BUILDING THE ULTIMATE BUDGET-FRIENDLY LOW EARTH ORBIT SATELLITE GROUND STATION

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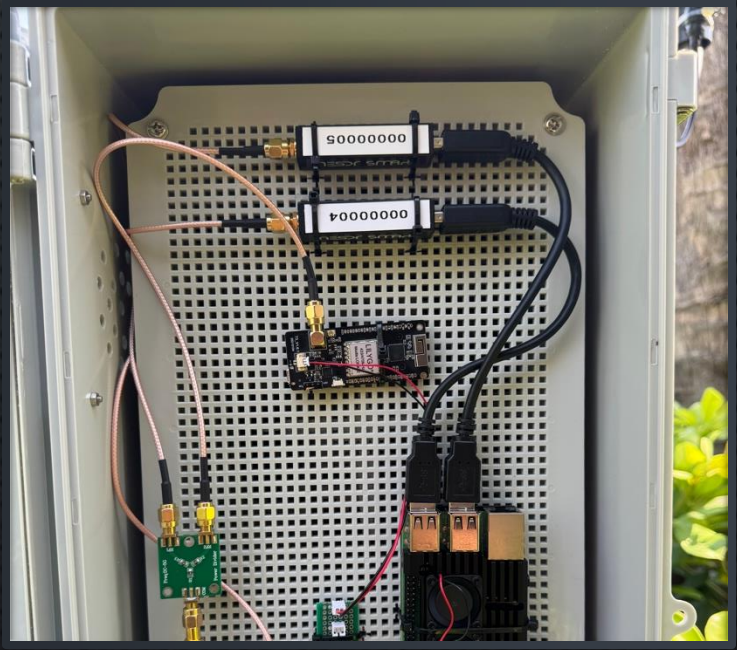
DEFCON32 – AEROSPACE VILLAGE

AGENDA

- Introduction
- Why this workshop?
- Basic concepts
- Ground Stations
  - Antennas
    - Lab 1: Construction of Ground Plane Antenna
  - Receivers
    - Lab 2: RTL-SDR Tools
  - Software
    - Lab 3: SDR++
    - Lab 4: Gpredict
    - Sattelite Reception Demo
- Expanding Ground Stations

Introduction

- Victor Fernandez Minguillon
- Father of 3
- Experience: 6 years in Offensive Security
- Senior Red Team Analyst @ United Airlines
- Pursuing Masters Degree in Cybersecurity
- X (@vickfedez). LinkedIn (victor.minguillon)



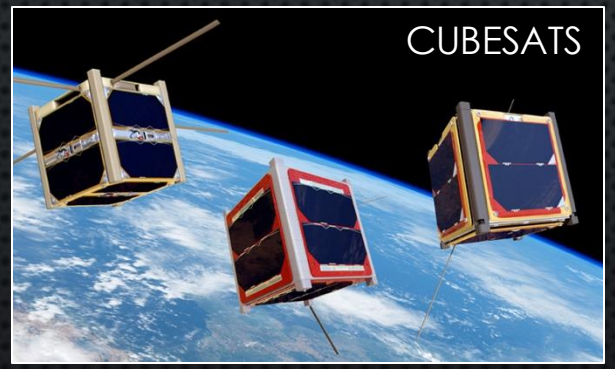
WHY THIS WORKSHOP?

- OBJECTIVE: BUILD A BUDGET FRIENDLY ~ $100 GROUND STATION

Basic Concepts – What is a Satellite?

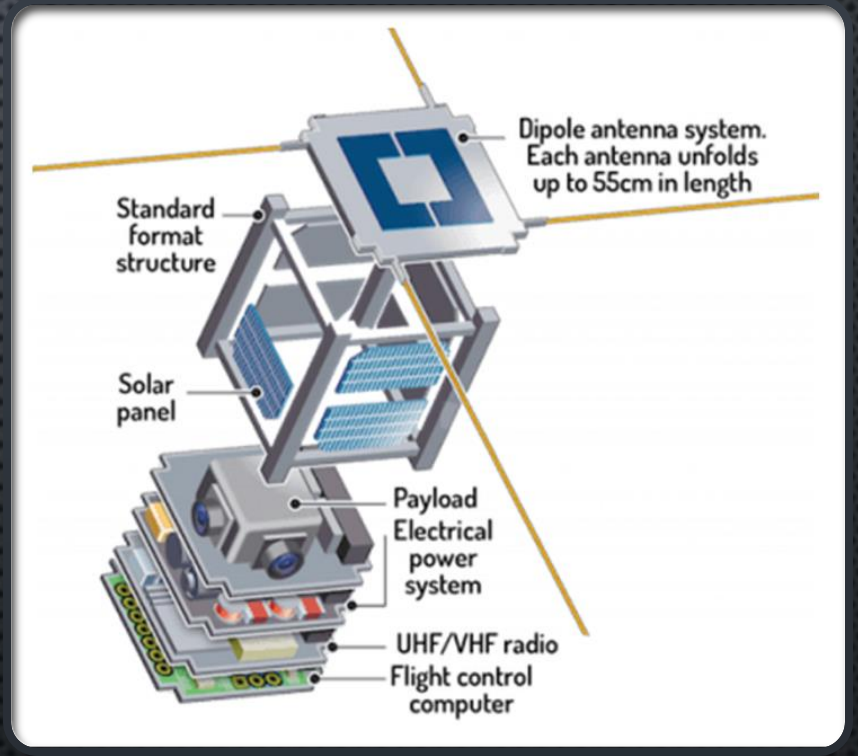
- A satellite is an object, typically a spacecraft, placed into orbit around the Earth, that provides different services such as: telecommunications, navigation aids, meteorological imagery, and science and research projects.

BASIC CONCEPTS – WHAT IS A SATELLITE?

