

*A Beginner's View of  
Easy Moonbouncing...*



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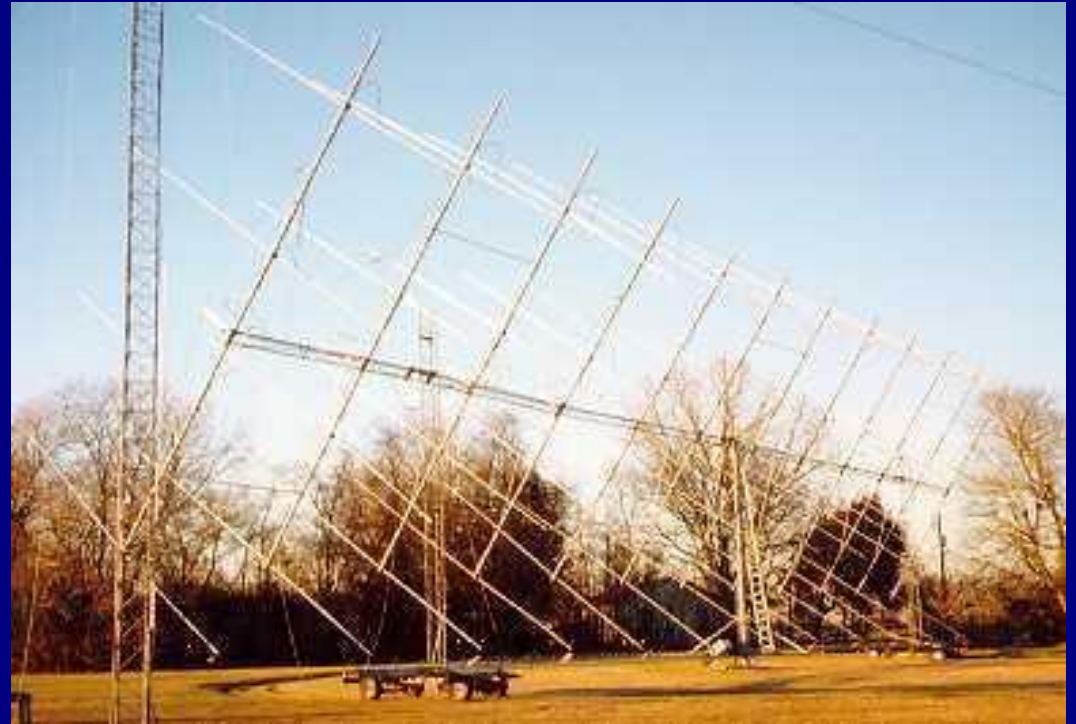
# My Objective

- GET YOU INTERESTED IN WORKING EARTH-MOON-EARTH QSOs.
  - Most hams believe exotic equipment, huge antennas, and very high power are needed to work EME.
  - You can enjoy the thrill of moonbounce with a modest setup.
    - Basically the equipment you may already have.



# *This Presentation*

- Why Moonbounce?
- The History
- A real challenge
- The Bands
- How Small a Station
- Visit VE2ZAZ EME
- Some Hints
- Optimize Noise Figure
- JT65
- The Software
- Moon Tracking
- Web References



W5UN – Mighty Big Antenna. 32 x 17 el. Yagis on 2m

# Why Moonbounce?

- **IT IS EXCITING!**
  - Most fun in ham radio is making rare, unusual, or difficult contacts. EME is the pinnacle of ham radio achievement.
- **ALLOWS TO WORK WORLDWIDE DX ON ANY BAND - 6M UP.**
  - No other unassisted mode provides this capability.
- **MOTIVATES YOU TO LEARN MORE ABOUT COMMS THEORY**
  - Propagation, noise, antenna phasing, polarization, space object tracking, etc.
- **PROVIDES AN INCENTIVE TO BUILD BETTER ANTENNAS.**
  - Complete EME arrays are not available commercially.

