A Low Power, 144 MHz, Earth-Moon-Earth Amateur Radio Station

Dr. William E. Keicher, KC1HTT

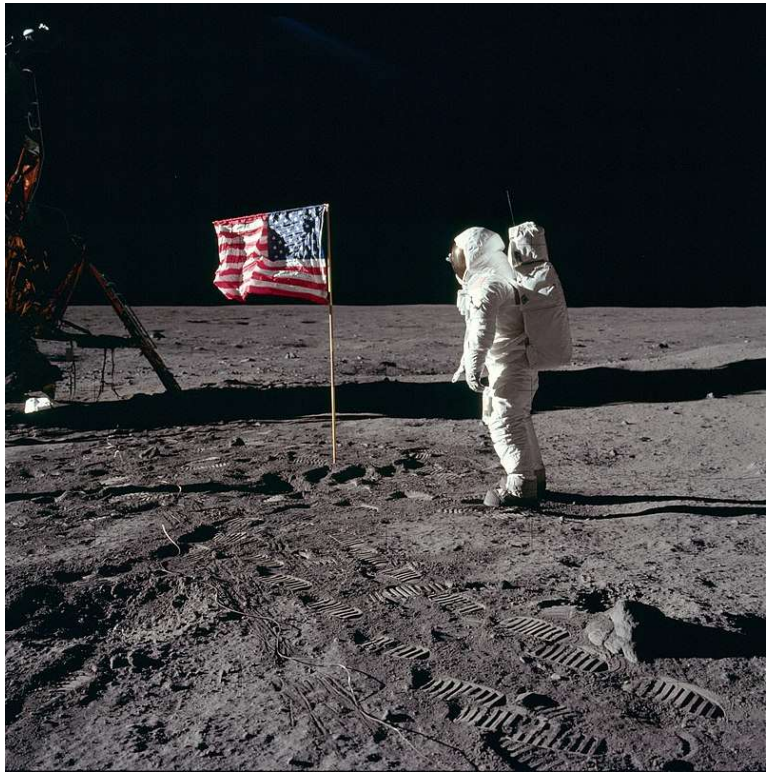
2019 VHF Super Conference

Sterling, Virginia

26 April 2019

Outline

- Objective
- Lunar Characteristics
- Ionospheric Propagation
- KC1HTT EME Station Description
- EME Operations
- Summary

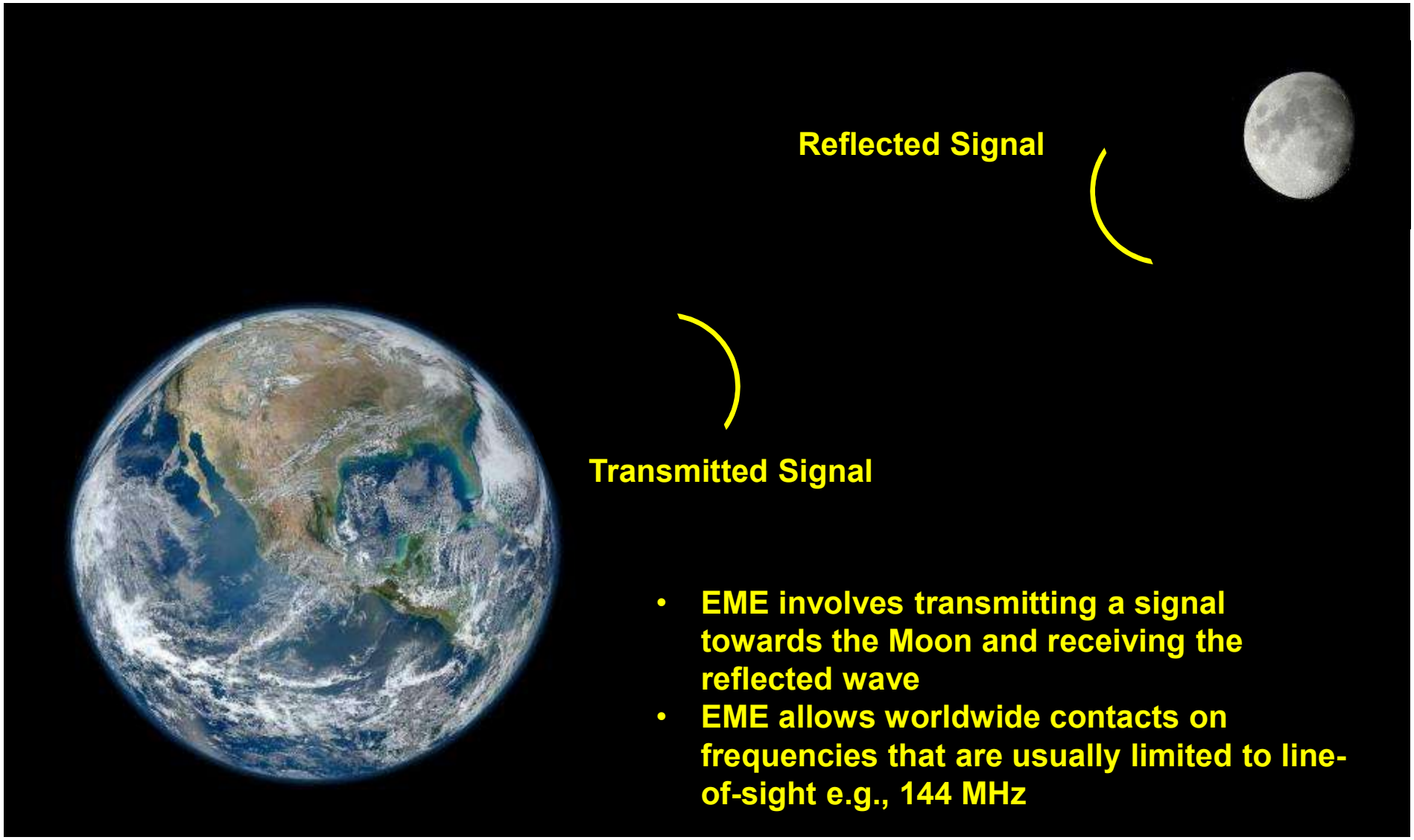


The Fiftieth Anniversary of Apollo 11 Landing on the Moon, 1969 – 2019

Project Selene Objective: Amateur Radio Communications via Moon Reflection

Σελήνη, Selene, Greek Goddess of the Moon

Amateur Radio Earth-Moon-Earth Communications Link

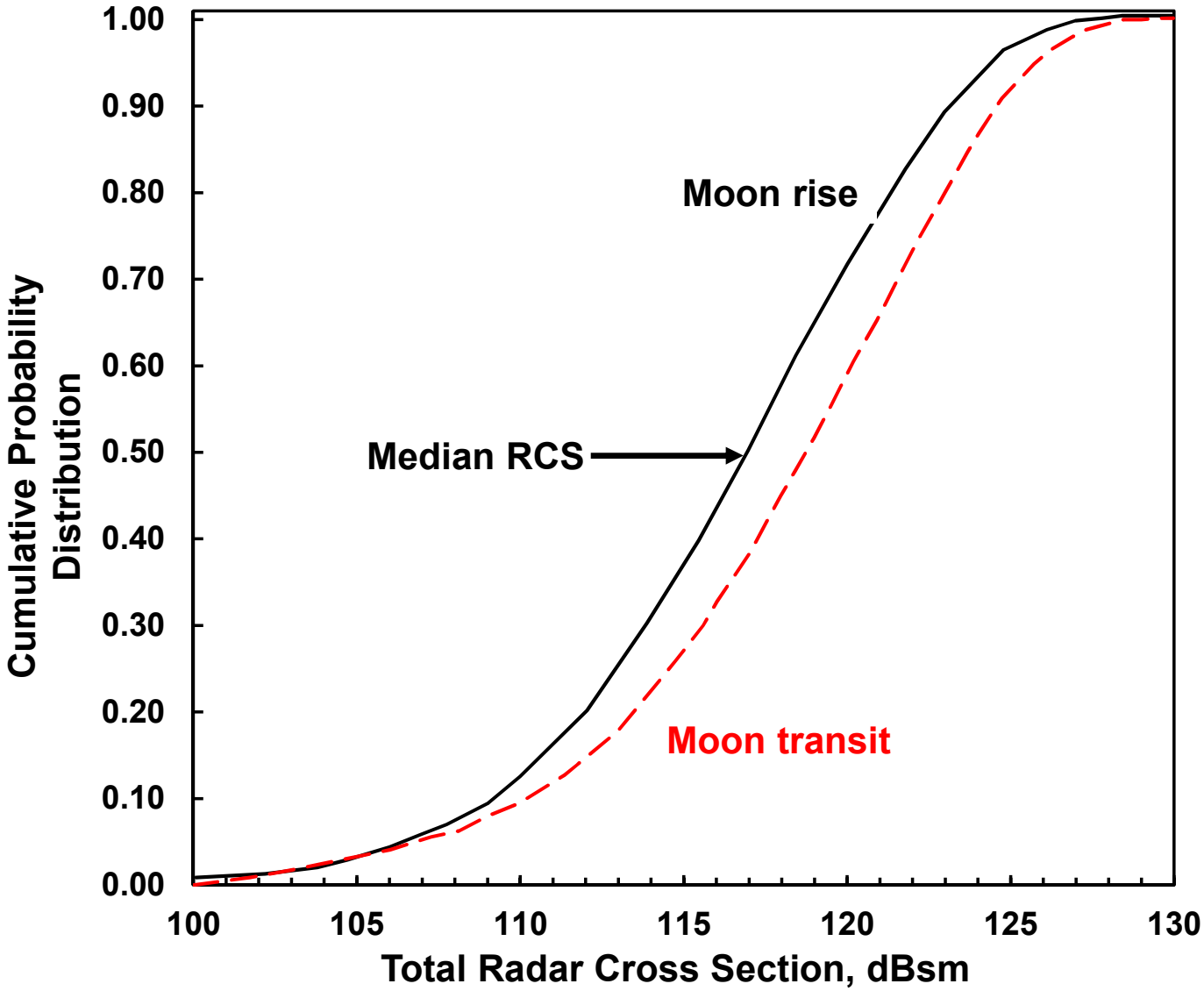


- EME involves transmitting a signal towards the Moon and receiving the reflected wave
- EME allows worldwide contacts on frequencies that are usually limited to line-of-sight e.g., 144 MHz

Key Lunar Characteristics

- Range
  - 3.84×10^8 m
- Lunar Diameter
  - 1.736×10^6 m
- Lunar Angular subtense
  - 9.03 mrad
- Lunar Geometric Cross Section Area
  - $A = 9.47 \times 10^{12}$ square meters
- Lunar Reflectivity at VHF and UHF
  - Reflectivity, ρ ~7.4%
  - Predominantly specular at VHF
- Median Lunar Radar cross section, σ_{Moon}
  - 118.45 dBsm or $\rho A = 7.01 \times 10^{11}$ square meters
  - Radar cross section has a Rician distribution - one major scatterer, many small scatterers
  - Linear polarizations are not altered significantly by lunar reflection
  - Slow fading times - several seconds at 144 MHz

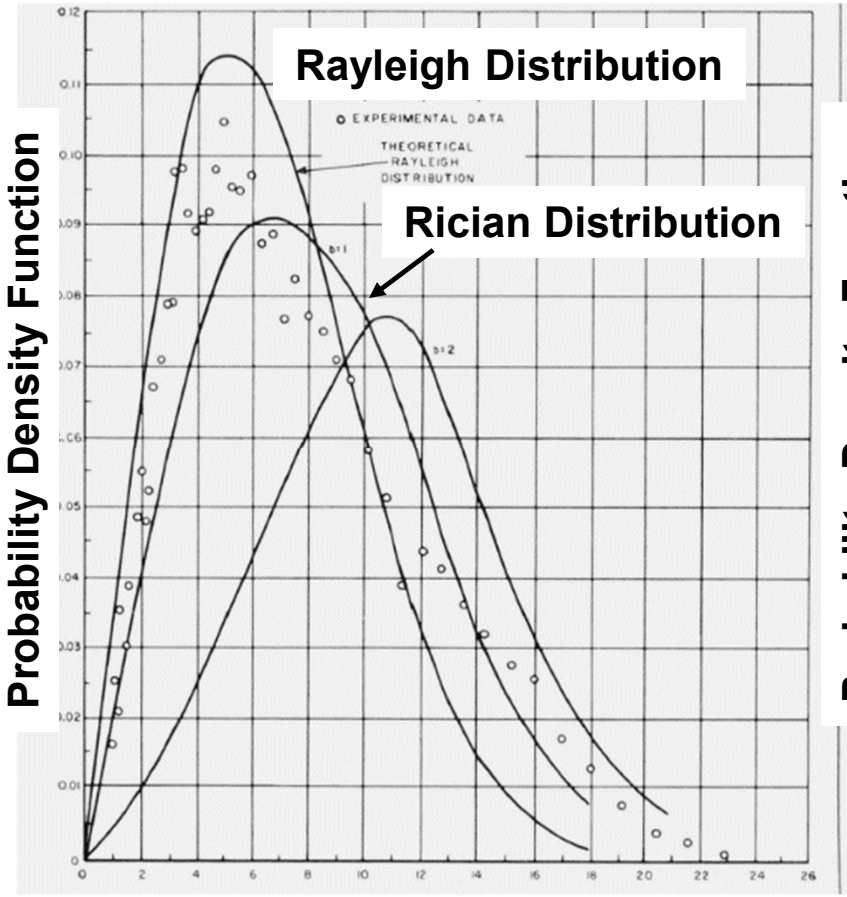
Measured Cumulative Total Radar Cross Section of the Moon at 425 MHz, February 8, 1960



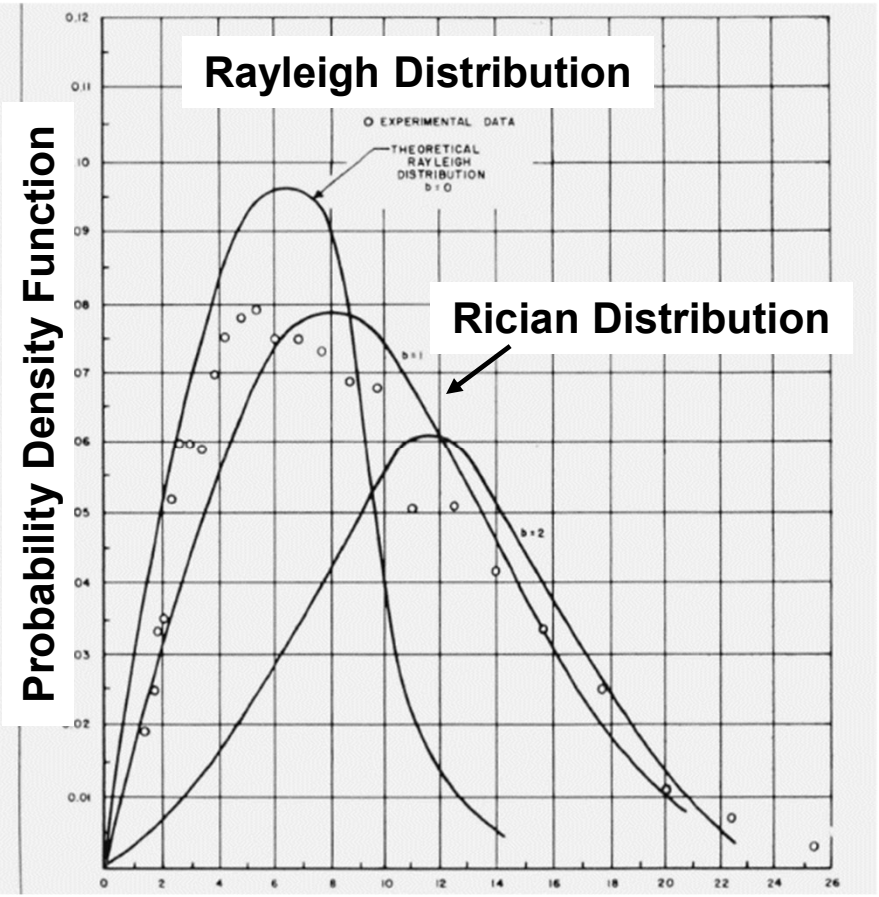
G. H. Millman and F. L. Rose, "Radar Reflections From the Moon at 425 Mc/s,"

