Earth-Moon-Earth Communications

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Outline

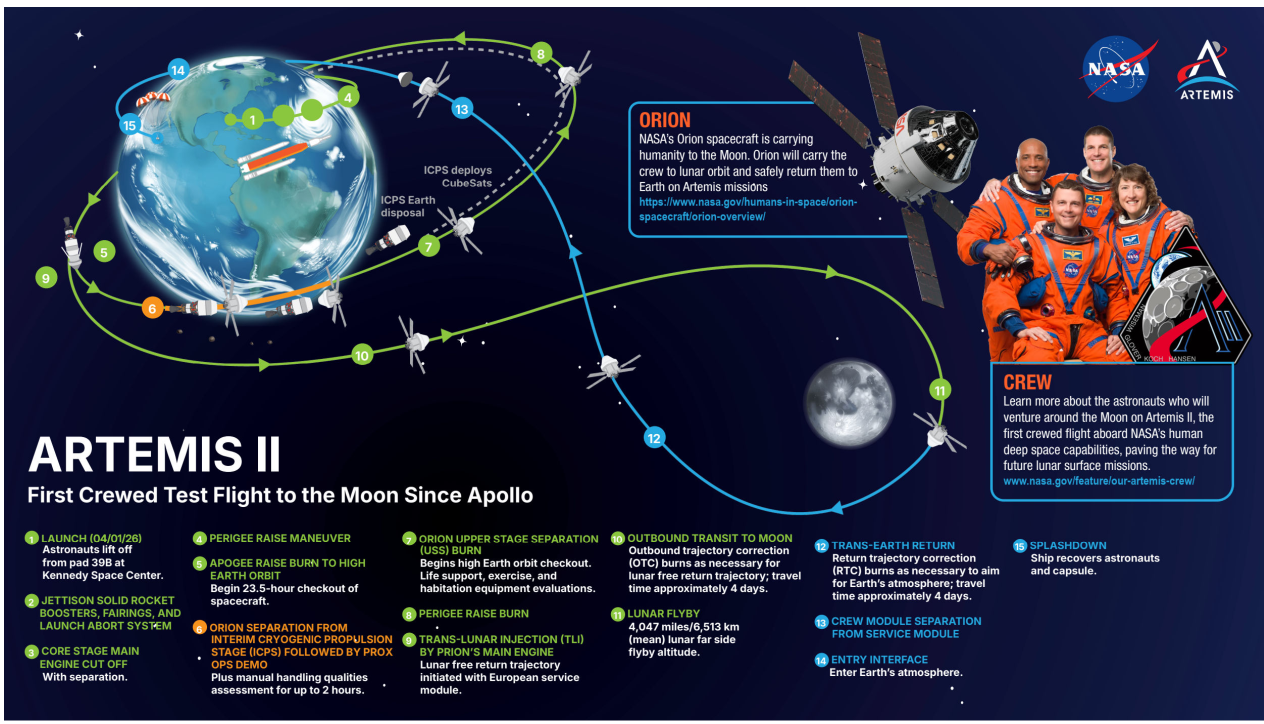
- What is Earth-Moon-Earth (EME) Communicaton?
- Channel Characteristics
- Modulation Format
- System Considerations
- Use of Software Defined Radios
- Future of Amateur Radio on the Moon
- Summary

EARTH-MOON-EARTH COMMUNICATIONS

AKA "Moonbounce"

https://www.baltimoresbest.net/moonbounces-inflatables/

Another Connection to the Moon…..



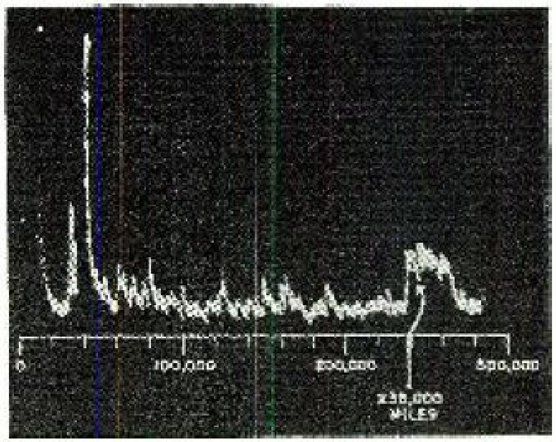
Christina Koch received BSEE and MSEE, and BS Physics from NC State

Engineering Building II (HQ of ECE Dept) has been renamed Koch Hall!

Using the Moon as a Passive Reflector

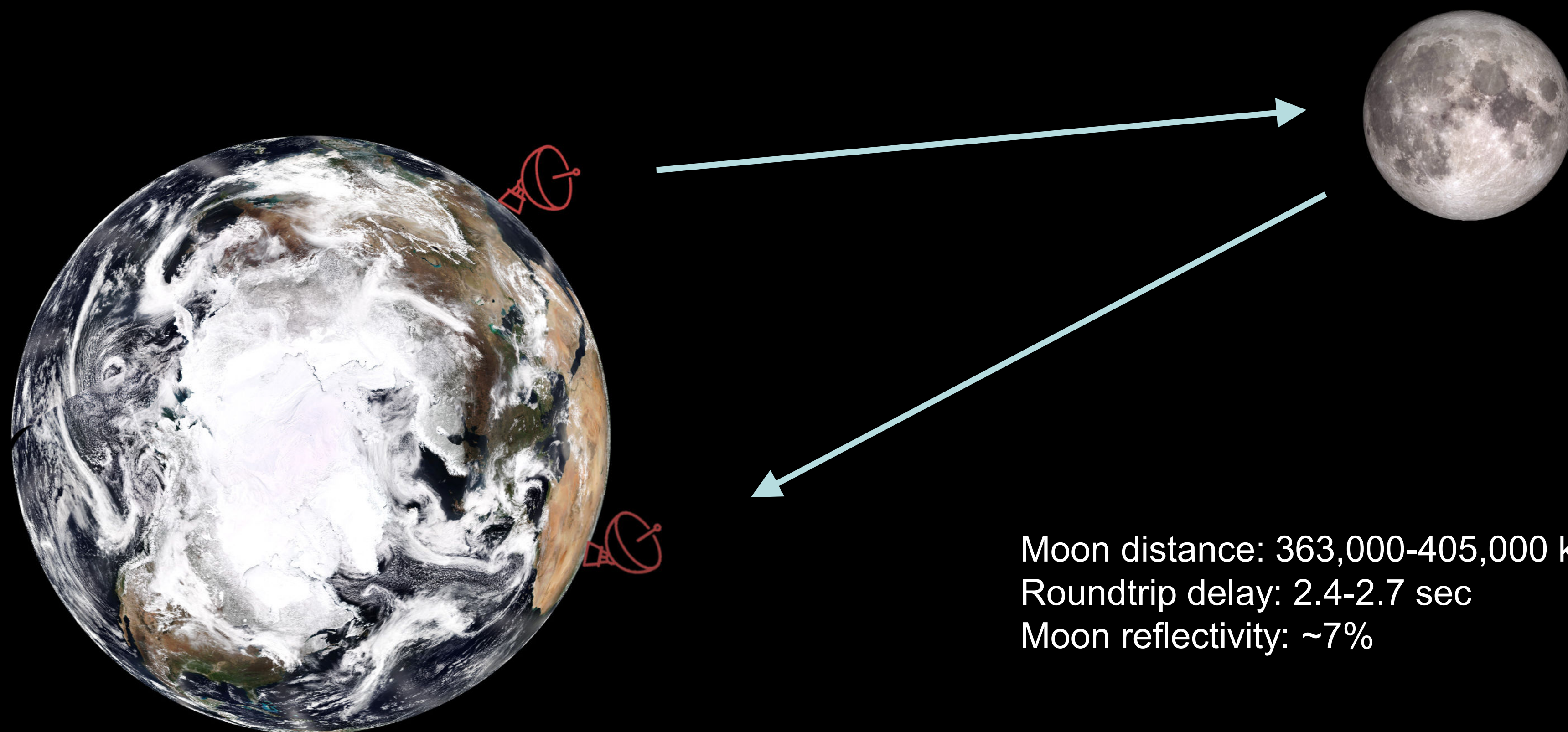
- First Proposed by W.J. Bray of the British General Post Office in 1940
- Inadvertently observed during German radio experiments in 1943
- First specific experiment: Project Diana, Ft. Monmouth NJ, 1946
- First radar astronomy measurement

