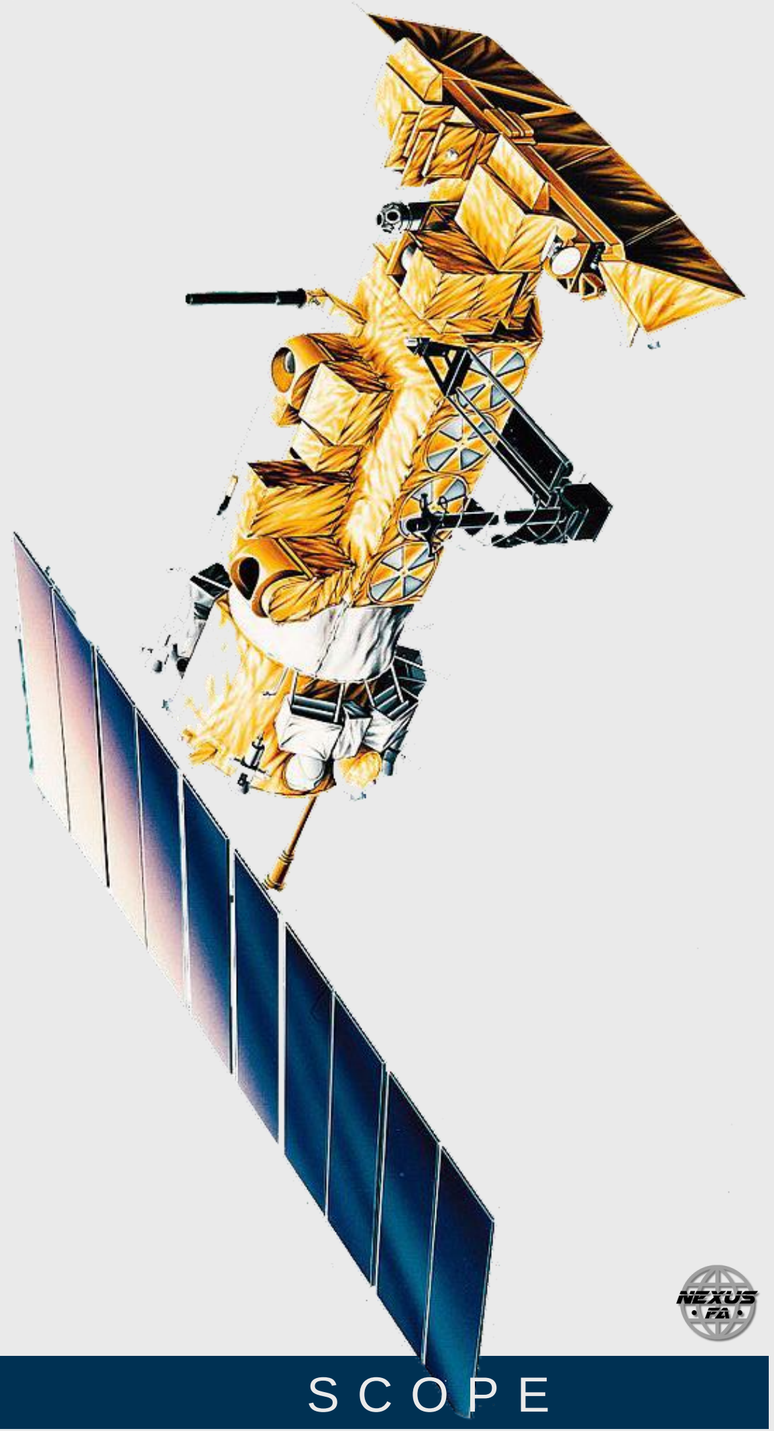
FEASIBILITY ANALYSIS

Calculation for NOAA 19 satellite link:

Enlace satelital NOAA 19 (Downlink)			
Parámetro del enlace	Valor (f = 137,1 MHz)	Valor (f=1698 MHz)	Unidad
PIRE Satélite	7	8	dBW
Ancho de banda	38000	4000000	Hz
Pérdidas de espacio libre	134	155,86	dB
Pérdidas en el receptor	0,6	0,6	dB
Temperatura de ruido en el receptor	54,66	54,66	K
Figura de ruido	0,75	0,75	dB
Temperatura de la antena	30	30	K
Temperatura del sistema	118,21	118,21	K
Relación energía por bit a densidad de ruido (E_b/N_O)	-	11	dB
Relación portadora a ruido (C/N)	12	3,2	dB/Hz
Constante de Boltzmann	$1,3806503 * 10^{-23}$	$1,3806503 * 10^{-23}$	J/K
Potencia de ruido	-162,07	-141,85	dBW
Downlink C/T	-170,8	-159,37	dBW/K
Pérdidas atmosféricas	3	3	dB
Estación terrena G/T	-40,79	-8,5	dB/K
Ganancia de la antena	-19,46	12,82	dBi

NOAA SATELLITES

Características	APT	HRPT
Frecuencias de transmisión	137,62 MHz 137,1 MHz 137,9125 MHz	1.698 MHz 1.707MHz 1.702,5 MHz
Polarización de la antena	Polarización Circular Mano Derecha (RHCP)	Polarización Circular Mano Derecha (RHCP), Polarización Circular Mano Izquierda (LHCP).
Modulación de la portadora de RF	Analógica AM/FM	BPSK, QPSK
Ancho de Banda	34 kHz	3,5 MHz
Líneas por trama	120 líneas/minuto (2 líneas/ segundo)	6 líneas/segundo (360 líneas/minuto)
Palabras Digitales por Línea	2.080 Palabras/línea	11.090 Palabras/línea
Velocidad de datos	41.600 bits/segundo (41,6 kB/s)	66.400 bits/segundo (665,4 kbps)
Tamaño de pixel	4 kilómetros	1,1 kilómetros
Km^2/pixel	Superficie de 16 km^2/pixel	Superficie de 1,21 km^2/pixel



