EARTH-MOON-EARTH COMMUNICATION

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EME – EARTH-MOON-EARTH

- What is it?
    - Using the moon as a passive reflector to communicate between two stations on earth at radio frequencies
- Who does it?
    - Amateur radio operators
    - Europe, US, Asia, Oceania, Africa
- Why do they do it?
    - Usually because of the technical challenge, it’s hard
    - The “ultimate” DX

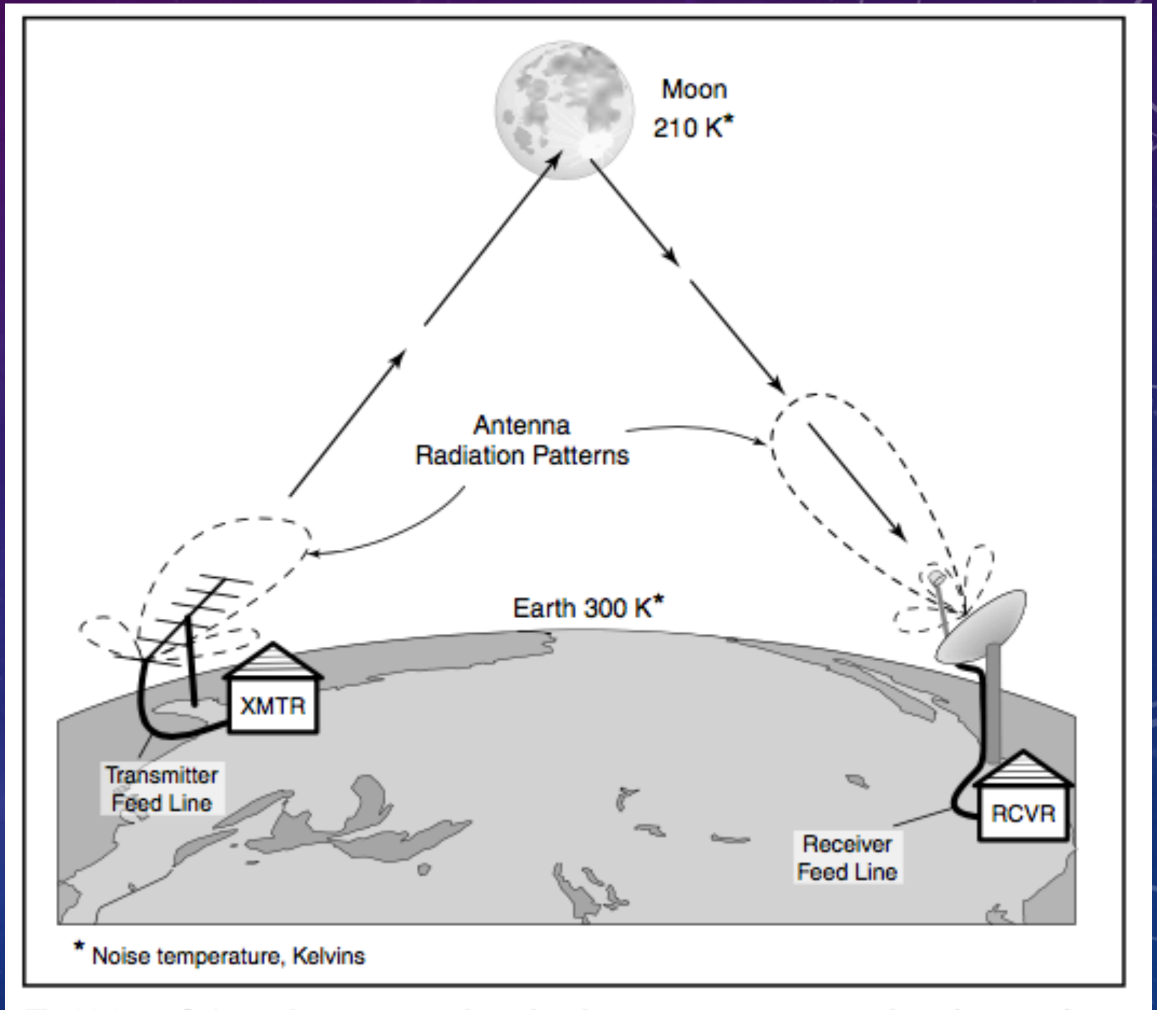
HISTORY OF EME

- 1953 W3GKP and W4AO detect lunar echoes on 144 MHz
- 1960 First amateur 2-way EME contact: W6HB works W1FZJ, 1296 MHz (EIMAC ARC)
- 1964 W6DNG works OH1NL, 144 MHz
- 1964 KH6UK works W1BU, 432 MHz
- 1970 WB6NMT works W7CNK, 222 MHz
- 1970 W4HHK works W3GKP, 2.3GHz
- 1972 W5WAX and K5WVX work WA5HNK and W5SXD, 50 MHz
- 1987 W7CNK and KA5JPD work WA5TNY and KD5RO, 3.4 GHz
- 1987 W7CNK and KA5JPD work WA5TNY and KD5RO, 5.7 GHz
- 1988 K5JL works WA5ETV, 902 MHz
- 1988 WA5VJB and KF5N work WA7CJO and KY7B, 10 GHz
- 2001 W5LUA works VE4MA, 24 GHz
- 2005 AD6FP, W5LUA and VE4MA work RW3BP, 47 GHz
- 2005 RU1AA works SM2CEW, 28 MHz
- 2009 GDØTEP works ZS6WAB, 70 MHz

Standing: Robert Sutherland W6UOV (now W6PO), Hank Brown W6HB, Bill Eitel W6UF, George M W Badger W6RXW (now W6TC), Al Clark W6MUC and Bob Morwood K6GLF.
Sitting: Ray Rinaudo W6KEV (was W6ZO then back to KEV), Charlie Anderson W6IVZ (now W6VW), Allan Beer K6GSO.

THE PATH

- As seen from Earth the moon has 0.5 degree subtended angle
- The distance to the moon from a point on Earth is constantly changing