Public Domain, https://commons.wikimedia.org/w/index.php?curid=4272440



111.5 MHz, 3kW,
24 dB antenna gain

By Unknown author - Retrieved September 9, 2014 from Tom Gootée, "Radar Reaches the Moon" in Radio News magazine, Ziff-Davis Publications, Inc., New York, Vol. 35, No. 6, April 1946, p. 25-27, 84, 86 archived on American Radio History website, Public Domain, https://commons.wikimedia.org/w/index.php?curid=35262234

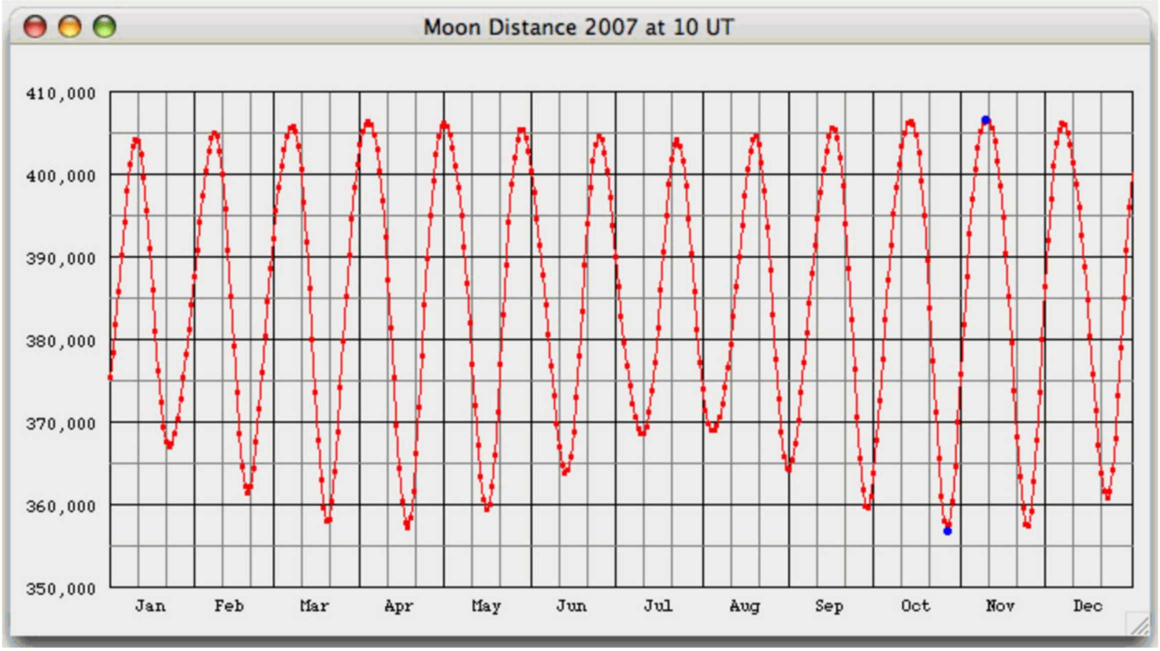


Moon distance: 363,000-405,000 km
Roundtrip delay: 2.4-2.7 sec
Moon reflectivity: ~7%

Not to scale ☺

Images: NOAA, cleanpng.com

Signal Variation with Distance



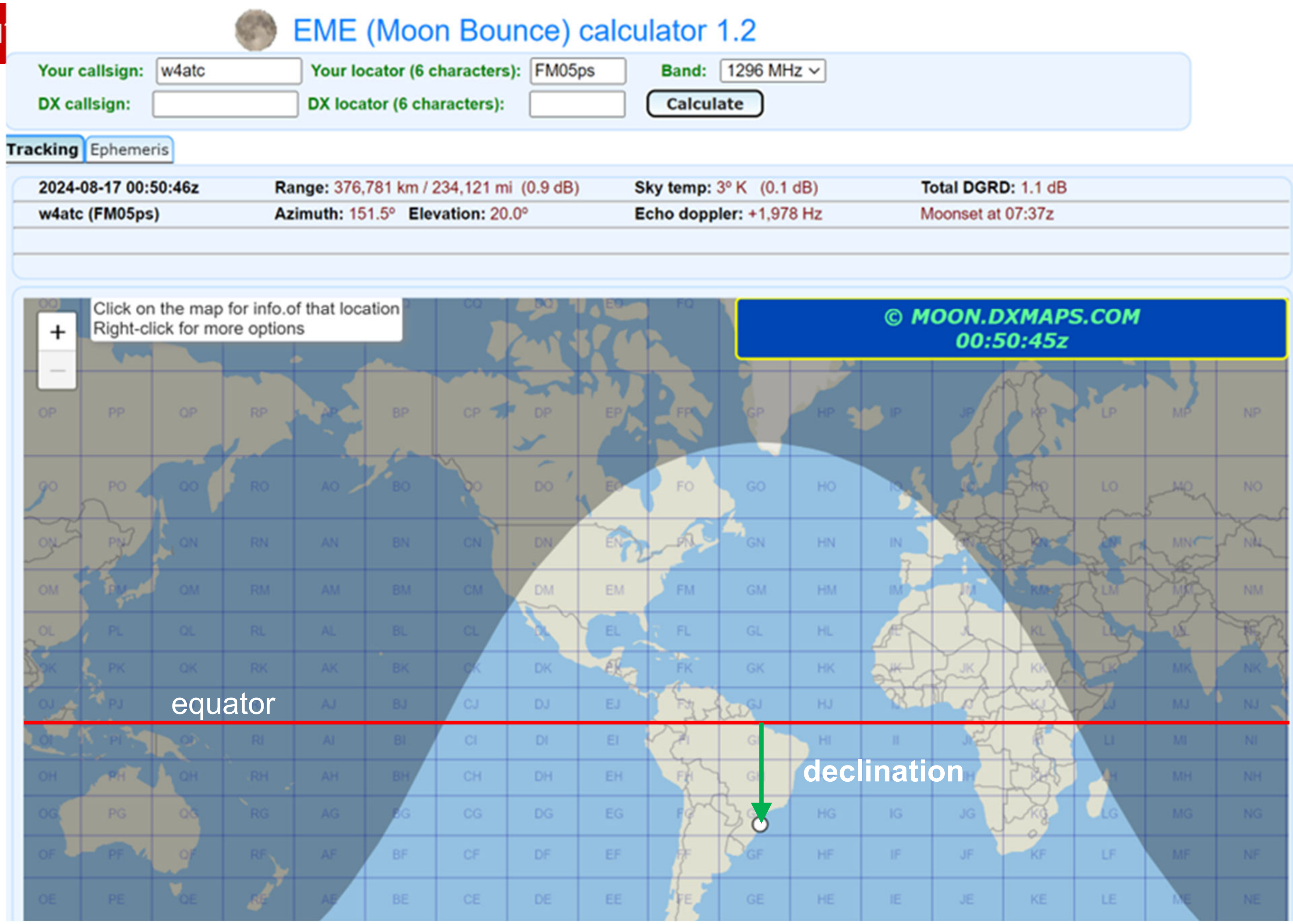
$$P_r = \frac{P_t G_t}{4\pi R^2} \frac{\sigma A_e}{4\pi R^2}$$