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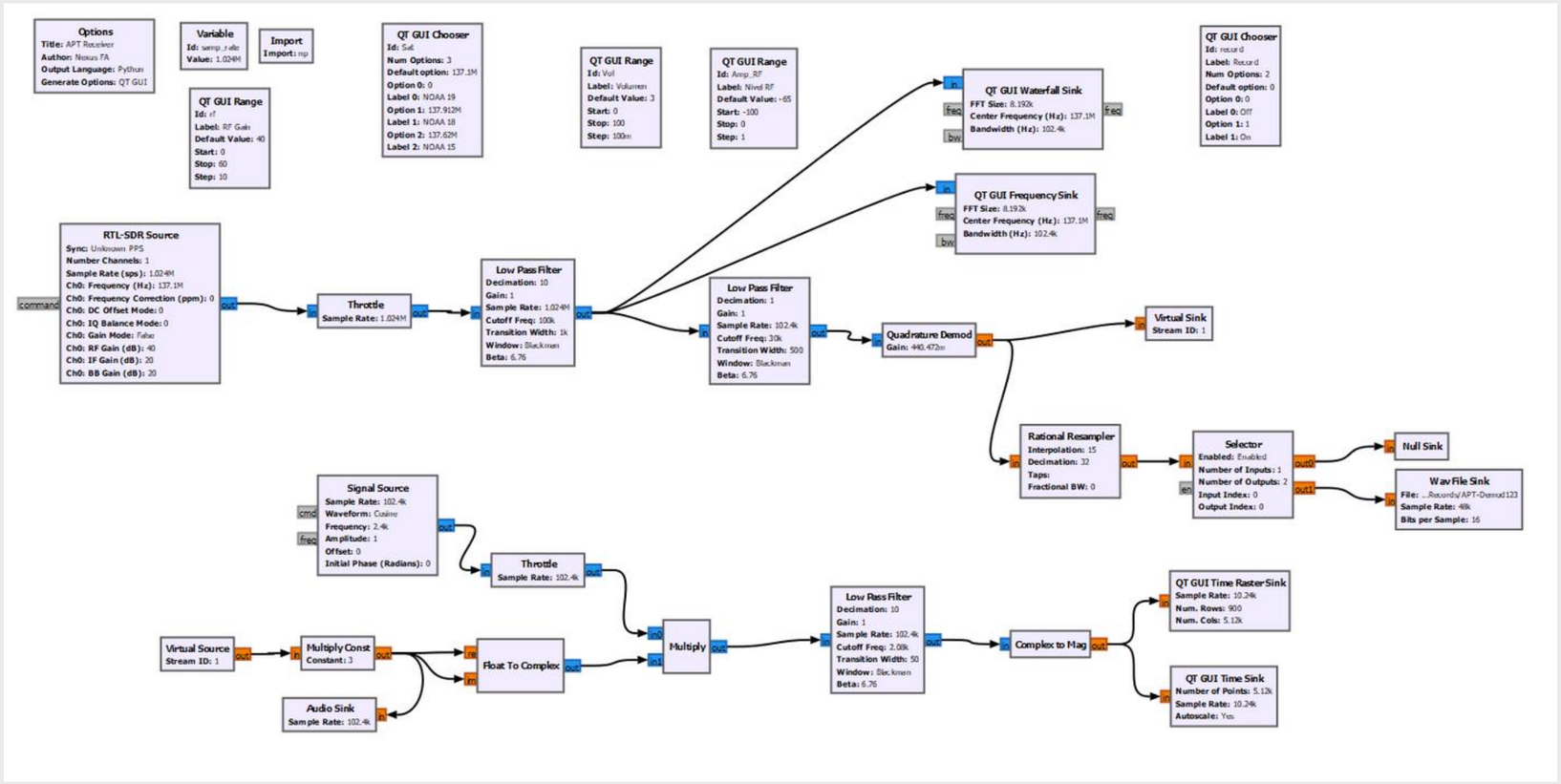
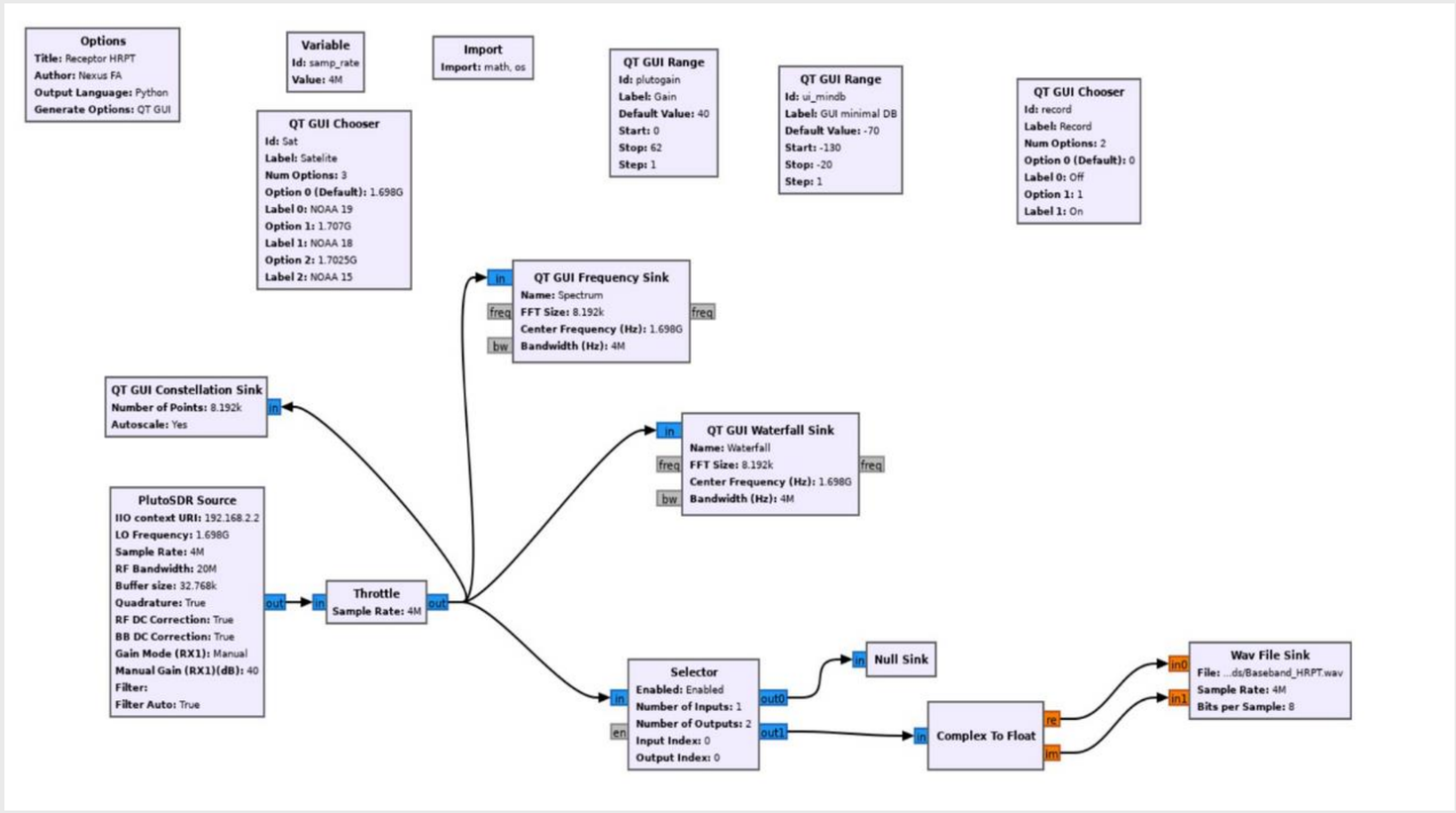
GNU RADIO