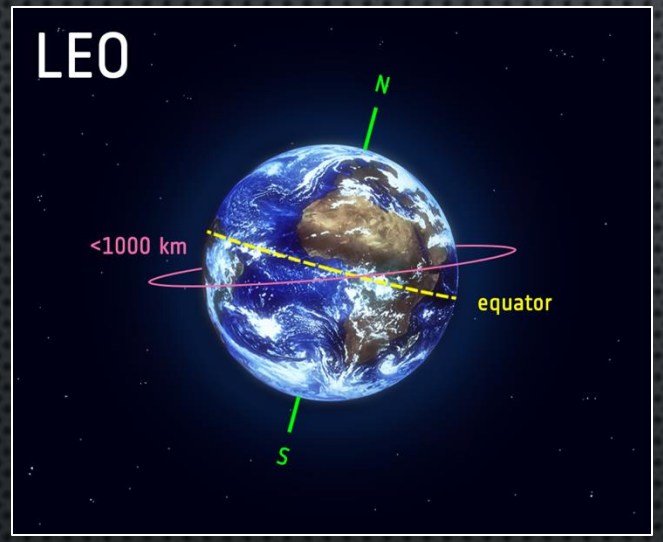


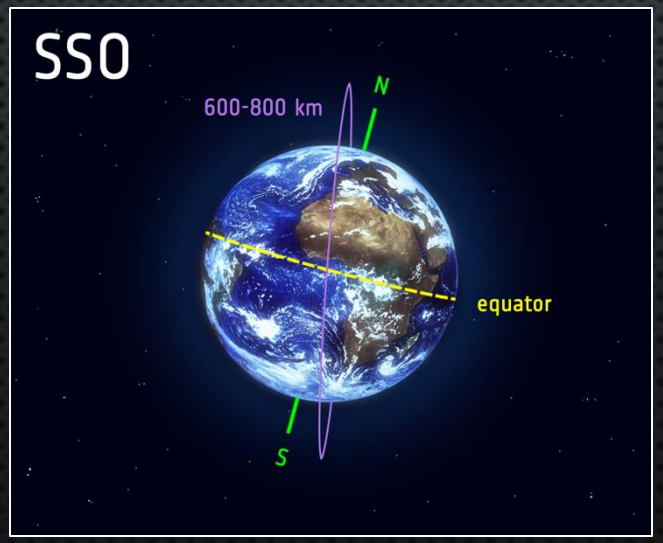
BASIC CONCEPTS – SATELLITES SUBSYSTEMS

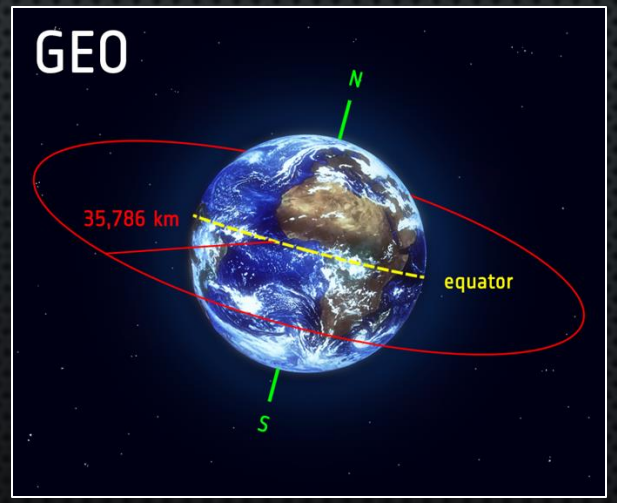
- Structure
- Electrical & Power System (EPS)
  - Solar panels, Batteries & Controller
- Attitude Determination and Control System (ADCS)
  - Computers that controls the attitude and telemetry
- Communication System
  - VHF/UHF Radios Antennas
    - To receive commands from Ground Stations (GS) and to transmit information back to GS
  - Antennas
    - Allow the communication with GS [Downlink (Sat -> GS), Uplink (GS -> Sat)]
- Payload
  - Science Sensors, like cameras, IR or magnetic field sensors, etc