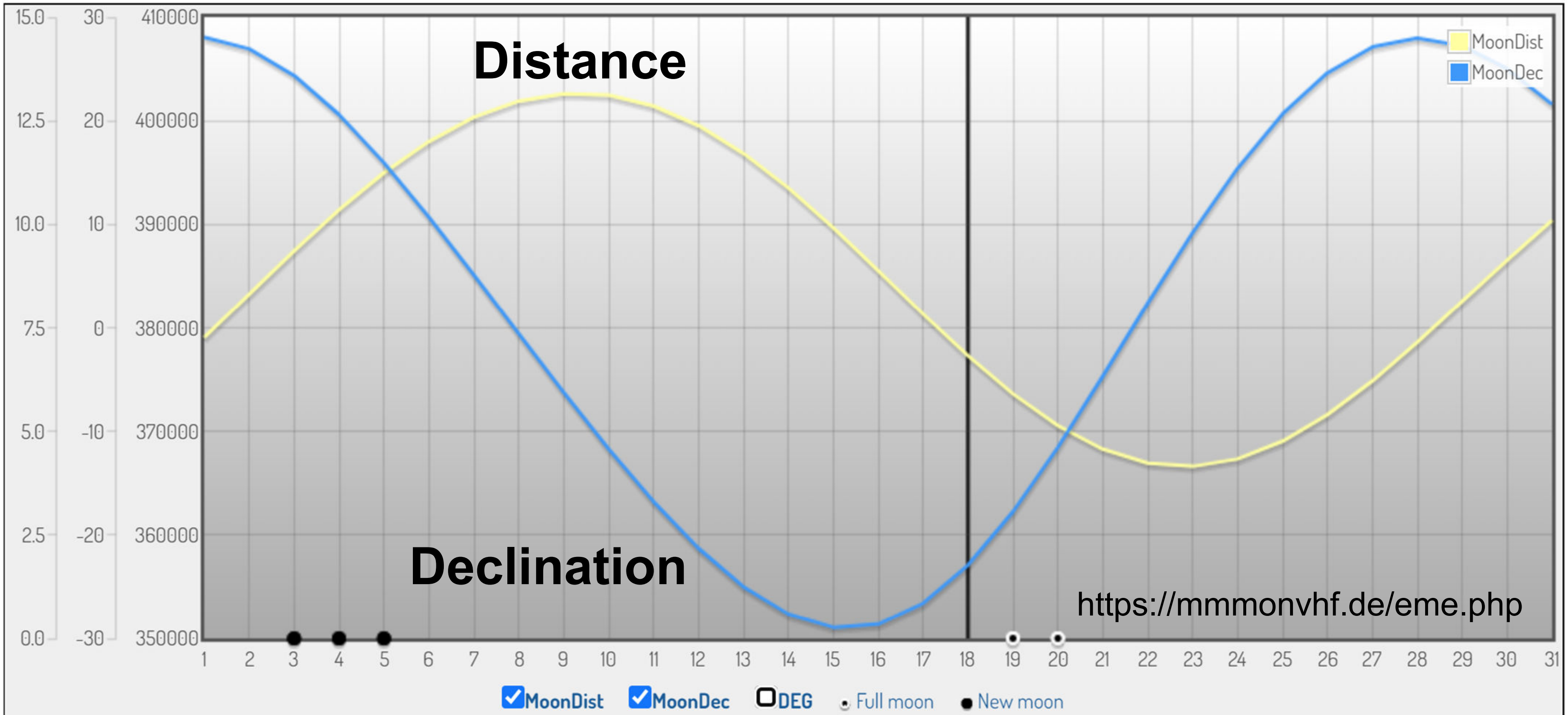
$$10 \log_{10}\left(\frac{406.7}{356.4}\right)^4 = 2.29\ dB$$

Image: http://www.jgiesen.de/moondistance/index.htm

Who can see the moon at the same time?

Contest Nov. 8-9, 2025
W4ATC logged
Over 40 contacts
Including: Australia, Austria, Canada, Czech Republic, Estonia, Germany, Hawaii, Italy, Japan, Poland, Russia





August 2024 Go

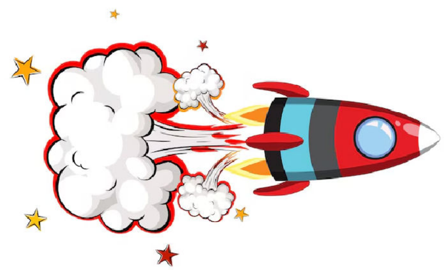
Todays 144MHz EME conditions: Degradation = 2.5 dB => Good

Background information:

Moon distance [km]: Earth-Moon distance. Mean distance is 384400 km. Minimim during perigee 356400 km. Maximum during apogee 406700 km. This translates to as much as 2.25dB difference in pathloss from apogee to perigee.

Moon declination [deg]: Moon declination in degrees north (+) and south (-) of the equator. Max declination up to 28.7 degrees.

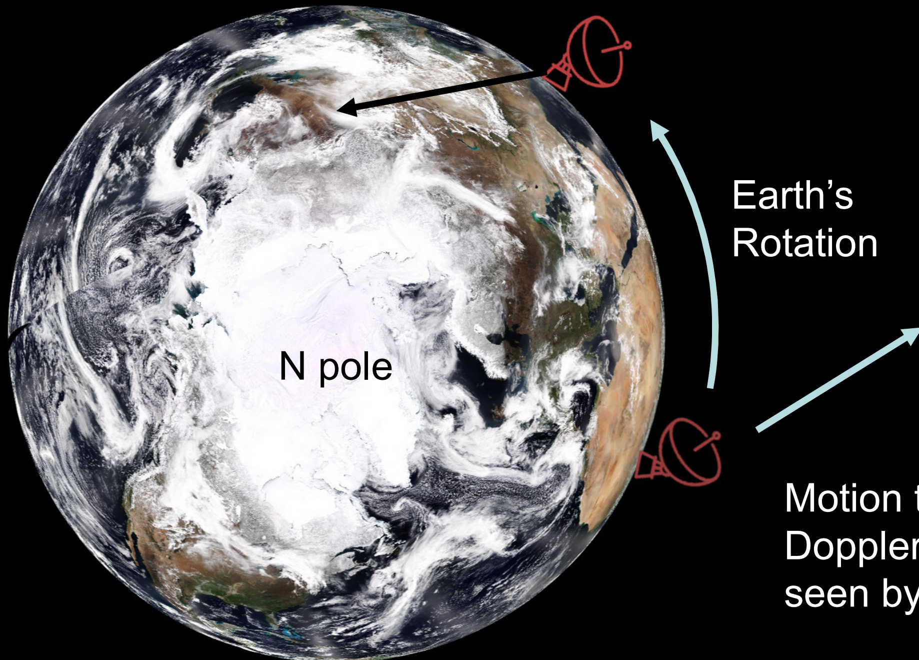
Roses are red ,
Roses are blue ,
Depending on their velocity relative to you.



Verse: source unknown
Images: Farm Direct, Freepik

Doppler Shift

Motion away from moon:
Doppler decreases frequency
seen by the moon



Motion toward moon:
Doppler increases frequency
seen by the moon

- Doppler shift at 1296 MHz: Up to +/- 3 kHz
- Common practice: "Constant Frequency on Moon" CFOM