APT reception scheme :



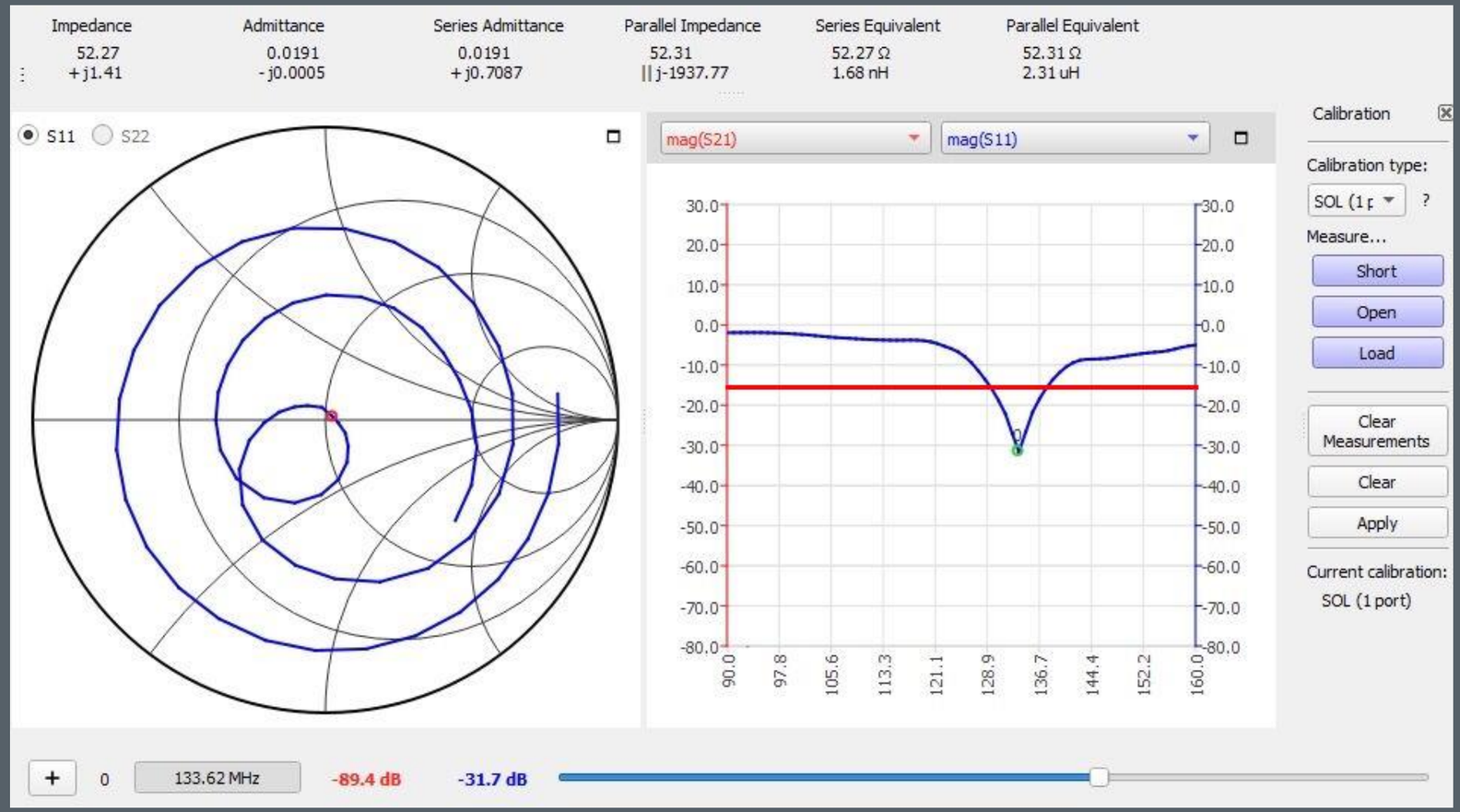
GNU RADIO

HRPT reception scheme:



S11 ANTENNA

APT



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Nano-VNA:

129-139 MHz S11

< -15 dB

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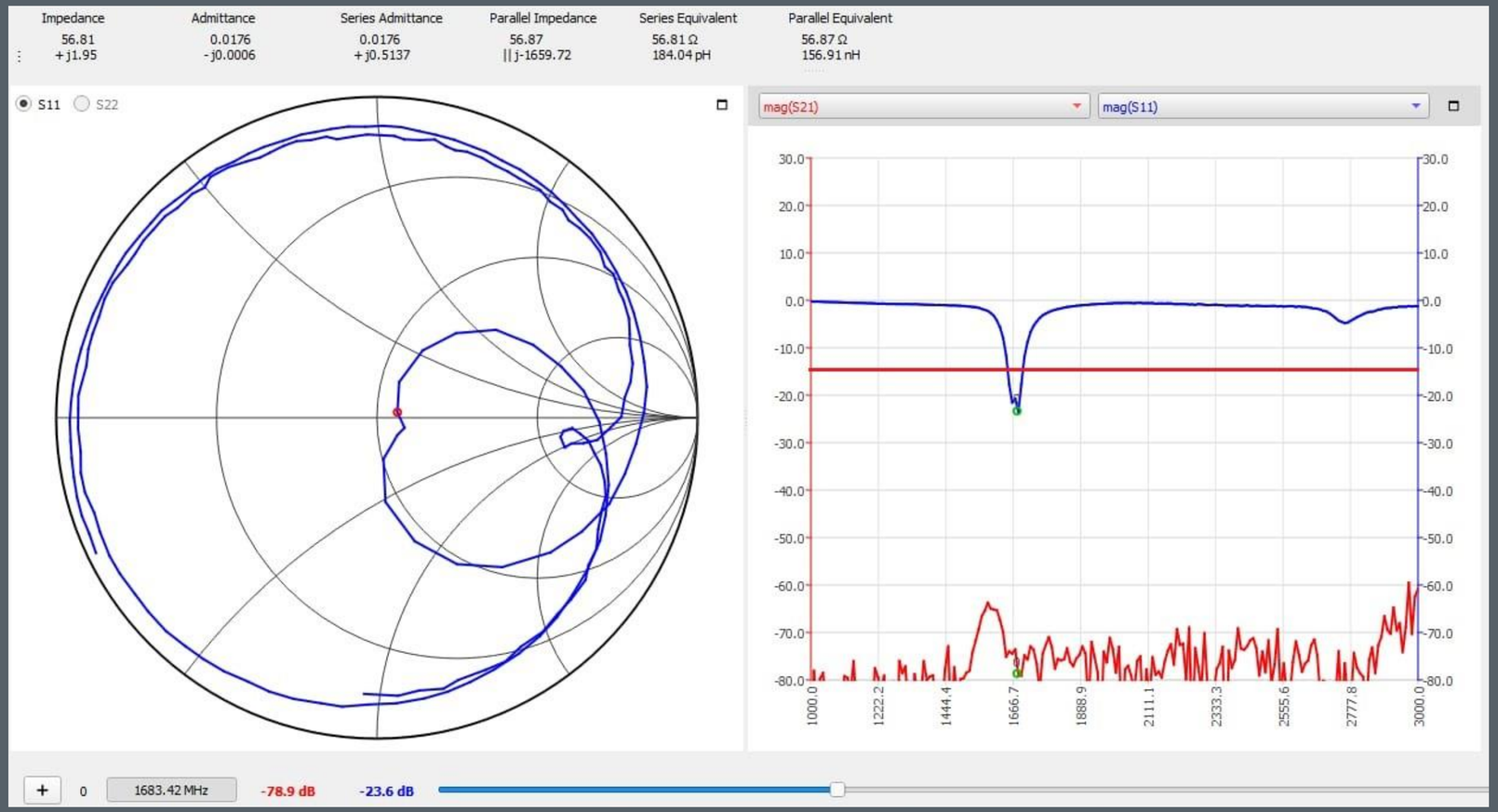
S11 ANTENNA