BASIC CONCEPTS - SATELLITE ORBITS







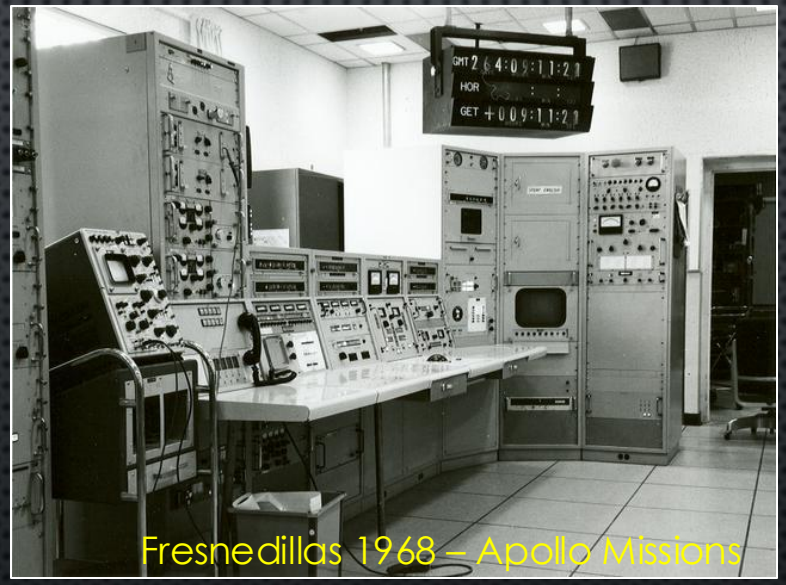
GROUND STATIONS - DEFINITION

- EQUIPMENT NECESARY TO COMMUNICETE WITH A SATELLITE OR SPACECRAFT FROM EARTH

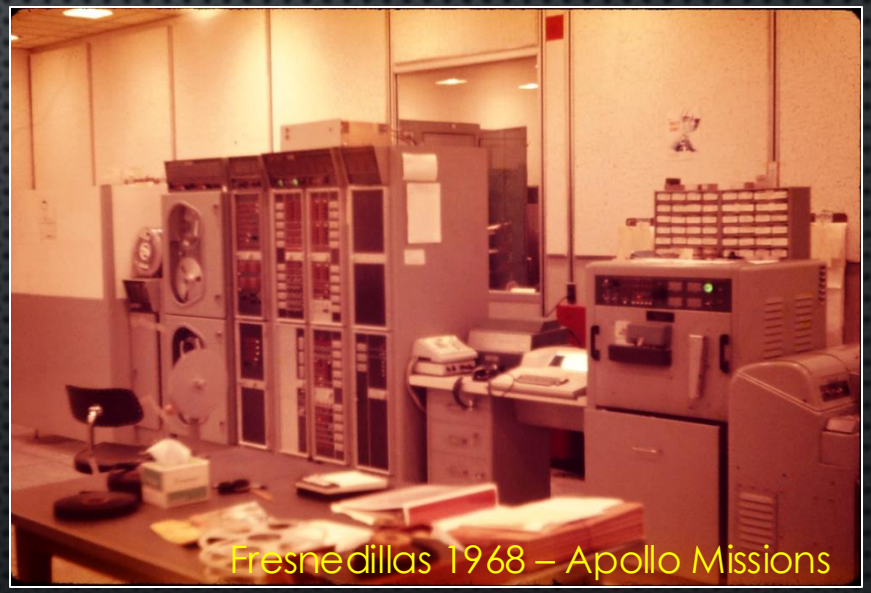
GROUND STATIONS - COMPONENTS

ANTENNA

RECEIVER



SOFTWARE



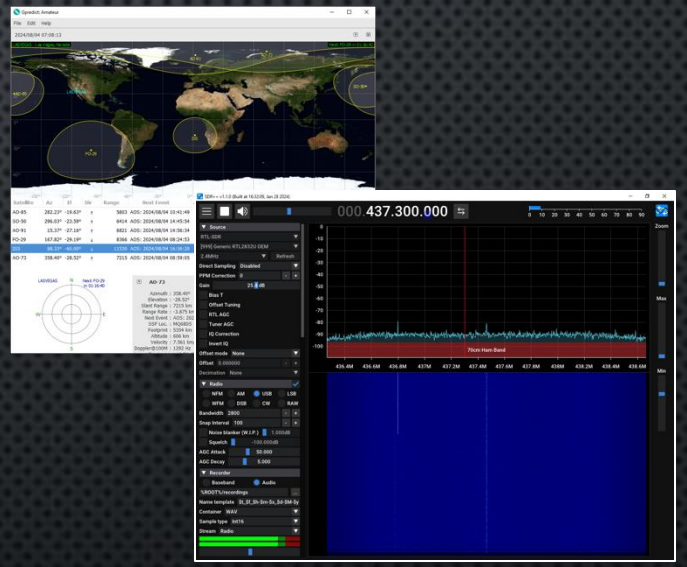
Photos by Alberto Martos. NASA Apollo Program Roster, Systems Engineer (1970 -1984)

GROUND STATIONS - COMPONENTS

ANTENNA

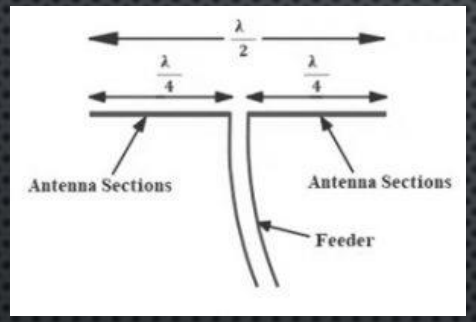
RECEIVER

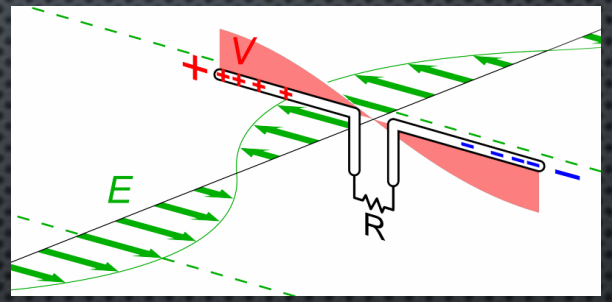
SOFTWARE



ANTENNAS - DEFINITION

- ELECTRICAL DEVICE, MADE OF WIRES OR RODS, THAT CONVERTS ELECTROMAGNETIC FIELDS PROPAGATED THROUGH THE SPACE INTO ELECTRICAL CURRENT, AND VICE VERSA.





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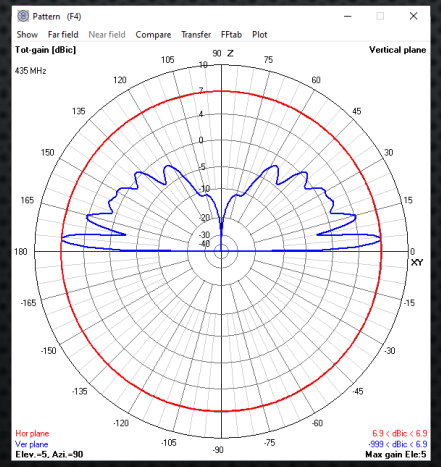
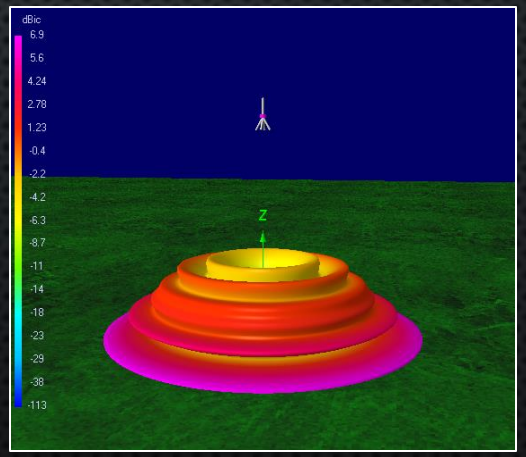
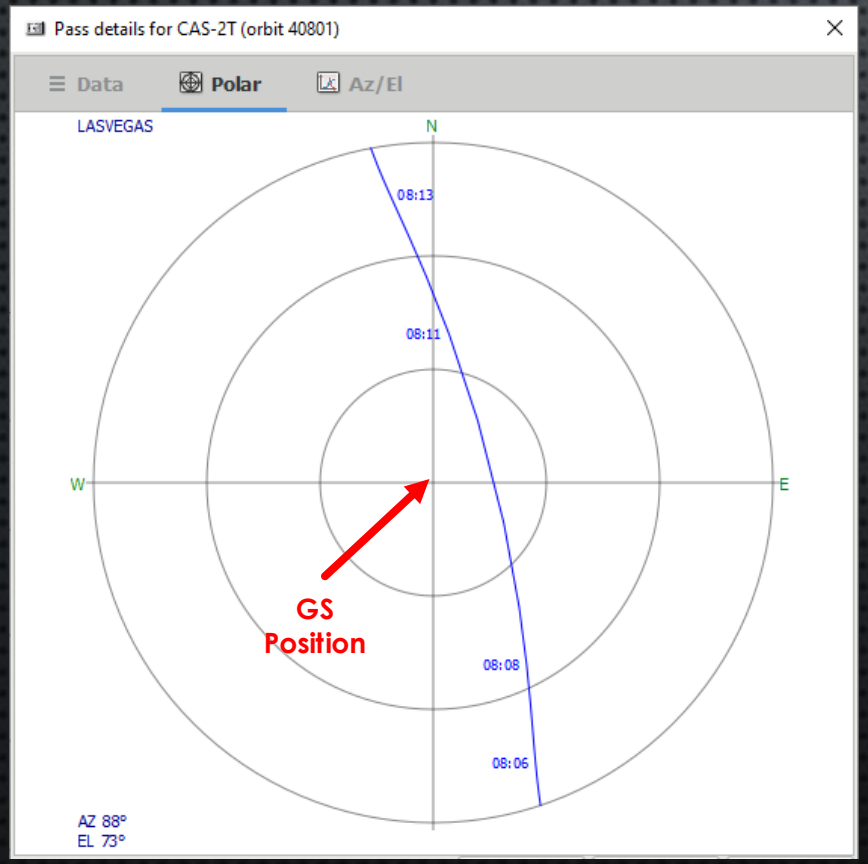
- KEY PARAMETERS
  - RESONANT FREQUENCY
  - RADIATION PATTERN & GAIN
  - IMPEDANCE