Probability Density Functions of Lunar Echo Amplitude at 425 MHz

Moon rise



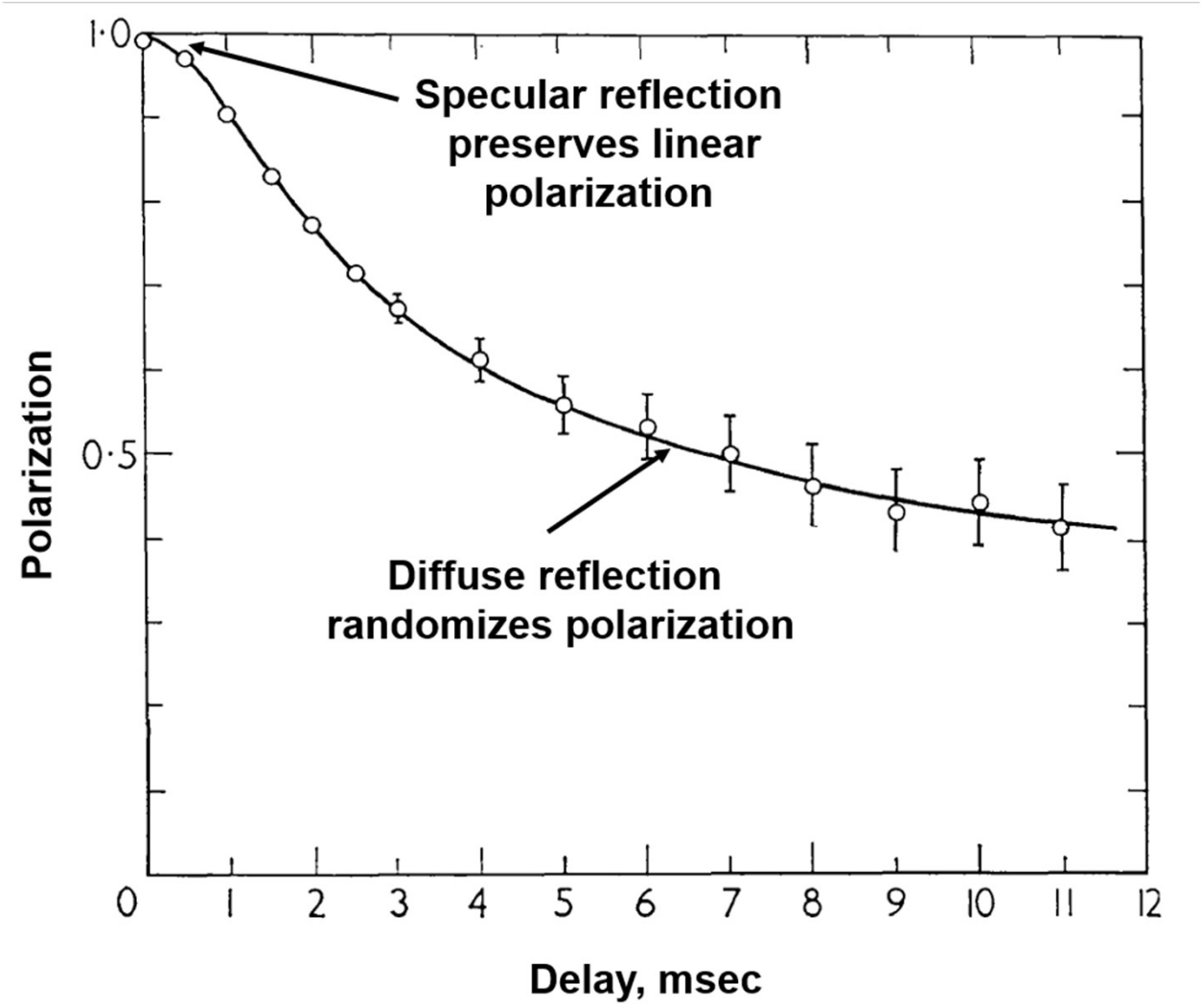
Moon transit



Rician distribution indicates a strong, steady reflection accompanied by many, smaller random reflections

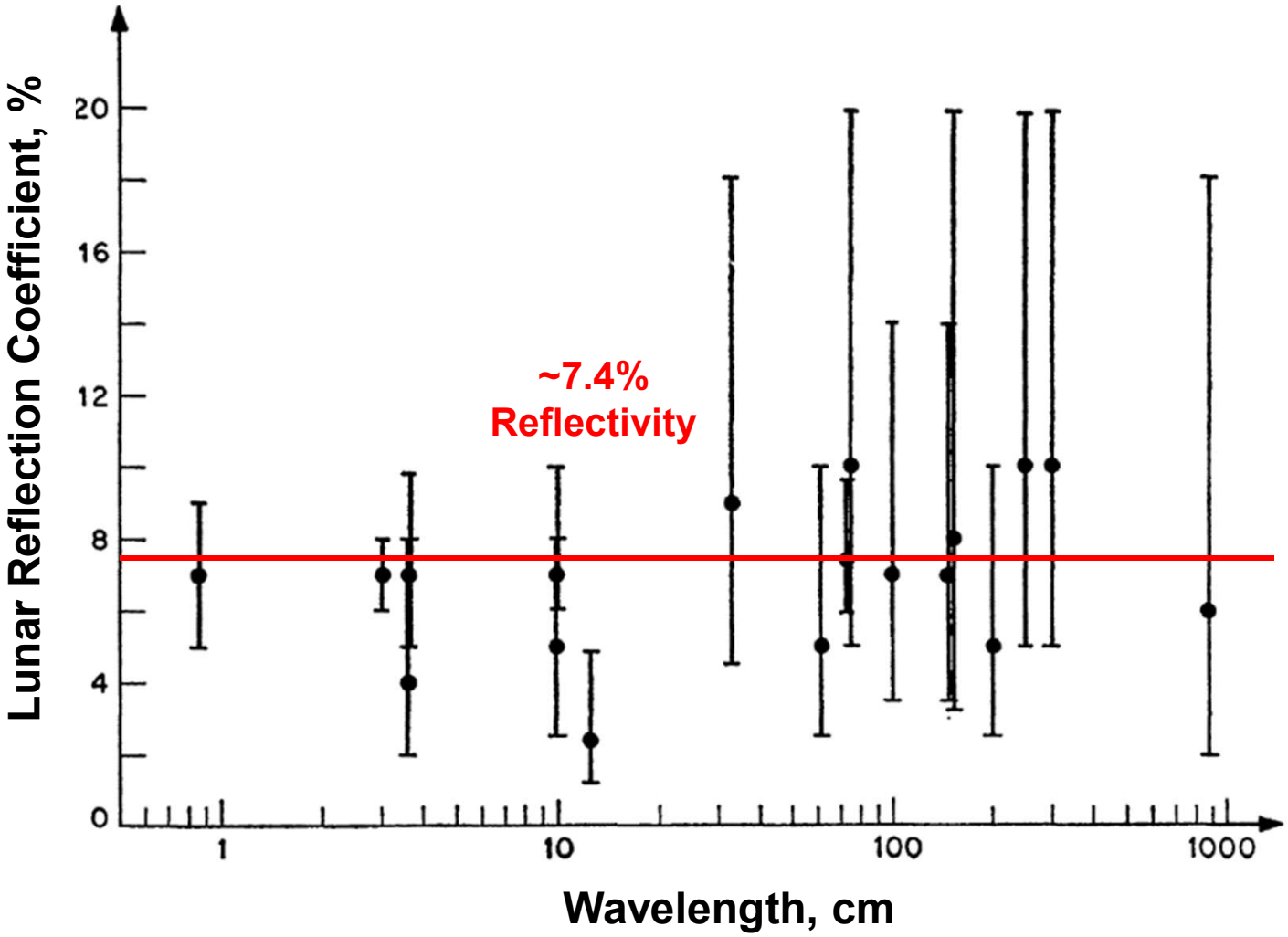
G. H. Millman and F. L. Rose, "Radar Reflections From the Moon at 425 Mc/s,".

Measured Polarization Versus Delay for Lunar Radar Echos at 440 MHz



G. H. Pettengill and J. C. Henry, "Radar Measurements of the Lunar Surface".

Lunar Reflection Coefficient as a Function of Wavelength

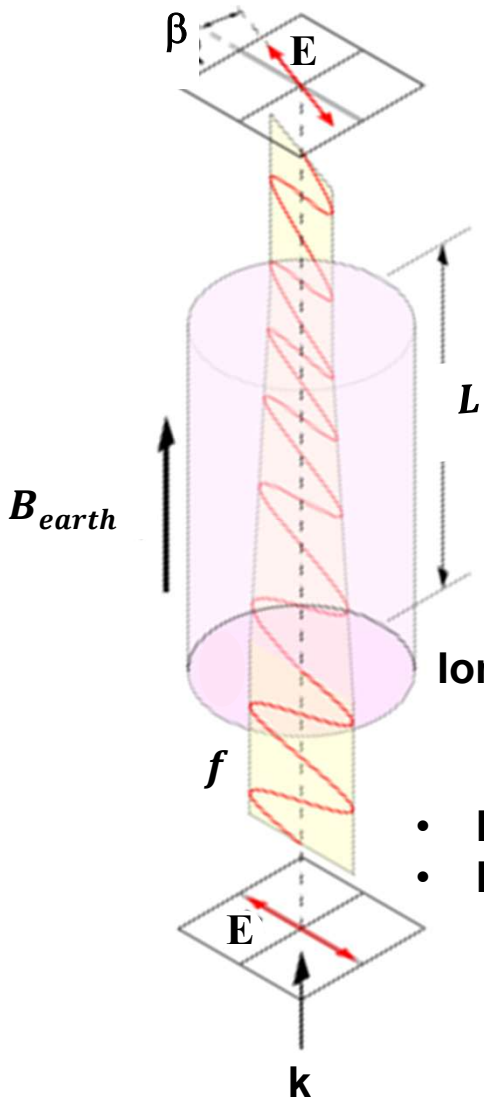


Lunar reflectivity is about 7% to 8 % from 30 MHz to 30 GHz

Pettengill and Shapiro, "Radar Astronomy".

Ionospheric Effects on VHF Propagation

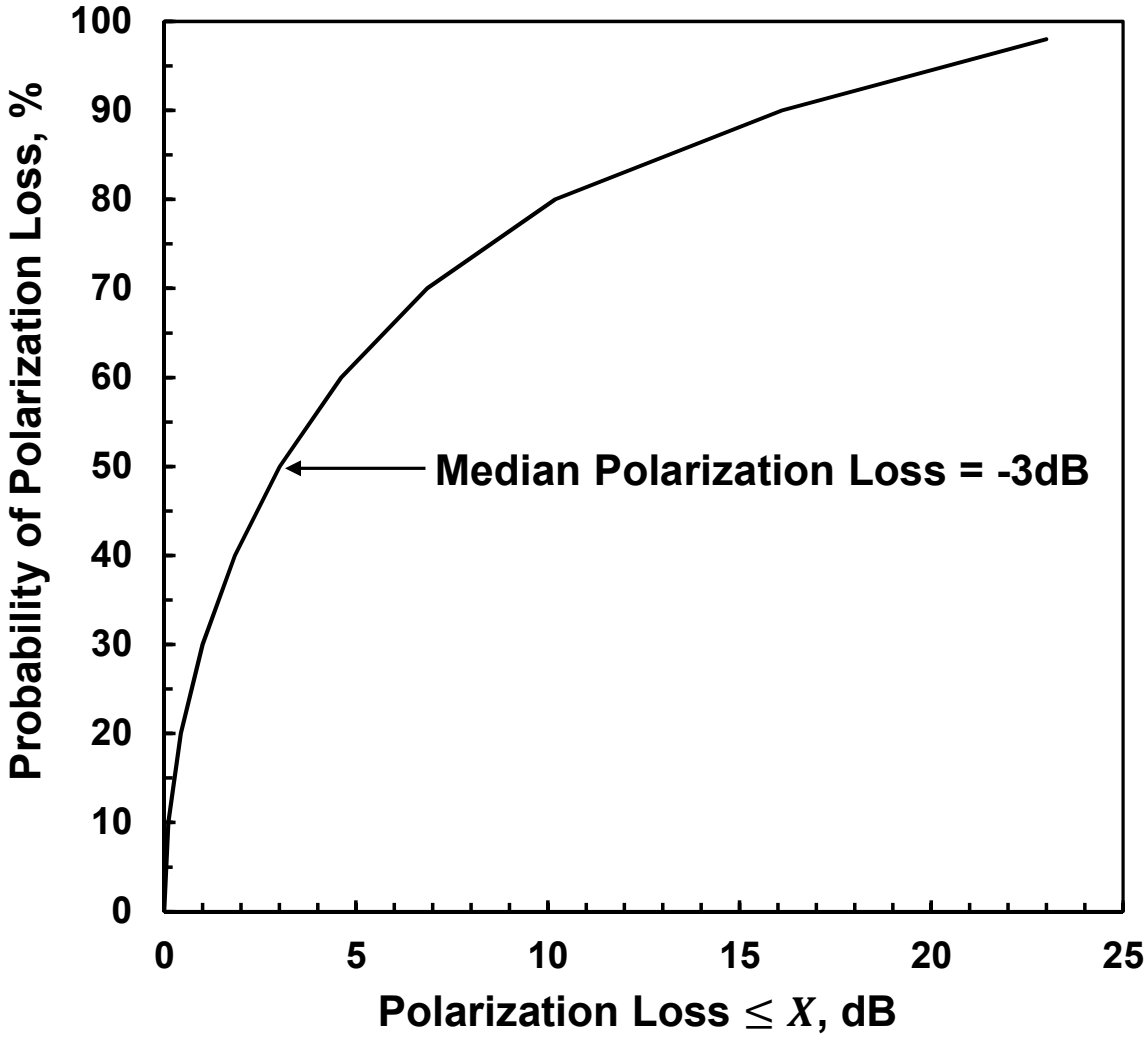
Ionospheric Faraday Rotation of Signal Polarization



Frequency	Maximum Estimated One-Way Faraday Rotation			
f MHz	β Degrees	β Radians	90 degree polarization shifts	Waves
50.19	10758.08	187.75	119.53	29.88
144.12	1304.73	22.77	14.50	3.62
432.07	145.17	2.53	1.61	0.40
1296.07	16.13	0.28	0.18	0.04

- Polarization rotation angle is a uniformly distributed random variable
- Expected polarization rotation is 45° @ 144 MHz

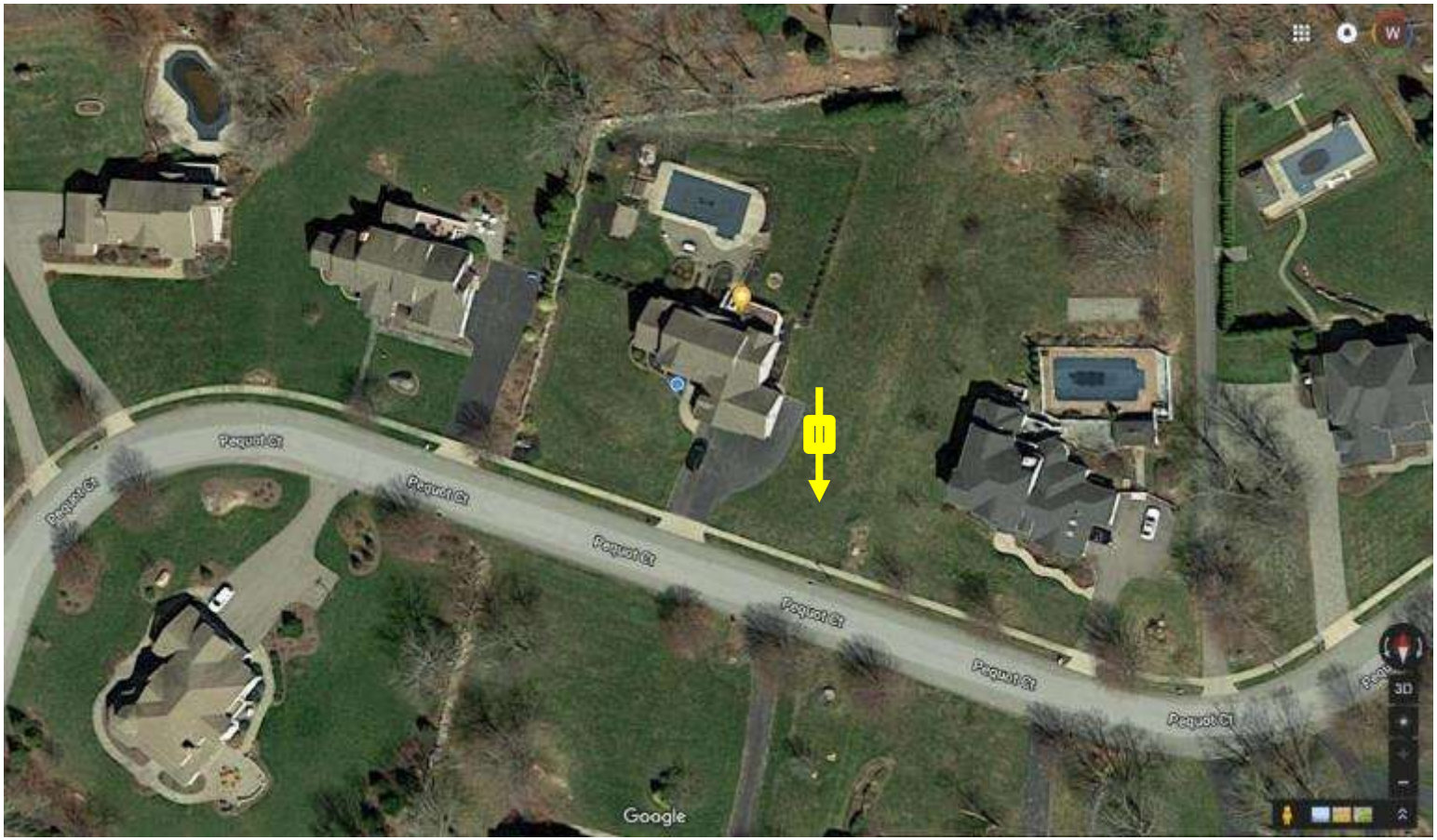
Probability of Polarization Loss



If the polarization rotation is assumed to be random and uniformly distributed from 0 to 90 degrees, then the expected rotation is 45 degrees and the loss is 3 dB or less for half the time