HRPT



Nano-VNA:

1644-1711 MHz

S11 < -15 dB

Antena

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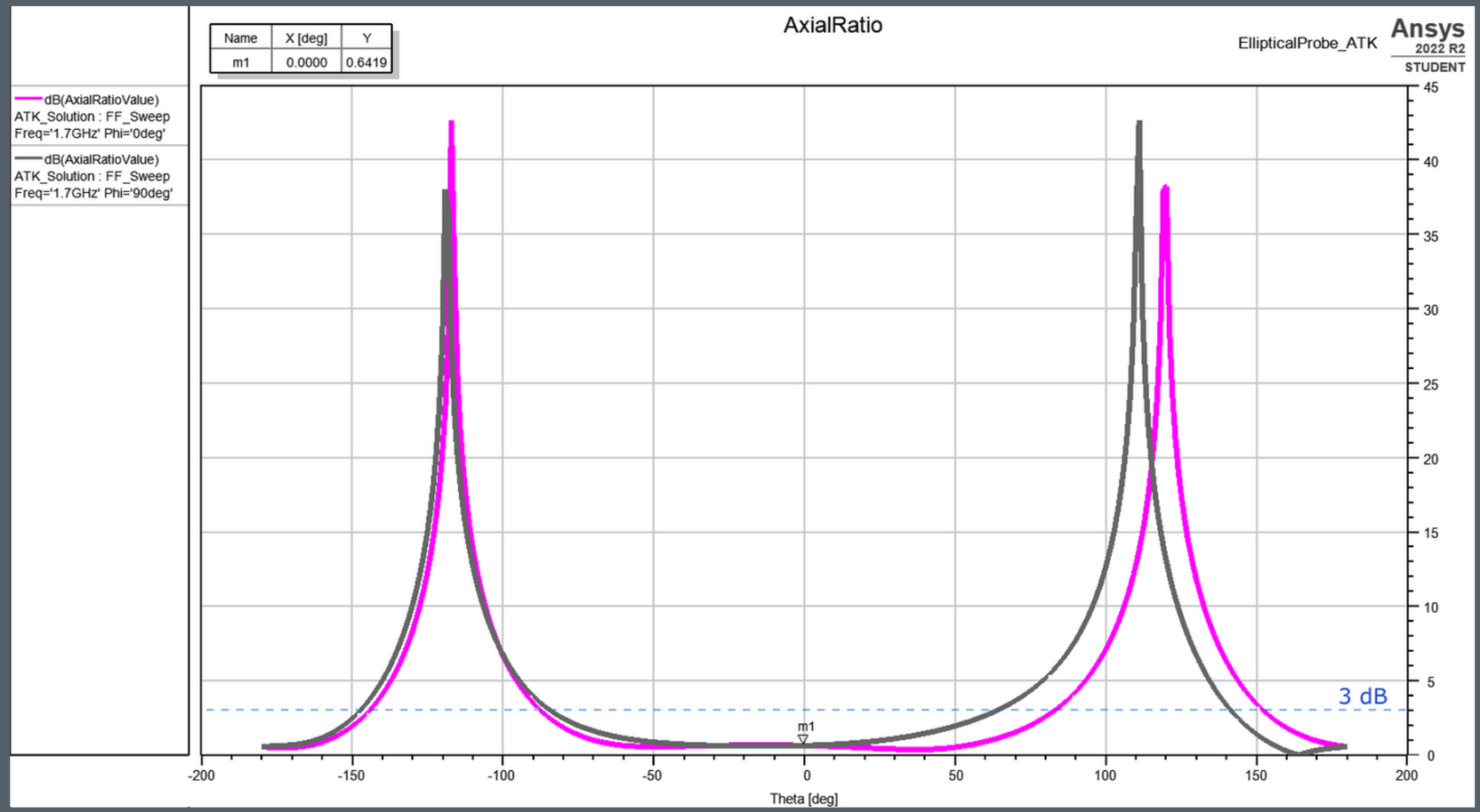
S11 ANTENNA

HRPT



Antena