Not to scale ☺

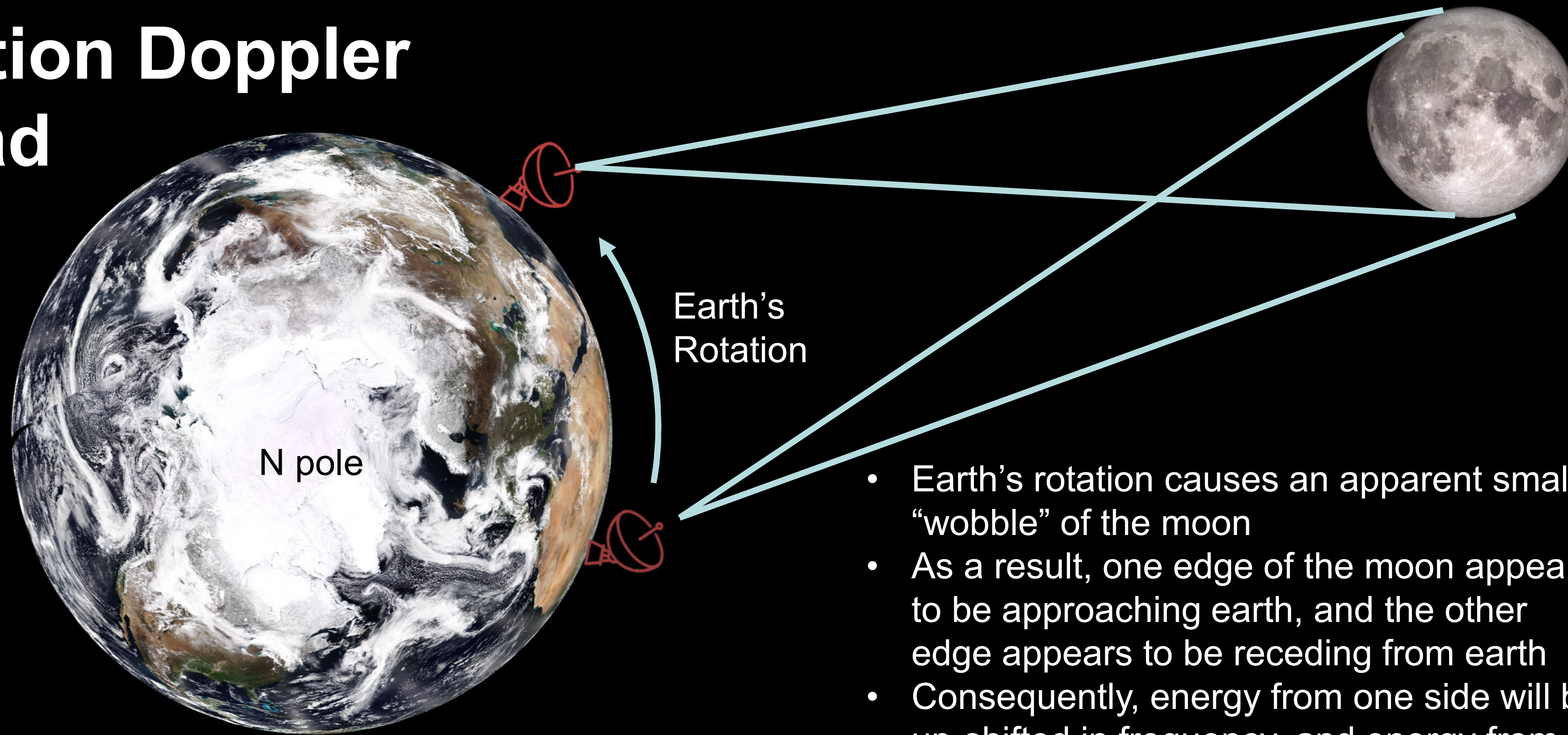
Images: NOAA, cleanpng.com

Libration

Libation

Images: NOAA, Libation Natural Wines,

Libration Doppler Spread



- Earth's rotation causes an apparent small "wobble" of the moon
- As a result, one edge of the moon appears to be approaching earth, and the other edge appears to be receding from earth
- Consequently, energy from one side will be up-shifted in frequency, and energy from the other side will be down-shifted
- At 1296 MHz, Doppler spread can be up to ~37 Hz, with median w50 of 4 Hz.
- Doppler spread causes fading

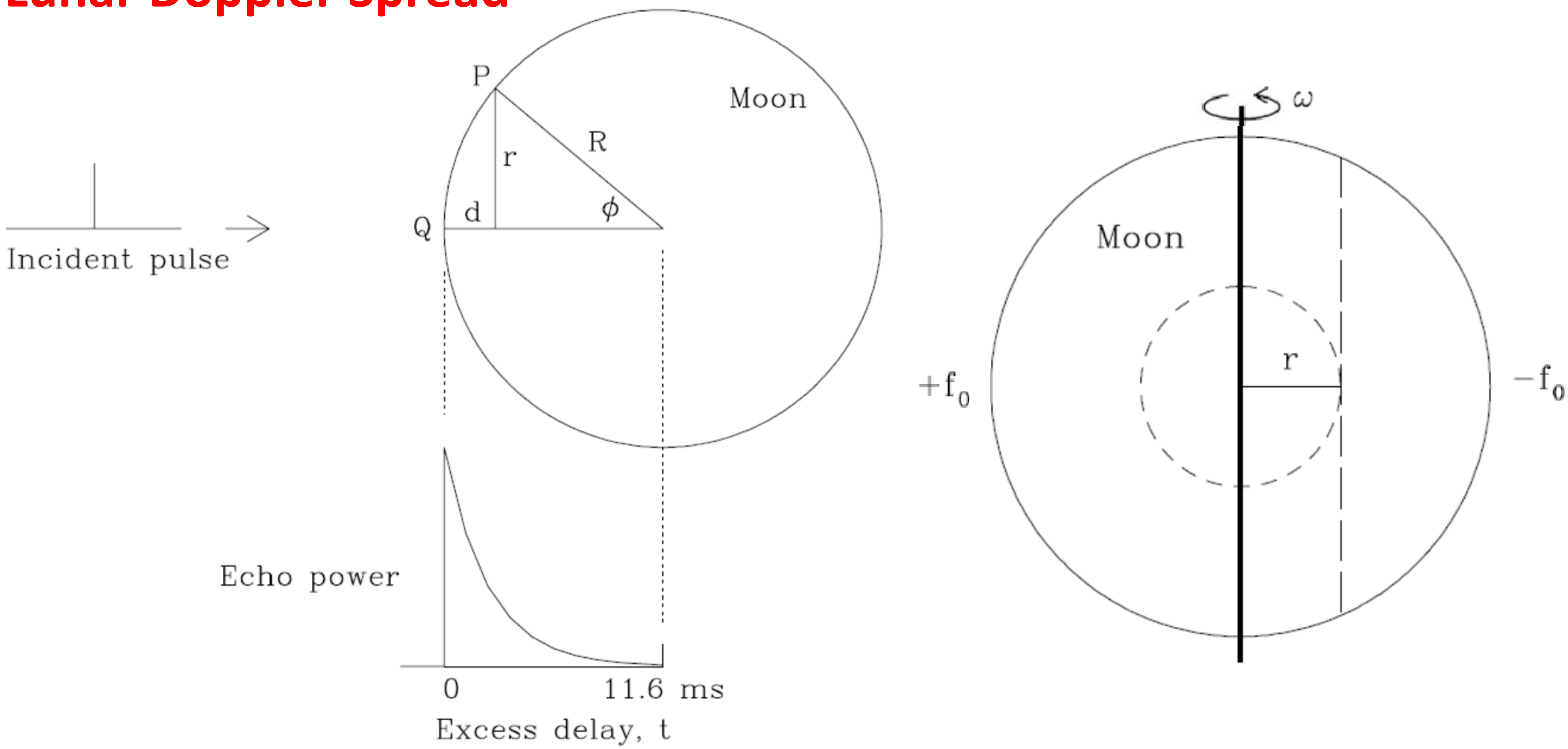
Not to scale ☺
Images: NOAA, cleanpng.com

Libration

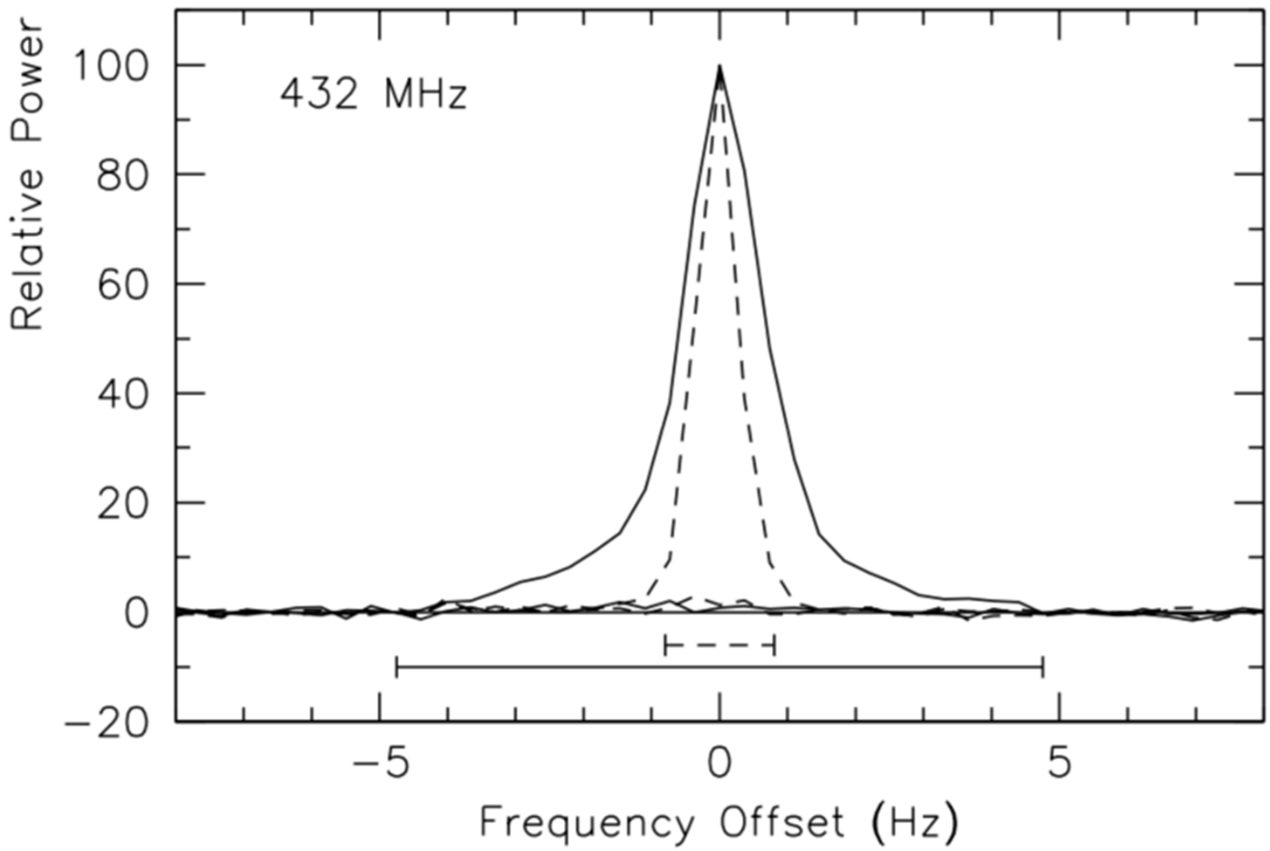
(Illustration is one of several types, but the one most relevant to eme)