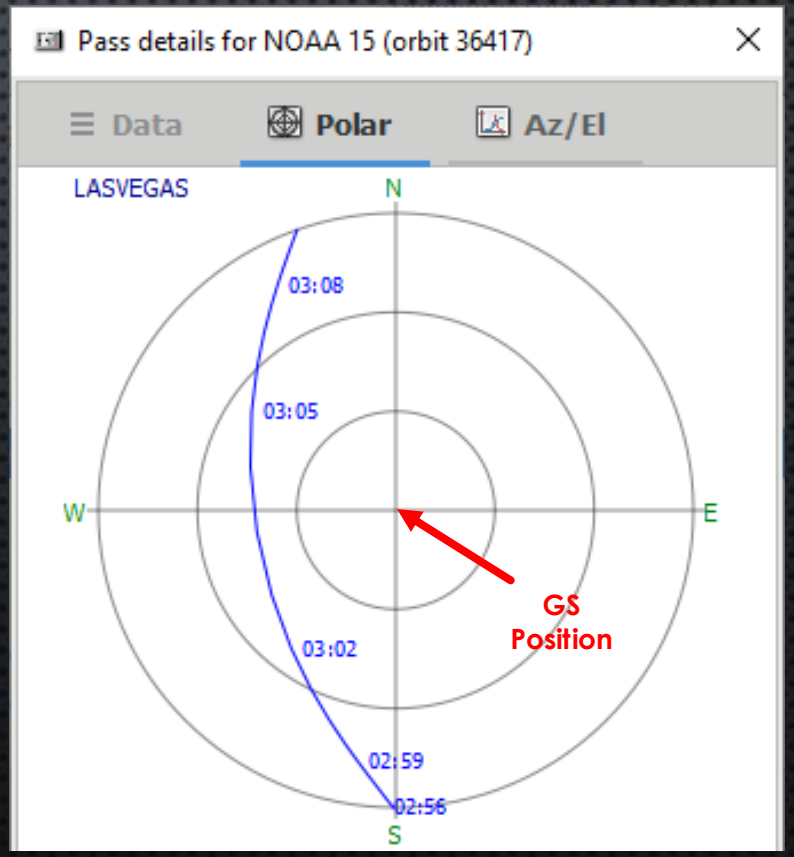




ANTENNAS – SATELLITE RECEPTION

- LEO SATTELLITE ORBITS HAVE PASSES OVER THE GROUND STATION COMING FROM DIFFERENT AZIMUTH DIRECTIONS, THE SIMPLEST ANTENNA MUST HAVE AN OMNIDIRECTIONAL AZIMUTH PATTERN, AND IDEALLY AN OMNIDIRECTIONAL GAIN PATTERN ON THE ELEVATION.





ANTENNAS - TYPES

TURNSTILE
CROSSED DIPOLES

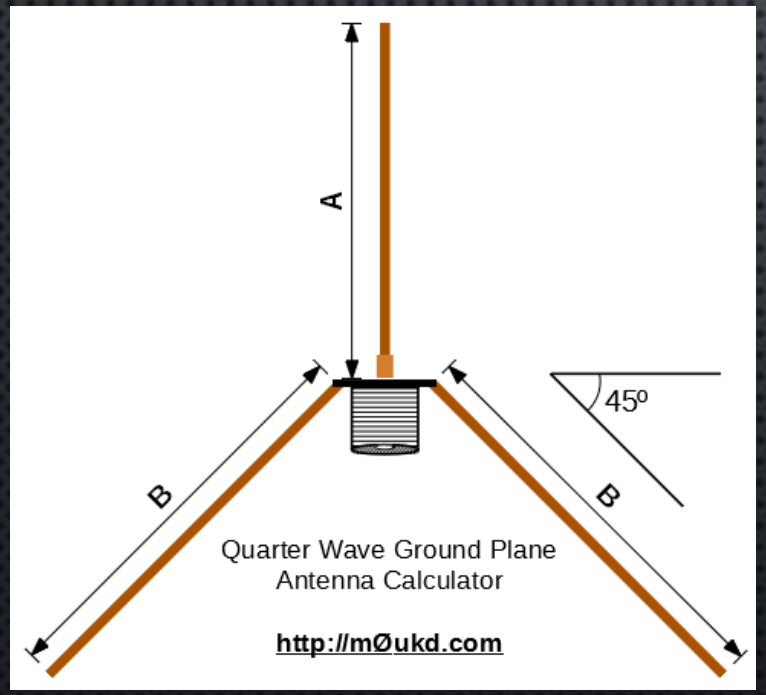
EGGBEATER

QFH

GROUND PLANE

	Turnstile	Eggbeater	QFH	G. PLANE
Gain 90°	2-3dB	5dB	4-5dB	-30dB
Gain 30°	3dB	3dB	3dB	1.4dB
Gain 15°	1dB	-5dB	2dB	4dB
Polarization	RHCP	RHCP	RHCP	Linear
Complexity	Medium	High	High	Low