KC1HTT Earth Moon Amateur Earth Radio Station

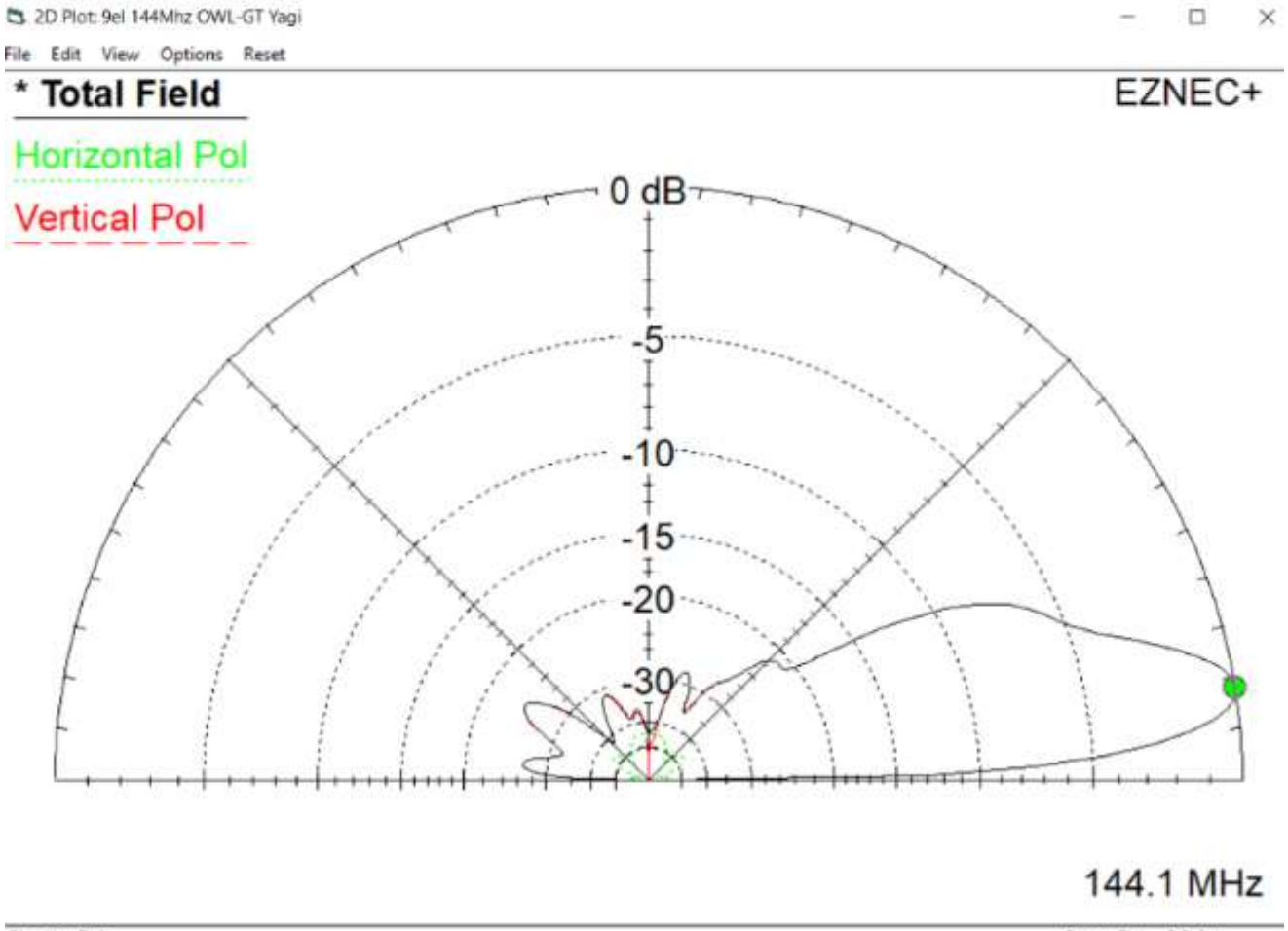
Location of KC1HTT EME Station - Pawcatuck, Connecticut (FN41bj)



Residential area, each EME session requires setup and breakdown

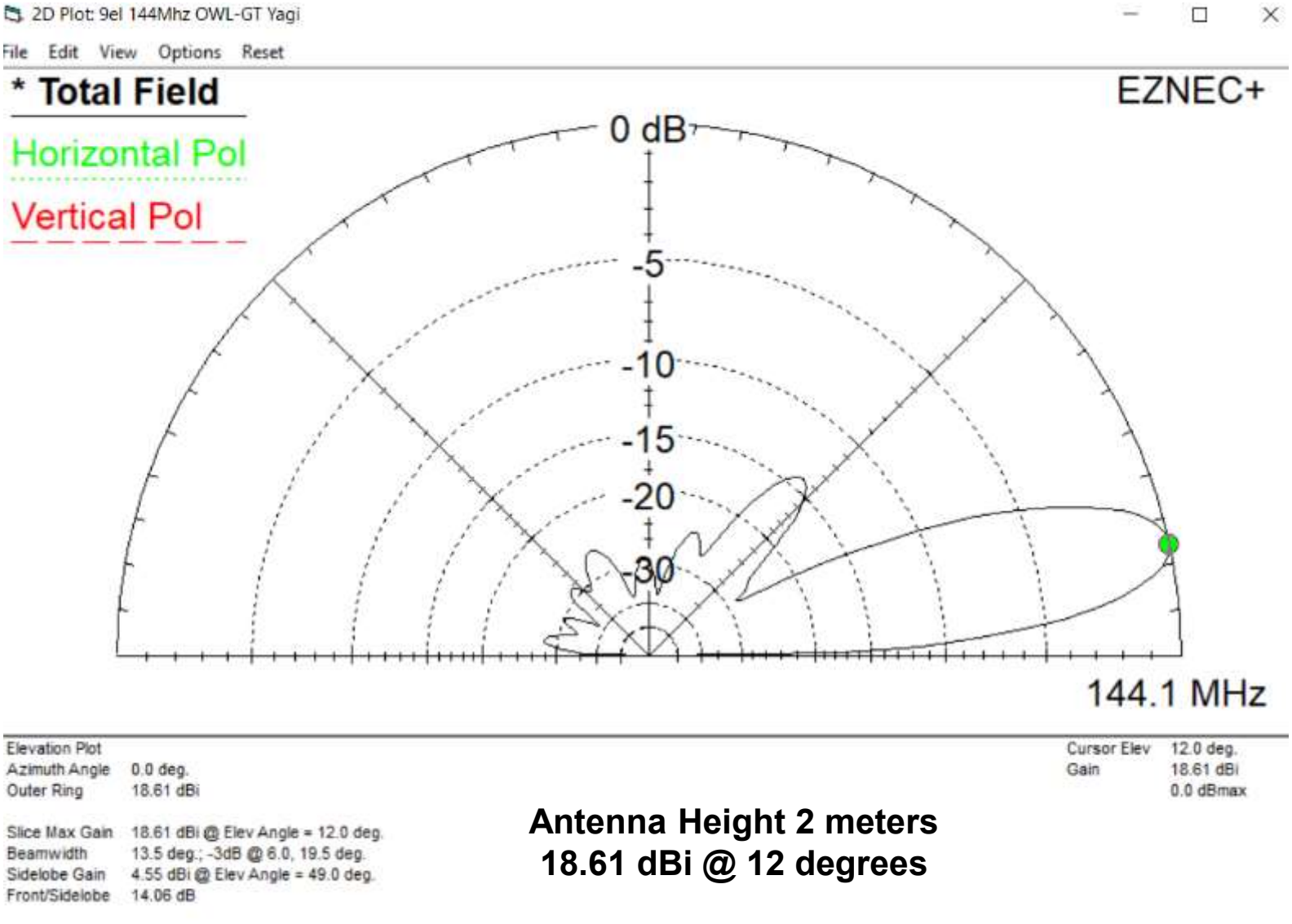
Antenna Studies: Vertical or Horizontal Polarization?

Vertical Polarization, 9 element Yagi, One Wavelength Above Ground, 0 degree Elevation



Antenna Height 1 wavelength
14.85 dBi, @ 9 degrees
13.24 dBi @ 5 degrees

Horizontal Polarization, 9 element Yagi, One Wavelength Above Ground, 0 degree Elevation



Antenna Height 2 meters
18.61 dBi @ 12 degrees

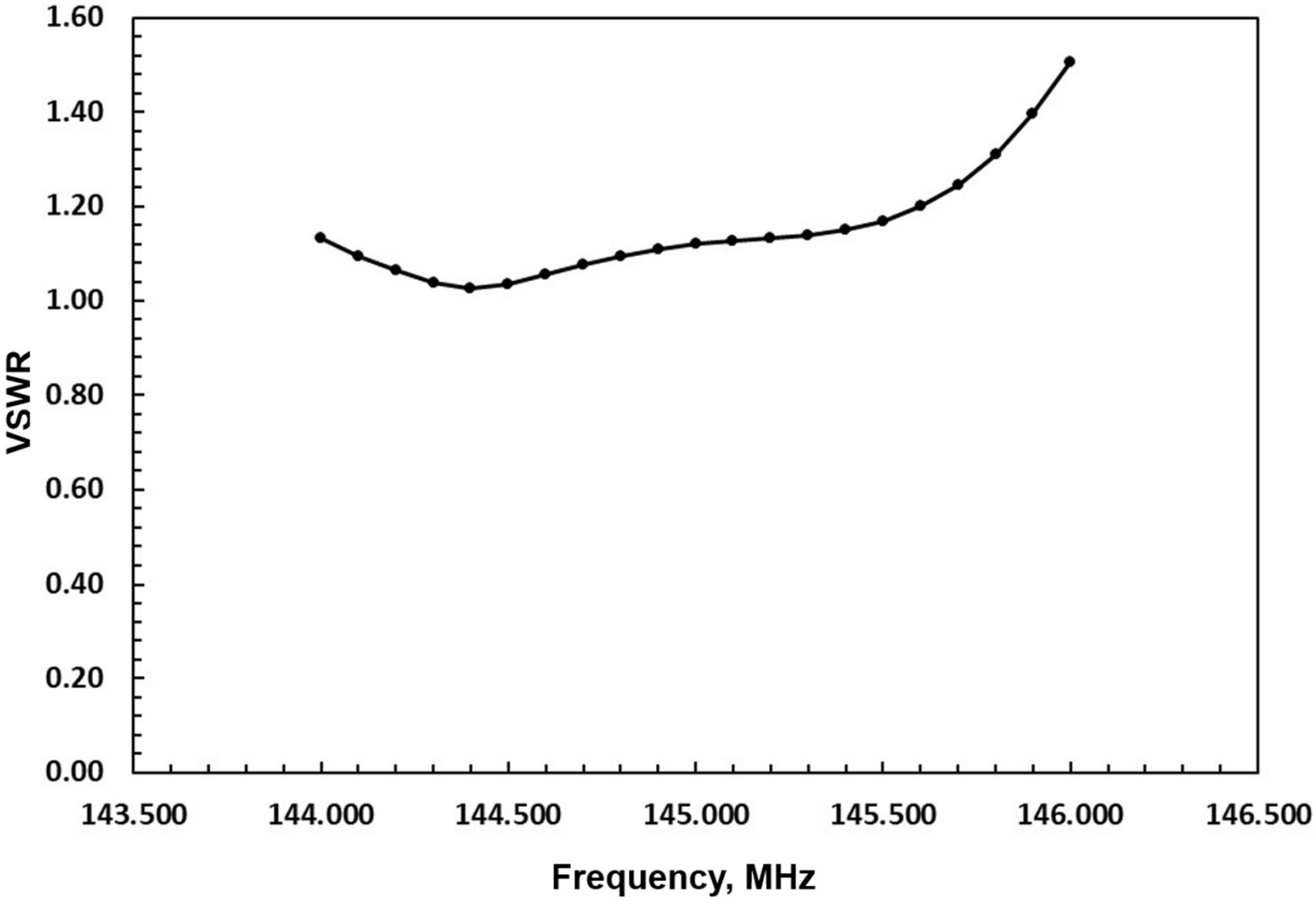
Estimated Effect of Ground on 2M9SSB Yagi One Wavelength Height

- **Yagi Horizontal Polarization**
  - **Between 10 and 30 degrees pointing angle, horizontally polarized Yagi antenna has a higher gain than a vertically polarized Yagi**

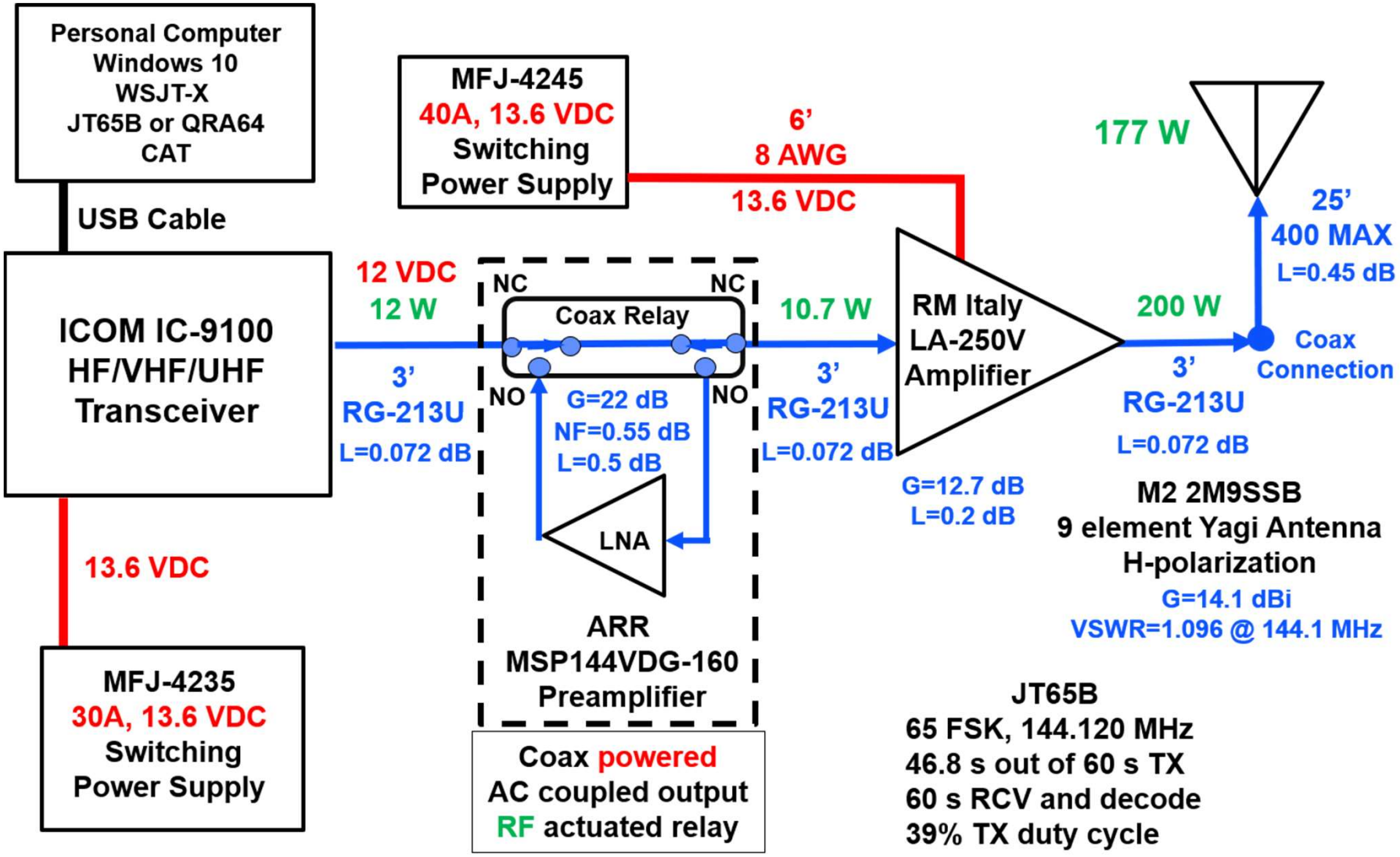
- **Conclusion**
  - **Use H polarized Yagi antenna to obtain higher gain**
  - **Ionosphere will randomly change the polarization at the EME receiver**

M^2 2M9SSB Antenna on Hand-Pointed Mount on East Side of Home

Measured *in situ* VSWR of M² 2M9SSB Yagi Antenna



KC1HTT 144 MHz EME Station



KC1HTT EME Station Cost

EME Amateur Radio Station Component	Cost
ICOM IC-9100 Transceiver	$2,179.95
MFJ 4235 13.6 VDC 30A Power Supply for IC-9100	$ 135.95
MFJ-264 50 ohm dummy load	$ 64.95
ARR MSP144VDG-160 VOX LNA	$ 312.29
RM Italy LA 250V	$ 549.99
MFJ 4245 13.6 VDC 40A Power Supply for Linear Am	$ 139.95
M2 2M9SSB Yagi Antenna	$ 283.99
MFJ-849 Digital HF VHF UHF Power SWR Meter	$ 164.95
25' DX 400 Max Coaxial Cable	$ 44.49
3' RG-213U	$ 20.49
3' RG-213U	$ 20.49
3' RG-213U	$ 20.49
Chunzehui F-1008 Anderson Power Pole Distributior	$ 75.00
MFJ-4603 Window feedthrough	$ 89.95
ALF-ATT3G50UBHP Surge arrestor	$ 61.99
MFJ 1919EX Tripod	$ 154.95
Antenna Analyzer N1201 SA	$ 180.99
EZNEC+ v6 software	$ 149.00
WSJT-x v2.0	$ -
TOTAL	$4,649.86

KC1HTT EME Station

- Operator — William Keicher
- QTH — Pawcatuck, CT, USA
- Grid — FN41bj
- CQ Zone — 5
- ITU Zone — 8
- Receiver — H pol
- Transmitter — 177 W, H pol
- Antenna Array — 1 x 9 element 2M9SSB
- Antenna Gain — 14.2 dBi
- Ground Gain @15° — 2.46 dB
- Total Antenna Gain — 16.66 dBi
- Power*Aperture — +39.14 dBW
- Mode — JT65B