https://www.cloudynights.com/topic/530699-parallax-libration-or-both/

Lunar Doppler Spread



Adapted from J. Taylor, “Frequency-dependent Properties of the EME Path,” 2010



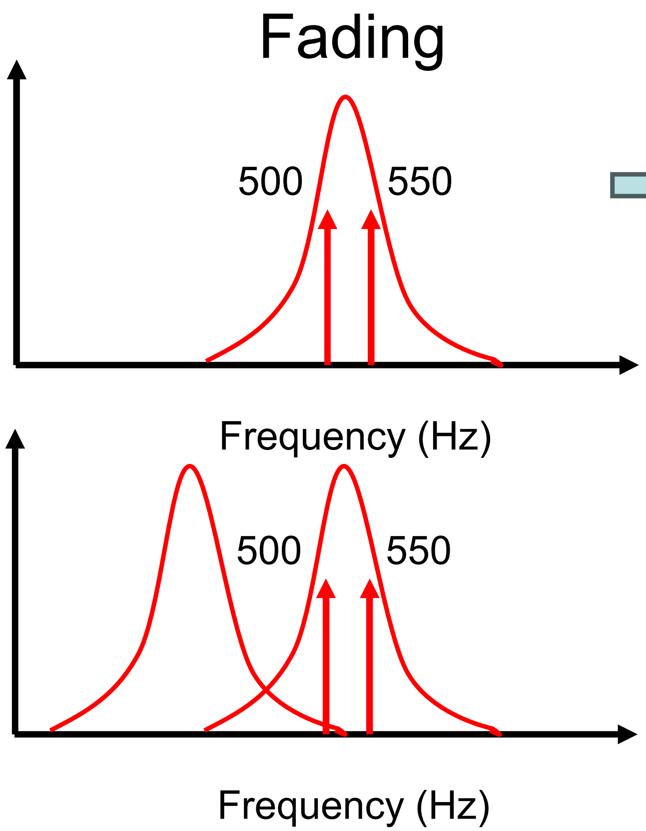
J. Taylor, “High-Accuracy Prediction and Measurement of Lunar Echoes,” QEX, Sept/Oct. 2016

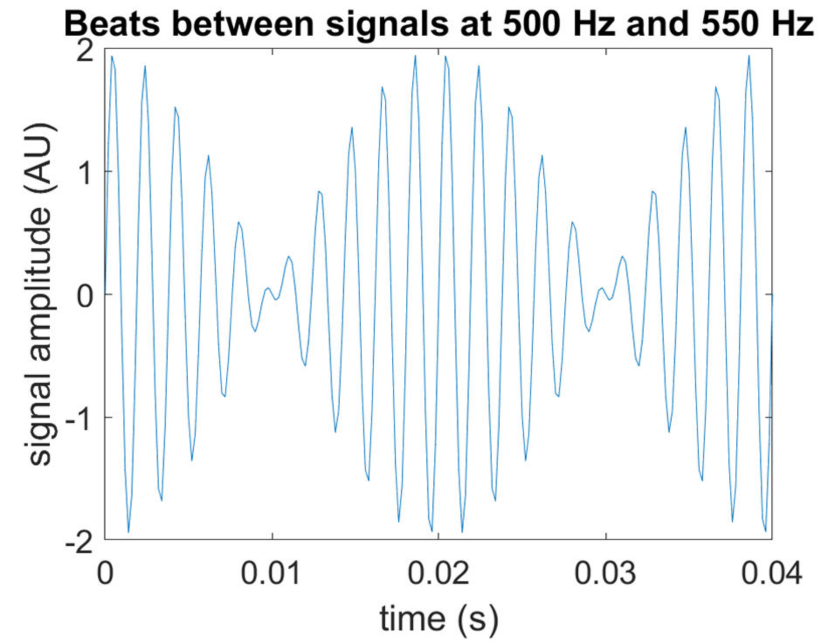
Median Doppler Spreads

Frequency (MHz)	Limb-to-Limb Maximum (Hz)	Limb-to-Limb Median (Hz)	w_{10} Median (Hz)	w_{50} Median (Hz)
144	4	2.2	1.1	0.4
432	12	7	3	1.2
1296	37	19	10	4
2304	65	35	20	8
3400	97	51	31	12
5760	164	86	60	25
10368	295	156	128	58

J. Taylor, “Frequency-dependent Properties of the EME Path,” 2010

Considerations from Doppler Spread



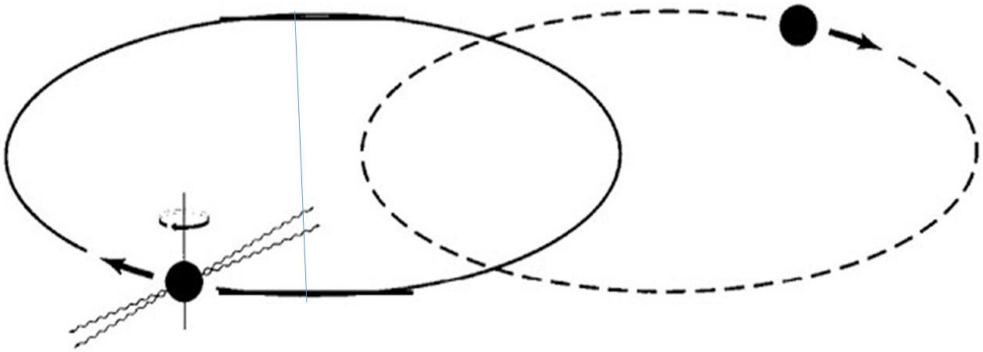


Minimum Tone Separation

Weak Signal Detection Techniques: WSJT-X

- Designed by team led by Joe Taylor, K1JT
  - Nobel Prize in Physics 1993 along with Russel Hulse for discovery of first binary pulsar and first indirect detection of gravitational waves

Binary Pulsar PSR B1913+16



PSR 13 +16 orbiting around a similarly massive star
(picture from the Nobel Lecture – Russell Hulse 1993)

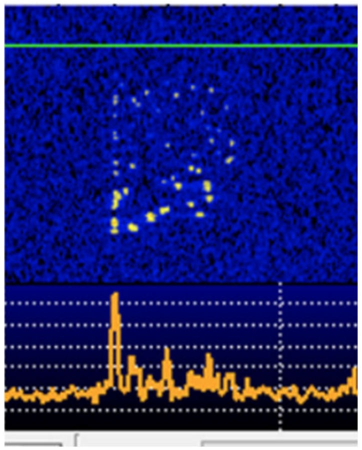
WSJT-X Protocol predominantly used at 1296 MHz: Q65

- Globally synchronized time frames, 22 “tone 0” symbols
- 65 tone frequency-shift keying
- Error correction coding: Q-ary Repeat-Accumulate (65,15) code, 6-bit symbols
- 2 symbols are “punctured” and not transmitted, yielding effective (63,13) code
  - Punctured bits represent 12 bit CRC computed from the remaining 13 message symbols
  - Message + CRC bits: 15 x 6 = 90 bits
  - Number of transmitted symbols/transmission: 63+22 = 85 symbols
- A priori decoding