ANTENNAS – GROUND PLANE CALCULATOR



MØUKD

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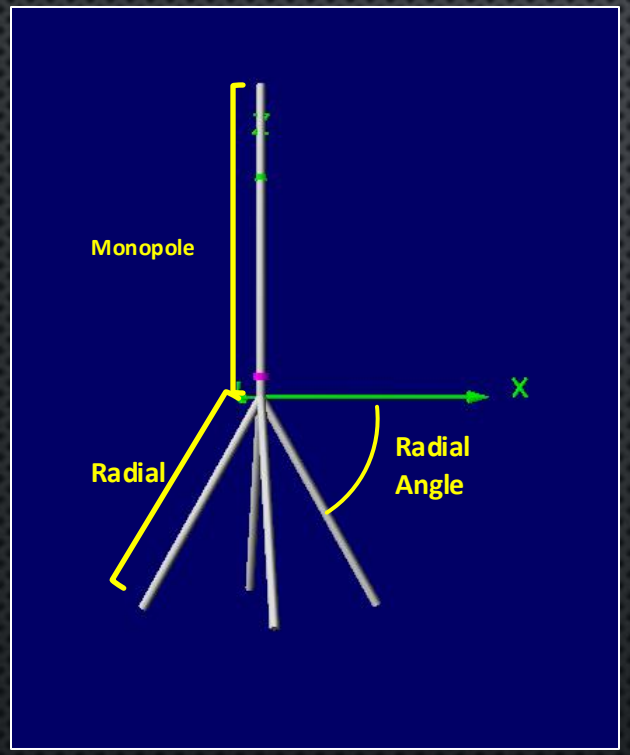
- International Space Station NA1ISS contact with GB4YOTA
- Building a 70MHz quarter wave ground plane
- Receiving SSTV images from the ISS – ARISS 20th Anniversary
- 1/4 Wave Antenna Calculator
- A long break...
- My first 23cm 1297MHz contact!
- Icom IC-7100 SO-239 to N-Type
- Reviews
- RSGB 21/28MHz Contest
- Practical Wireless 70MHz Contest
- RSGB 2nd 70MHz Contest
- Two years in the making – 70MHz 300w Amplifier
- 5th 144MHz Backpackers

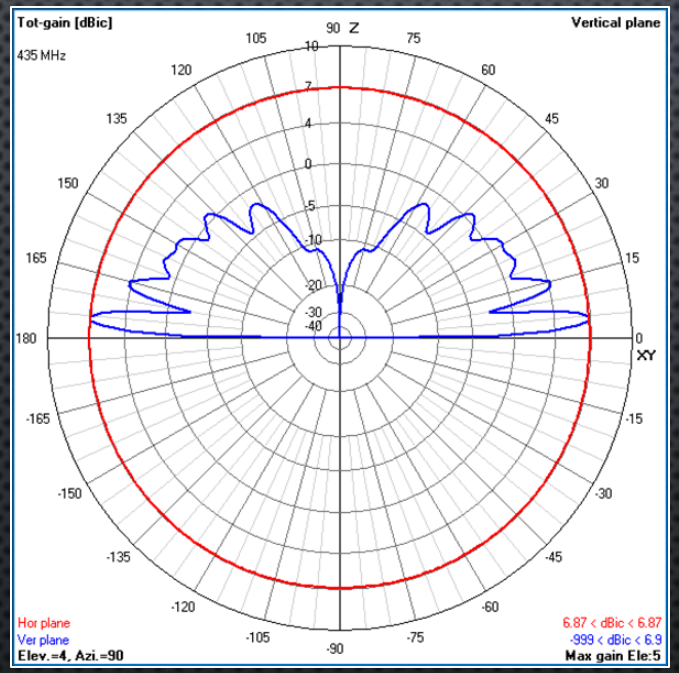
1/4 Wave Ground Plane Antenna Calculator

Quarter Wave Ground Plane Antenna Calculator	
Frequency	435.0 MHz
Velocity Factor (see text*)	0.95 vf
Give me the results in...	(•) mm (MilliMetres) ( ) cm (Centimetres) ( ) m (Metres) ( ) in (Inches) ( ) ft (Feet)
Calculate My Quarter Wave!	
A. Vertical Monopole Radiating Element (λ*0.25)*vf	163.8 mm
B. Radials (λ*0.28)*vf	183.4 mm
Actual wavelength	689.7 mm
Clear Form	

https://m0ukd.com/calculators/quarter-wave-ground-plane-antenna-calculator/

ANTENNAS – GROUND PLANE SIMULATION





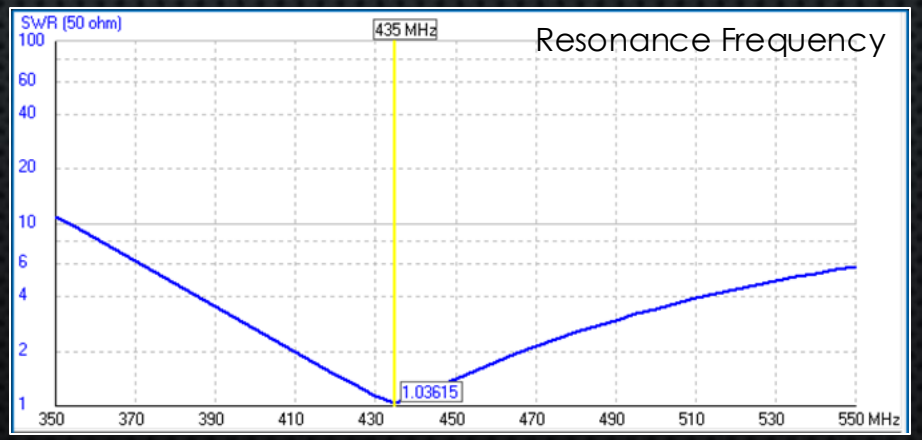
Max Gain: 6.9dBi at 5° Elevation
afterwards gain decreases rapidly.