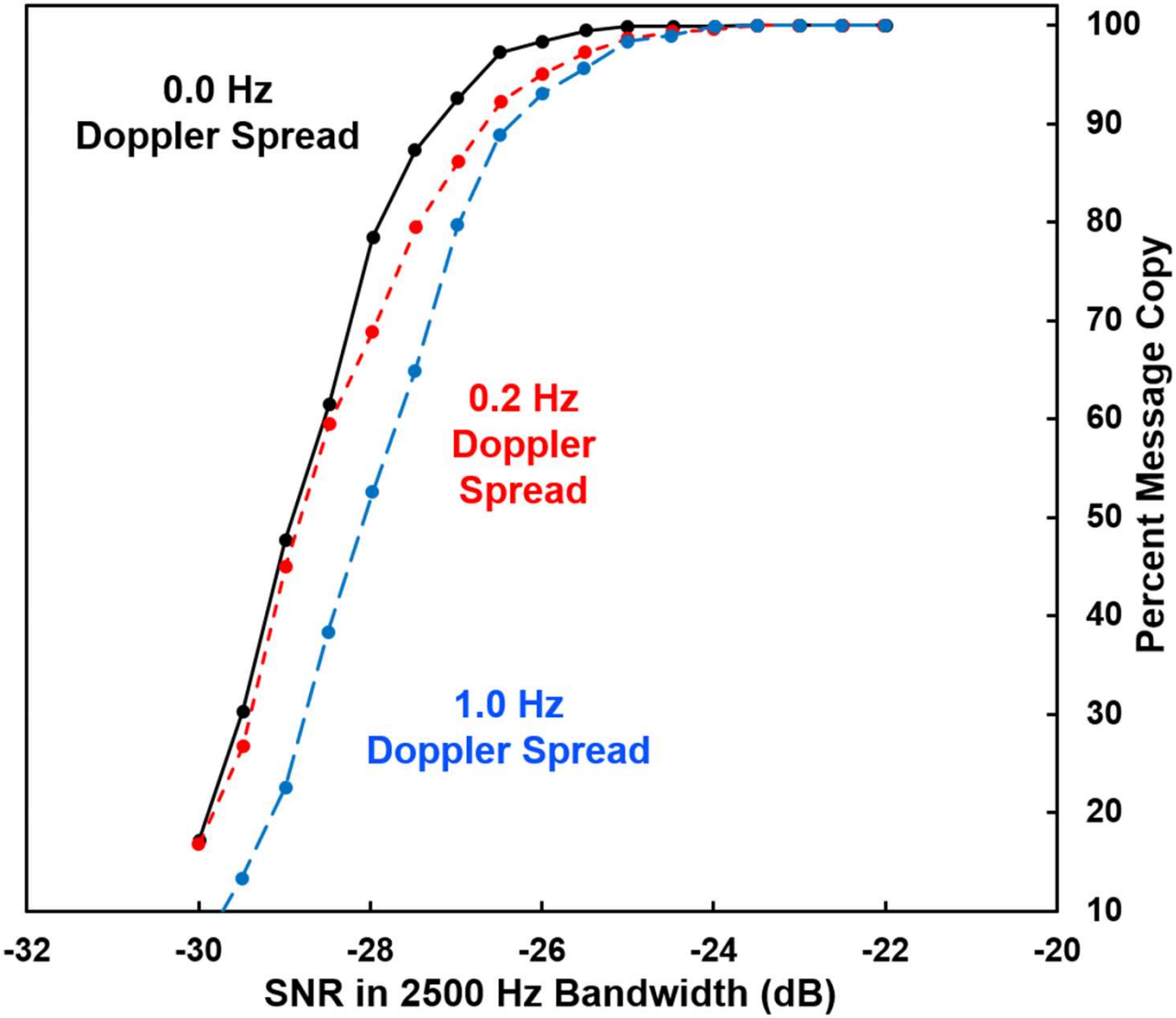
JT65B Waveforms and Signal Processing

JT65B "Long Message" Waveform and Processing

- FSK65 Modulation – frequency shift keying using 65 separate tones
  - 64 tones (or symbols) reserved for 64-ary alphabet
  - Each symbol carries 6 bits
  - 65th tone at 1270.5 Hz reserved for frequency and time synchronization
- FEC - Low rate Reed-Solomon code – RS(63,12)
  - Rate = 0.19 code
  - 72 message bits and 306 error correction bits (378 bits total) are encoded into 63 symbols for transmission
- Interleaving of 63 symbols in 7 x 9 matrix in rows, read out in columns
- Alternating one minute transmissions starting 1 second after UTC minute
  - 126 transmissions intervals each of 0.372 seconds transmitting one of 65 frequencies
  - 63 synchronization tones transmitted at 1270.5 Hz each for a 0.372 seconds duration
  - 63 symbols transmitted each of 0.372 seconds duration
  - 63 Sync and 63 symbol transmissions are interleaved in a pseudorandom sequence
  - Each transmission ends after 47.8 seconds after UTC minute
- Franke-Taylor algebraic soft-decision algorithm
- Deep Search decode – requires *CALL3.TXT* call sign database
  - Only hypothetical messages combining CQ or the user's own callsign with a callsign and locator from the callsign database will be tested against the received information
  - 262 million call sign possibilities

S. J. Franke and J. H. Taylor, "Open Source Soft-Decision Decoder for the JT65 (63,12) Reed-Solomon Code"

JT65B Long Message Performance

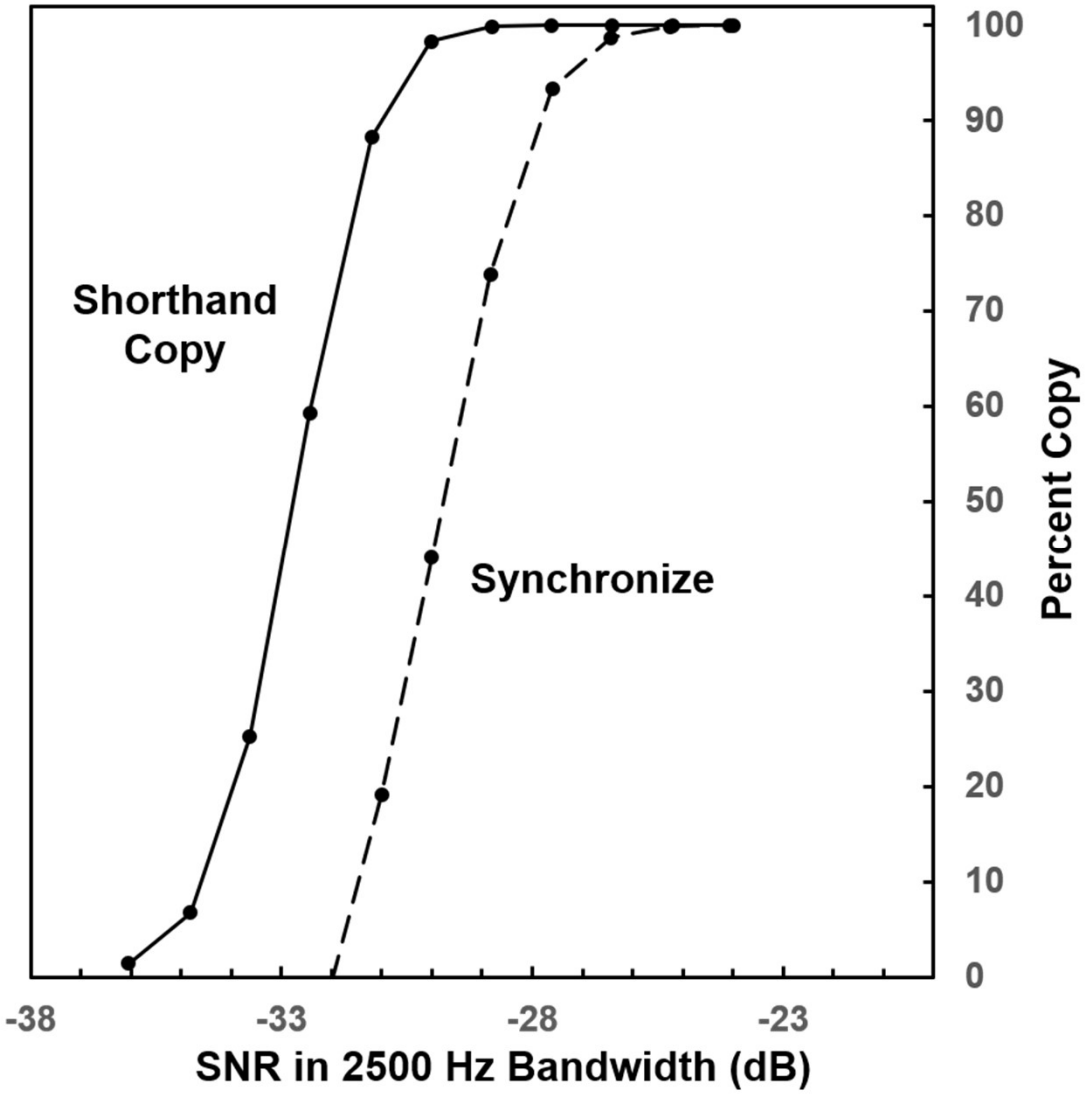


S. J. Franke and J. H. Taylor, "Open Source Soft-Decision Decoder for the JT65 (63,12) Reed-Solomon Code"

JT65B Shorthand Messages

- Shorthand (SH) message tones and sync tone are time interleaved and repeated
  - Sync 1270.5 Hz
  - RO 1378.2 Hz
  - RRR 1432.0 Hz
  - 73 1485.9 Hz

- Tone duration is 1.486 seconds
- 32 sync, 32 SH tones in 47.55 seconds
- Decoder looks for frequency difference, Δf, between sync and SH tones
  - RO 107.7 Hz
  - RRR 161.5 Hz
  - 73 215.4 Hz



S. J. Franke and J. H. Taylor, "Open Source Soft-Decision Decoder for the JT65 (63,12) Reed-Solomon Code"

KC1HTT – RX1AS JT65B QSO

Transmitted JT65B Messages	Meaning
• CQ KC1HTT FN41 *	KC1HTT in grid square FN41 calls to anyone listening
• KC1HTT RX1AS KO59 *	RX1AS in grid square KO59 responds to KC1HTT
• RX1AS KC1HTT FN41 OOO *	KC1HTT Reports sufficient SNR
• RO ...	RX1AS "Roger, sufficient SNR"
• RRR ...	KC1HTT "Roger, roger, roger"
• 73 ...	RX1AS "Best regards"
• 73 …	KC1HTT "Best regards"

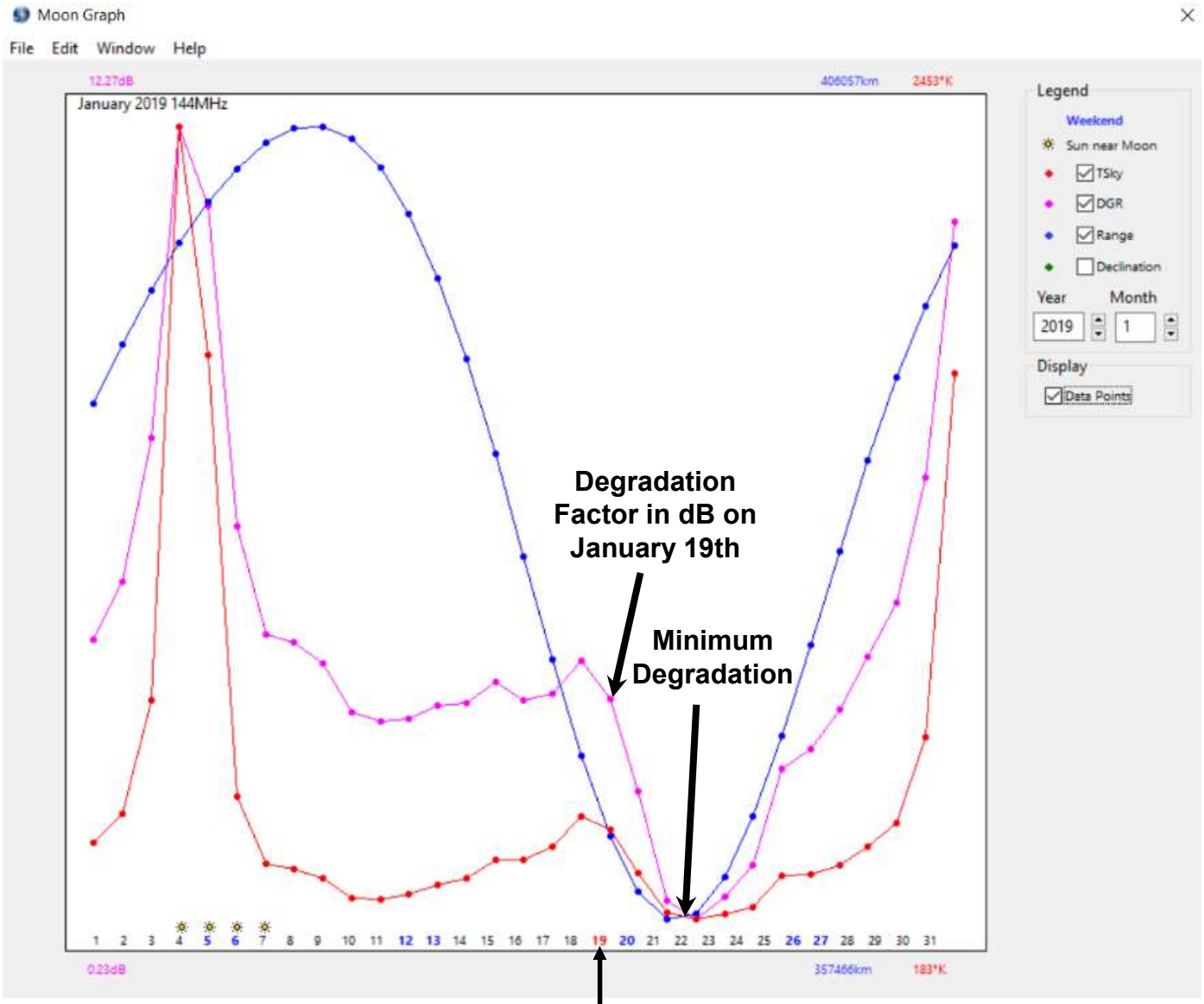
*** 72 bit message encoded in 378 bits and sent only once using 63 FSK tones + 63x sync tone**
(…) Indicates repeated shorthand (SH) message tones + interleaved sync tone

Earth-Moon-Earth Operations

19 January 2019 EME QSOs

Nighttime Moon rising, waxing gibbous (94%)

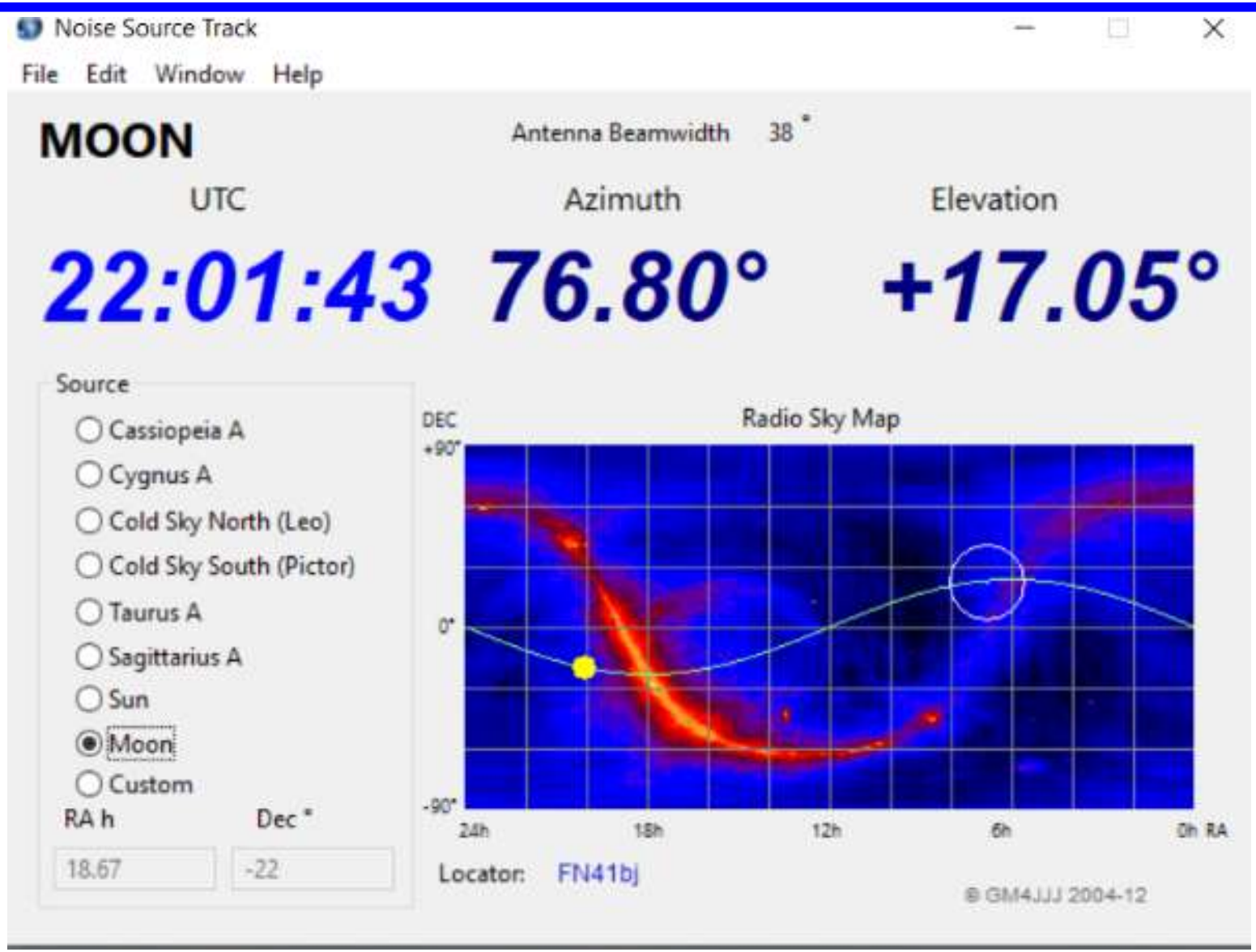
Moon Sked Software Predictions for 19 January 2019