Q65 Details

SNR in 2500 Hz bandwidth yielding 50% decode probability

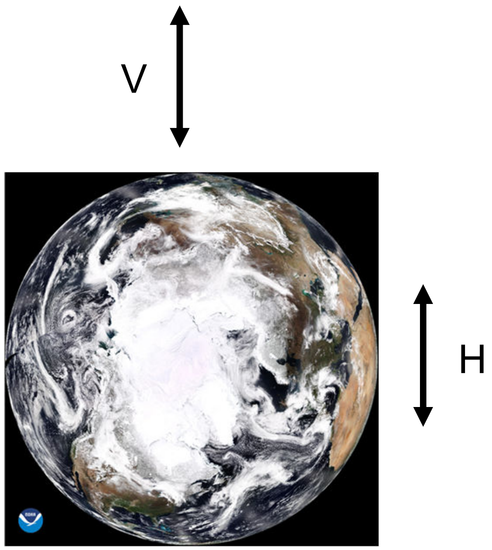
T/R Period (s)	Symbol Length (s)	"A" Tone Spacing (Hz)	"A" Occupied Bandwidth (Hz)	Transmission Duration (s)	SNR (dB)	Max AP SNR (dB)
15	0.150	6.667	433	12.8	-22.2	-23.7
30	0.300	3.333	217	25.5	-24.8	-26.6
60	0.600	1.667	108	51.0	-27.6	-30.2
120	1.333	0.750	49	113.3	-30.8	-32.5
300	3.456	0.289	19	293.8	-33.8	-37.4



Q65-60C
Common
For 1296 MHz

T/R Period (s)	A Spacing (Hz)	A Width	B Spacing (Hz)	B Width	C Spacing (Hz)	C Width	D Spacing (Hz)	D Width	E Spacing (Hz)	E Width
15	6.67	433	13.33	867	26.67	1733	N/A		N/A	
30	3.33	217	6.67	433	13.33	867	26.67	1733	N/A	
60	1.67	108	3.33	217	6.67	433	13.33	867	26.67	1733
120	0.75	49	1.50	98	3.00	195	6.00	390	12.00	780
300	0.29	19	0.58	38	1.16	75	2.31	150	4.63	301

Polarization for EME paths

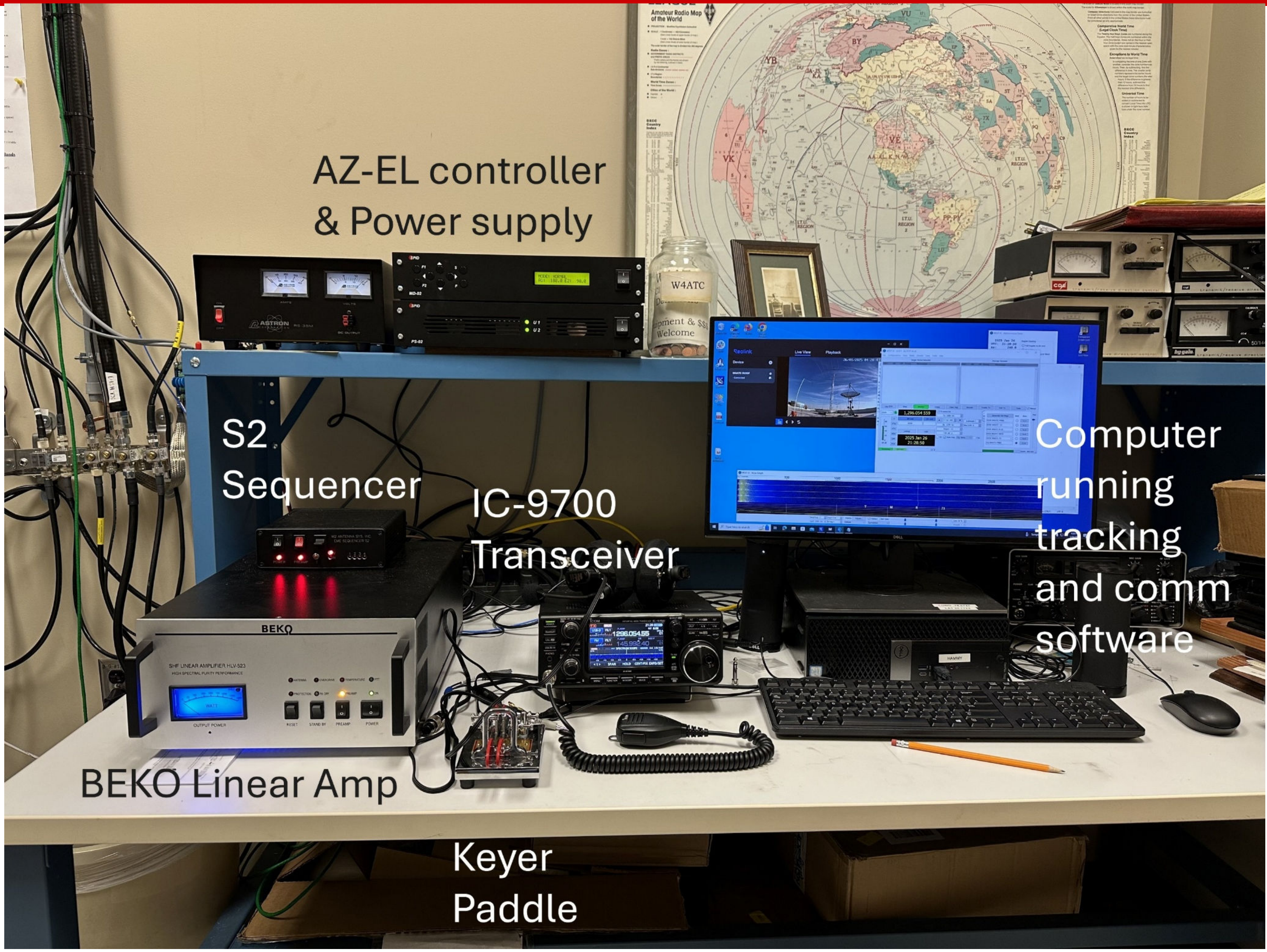


- Linear Polarization
  - "Vertical" polarization at one location on earth not necessarily "vertical" at another location
  - Faraday rotation below 1 GHz
  - Mitigation: ability to rotate linear polarization at each station
- Circular polarization
  - Polarization sense reverses upon reflection
  - Use opposite sense for transmit and receive
  - Standard for EME at 1296 MHz

W4ATC EME Dish

Koch Hall

- Location: ~~Engineering~~ building II
- 2.4m Dish Antenna, Bundle from RF Hamdesign:
  - 28 dBi gain at 1296 MHz
  - Tripod
  - 2.4m Dish
  - AZ/EL positioner
  - Dual polarization feedhorn (RH,LH)


AZ-EL controller
& Power supply
S2
Sequencer
IC-9700
Transceiver
Computer
running
tracking
and comm
software
BEKO Linear Amp
Keyer
Paddle
BEKO
W4ATC

Estimated Received Signal Level

$$P_r = \frac{P_t G_t}{4\pi R^2}\frac{\sigma A_e}{4\pi R^2}; \quad G_t = \frac{4\pi}{\lambda^2}A_e \quad \sigma = 0.065\pi R_m^2$$

$$= \frac{P_t A_e^2 \sigma}{4\pi\lambda^2 R^4}$$

$$= 1.049 \times 10^{-19} \text{ W}$$

P_t = 300 W
G_t = 28 dB
R_m = 1734.4 km
λ = 0.2315 m
R = 370,709 km

Aside: Voyager I Received Power at 1 light day (Nov 2026)

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2$$

$$= 3.41 \times 10^{-19}\,\mathrm{W}$$

P_t = 18 W
G_t = 48 dBi
λ = 0.0356 m
G_r = 74 dBi
(70 m DSN; e.g. Goldstone)
R = 2.59 x 10^{10} km
(1 light day)

23 cm eme power from W4ATC: $= 1.049 \times 10^{-19}$ W

Power received at the terminals of the W4ATC antenna is comparable to or less than the power at the terminals of a DSN dish from the Voyager I at 1 light day distance!