Elev.	Gain (dBi)
5	6.9
15	4.1
30	1.4
45	-0.1
60	-2.5
90	-50.0

Ok for receiving satellites up to 45° elevation. When satellite is overhead of Receiving station, the antenna doesn't receive any signal (90° elevation)

λ (m) = 300 / 435 MHz = 0.6897m

Monopole = λ/4 * 0.97 = 167.3mm
Radial = λ/4*0.73 = 125.9mm
Radial Angle = 60°



Ground Plane Antenna simulation with ***4nec2***

LAB 1: CONSTRUCTION OF GROUND PLANE ANTENNA

LAB 1 – ANTENNA KIT

- SO-239 Connector
- Monopole Copper Rod
- 4 x Radials Copper Rod pre soldered
- 4 x M3 Screws and nuts
- PETG 1 ¼ pipe antenna mount

Lab 1 – Exercise (25 minutes)

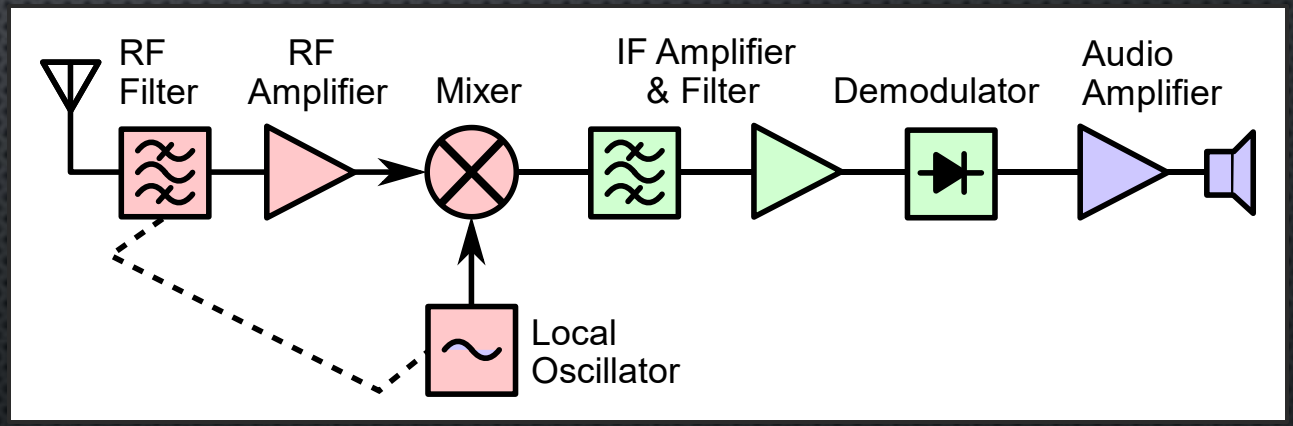
- 1. Solder the monopole to the SO-239 connector
- 2. Mount radials on SO-239 connector to PETG 1 ¼ pipe adapter
- 3. Bend the radials to 60 degrees

DEMO: MEASURING GROUND PLANE ANTENNA

RECEIVERS - DEFINITION

- RADIO RECEIVER IS AN ELECTRONIC DEVICE THAT RECEIVES RADIO WAVES FROM AN ANTENNA AND CONVERTS THE INFORMATION CARRIED BY THEM TO A USABLE FORM (SOUND, DATA, IMAGES