# *A Bit of EME History*

- **1946:** First experiments by US Mil. in Project Diana. 3,000 watts at 111.5 MHz into dipole array
- **Following years,** Moon used for Teletype between mainland and Pearl Harbor
- **1953:** First Amateur detection between W4AO and W3GK on 2m
- **1960:** First EME QSO on 1296 MHz by W1BU club in MA.
- **1965:** Arecibo Observatory Mounbounce contacts on 430 MHz with tens of kW !



# *The Anatomy of an EME QSO*

- **AVERAGE MOON DISTANCE:**  
**384,000km**
  - Average Round Trip: 770,000km!
  - Propagation Path Loss: 250+ dB!
  - Echo delay: ~ 2.4 Seconds
- **93% OF WAVE ABSORPTION BY MOON**
  - Only 7% wave reflection
- **ANGLES AND BEAMWIDTH**
  - Moon is ~ 1 degree wide when seen from earth
  - Antenna is 0.00....1 degree wide when seen from the moon!



# *Impairments in an EME QSO*

- **POLARIZATION OFFSET**
  - 90-degree polarization offset between stations, forget it!
    - FARADAY ROTATION: Polarization rotation due to Ionosphere and earth's magnetic field. At 432MHz, up to 1.5 complete rotation, at 1296MHz 0.25 rotation. Negligible at higher F.
    - SPATIAL OFFSET: Geometry of the path between two stations.
- **LIBRATION FADING**
  - Signal fading caused by the movement of the moon and surface imperfections.
  - The higher the frequency, the faster the fading
- **COSMIC NOISE, SUN NOISE**
  - When Moon has noisy sky in background, forget it!
  - When Sun and Moon line up, forget it!
- **QRM, QRN...**



# *What Band to use?*

- **50MHz:** Not very popular: Big antennas, lots of QRN, no preamp required, KW+ a must. Difficult.
- **144MHz:** Most popular band, tons of stations work random JT-65 QSOs. A pair of long boom yagis and 500-1000W will keep you active.
- **432MHz:** Fewer stations, more difficult to work random. Activity Periods. A pair of long boom Yagis or 4 yagis a good entry point. 400W+ an asset. Preamp is a must. QRN nil!
- **1296MHz:** More and more stations, probably more than on 432MHz. A 10+ foot dish is the way to go. 100W+ a must.
- **2304MHz:** Fewer stations, must plan skeds. More exotic gear to generate the high output RF power. Skeds only.
- **>2304MHz:** Experiments, lots of experiments. TWTs, fancy stuff, waveguides. Some activity. Skeds only.



# *Big Guns are an Asset!*

- THEY DO ALMOST ALL OF THE WORK!
- THERE ARE A LOT OF THEM, ESPECIALLY IN EUROPE.



HB9Q Club – 15m Dish (70cm, 23cm, 13cm), 8 x 19 el. Yagis (2m), 11 el. Yagi (6M)

# How Small Can an EME Station Be?

- Single long-boom Yagi
- 80W
- No Preamp
- No Elevation Rotor

Success in JT-65!

- 4 x long-boom Yagis
- 45W
- Low NF Preamp

Success in CW!