Position of the Moon and Sun During 19 January 2019 QSOs

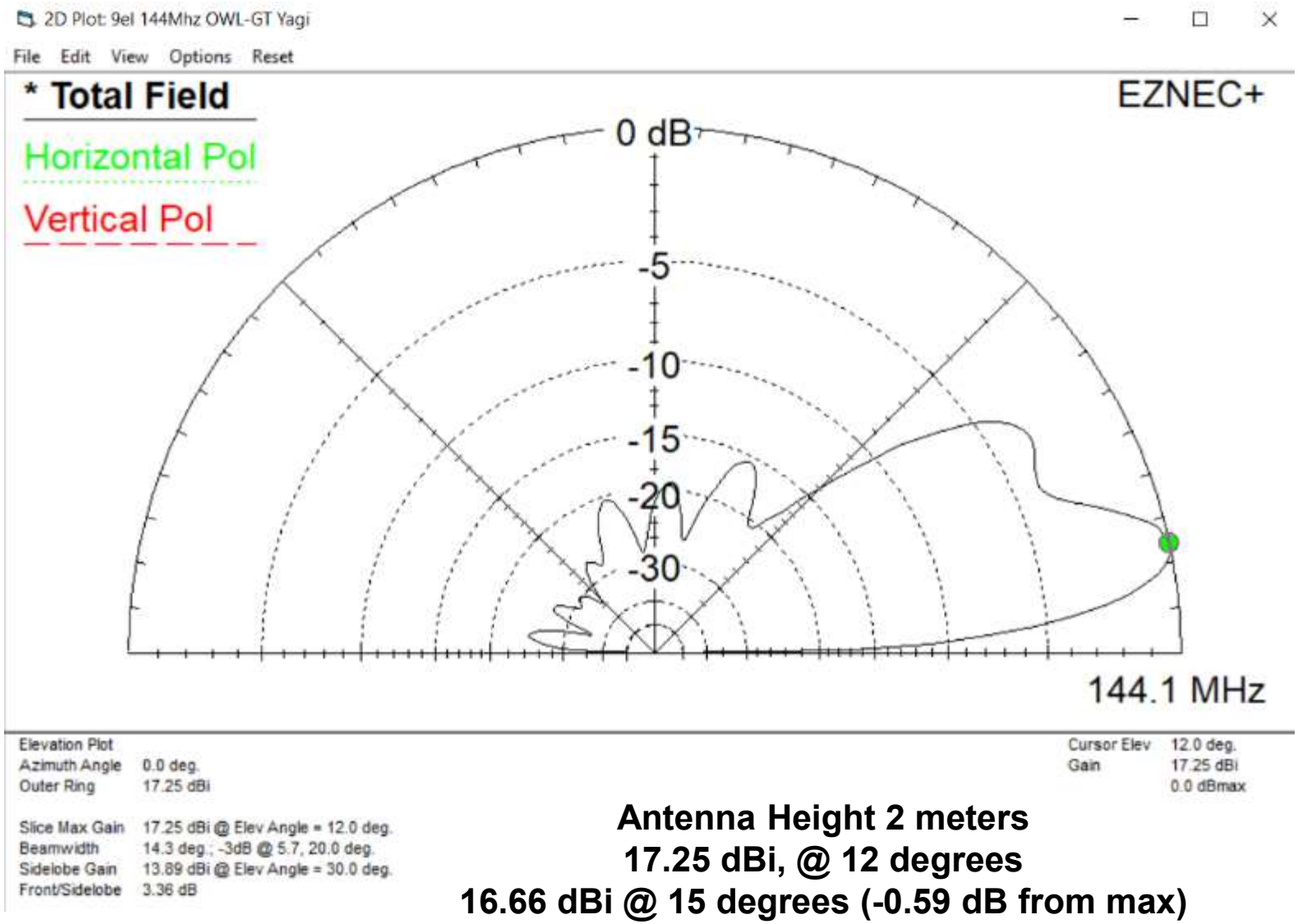
D. Anderson, "GM4JJJ Amateur Radio"

Position of the Moon on Radio Sky Map, 19 January 2019



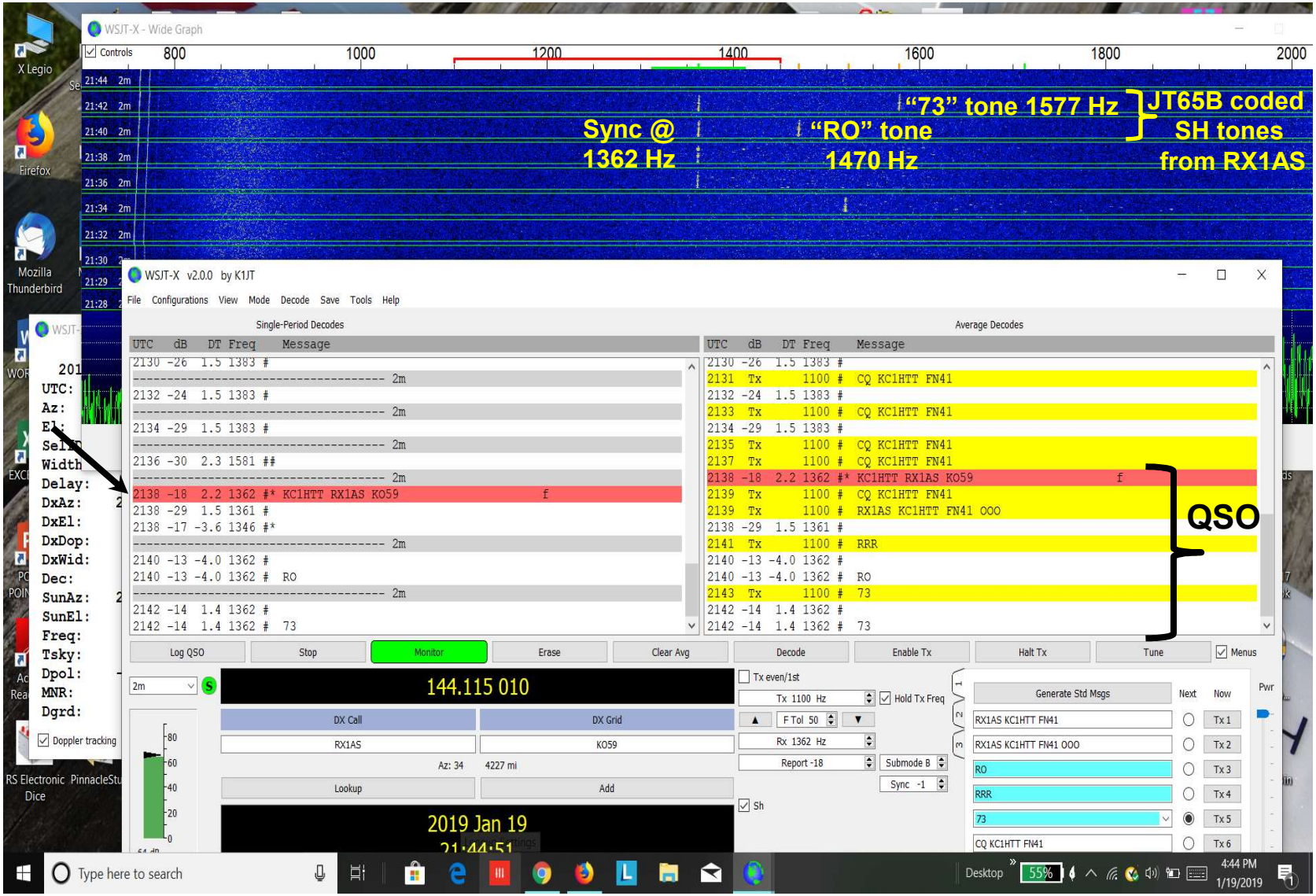
Location of KC1HTT EME Station - Pawcatuck, Connecticut, 19 January 2019

H Pol, 9 element Yagi, One Wavelength Above Ground, 15 degree Elevation



Antenna Height 2 meters
17.25 dBi, @ 12 degrees
16.66 dBi @ 15 degrees (-0.59 dB from max)

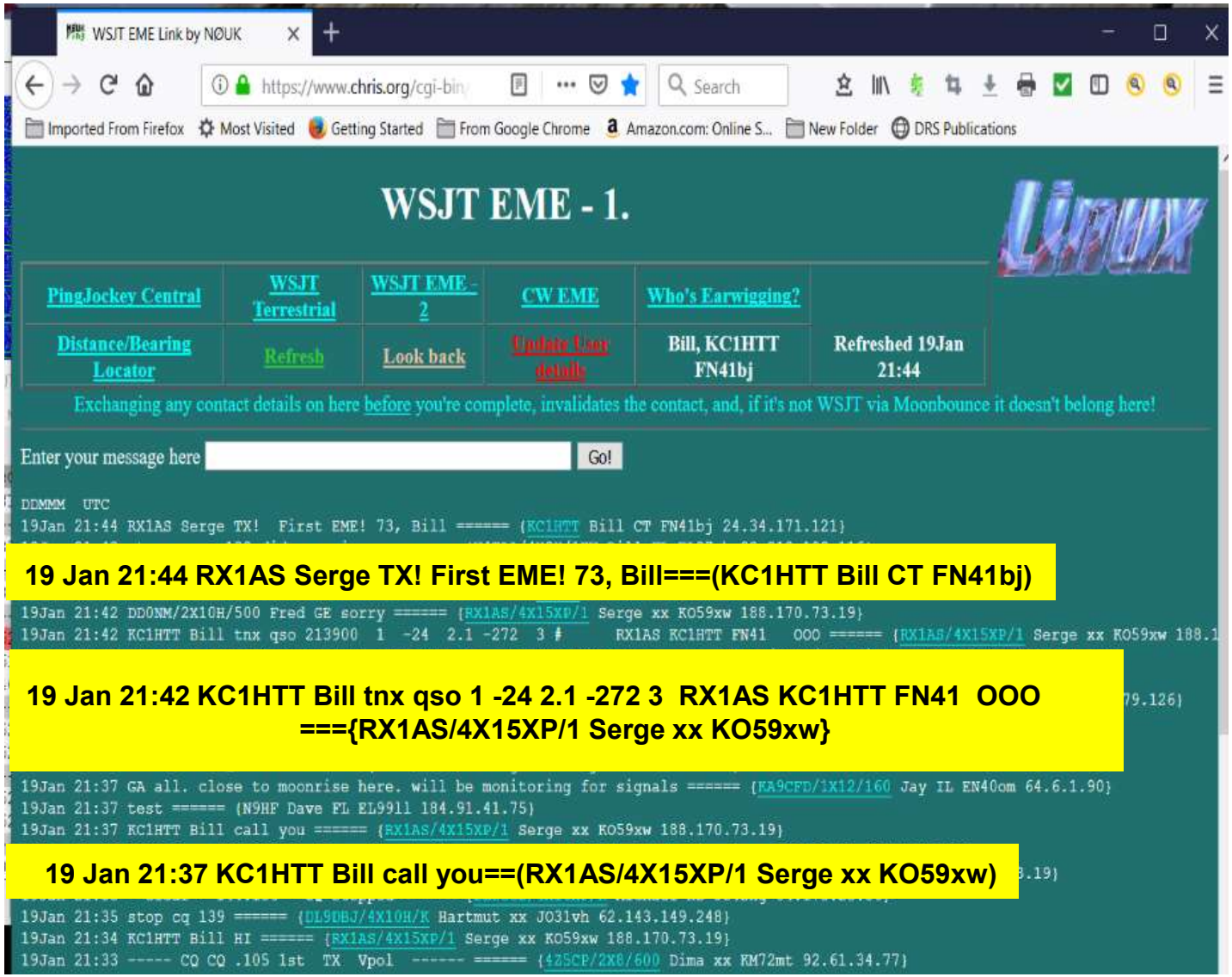
Frequency Spectrum of RX1AS JT65B Coded Signal – "Waterfall" Display



KC1HTT - RX1AS QSO Analysis: SNR

2137	CQ KC1HTT FN41		KC1HTT calls CQ
2138	KC1HTT RX1AS KO59	SNR = - 18 dB	RX1AS calls KC1HTT, 2.2 second delay
2139	RX1AS KC1HTT FN41 OOO	SNR = - 24 dB	KC1HTT reports sufficient SNR
2140	RO	SNR = - 13 dB	RX1AS “Roger, sufficient SNR”
2141	RRR		KC1HTT “Roger, Roger, Roger”
2142	73	SNR = - 14 dB	RX1AS “Best regards”
2143	73		KC1HTT “Best regards”

Text Messages Sent Before and After QSO Between RX1AS and KC1HTT on WSJT EME – 1 Bulletin Board



C. Cox, "WSJT EME Link by NØUK - chrisc at chris.org"

CONFIRMATION! RX1AS QSL Card Sent to KC1HTT

EUROPEAN RUSSIA

RX1AS

WAZ: 16 ITU: 29 LOC: KO59XW

TO RADIO: KC1HTT VIA:

DAY	MONTH	YEAR	UTC	RST	MHz	MODE 2X	QSO VIA
19	01	2019	21.38	"0"	144	❑ TROPO ❑ AUR ❑ MS ❑ ES ☑ EME ❑ FAI ❑ ION ❑ AUE	JT65B
					UP:		
					DW:		

Serge A. Spiridonov
Ryabowskoe sh.117 korp.3 - 73
St-Petersburg 195043
Russia

PSE QSL TNX

REMARKS:

UA1OMS QSLprint http://www.quadrat.ru/qsl

RX1AS EME Station

- Operator — Sergey. A. Spiridonov
- QTH — St Petersburg, Russia
- Grid — KO59xw
- CQ Zone — 16
- ITU Zone — 29
- Receiver — V and H pol
- Transmitter — V or H pol, 1000 W
- Antenna Array — 4 x 15 element XP Yagi
- Antenna Gain — 23.5 dBi (est.)
- Power*Aperture — +53.5 dBW
- Mode — MAP 65

Moon Sked Parameters for 19 January 2019 EME QSOs

Operation during Moonrise, beam elevation = 12°

		KC1HTT				RX1AS						
DATE	Time UTC	AZ	EL	MNR	POL	AZ	EL	DGR	Tsky	Range, km	Dop	Echo Width
2019-01-19 Saturday	21:30	072°	+12°	7 dB	-58°	195°	+50°	3.0dB	388°K	360981	+173 Hz	1.58 Hz
2019-01-19 Saturday	22:00	077°	+17°	4 dB	-65°	205°	+49°	3.0dB	386°K	360906	+160 Hz	1.50 Hz

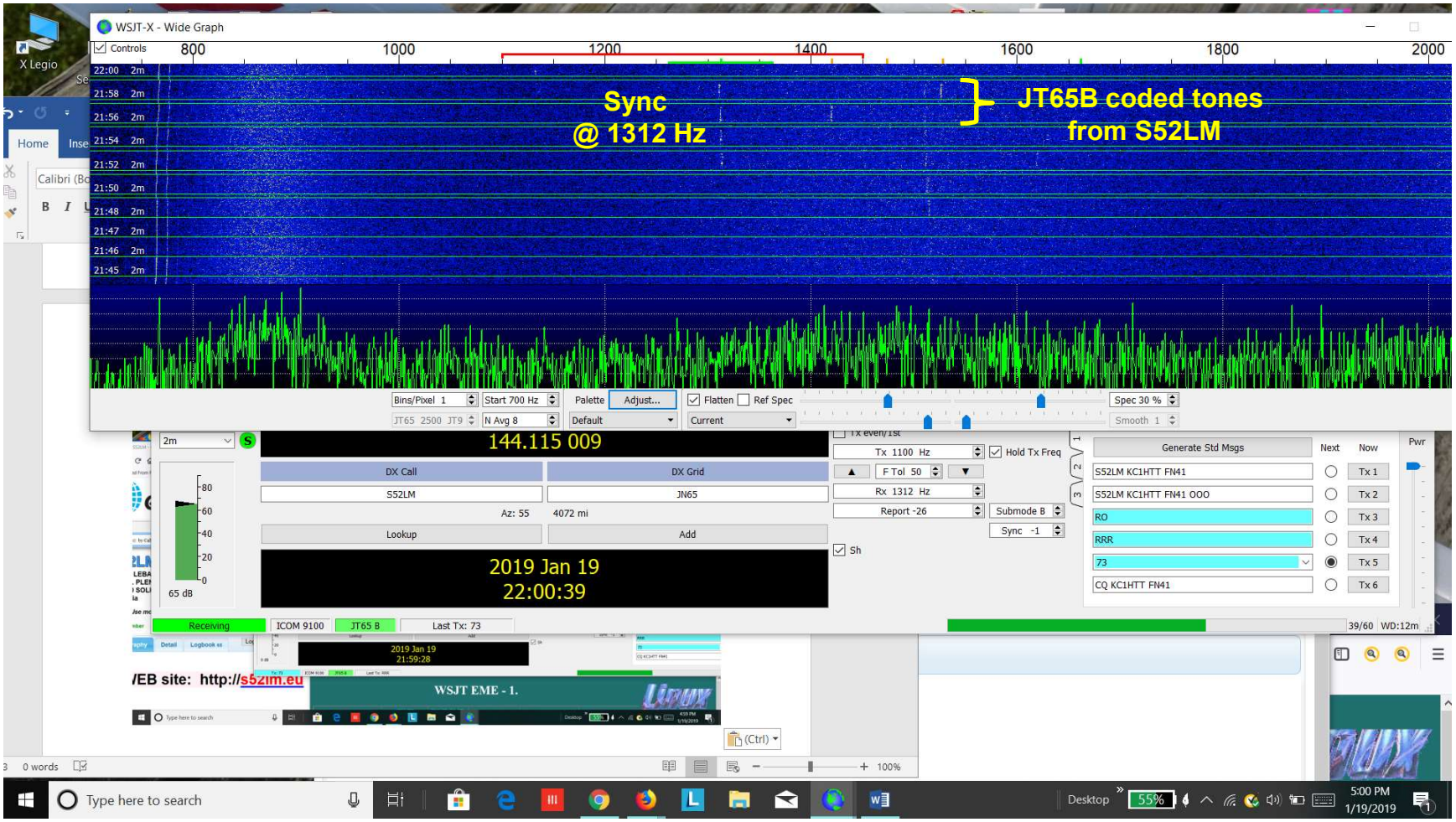
		KC1HTT				S52LM						
DATE	Time UTC	AZ	EL	MNR	POL	AZ	EL	DGR	Tsky	Range, km	Dop	Echo Width
2019-01-19 Saturday	22:00	077°	+17°	12 dB	-52°	181°	+65°	3.0dB	386°K	360906	+189 Hz	1.62 Hz

Range to the Moon was 360,906 kilometers for a roundtrip of 721,812 kilometers or 448,513 miles or 2.408 light seconds