    - Approximately 250,000 miles
- Moon moves at about 15 degrees per hour



RADAR EQUATION

- $\text{Loss} = (N * R^2 * \text{lambda}^2)/(64 * \text{Pi}^2 * D^4)$ with isotropic transmit/receive antennas
  - D – distance to target
  - R – radius of target
  - Lambda – wavelength (1/frequency)
  - N - reflection coefficient, moon ~ 0.065
- Freespace is not lossy, energy spreads out as D^2 => to & from the target becomes D^4
- Path loss increases with frequency as ^2
  - but for constant aperture antennas gain increases with frequency as ^2 for both transmit and receive or ^4 in total
  - ^2 loss / ^4 gain = ^2 loss ***DECREASE*** with frequency
- Caveat: equation assumes the target is over-illuminated, may be violated at microwave frequencies

LINK BUDGET

SNR = Ta + Tp – Pl + Ra - Rs

Ta: transmit antenna gain
Tp: transmit power dbm
Pl: path loss
Ra: receive antenna gain
Rs: receive sensitivity, -174dbm/Hz @290K

144 MHz JT-65 example: 500w, 2Hz BW, 2.5wl yagi

SNR = 13 + 57 – 252 + 13 + 171 = 2Db

144 MHz CW example: 1000w, 50Hz BW, 2.5wl yagi

SNR = 13 + 60 – 252 + 13 + 157 = -9Db

1296 MHz example: 200w, 50Hz BW, 3m dish

SNR = 30 + 53 – 271 + 30 + 160 = 2Db

Frequency MHz	Average path loss DB
50	244
144	252
432	261
1296	271
2304	276
3456	279
5760	283

OTHER LOSS COMPONENTS

- Atmospheric absorption
- Cosmic, Galactic and manmade noise
- Receiver noise
- Antenna pointing
- Transmit power
- Cross polarization
- Faraday rotation
- Doppler shifting, spreading, libration
- Frequency stability