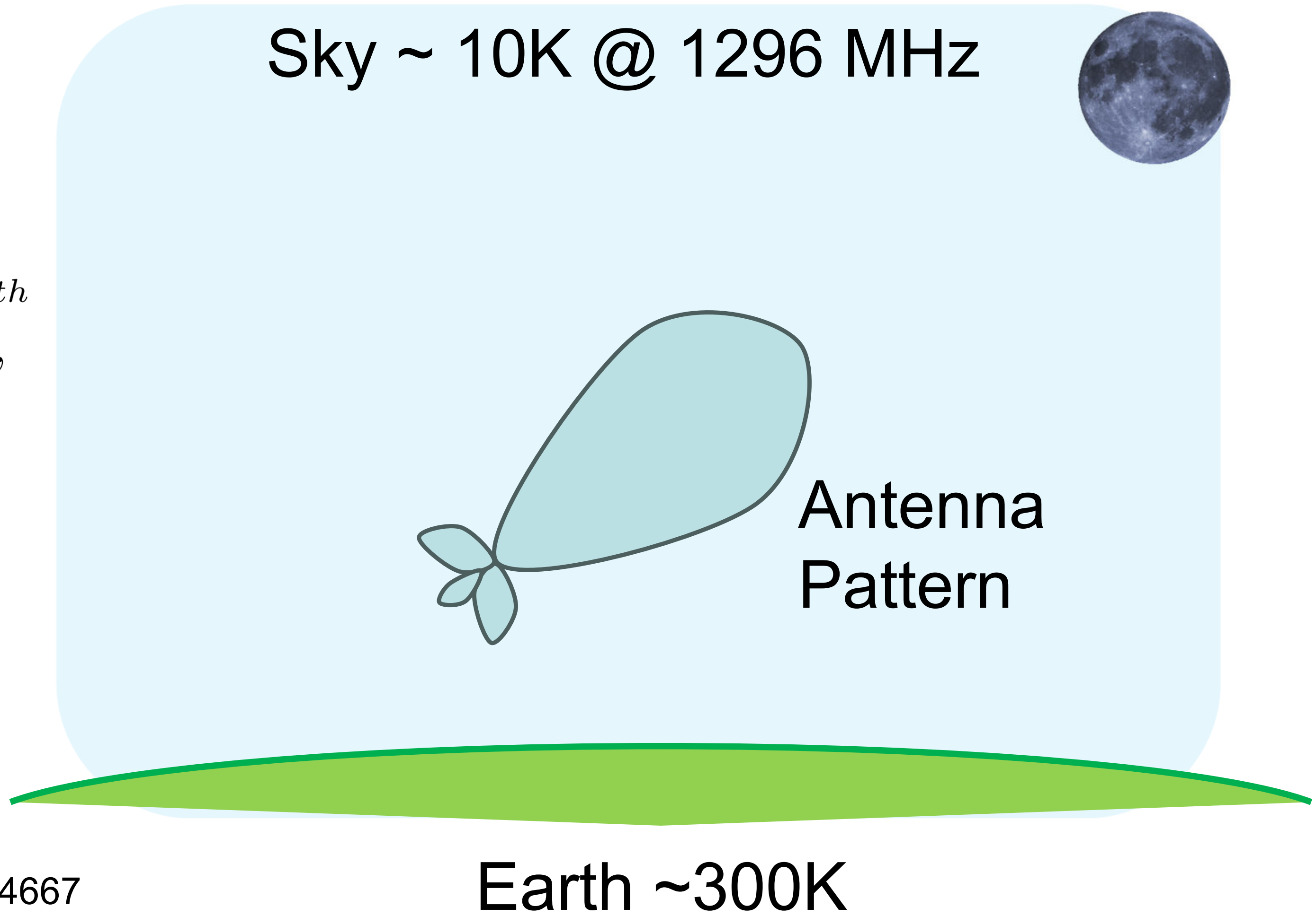
(*However, the DSN receives 160 bps from Voyager 1, while we receive 77/60 = 1.3 bps…)*

Antenna Temperature

$$T_A = \eta_{SP} T_{Sky} + (1 - \eta_{SP}) T_{Earth}$$

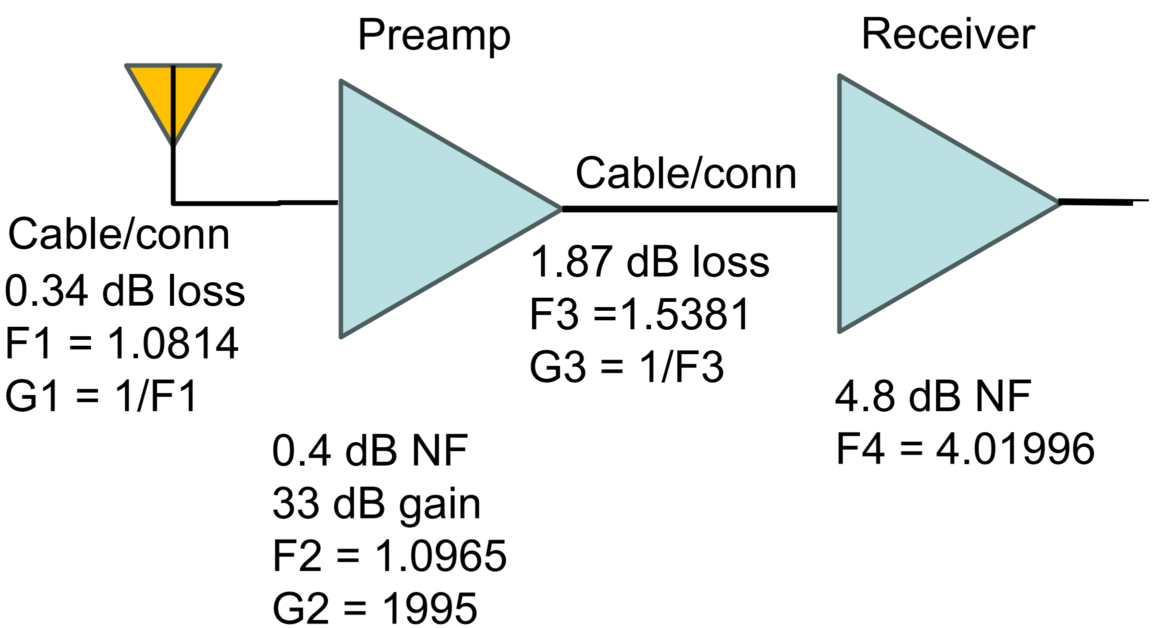
η_{SP} is the "spillover efficiency"

$$\begin{aligned} T_A &= 0.85 \times 10 + 0.15 \times 150 \\ &= 31\,K \end{aligned}$$



https://www.freeiconspng.com/img/44667

System Noise Factor and Noise Temperature



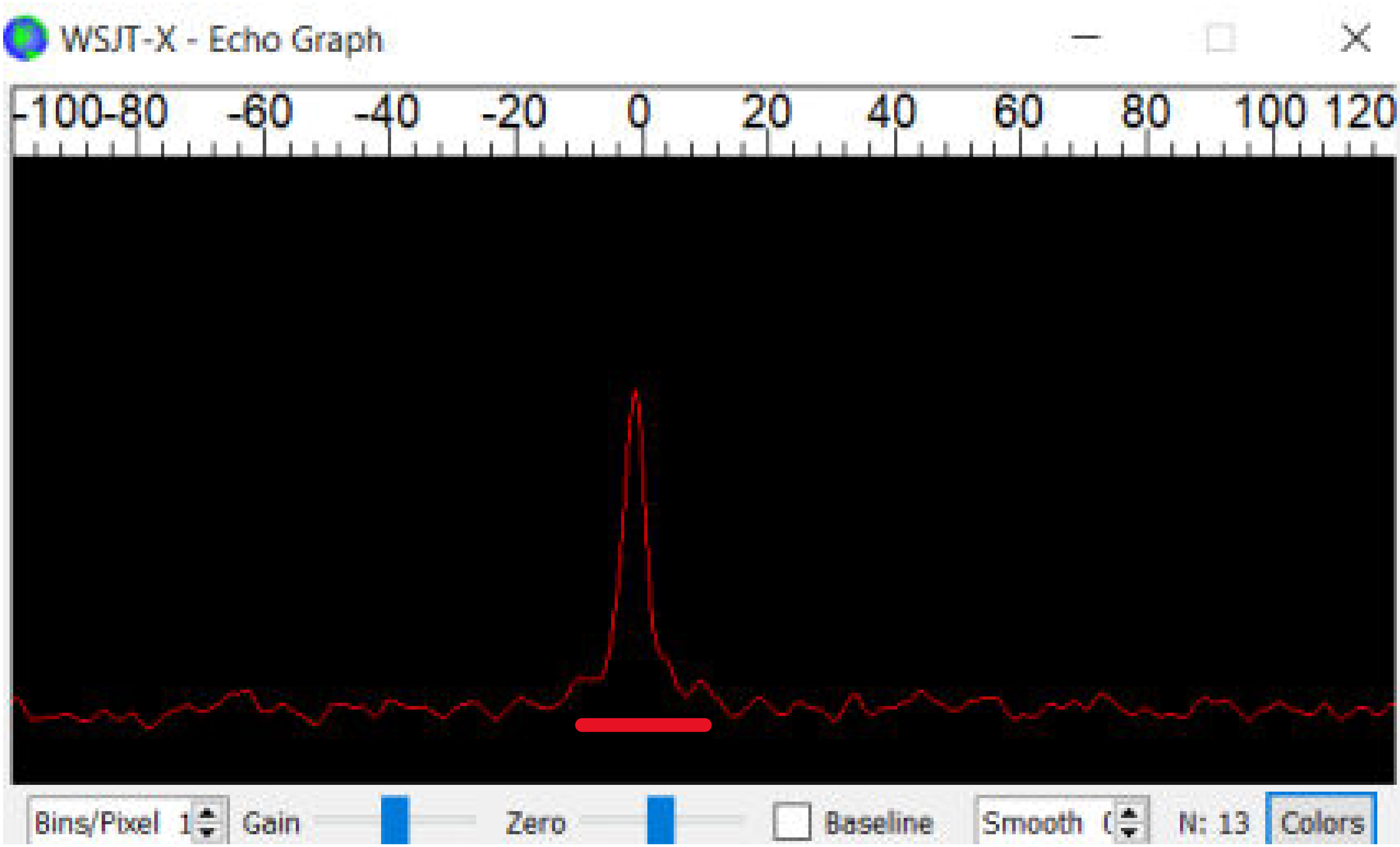
$$
\begin{aligned}
F_{Sys} &= F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} \\
&= 1.188 \\
T_{Sys} &= (F_{Sys} - 1)\, T_0; \quad T_0 = 290K \\
&= 54.5K
\end{aligned}
$$