AM/FM/SW Analog Receiver



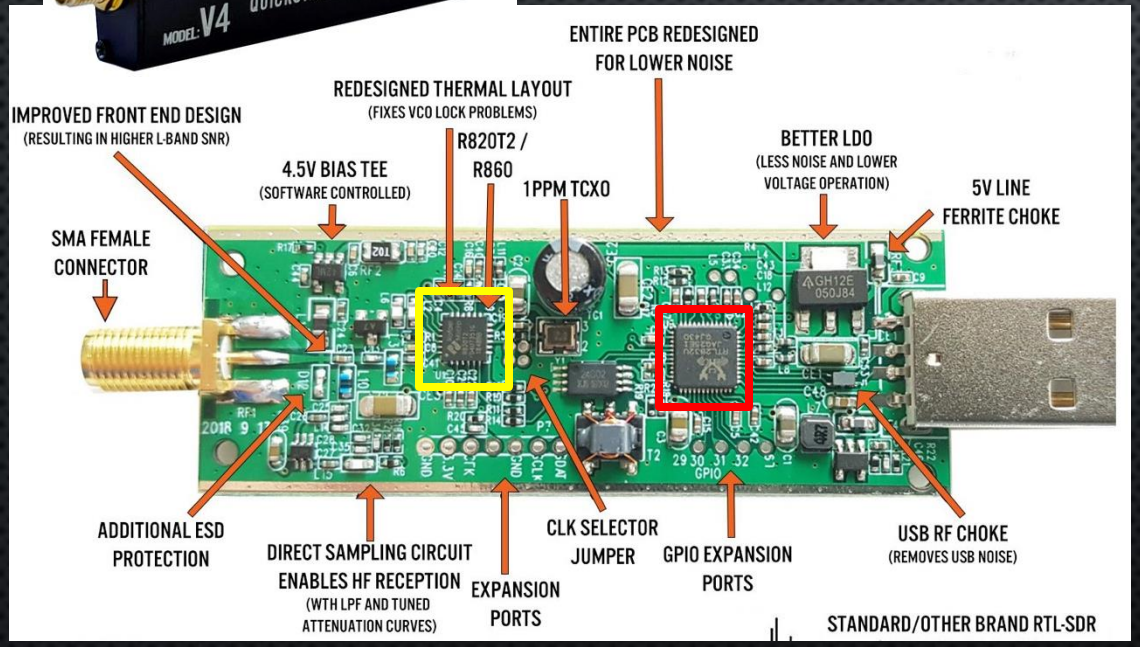
Analog Receiver Building Blocks

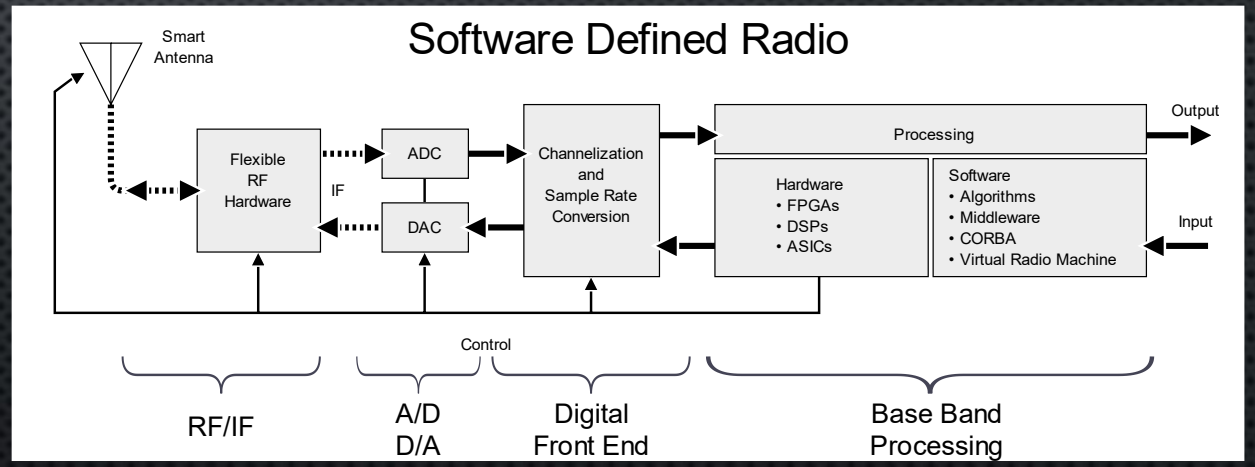
Images By Chetvorno - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid=46222556

RECEIVERS – SDR (SOFTWARE DEFINED RADIO)

- SDR's ARE THE NEW TYPE OF RADIOS, WHERE MOST OF THE HARDWARE CIRCUITS HAS BEEN ELIMINATED BY DIGITALIZING THE SIGNALS AND AFTERWARDS PROCESSING WITH A DEDICATED CHIPS OR A COMPUTER

RTL-SDR Receiver





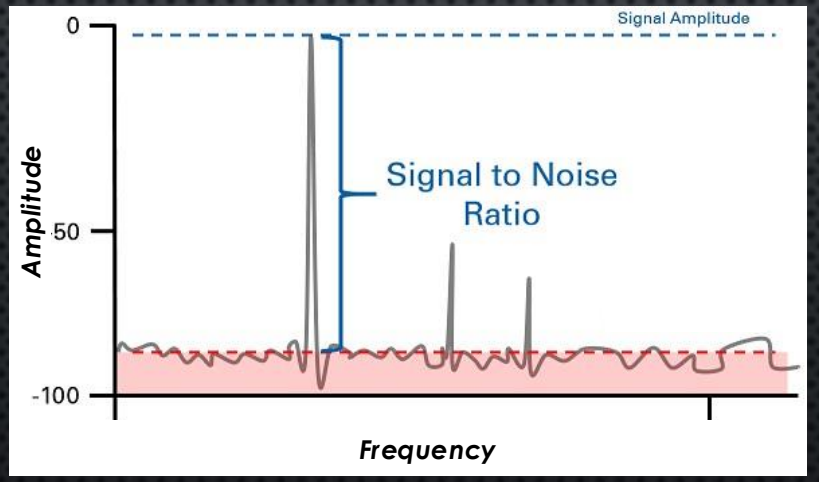
Generic SDR Receiver

RECEIVER – KEY CONCEPTS

- FREQUENCY RANGE & FREQUENCY STABILITY
  - Range of frequencies the receiver can receive and stability of the receiver to maintain the tuning in the selected frequency
- SENSITIVITY
  - Minimum level of radiofrequency signal the receiver can demodulate. Depending on the modulation type the requirements may be different. The standard is called MDS (Minimum Discernable Signal) corresponding to a 3 dB signal vs. noise ratio.
- SELECTIVITY
  - Capability of the receiver to resolve signals from different frequencies
- BANDWITH
  - It can be adjusted in most receivers to adapt to demodulated signal. It's different by modulation type. (CW requires 500Hz, BROADCAST FM requires120 kHz, TV SAT 27 MHz, …)

RECEIVERS – THE SIGNAL/NOISE RATIO

- When we connect a receiver to an antenna, we don't' receive only the signal we have tuned, we receive as well NOISE.
- NOISE is made by galactic, atmospheric and hearth, man made noise (motors, lights, etc) and electronics noise (thermal noise).
- To successfully demodulate a RF signal, it must have a higher power than base noise.



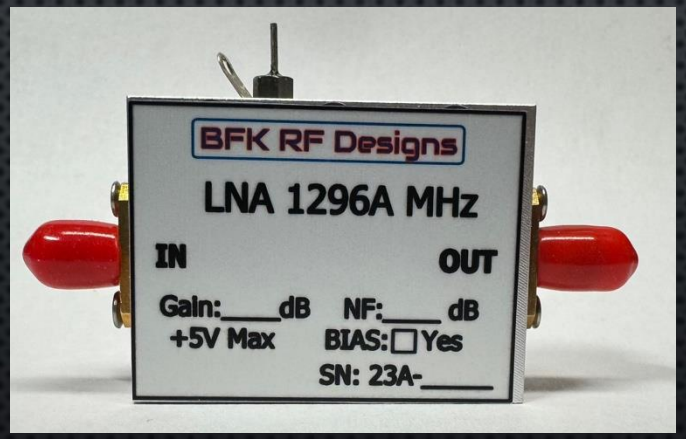
- Depending on the modulation type used the required signal/noise ratio to successfully demodulate change.
  - CW (telegrafy) –> 3 dB NOAA-18 SAT FM APT image –> 30 dB

RECEIVERS – LOW NOISE AMPLIFIERS (LNA)

- SATELLITE SIGNALS ARE USUALLY VERY WEAK REQUIRING RECEIVERS WITH HIGH SENSITIVITY. TO INCREASE SENSITIVITY OF RECEIVERS AS RTL-SDR, USUALLY LNA'S ARE USED.
- LNA
  - IS A SIGNAL AMPLIFIER, THAT AMPLIFIES THE SIGNAL, THE NOISE CAPTURED BY THE ANTENNA AND HAS A VERY LITTLE CONTRIBUTION OF OWN NOISE, BECAUSE USE A VERY SPECIFIC DEVICES AND DESIGNS.