NOISE IS THE ENEMY ON RECEIVE

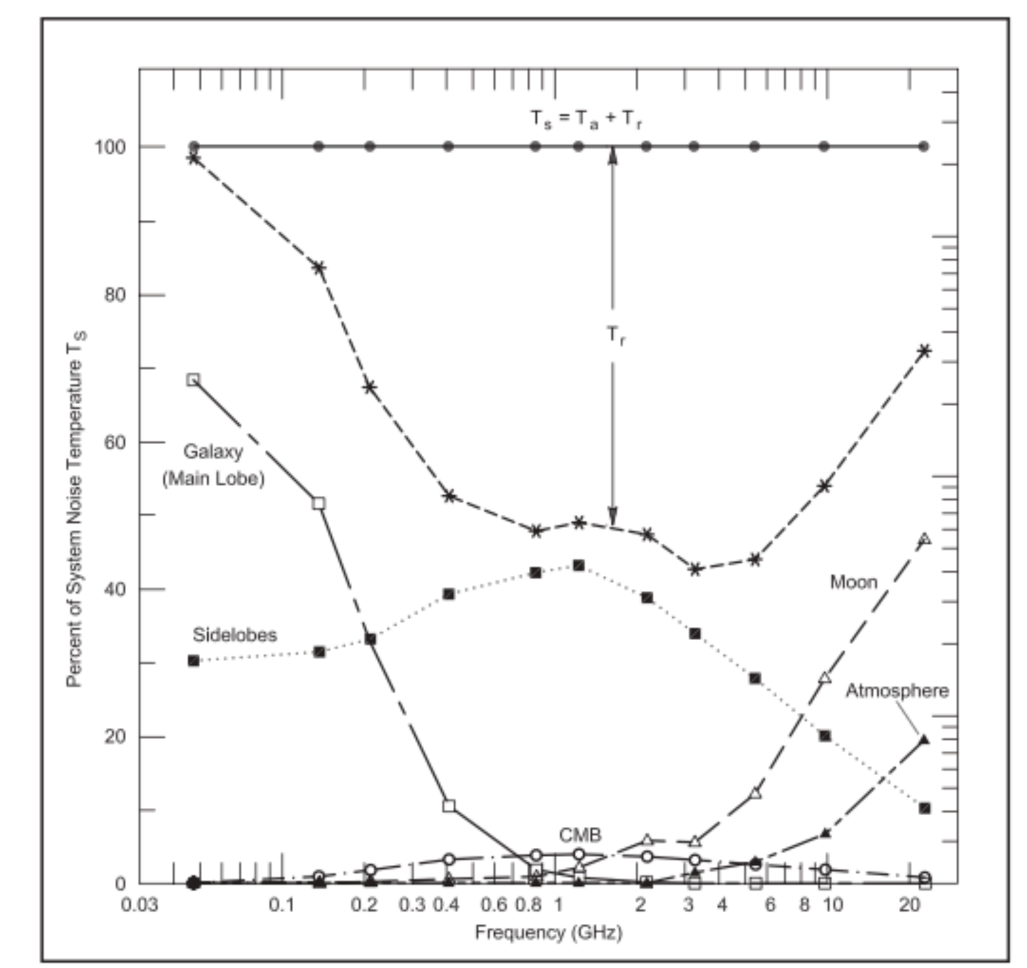
1-3 GHz is the lowest noise spectrum

5GHz and above moon black body radiation and atmospheric loss become significant

Below 1 GHz Galactic and manmade noise dominates

Low noise on receive requires:

1) a great LNA, T/R, zero feedline loss
2) minimal side lobes that “see” the earth



ANTENNA GAIN IS GOLD

- Works on both transmit and receive
  - High power transmit is not always helpful, if you can't hear them …
- Up to the point of under-illuminating the moon, ~6db beamwidth of 0.5 degrees, 50Db
- Can always choose to under-illuminate a big dish: minimize side lobes that "see" the earth
  - Helps hearing the low power guys