Noise Power and Signal-to-Noise Ratio

$$
\begin{aligned}
P_N &= k_B(T_A + T_{Sys})B \\
&= 1.38 \times 10^{-23} \times (31 + 55) \times 2500 \\
&= 2.97 \times 10^{-18}\, W
\end{aligned}
$$

$$SNR = \frac{P_r}{P_N} = \frac{1.05 \times 10^{-19}}{2.97 \times 10^{-18}} = 0.0354 \text{ or } -14.5\, dB$$

W4ATC First Echoes, May 30, 2024



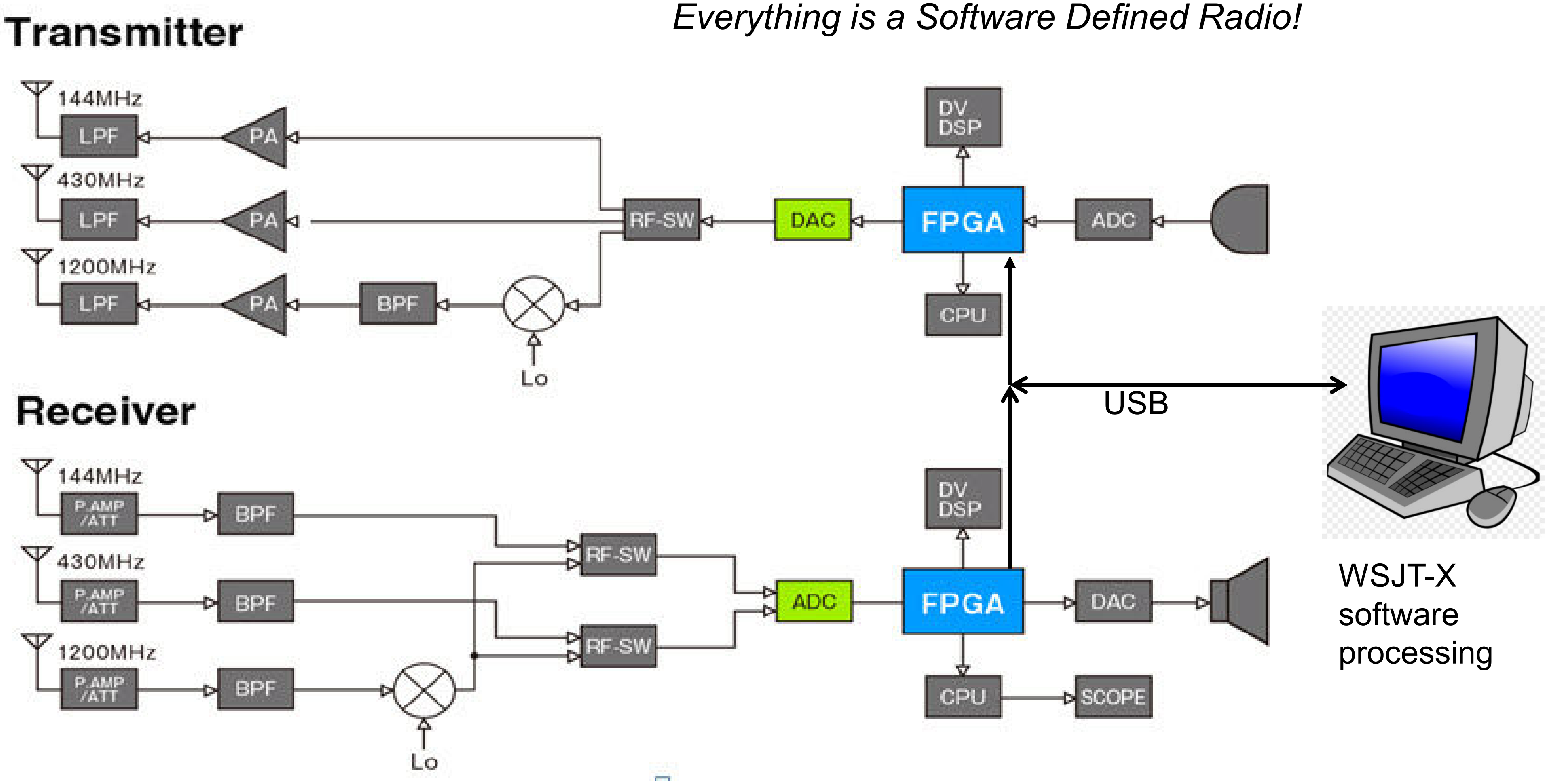
SNR typically around -17 dB

What do the signals sound like?

What do the signals sound like?

IC-9700 Block Diagram

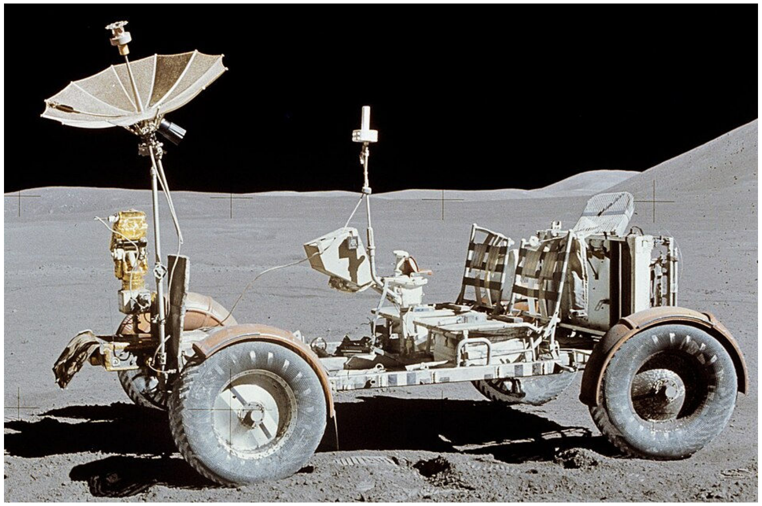
Everything is a Software Defined Radio!



WSJT-X software processing

Portable Home Station at WY3O

Folding antenna from Sub-Lunar Systems
First eme contact: Hawaii!



Antenna inspired by Apollo rover antenna
(Apollo 15 rover shown)

Next: Amateur Radio on the Moon

- Amateur Radio Exploration (AREx)
  - Amateur Radio Satellite Corporation (AMSAT)
  - Amateur Radio on the International Space Station (ARISS)
- Charged by NASA to develop Amateur Radio Activities for Lunar Missions
  - Operational Systems and Educational capabilities to engage youth and public in STEM/STEAM

- Concepts include:
  - Cameras for earth, moon, and vehicle imaging
  - Voice, digital, video
  - 5 GHz and 10 GHz links
  - **Enabled by SDRs**

Summary

- Space communication is only going to increase in importance
  - Increasing role of satellites
  - Importance of moon for science and solar system exploration
- Software Defined Radios are key enablers addressing challenges of Doppler shift, Doppler spread, demodulation, error correction
- With the power of SDRs, amateur radio operators can communicate by actually bouncing radio signals off the moon!
- Future lunar missions will include STEM programs using amateur radio


09/05/2025 08:20:02 pm FRI
W4ATC Dish in Action
W4ATC ROOF