**SIMPLE BASIC QSOs,  
NOT RAG CHEWING!**



# *VA3TO – 2M EME, 112 Countries*



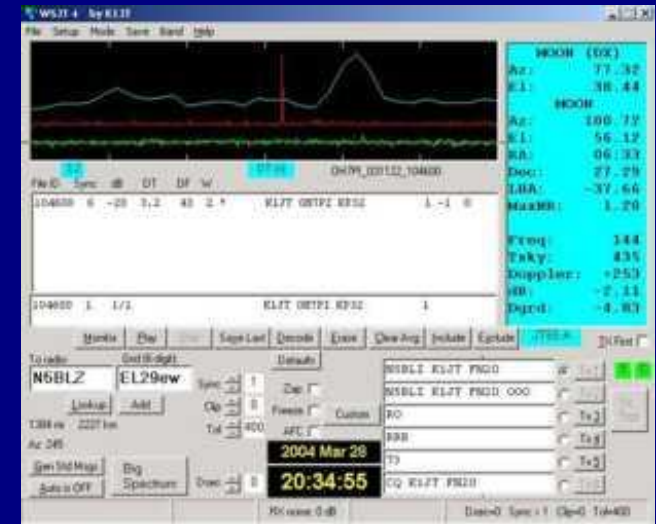
# *EME at VE2ZAZ... Outside*





# EME at VE2ZAZ... Inside

- Rig: TS-790A (separated Tx and Rx ports)
- Amp: Mirage D1010 brick (~100 W).
  - Future: AM-6155 FAA amp (~400W)
- Sequencer: "At Last" Sequencer (VE2ZAZ)
- Audio Filter: JPS NIR-10 DSP
- PC and Sound Card:
  - WSJT Software
  - Spectran Sound analysis/filter Software
  - Nova For Windows tracking Software
  - N0UK JT-65 EME Logger Website
  - MultiKeyer CW Keyer Software



# *Some Hints for a Small EME Station*

- **Minimize Losses Between Antenna and Preamp.**
  - Any attenuation is a direct deterioration of the Noise Figure.
    - Best possible coax. RG-214 not good enough. LMR series better.
    - Use N-Type connections everywhere, even at 144MHz.
- **Rule out old Yagi designs**
  - Constant element spacing not a good indication of modern design.
  - Modern modeled antenna designs are best. K1FO long boom design is a baseline.
- **Every Watt Counts. Use the best possible TX feedline.**
  - At >432MHz, Heliax or equiv. Is a MUST!

# *More Hints for a Small EME Station*

- **At 432MHz and Above, use a preamp with very low NF.**
  - NF < 0.5B recommended.
- **Transverters Work Great**
  - Are Cheaper.
  - Can be located remotely to minimize feedline losses.
- **Operate When Moon Conditions are Best**
  - The 2dB difference in path loss can “make or break” a QSO.
  - Avoid high sky noise.
- **Exploit Ground Gain, up to 6 dB due to ground reflections.**
  - Especially applicable to 50MHz and 144 MHz



# More EME Hints...

- **Be careful about Amplifier Over-Stress from JT65.**
  - JT65 runs 50 secs at full power, 70 secs off.
  - Use a fan on linear bricks. 24V fan on 13.8V is quiet and effective.
  - Derate output power (from p.e.p. specs) on tube-type amplifiers.
- **Avoid Hot-Switching Coaxial Relays**
  - Wears out contacts at much accelerated rate.
- **Be on Frequency**
  - Measure your TX frequency offset and compensate for it.
  - Use a Frequency Counter with a GPS Reference.
    - Especially applicable to 1296MHz and above.
  - Remember RX Doppler compensation...
    - The higher the F, the larger the Doppler (proportional)
    - At 432MHz Doppler varies +/- 1KHz.

# *Even More EME Hints...*

- Synchronize your PC to UTC Time
  - To the nearest second.
  - Win2K, WinXP, Vista have this built in.
- Polarization Control is an Asset
  - Feedpoint rotation on dishes.
  - Cross-Yagi array
- Watch for Coaxial Cable Power Handling Capability.
  - At 432MHz, surprisingly low.
    - RG-214 = ~ 300W
    - 9913 = ~ 400W
  - Another reason to use Heliax coaxial cable.

# Optimize your Noise Figure

- A “typical” Setup

The screenshot shows the AppCAD - [NoiseCalc] application window. The title bar includes 'AppCAD - [NoiseCalc]' and standard window controls. The menu bar contains 'File', 'Calculate', 'Application Examples', 'Options', and 'Help'. The main interface features a 'NoiseCalc' title, a 'Set Number of Stages' input field set to '5', and buttons for 'Calculate [F4]', 'Clear', and 'Main Menu [F8]'. Below this is a table with columns for Stage 1 through Stage 5. Each stage has a small schematic icon above its name. The table lists various parameters for each stage and a summary 'Stage Analysis' section. At the bottom, there are three sections: 'Enter System Parameters', 'System Analysis', and a list of other system parameters. The 'System Analysis' section has a red circle around the 'Gain = 167.80 dB' value.