DOPPLER IS THE ENEMY

- Doppler effects destroy frequency coherence of the signal:
  - Libration fading: differential doppler from the opposing limbs of the moon
- Surface roughness and moon diameter destroy temporal and phase coherency of the signal
  - Reflections arrive at differing times
- Above 3 GHz the combination becomes deadly
  - 47 GHz EME had >100 Hz frequency spreading and 100us temporal spreading
  - 47 GHz doppler change required computer to auto tune the receiver: 1 KHz/minute

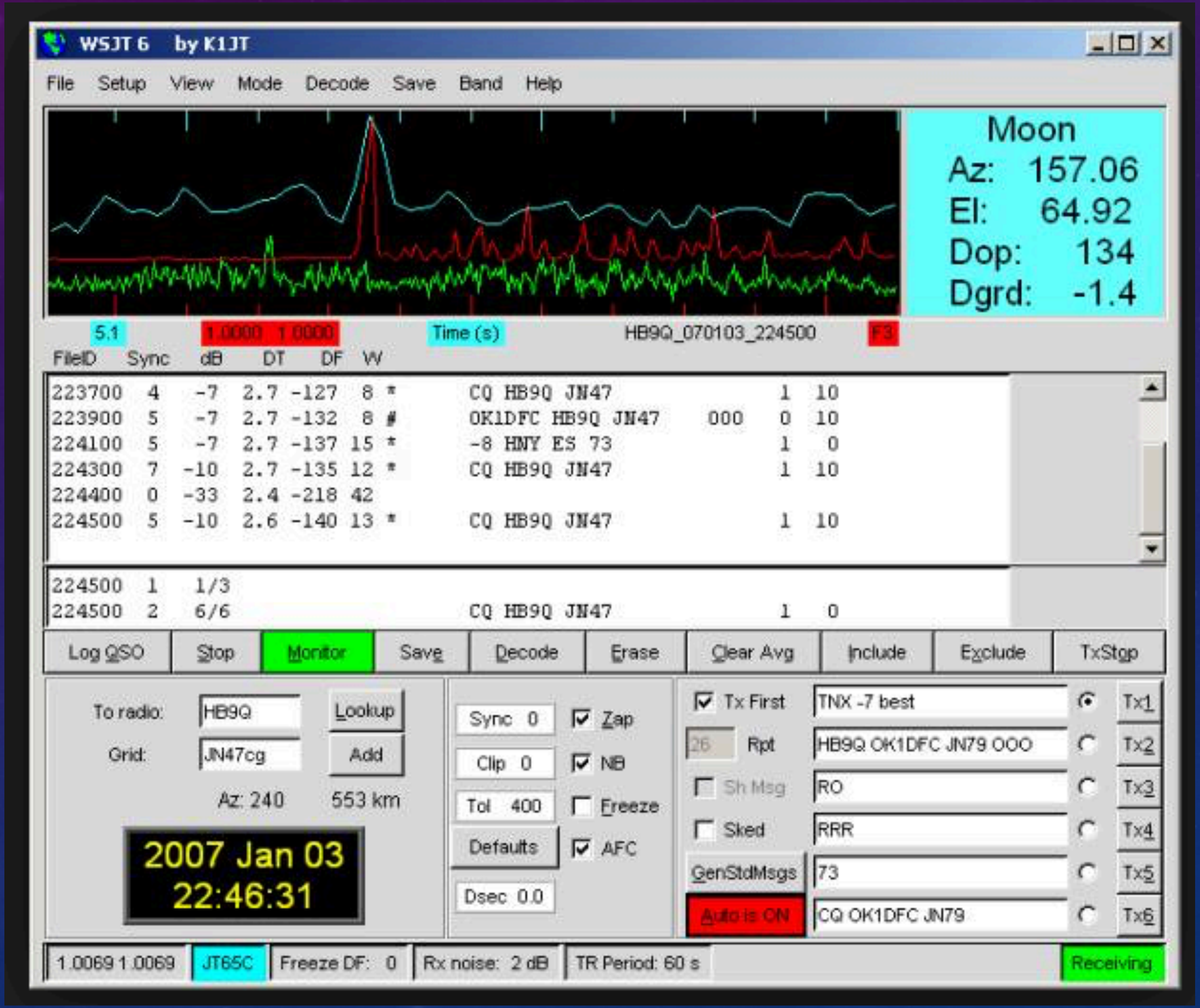
POLARIZATION IS THE ENEMY

- At low frequencies Faraday rotation in the atmosphere produces lock-out
  - 144/432 linear is a disadvantage
- Geometric polarization offset is always a concern
  - At 1296,2304 everyone uses circular, it works well!
- At mm-wave frequencies reflected polarization is random due to roughness