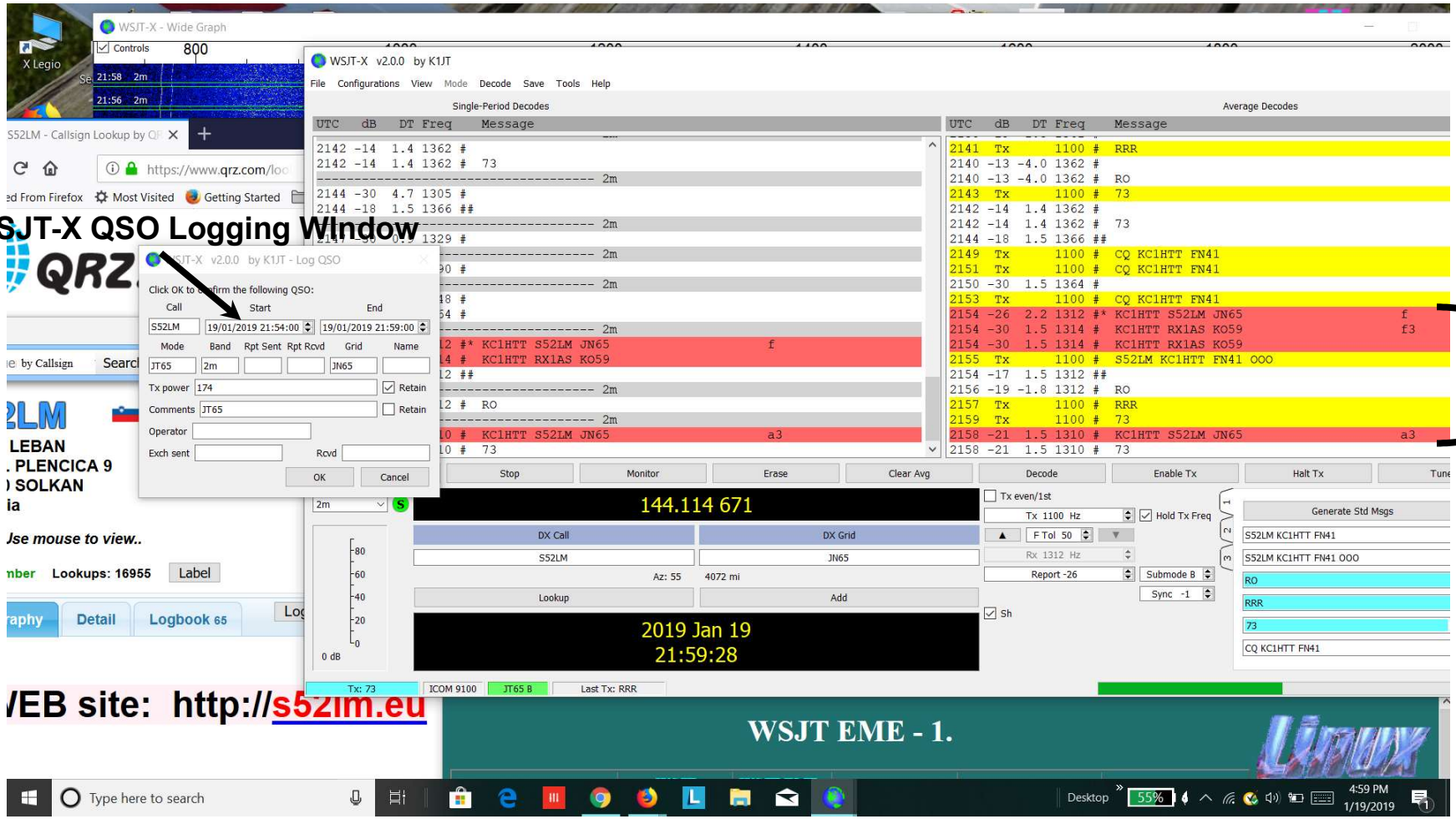
Calculation of the SNR During the KC1HTT – RX1AS QSO

KC1HTT - RX1AS EME QSO	MKS Units	dB
Common Parameters		
Frequency, Hz	144,115,000	81.59
Wavelength, m	2.080	3.18
Range, m	360,931,000.00	85.57
Mean Lunar Cross Section, m2		118.45
kTB, watts	1.00094E-17	-170.00
Tsky, K	388	25.89
Sky noise, kTB, watts	1.33918E-17	-168.73
$(4 * \pi)^3$	1984.40	32.98
KC1HTT		
Transmitter Power, P1 (watts)	180	22.55
2M9SSB Antenna Gain, 14.2 dB + 2.46 dB GG		16.66
Receiver Noise Figure, F1	1.417	1.51
Receiver Noise, N1 (watts)	2.75751E-17	-165.59
Receive Polarization Loss, LP1		3.00
Receive Doppler Spreading Loss, LD1		1.00
Received signal, S1 (watts)	3.71448E-19	-184.30
SNR at KC1HTT Receiver		-18.71
RX1AS		
Transmitter Power, P2 (watts)	1000	30.00
Antenna Gain, G2		23.50
Receiver Noise Figure, F2	1.25	0.97
Receiver Noise, N2 (watts)	2.59035E-17	-165.87
Receive Polarization Loss, LP2		0.10
Receive Doppler Spreading Loss, LD2		1.00
Received signal, S2, (watts)	1.30368E-19	-188.85
SNR at RX1AS Receiver		-22.98

Frequency Spectrum of S52LM JT65B Coded Signal – "Waterfall" Display

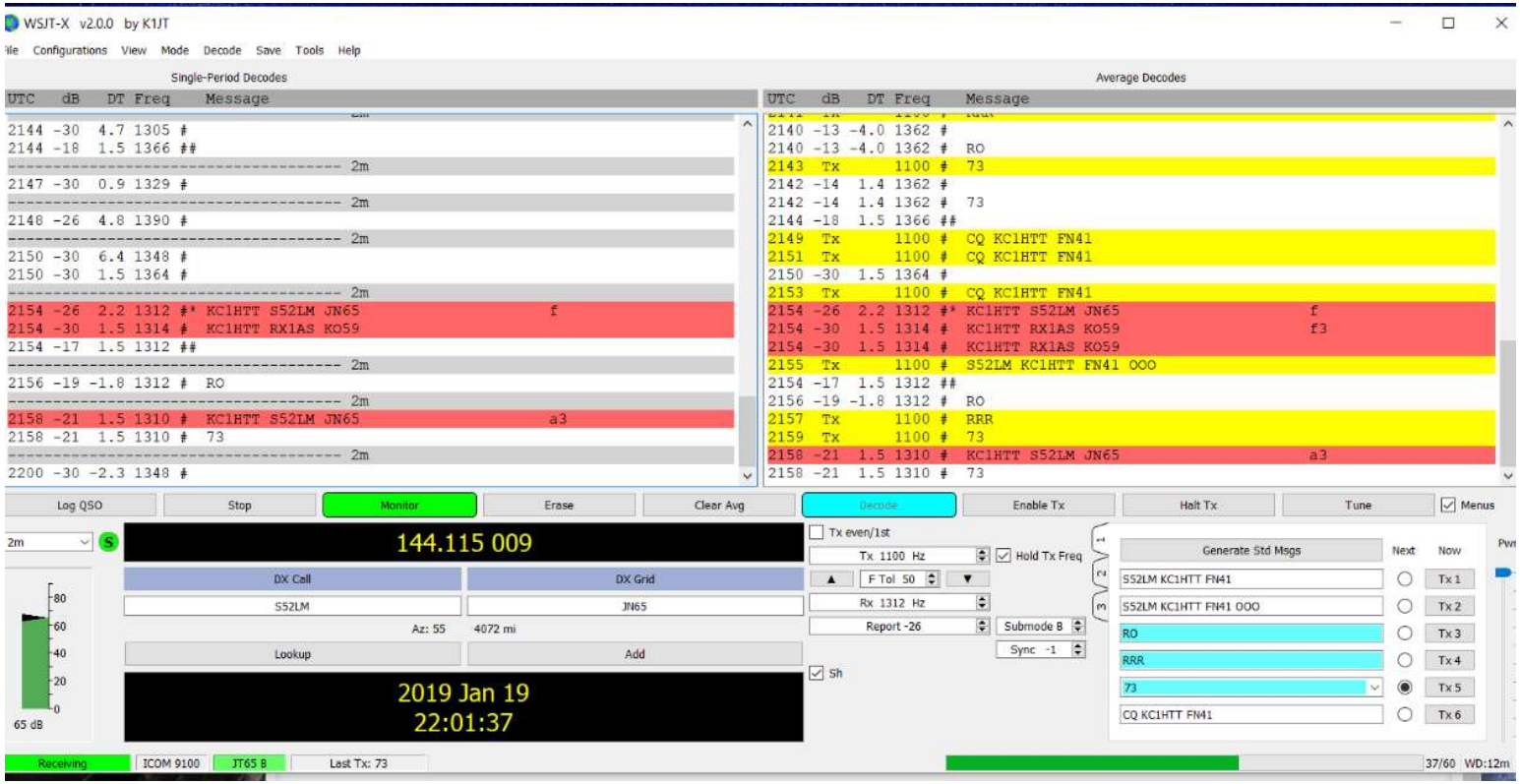


WSJT-X JT65B Screenshot of S52LM, Solkan, Slovenia QSO



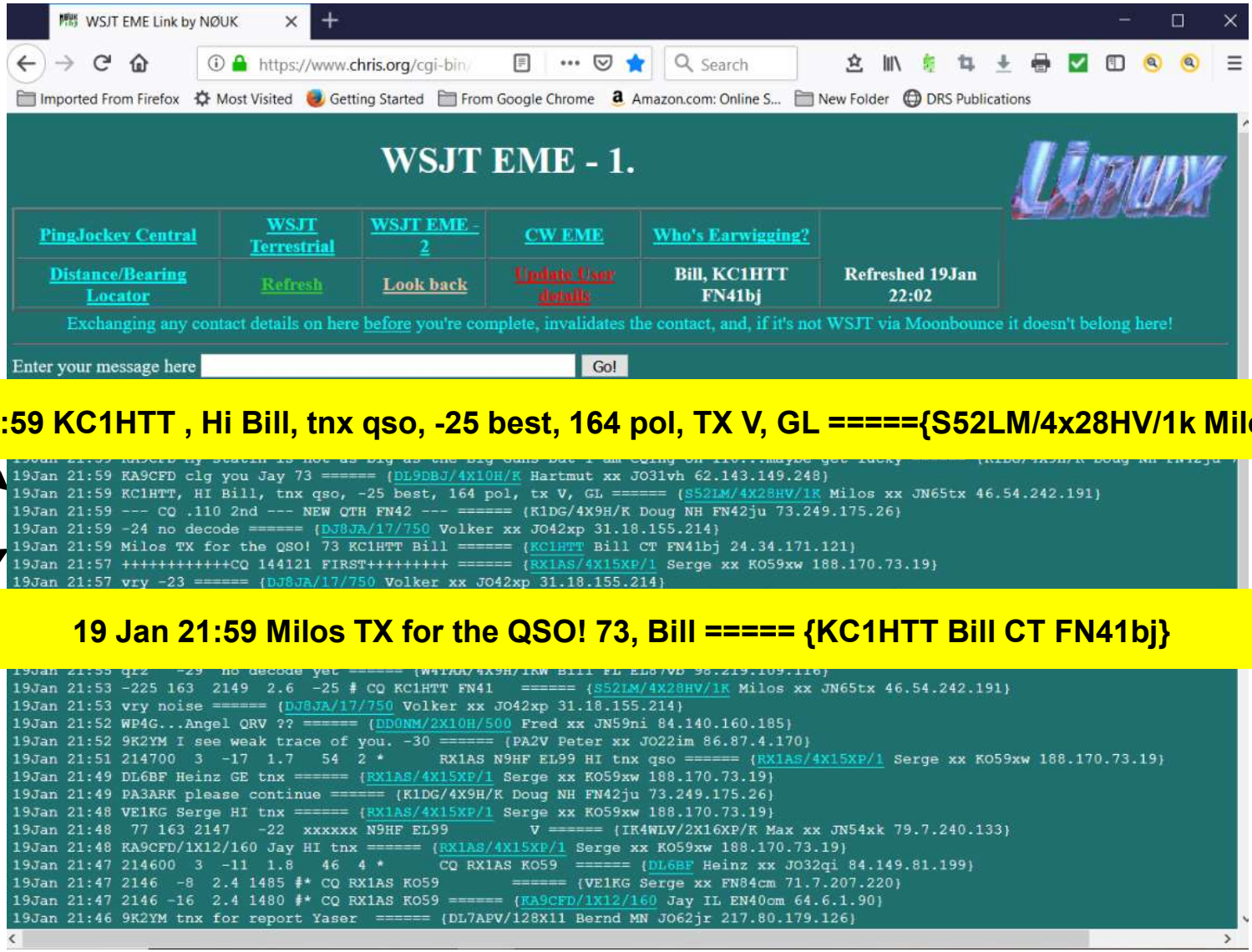
KC1HTT - S52LM QSO Analysis: SNR

Roundtrip time delay 2.4 seconds, -0.2 second error



2153	CQ KC1HTT FN41		KC1HTT calls CQ
2154	KC1HTT S52LM JN65	SNR = - 26 dB	S52LM calls KC1HTT, 2.2 sec delay
2155	S52LM KC1HTT FN41 OOO	SNR = - 25 dB	KC1HTT reports sufficient SNR
2156	RO	SNR = - 19 dB	S52LM “Roger, sufficient SNR”
2157	RRR		KC1HTT “Roger, Roger, Roger”
2158	73	SNR = - 21 dB	S52LM “Best regards”
2159	73		KC1HTT “Best regards”

Text Messages Sent After QSO Between S52LM and KC1HTT on WSJT EME – 1 Bulletin Board



19 Jan 21:59 KC1HTT , Hi Bill, tnx qso, -25 best, 164 pol, TX V, GL =====\{S52LM/4x28HV/1k Milos xx\}

19 Jan 21:59 Milos TX for the QSO! 73, Bill ===== \{KC1HTT Bill CT FN41bj\}

C. Cox, "WSJT EME Link by NØUK - chrisc at chris.org"

CONFIRMATION! S52LM QSL Card Sent to KC1HTT


CQ ZONE 15
ITU ZONE 28

CFM QSO WITH KC1HTT

DXCC 2M 2008 WAC 2M 1997

DATE	GTM	2 WAY	MHz	RST
19.01.2019	21:54	JT65B	144	"0"

TROPO ☐ EME ☒ Es ☐ FAI ☐ MS ☐

73 DE Milos

MILOŠ LEBAN
TRG PLENČIČA 9
SI - 5250 SOLKAN
SLOVENIA

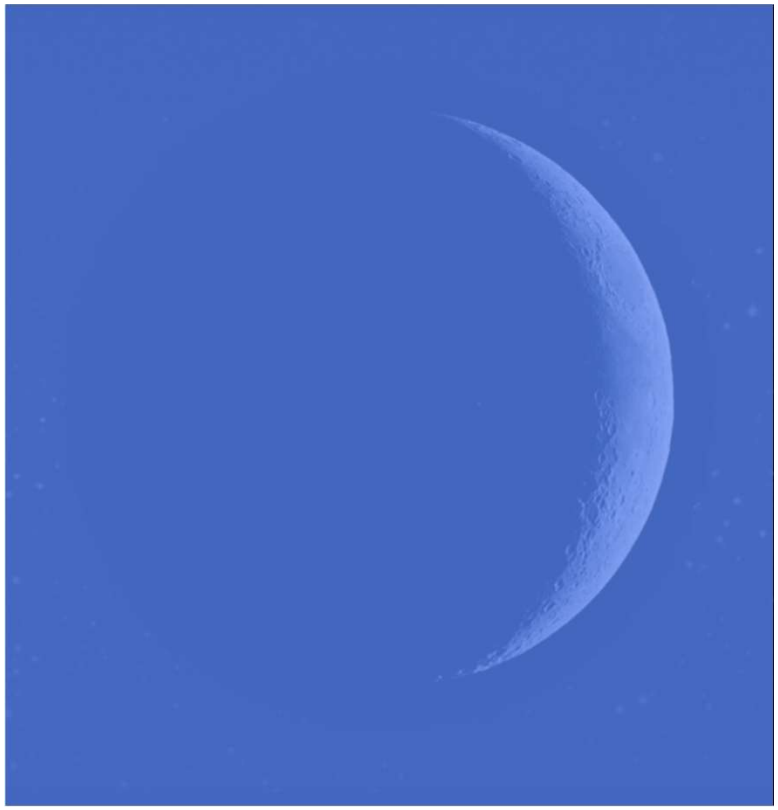
S52LM EME Station FIXED

• Operator	Milos Leban
• QTH	Solkan, Slovenia
• Grid	JN65tx
• CQ Zone	15
• ITU Zone	28
• Receiver	V and H
• Receiver NF	0.2 dB
• Transmitter	V or H, 1000 W
• Antenna Array	4 x 2M28XP Yagi
• Antenna Gain	21.14 dBi
• Power*Aperture Product	+51.14 dBW
• Mode: MAP 65	