LNA for all

BFK RF Designs

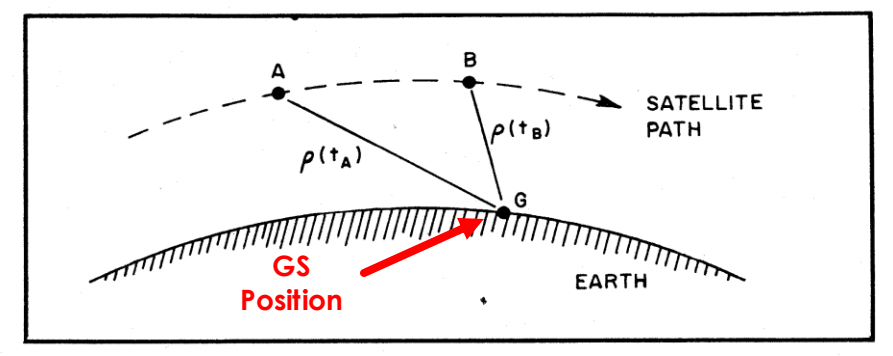


KHUNE

NF (dB)	1dB	0.35dB	0.45dB
Gain (dB)	23,5dB (Broadband)	22dB (Selective)	20dB (Selective)
Cost	$	$$	$$$$$

RECEIVERS – THE DOPPLER EFFECT

- Satellites transmit their signals on a fix frequency, but they are moving with respect the observer (Ground station) due to their circular orbit around hearth. The exception are satellites in GEO orbit, that are always in the same position in the Sky.
- The relative movement of the satellite vs the observer produces a change of the received frequency due to the DOPPLER EFFECT



Doppler shift: $\Delta f = f^* - f_o = \pm \frac{v_r}{c} f_o$

When this distance between source and observer is
decreasing, a "+" sign is used ($f^* > f_o$)
increasing, a "−" sign is used ($f^* < f_o$)

- The amount of frequency change is proportional to the transmit frequency and the relative speed of the satellite vs. the observer
- Current tracking software's does the proper calculation and correct the reception frequency a very fast speed to ensure proper reception of the signal

LAB 2: RTL-SDR TOOLS

RTL-SDR TOOLS - INSTALLATION

- SUDO APT SEARCH RTL-SDR
- SUDO APT INSTALL RTL-SDR

RTL-SDR TOOLS - OVERVIEW

```
sat@sat-groundstation:~ $ rtl_
rtl_adsb    rtl_biast   rtl_eeprom  rtl_fm      rtl_power   rtl_sdr     rtl_tcp     rtl_test
```

RTL-SDR TOOLS – EXERCISE (5 MINUTES)

- 1. Install RTL-SDR
- 2. Modify RTL-SDR EEPROM memory with a new Serial Number of your choice
- Explore the rest of the RTL-SDR tools

LAB 3: SDR++

SDR++ - DESCRIPTION

- SDR++ is a cross-platform and open source SDR software with the aim of being bloat free and simple to use.
- Features:
  - Multi VFO
  - Wide hardware support (both through SoapySDR and dedicated modules)
  - SIMD accelerated DSP
  - Cross-platform (Windows, Linux, MacOS and BSD)
  - Full waterfall update when possible. Makes browsing signals easier and more pleasant
  - Modular design (easily write your own plugins)

https://www.sdrpp.org

SDR++- INSTALLATION

- https://github.com/AlexandreRouma/SDRPlusPlus/releases/tag/nightly
- sudo dpkg -i package_file.deb

SDR++ - APPLICATION OVERVIEW DEMO

SDR++ – Exercise (15 minutes)

- Explore SDR++ application, their modules and configurations on 434.9 MHz freq

LAB 4: GPREDICT

GPREDICT - DESCRIPTION

- Gpredict is a real-time satellite tracking and orbit prediction application. It can track a large number of satellites and display their position and other data in lists, tables, maps, and polar plots (radar view). Gpredict can also predict the time of future passes for a satellite, and provide you with detailed information about each pass.

GPREDICT - INSTALLATION

- SUDO APT INSTALL GPREDICT

GPREDICT - APPLICATION OVERVIEW DEMO

GPREDICT – EXERCISE (15 MINUTES)

- Add a location of your Ground Station
- Add the following satellites on different modules
- Weather module:
  - NOAA 15
  - NOAA 18
  - NOAA 19
  - Meteor 2-4
- Ham Radio:
  - ISS
  - SO-50

SDR++ & GPREDICT LIVE DEMO

Expanding Ground Stations

- Expanding to LoRa modulation and decoding with TinyGS
- Automation of tracking, capturing and Decoding* using SatNogs
- Decoding of manually recorded signals using SatDump
- Usage of diplexer and power dividers to simplify antenna architecture
- Client-Server Ground Station Architecture
- SigDigger

THANK YOU

- All Workshop Attendees
- Aerospace Village Organization and Volunteers
- Alejandro Fernandez Ponce – EA4BFK

References

- https://www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits
- CubeSat Handbook - From Mission Design to Operations book
- ARRL Handbook for Radio Communications
- ARRL Antenna book for Radio Communications
- Ground plane calculator:
  - https://m0ukd.com/calculators/quarter-wave-ground-plane-antenna-calculator/
- 4nec2:
  - https://www.qsl.net/4nec2/
- 4Nec2 Study resources:
  - https://www.gunthard-kraus.de/

References

- NanoVNA:
  - https://nanovna.com
- LNA4ALL:
  - http://lna4all.blogspot.com
- RTL-SDR:
  - https://www.rtl-sdr.com
- SDR++:
  - http://sdrpp.org
- Gpredict:
  - https://oz9aec.dk/gpredict/

References

- AMSAT Cubesat Simulator:
  - http://cubesatsim.org
- Tiny GS Project:
  - https://tinygs.com
- SatNogs Project:
  - https://satnogs.org
- SATDump:
  - https://www.satdump.org
- Diplexer:
  - https://kw4fb.com/micro-diplexer/
- Sigdigger:
  - https://batchdrake.github.io/SigDigger/