MODES TO THE RESCUE

- Joe Taylor, KJ1JT, wrote a program in 2001 based on a 1996 paper by Phil Karn ka9q and Tom Clark w3iwi
- JT-44/65 revolutionized EME for small stations
  - Improves SNR ~10db -> lower power, smaller antennas
- MFSK with forward error correction
  - More efficient use of bandwidth and transmit power, 2.7Hz BW filters
  - FEC addresses channel fading better than cw repetition
- Generated a war with CW proponents that continues to this day
  - Deep Search was controversial

JT65 SCREEN SHOT



BAND ACTIVITY

- 144 MHz by far the most activity: 1000 stations, faraday lockout, JT65
- 1296 MHz second most popular, 300 stations, smaller antennas, on faraday lockout, small cw possible
- 432 comes in third, much like 144 but smaller antenna
- Microwave bands: 2304/3456/5760/10368/24192 low activity, more $ in equipment
- 50 MHz is a specialty band, huge antennas

CHALLENGES IN BUILDING A STATION

- The biggest challenge is always the antenna
  - High gain is needed: pays off on transmit as well as receive
  - Tracking is hard, particularly as antenna gain increases
- 2nd biggest challenge is transmit power: SSPAs have recently made this easier
- 3rd is assembling and debugging a complex system: antenna, tracking, computer, software, transmitter, lna, T/R switching

EXAMPLE SMALL STATION

K2UYH portable: 1296 MHz DXpedition
7’ stress dish
150 watt SSPA
TS-2000x
Laptop computer for JT-65

EXAMPLE LARGE STATION

HB9Q: multi-band superstation
EME club
144MHz through 10 GHz

10M solid dish
15M screened dish
8 long yagi’s on 144

Legal limit through 1296

- **144 MHz: If you have 1 yagi and 100 watts you are capable to work us!**
- **432 MHz: If you have 1 yagi and 30 watts you are capable to work us!**
- **1296 MHz: If you have 1 yagi and 25 watts you are capable to work us!**
- **23xx MHz: If you have 1 yagi and 50 watts you are capable to work us!**
- **3400 MHz: If you have 1m dish and 50 watts you are capable to work us!**
- **5760 MHz: If you have 90cm dish and 50 watts you are capable to work us!**
- **10xxx MHz: If you have 77cm dish and 10 watts you are capable to work us!**

W6YX

- Active on 144, 432, 1296, 2304 and 10 GHz
- 144 MHz: 4x2.5wl xpol yagi's, 1500w, JT-65
- 432 MHz: 8x2wl yagi's, JT-65
- 1296 MHz: 8M dish, 600w, CW, SSB, JT-65
- 2304 MHz: 8M dish, 200w, CW, JT-65
- 10 GHz: 5m dish, 200w, CW, SSB, JT-65