Calculation of the SNR During the KC1HTT – S52LM QSO

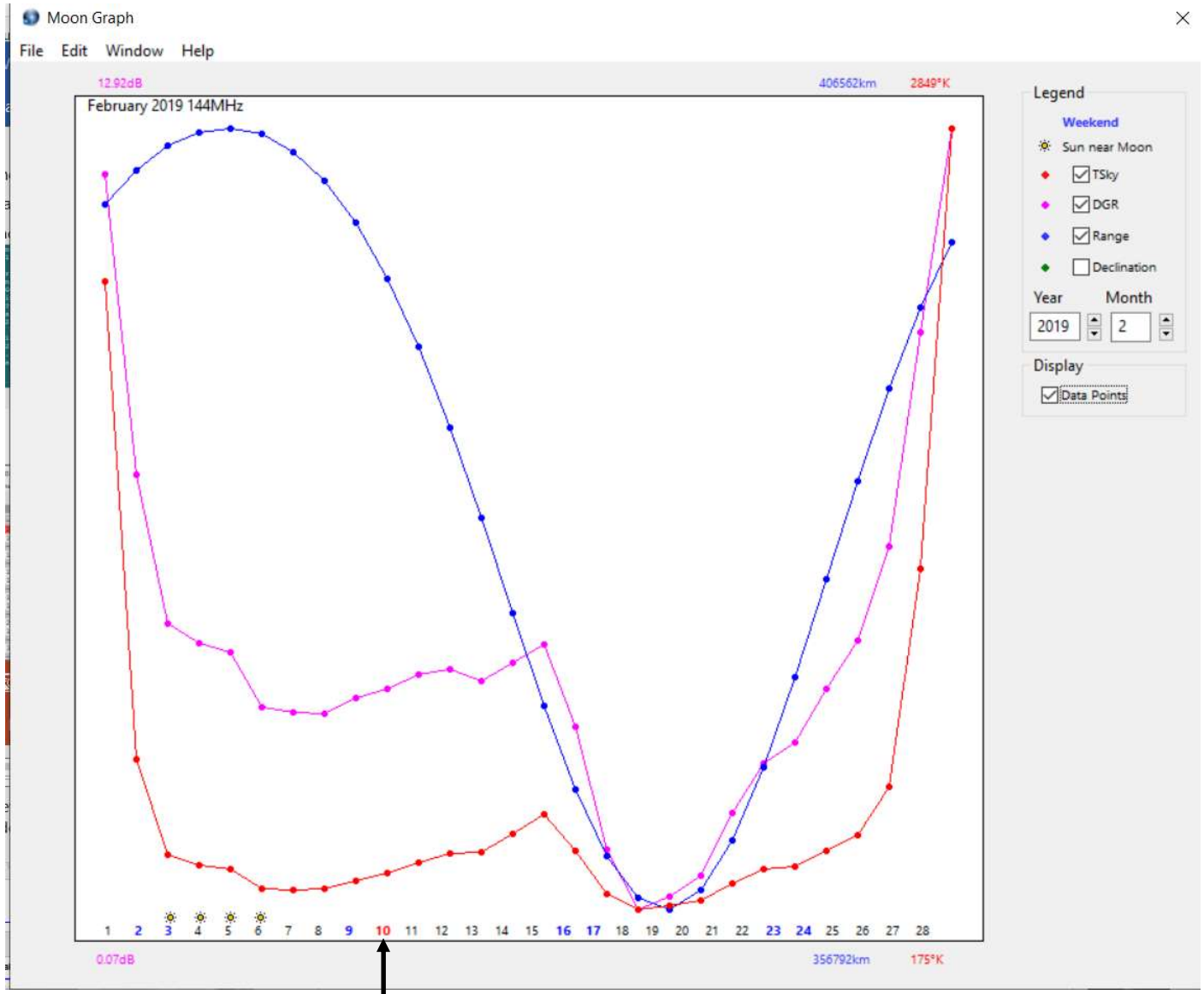
KC1HTT - S52LM EME QSO	MKS Units	dB
Common Parameters		
Frequency, Hz	144,115,000	81.59
Wavelength, m	2.080	3.18
Range, m	360,931,000.00	85.57
Mean Lunar Cross Section, m2		118.45
kTB, watts	1.00094E-17	-170.00
Tsky, K	388	25.89
Sky noise, kTB, watts	1.33918E-17	-168.73
$(4 * \pi)^3$	1984.40	32.98
KC1HTT		
Transmitter Power, P1 (watts)	180	22.55
2M9SSB Antenna Gain, 14.2 dB + 2.46 dB GG		16.66
Receiver Noise Figure, F1	1.417	1.51
Receiver Noise, N1 (watts)	2.75751E-17	-165.59
Receive Polarization Loss, LP1		3.00
Receive Doppler Spreading Loss, LD1		1.00
Received signal, S1 (watts)	2.15724E-19	-186.66
SNR at KC1HTT Receiver		-21.07
S52LM		
Transmitter Power, P2 (watts)	1000	30.00
2 x Antenna Gain, G2		21.14
Receiver Noise Figure, F2	1.25	0.97
Receiver Noise, N2 (watts)	2.59035E-17	-165.87
Receive Polarization Loss, LP2		0.10
Receive Doppler Spreading Loss, LD2		1.00
Received signal, S2, (watts)	7.5713E-20	-191.21
SNR at S52LM Receiver		-25.34

10 February 2019 EME QSO

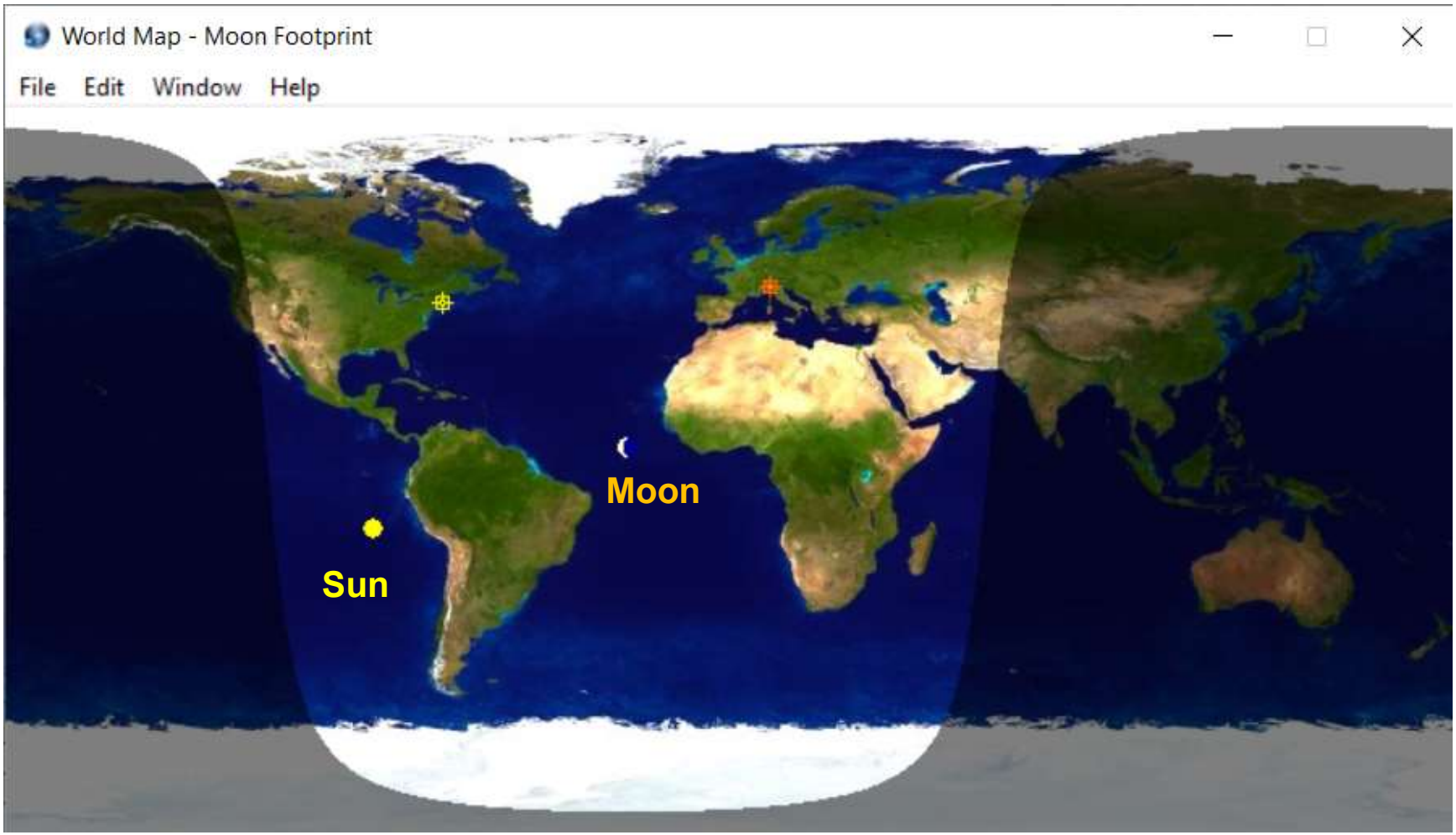


Daytime, Moon waxing crescent (24%)

Moon Sked Software Predictions for 10 February 2019



Position of the Moon and Sun During 10 February 2019 QSO



D. Anderson, "GM4JJJ Amateur Radio"

Position of the Moon on Radio Sky Map, 10 February 2019

File Edit Window Help

MOON

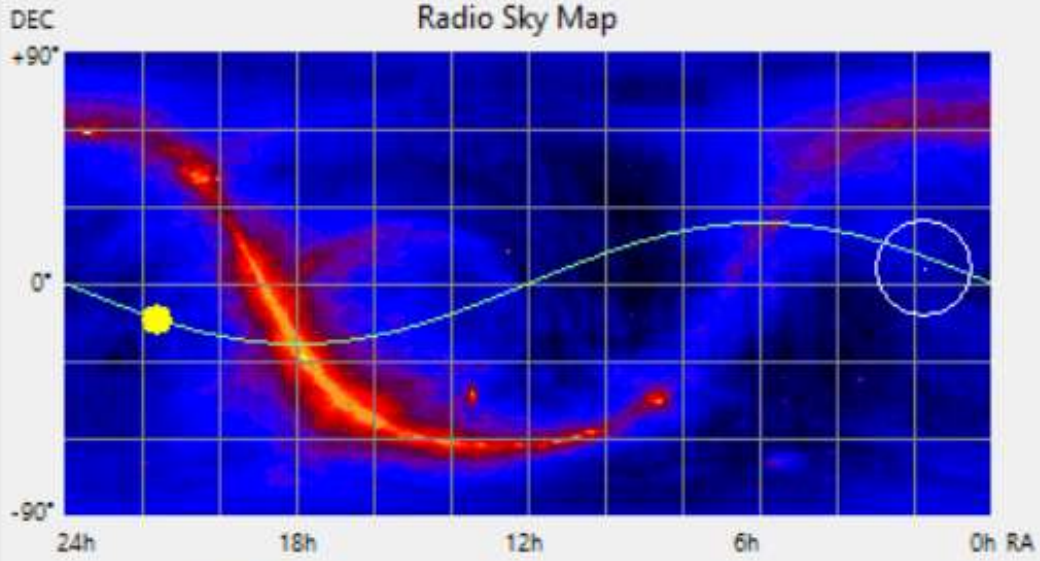
Antenna Beamwidth 38 °

UTC	Azimuth	Elevation
18:05:25	118.37°	+34.53°

Source

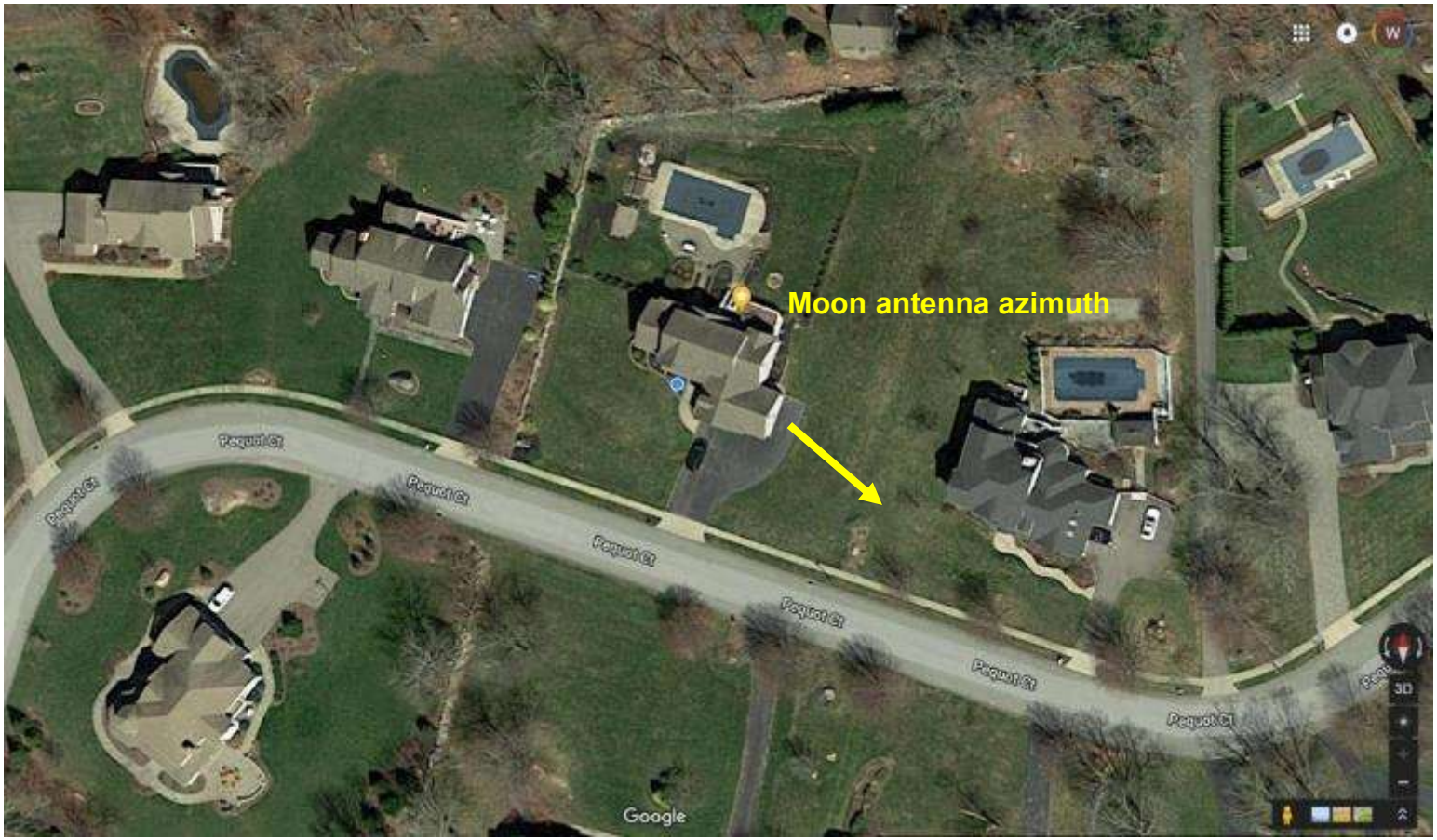
- ○ Cassiopeia A
- ○ Cygnus A
- ○ Cold Sky North (Leo)
- ○ Cold Sky South (Pictor)
- ○ Taurus A
- ○ Sagittarius A
- ○ Sun
- ◉ Moon
- ○ Custom