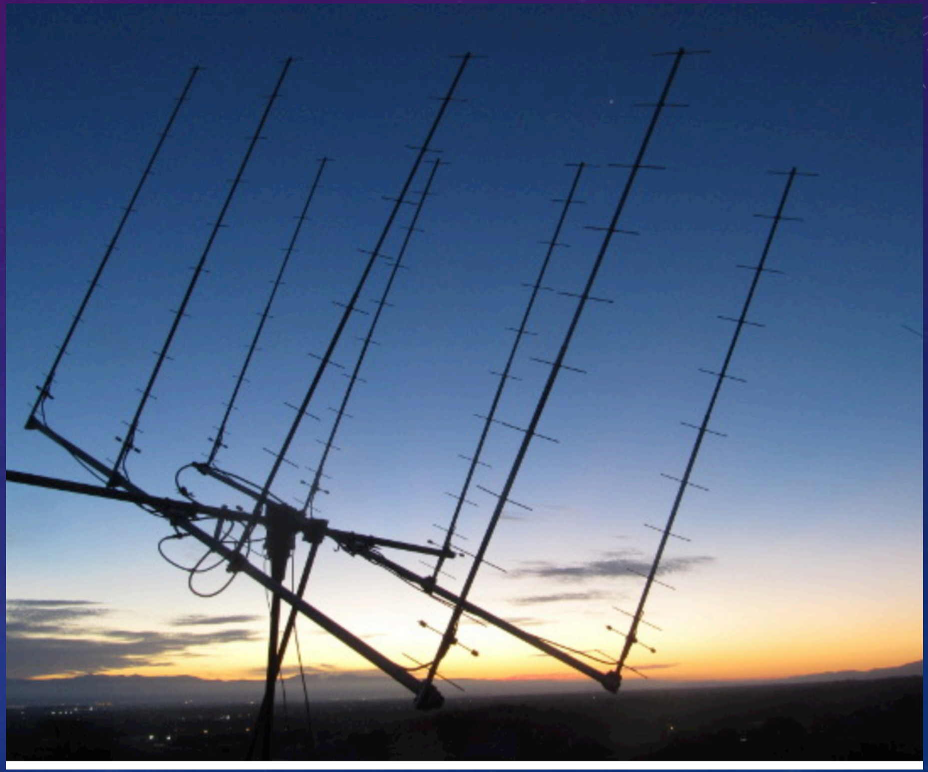
CHALLENGES @ W6YX

- Stuff continually breaks
  - Infrequently used, open field with rodents, minimal time for maintenance
- 144 MHz local interference
  - 145.23 repeater is 600' away
  - Big notch cavities required ahead of the LNAs
- Line-of-sight to Silicon Valley at moonrise: noise from millions of computers, wifi hot spots …
  - European window is at moonrise ☹
- West coast window to Europe is 3 hours shorter than on the East coast

RECENT EME HISTORY @ W6YX

- 1999 W6QI and AD6FP operate CW on 144 from a portable table in the field
  - 6 QSOs
  - 2x1.5wl yagi's and 800w
- 2005 first year on 1296
  - 6m dish, 80w, 20 QSO's
- 2015 multi-op, all band, all mode, 13 operators
  - 8m dish 1296/2304, 4x2.5wl xpol yagi 144, 8xyagi 432, 5m dish 10G
  - 383 QSOs!! 168 multipliers (states & dx entities)

RECORDINGS



RECOMMENDATIONS FOR STARTING OUT

- Choose 144 or 1296, most activity, plenty of big stations
  - My preference is 1296, no faraday, still 50% cw, but tracking and xmit power are harder
  - 144MHz, easy antenna and tracking, no cw, faraday rotation
- Start with JT65: vastly improves the chance of success
- Be prepared to spend 75% or more of your time on mechanical
- Find a mentor or ask questions to moon-net: http://mailman.pe1itr.com/mailman/listinfo/moon-net
- Start small, work some big stations, get infected

ABOUT ME, AD6FP

- First licensed in 1968 as WA2EIW
  - Operated mostly 50-432 MHz terrestrial from NJ
- Relicensed in 1998 as AD6FP
  - Operated 1 year on HF then got interested in 10 GHz
  - First homebrew 10 GHz radio in 2000
  - Hold/held terrestrial distance records on 10, 24, 47 and 78 GHz
  - First 47 GHz EME in 2005 with RW3BP
  - Started building W6YX EME station in 2000
- Employed in computer industry since 1978, currently CTO/Founder of Cerebras Systems

QUESTIONS ?

- W6PQL SSPA: https://www.w6pql.com
- AD6IW LNAs: http://www.ad6iw.com
- JT65: https://physics.princeton.edu/pulsar/k1jt/
- Antenna tracking: http://www.f1ehn.org, http://www.w2drz.ramcoinc.com
- AD6FP@LBACHS.COM