RA h: 18.67 Dec °: -22

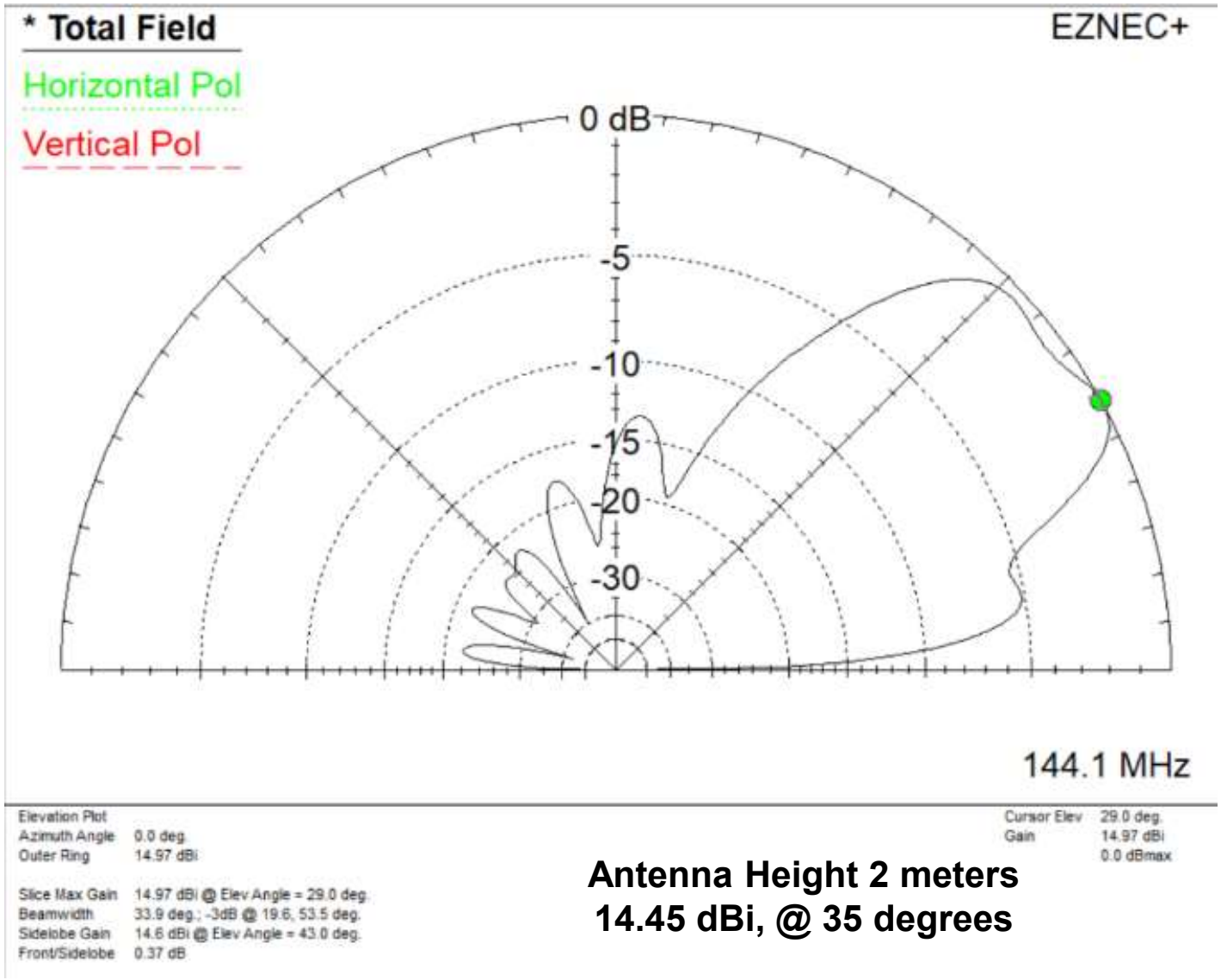


Locator: FN41bj

Location of KC1HTT EME Station - Pawcatuck, Connecticut, 10 February 2019



KC1HTT H Pol, 9 element Yagi, One Wavelength Above Ground, 35 degree Elevation

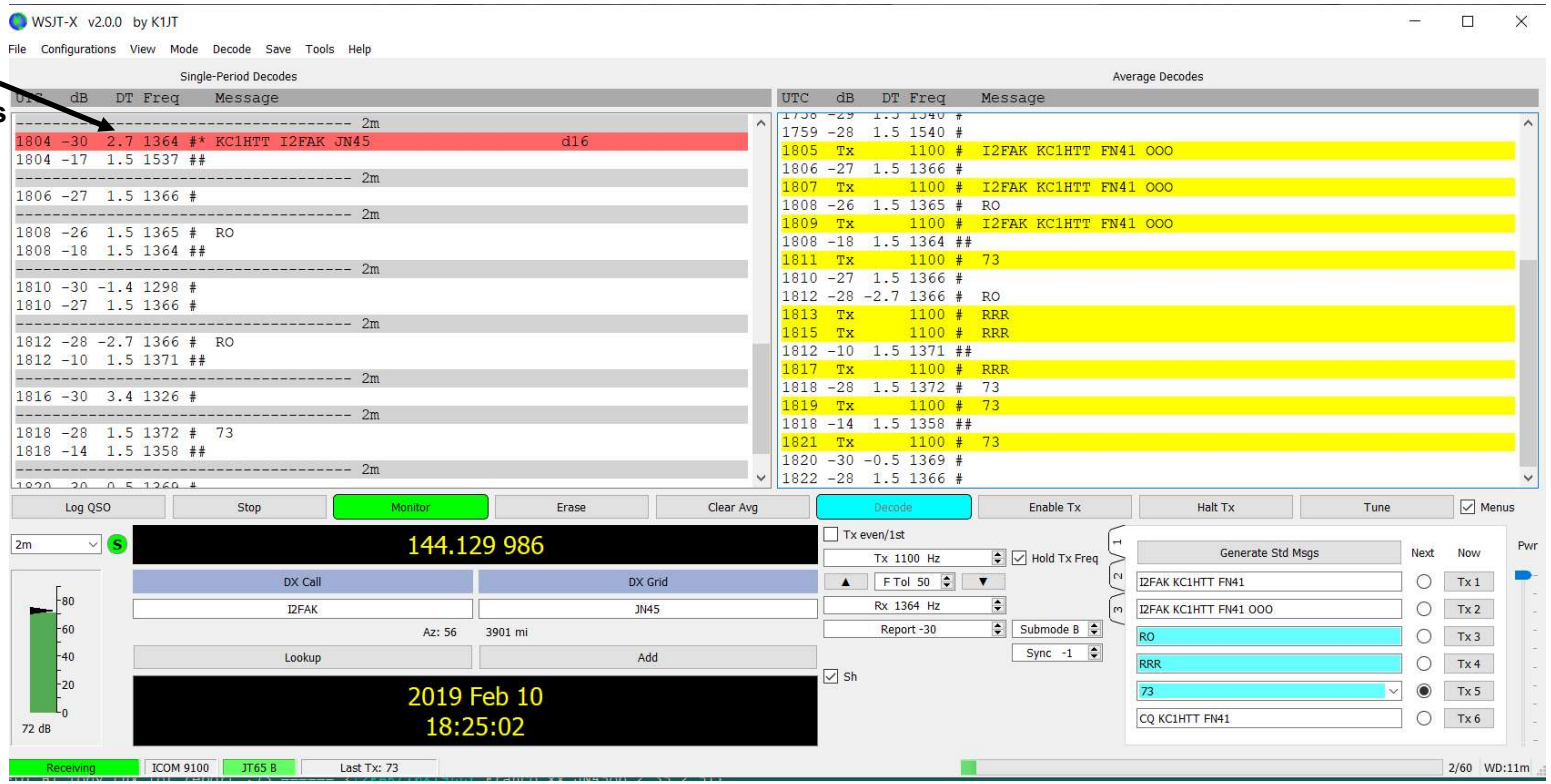


Antenna Height 2 meters
14.45 dBi, @ 35 degrees

KC1HTT - I2FAK QSO Analysis: SNR

Roundtrip time delay

2.7 seconds EXACT!



1804	KC1HTT I2FAK JN45	SNR = - 30 dB	I2FAK calls KC1HTT, 2.7 second delay
1807	I2FAK KC1HTT FN41 OOO	SNR = - 26 dB	KC1HTT reports sufficient SNR
1812	RO	SNR = - 28 dB	I2FAK "Roger, sufficient SNR"
1817	RRR		KC1HTT "Roger, Roger, Roger"
1818	73	SNR = - 28 dB	I2FAK "Best regards"
1819	73		KC1HTT "Best regards"

Undecoded calls occurred at 1805 1806, 1808, 1809, 1810, 1811, 1813, 1814, 1815, 1816. **Undecoded even time (red) I2FAK calls were caused by I2FAK alternating TX polarizations.**

Text Messages Sent Before and After QSO Between I2FAK and KC1HTT on WSJT EME – 1 Bulletin Board

10 Feb 18:22 I2FAK de KC1HTT TNX for QSO! 73, Bill ==={KC1HTT Bill CT FN41bj}

```
10Feb 18:22 I2FAK de KC1HTT TNX for  QSO! 73, Bill ====== {KC1HTT Bill CT FN41bj 24.34.171.121}
10Feb 18:21 W2LPL ge Les. What program do you use for QRA mode? ====== {SM7EOI/4X9H/700 Toby xx JO86fp 213.65.238.70}
10Feb 18:20 KC1HTT Bill I have yr 73 many tnx for 1st qso B-26 ====== {I2FAK/16X19LLY Franco xx JN45ob 2.35.2.51}
```

10 Feb 18:20 KC1HTT Bill I have yr 73, many tnx for 1st qso B-26 === {I2FAK/16X19LLY Franco xx JN45ob}

```
10Feb 18:14 VE1KG cq 144.115 second  ====== {VE1KG Serge xx FN84cm 76.11.40.48}
10Feb 18:13 UA6AQN Sergey GE tnx for report , 73 ====== {I2FAK/16X19LLY Franco xx JN45ob 2.35.2.51}
10Feb 18:12 W2LPL4XP9KW Les Tnx QSO  B-23 ====== {9A1LK/4X8/700 Slavko xx JN65th 149.202.124.102}
10Feb 18:11 VE1KG Serge , I am always out  there ====== {W2LPL4XP9KW Les NJ FN20sk 73.150.76.150}
10Feb 18:11 9A1KL, tnx - 127   92 102  1806  2.2  -25 # W2LPL 9A1LK JN65 OOO   1   63   76 V ====== {W2LPL4XP9KW Les NJ FN20sk 73.150.76.150}
10Feb 18:11 KA9CFD Jay best -28 dB, but no decodes...sri... ====== {OH4LA/4X17 Pasi xx KP20lg 85.76.75.229}
10Feb 18:11 GE all, CQ 123  1st ====== {OE5KE/2X12H/K Adolf xx JN78eg 81.10.141.7}
10Feb 18:10 VE1KG cq 144.115 second  ====== {VE1KG Serge xx FN84cm 76.11.40.48}
10Feb 18:10 I2FAK Franco  de  -13 ====== {UA6AQN Sergey MN KN96vc 31.181.86.214}
10Feb 18:10 TU Pasi 73 ====== {KA9CFD/1X12/300 Jay IL EN40om 69.161.33.137}
10Feb 18:09 stop CQ no traces ====== {WP4G/4X9XP/800W Angel xx FK68wk 23.172.64.151}
10Feb 18:09 KA9CFD Jay OK i stop calling you.....We work later....Tnc fer call...73 ====== {OH4LA/4X17 Pasi xx KP20lg 85.76.75.229}
10Feb 18:06 les  are you still out there??? ====== {VE1KG Serge xx FN84cm 76.11.40.48}
10Feb 18:06 SM7EOI Hi Toby tnx for report ,73 ====== {I2FAK/16X19LLY Franco xx JN45ob 2.35.2.51}
10Feb 18:06 ----- CQ CQ .133 1st ------ ====== {UR3EE/4X/1K Arthur xx KN88dc 92.61.34.77}
10Feb 18:06 I2FAK Franco, yes, I am working on it now... ====== {OK2OCT Martin xx JN89nl 46.33.115.249}
10Feb 18:05 Anyone for a test of QRA mode? ====== {W2LPL4XP9KW Les NJ FN20sk 73.150.76.150}
10Feb 18:05 I stopped. tnx for listen ====== {KA9CFD/1X12/300 Jay IL EN40om 69.161.33.137}
10Feb 18:04 OH4LA/4X17 Pasi ok ====== {R1AY/1X15H/250 Serge xx KP50bs 217.118.78.83}
10Feb 18:04 OK2OCT  Martin FB congrats  ====== {I2FAK/16X19LLY Franco xx JN45ob 2.35.2.51}
10Feb 18:04 I2FAK ge Franco. -17 ====== {SM7EOI/4X9H/700 Toby xx JO86fp 213.65.238.70}
10Feb 18:04 OH4LA Pasi, any sign? ====== {KA9CFD/1X12/300 Jay IL EN40om 69.161.33.137}
10Feb 18:03 R1AY Serge I could, but antenna array is turned to West...for moon....:o) ====== {OH4LA/4X17 Pasi xx KP20lg 85.76.75.229}
10Feb 18:03 OH4LA Pasi, ok one last call this sequence ====== {KA9CFD/1X12/300 Jay IL EN40om 69.161.33.137}
10Feb 18:03 OK2OCT Martin qsl card ? sure  ====== {I2FAK/16X19LLY Franco xx JN45ob 2.35.2.51}
10Feb 18:02 I2FAK Franco, vy tnx, my second eme qso ever, Ahoj ====== {OK2OCT Martin xx JN89nl 46.33.115.249}
10Feb 18:02 Nikola tnx for try   ub -22  JT65B 180000 2 -22 dB 2.9 s -64 Hz 2 W Freq 1206 Hz   VA3DIF YT3N KN04    cul 73  ====== {VA3DIF Ian ON FN04ll
10Feb 18:02 KA9CFD Jay OK monitoring still.119 here....:o) ====== {OH4LA/4X17 Pasi xx KP20lg 85.76.75.229}
10Feb 18:02 OH4LA/4X17 Pasi GE. Can you tropo test on 432 CW? ====== {R1AY/1X15H/250 Serge xx KP50bs 217.118.78.83}
10Feb 18:02 KC1HTT Bill running  ====== {I2FAK/16X19LLY Franco xx JN45ob 2.35.2.51}
```

10 Feb 18:02 KC1HTT Bill running === {I2FAK/16X19LLY Franco xx JN45ob}

CONFIRMATION! I2FAK eQSL Card Sent to KC1HTT

I2FAK - Franco Giorgi, Via Novarini 15bis, 27043 Broni (PV), ITALY

ww loc. JN45OB

Confirming EME QSO with Radio Station KC1HTT

Day	Mo.	Yr.	GMT	MHz	2-way QSO			R	S	T	QSL	
					CW	SSB	JT65				pse	tnx
10	02	19	18:19	144			X	4	0	4		X

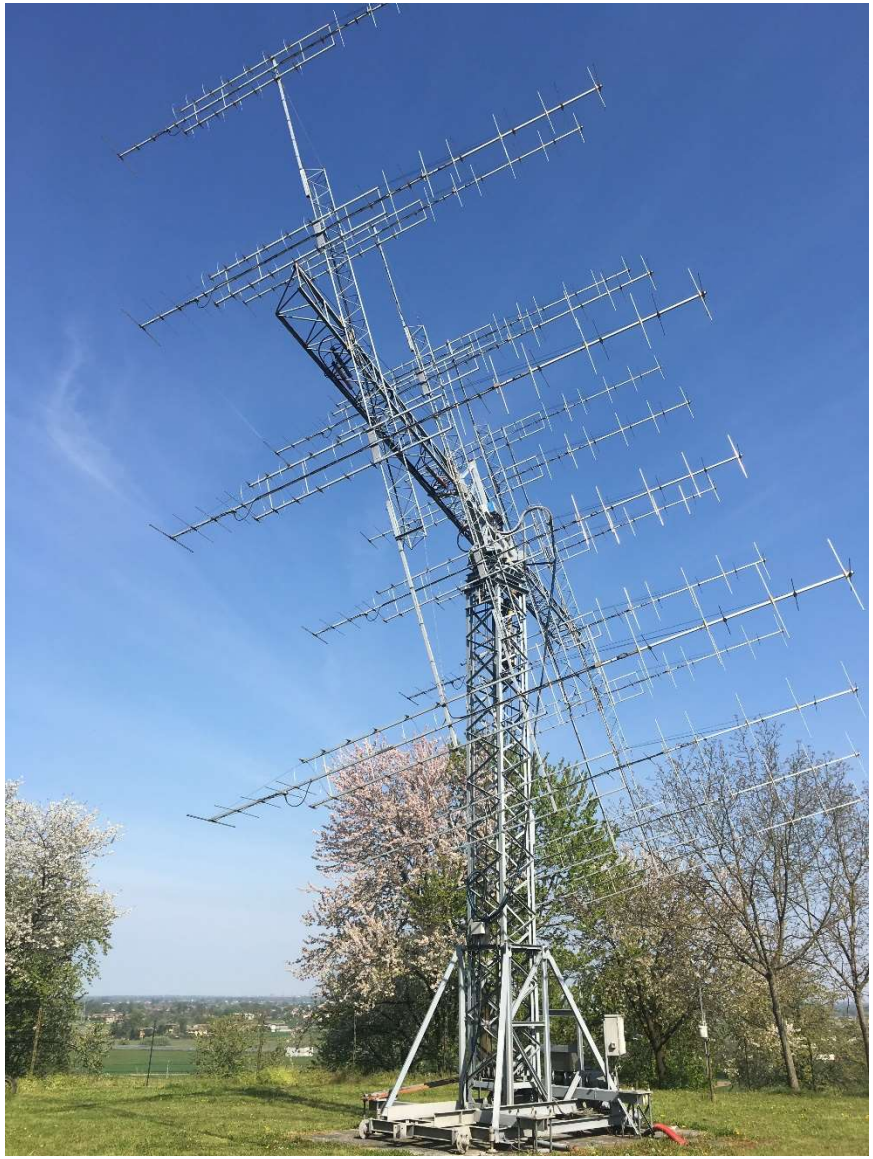
RX: IQ+ dual Pol. Pre Amp: 0,25dB Remarks: Tnx for 1st EME QSO

ANT: 16 X 19LLY H
16 X 6el. Yagi V

PA: 1,5kW vy 73/DX de

I2FAK EME Station

- Operator — Franco Giorgi
- QTH — Broni, Italy
- Grid — JN45ob
- CQ Zone — 15
- ITU Zone — 28
- Receiver — V and H
- Receiver NF — 0.2 dB
- Transmitter — V or H, 1500 W
- H Antenna Array — 16 x 19 LLY
- V Antenna Array — 16 x 6 el Yagi
- LLY H-pol Ant Gain — 25.7 dBi
- Yagi V-pol Ant Gain — 23.5 dBi
- Power*Aperture Product
  +55.2 dBW or +57.4 dBW
- Mode: MAP 65



Moon Sked Calculations for KC1HTT I2FAK QSO

Operation at beam elevation angle = 34°

		KC1HTT				I2FAK						
Date UTC	Time UTC	Az	El	MNR	POL	Az B	El B	DGR	Tsky	Range, km	Dop	Echo Width
2019-02-10 Sunday	18:00	117	+34°	2 dB	-73°	227°	+40°	3.7dB	300°K	395953	+85 Hz	2.55 Hz
2019-02-10 Sunday	18:30	124	+38°	1 dB	-74°	234°	+36°	3.7dB	300°K	395866	+55 Hz	2.57 Hz

Range to the Moon was 395,953 kilometers for a roundtrip of 791,906 kilometers or 492,067 miles or 2.642 light seconds

Calculation of the SNR During the KC1HTT – I2FAK QSO

VHF Super Conference

KC1HTT - I2FAK EME QSO	MKS Units	dB
Common Parameters		
Frequency, Hz	144,129,986	81.59
Wavelength, m	2.080	3.18
Range, m	395,942,000	85.98
Mean Lunar Cross Section, m2		118.45
kTB, watts	1.00094E-17	-170.00
Tsky, K	300	24.77
Sky noise, kTB, watts	1.03545E-17	-169.85
$(4 * \pi)^3$	1984.40	32.98
KC1HTT		
Transmitter Power, P1 (watts)	180	22.55
2M9SSB Antenna Gain		14.20
Receiver Noise Figure, F1	1.417	1.51
Receiver Noise, N1 (watts)	2.45377E-17	-166.10
Receive Polarization Loss, LP1		3.00
Receive Doppler Spreading Loss, LD1		2.00
Received signal, S1 (watts)	2.87786E-19	-185.41
SNR at KC1HTT Receiver		-19.31
I2FAK		
Transmitter Power, P2 (watts)	1500	31.76
16 x 19LLY Yagi Antenna Gain, G2		25.70
Receiver Noise Figure, F2	1.25	0.97
Receiver Noise, N2 (watts)	2.28662E-17	-166.41
Receive Polarization Loss, LP2		0.10
Receive Doppler Spreading Loss, LD2		2.00
Received signal, S2, (watts)	6.73365E-20	-191.72
SNR at I2FAK Receiver		-25.31

Comparative SNR Analysis

EME QSO SNR Evaluation

EME DX Station	EME QSO Date	Time (UTC)	Modeled KC1HTT Received SNR, dB	Measured KC1HTT Received SNR, dB	KC1HTT Measured - Modeled Difference, dB	Modeled EME DX Station Received SNR, dB	Measured EME DX Station Received SNR, dB	DX Station Measured - Modeled Difference, dB
RX1AS	1/19/2019	2130	-18.71	-18	0.71	-22.98	-24	-1.02
S52LM	1/19/2019	2200	-21.07	-26	-4.93	-25.34	-25	0.34
I2FAK	2/10/2019	1800	-19.31	-30	-10.69	-25.31	-26	-0.69
Average					-4.97			-0.46

- KC1HTT receiver noise figure (NF) is largely determined by the sky temperature
- Assumes all “big gun” EME stations compensate for received signal polarization
- Evaluation variables include
  - Range differences
  - Sky temperature (NF) differences
  - Antenna gain differences
  - Transmitter power: KC1HTT 180 Watts, EME “big gun” 1000 to 1500 Watts
- Conclusion
  - KC1HTT antenna gain is significantly affected by antenna elevation
  - KC1HTT antenna gain largely determined message SNR at “big gun” station
  - KC1HTT SNR greatly affected by polarization loss

Summary and Future Work

- **Performed EME system analysis to determine what was required for EME**
  - **Use radar equation**
  - **EZNEC+ antenna tradeoffs**
  - **Model EME performance**
  - **System requirements and cost**

- **Three successful "big gun" EME QSOs on 2 meters**
  - **19 January 2019: KC1HTT - RX1AS, European Russia**
  - **19 January 2019: KC1HTT – S52LM, Slovenia**
  - **10 February 2019: KC1HTT – I2FAK, Italy**

- **Minimum small EME station power aperture product, P*A is +39 dBW**
  - **Only able to work "big gun" stations with P*A > +50 dBW**
  - **Best to operate at low elevation angles during Moon rise or set**

- **Future work includes building a twin, 9-element, horizontally polarized, Yagi array**