		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
<b>Stage Data</b>	<b>Units</b>					
Stage Name:		4 x Coax	Coupler+ Relays	Preamp	Coax	Radio
Noise Figure	dB	0.5	0.2	0.9	1.5	5
Gain	dB	-0.5	-0.2	20	-1.5	150
Output IP3	dBm	0	0	0	0	0
dNF/dTemp	dB/°C	0	0	0	0	0
dG/dTemp	dB/°C	0	0	0	0	0
<b>Stage Analysis:</b>		0	0	0	0	0
NF (Temp corr)	dB	0.50	0.20	0.90	1.50	5.00
Gain (Temp corr)	dB	-0.50	-0.20	20.00	-1.50	150.00
Input Power	dBm	0.00	-0.50	-0.70	19.30	17.80
Output Power	dBm	-0.50	-0.70	19.30	17.80	167.80
d NF/d NF	dB/dB	0.78	0.81	0.98	0.01	0.04
d NF/d Gain	dB/dB	-0.22	-0.19	-0.02	-0.02	0.00
d IP3/d IP3	dBm/dBm	0.00	0.00	0.00	0.00	1.00

Enter System Parameters:

Input Power	0	dBm
Analysis Temperature	25	°C
Noise BW	1	MHz
Ref Temperature	25	°C
S/N (for sensitivity)	0	dB
Noise Source (Ref)	290	*K

System Analysis:

Gain =	167.80	dB
Noise Figure =	1.72	dB
Noise Temp =	140.99	*K
SNR =	112.25	dB
MDS =	-112.25	dBm
Sensitivity =	-112.25	dBm
Noise Floor =	-172.25	dBm/Hz

Input IP3 =	-167.80	dBm
Output IP3 =	0.00	dBm
Input IM level =	335.60	dBm
Input IM level =	335.60	dBc
Output IM level =	503.40	dBm
Output IM level =	335.60	dBc
SFDR =	-37.03	dB

Normal [Click for Web: APPLICATION NOTES - MODELS - DESIGN TIPS - DATA SHEETS - S-PARAMETERS](#)

# Optimize your Noise Figure

- A better setup

The screenshot shows the AppCAD - [NoiseCalc] application window. The main window title is "AppCAD - [NoiseCalc]". The menu bar includes "File", "Calculate", "Application Examples", "Options", and "Help". The main area is titled "NoiseCalc" and features a "Set Number of Stages" field set to "5" and a "Calculate [F4]" button. Below this is a table with columns for Stage 1 through Stage 5. The table contains various parameters such as Stage Name, Noise Figure, Gain, Output IP3, dNF/dTemp, dG/dTemp, Stage Analysis, NF (Temp corr), Gain (Temp corr), Input Power, Output Power, dNF/dNF, dNF/dGain, and dIP3/dIP3. A green circle highlights the "4 x Coax" entry in the Stage 1 Name column. Below the table are three sections: "Enter System Parameters:", "System Analysis:", and a summary of key parameters. A red circle highlights the "Gain" value of 168.10 dB in the System Analysis section.

		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
<b>Stage Data</b>	<b>Units</b>					
Stage Name:		4 x Coax	Coupler+ Relays	Preamp	Coax	Radio
Noise Figure	dB	0.2	0.2	0.9	1.5	5
Gain	dB	-0.2	-0.2	20	-1.5	150
Output IP3	dBm	0	0	0	0	0
dNF/dTemp	dB/°C	0	0	0	0	0
dG/dTemp	dB/°C	0	0	0	0	0
<b>Stage Analysis:</b>		0	0	0	0	0
NF (Temp corr)	dB	0.20	0.20	0.90	1.50	5.00
Gain (Temp corr)	dB	-0.20	-0.20	20.00	-1.50	150.00
Input Power	dBm	0.00	-0.20	-0.40	19.60	18.10
Output Power	dBm	-0.20	-0.40	19.60	18.10	168.10
dNF/dNF	dB/dB	0.78	0.81	0.98	0.01	0.04
dNF/dGain	dB/dB	-0.22	-0.19	-0.02	-0.02	0.00
dIP3/dIP3	dBm/dBm	0.00	0.00	0.00	0.00	1.00

Enter System Parameters:

Input Power	0	dBm
Analysis Temperature	25	°C
Noise BW	1	MHz
Ref Temperature	25	°C
S/N (for sensitivity)	0	dB
Noise Source (Ref)	290	°K

System Analysis:

Gain	168.10	dB
Noise Figure	1.42	dB
Noise Temp	112.22	°K
SNR	112.55	dB
MDS	-112.55	dBm
Sensitivity	-112.55	dBm
Noise Floor	-172.55	dBm/Hz

Input IP3	-168.10	dBm
Output IP3	0.00	dBm
Input IM level	336.20	dBm
Input IM level	336.20	dBc
Output IM level	504.30	dBm
Output IM level	336.20	dBc
SFDR	-37.03	dB

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# Optimize your Noise Figure

- A Much Better Setup

AppCAD - [NoiseCalc]

File Calculate Application Examples Options Help

NoiseCalc Set Number of Stages = 5 Calculate [F4] Clear Main Menu [F8]

Stage Data	Units	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Stage Name:		4 x Coax	Coupler+ Relays	Preamp	Coax	Radio
Noise Figure	dB	0.2	0.2	0.3	1.5	5
Gain	dB	-0.2	-0.2	20	-1.5	150
Output IP3	dBm	0	0	0	0	0
dNF/dTemp	dB/°C	0	0	0	0	0
dG/dTemp	dB/°C	0	0	0	0	0
<b>Stage Analysis:</b>		0	0	0	0	0
NF (Temp corr)	dB	0.20	0.20	0.30	1.50	5.00
Gain (Temp corr)	dB	-0.20	-0.20	20.00	-1.50	150.00
Input Power	dBm	0.00	-0.20	-0.40	19.60	18.10
Output Power	dBm	-0.20	-0.40	19.60	18.10	168.10
d NF/d NF	dB/dB	0.88	0.91	0.97	0.01	0.05
d NF/d Gain	dB/dB	-0.12	-0.09	-0.03	-0.02	0.00
d IP3/d IP3	dBm/dBm	0.00	0.00	0.00	0.00	1.00

Enter System Parameters:

Input Power	0	dBm
Analysis Temperature	25	°C
Noise BW	1	MHz
Ref Temperature	25	°C
S/N (for sensitivity)	0	dB
Noise Source (Ref)	290	°K

System Analysis:

Gain	168.10	dB
Noise Figure	0.84	dB
Noise Temp	61.74	°K
SNR	113.14	dB
MDS	-113.14	dBm
Sensitivity	-113.14	dBm
Noise Floor	-173.14	dBm/Hz

Input IP3	-168.10	dBm
Output IP3	0.00	dBm
Input IM level	336.20	dBm
Input IM level	336.20	dBc
Output IM level	504.30	dBm
Output IM level	336.20	dBc
SFDR	-36.64	dB

Normal Click for Web: APPLICATION NOTES - MODELS - DESIGN TIPS - DATA SHEETS - S-PARAMETERS

$$F_{\text{sys}} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots + \frac{F_n - 1}{G_1 G_2 \dots G_{n-1}}$$

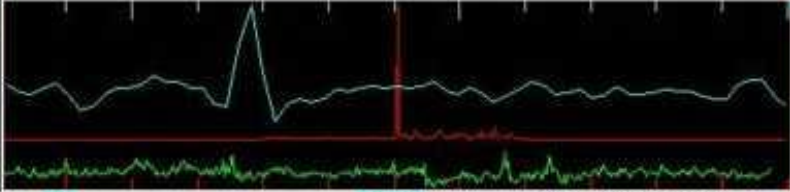
# *JT65 – The Small Station's Best Friend*

- Modulation mode created by Joe Taylor – K1JT in 2003
- Software actually called WSJT.
- Uses a PC and its sound card, Windows-based.
- DSP techniques optimized for extremely weak but slowly-varying signals (e.g. meteor scatter and moonbounce)
- Uses 63-frequency shift keying with constant phase
  - Single tone and continuous phase: Usable on a non-linear transmitter and power amplifier!
- Decode signals many decibels below the noise floor, even without signals being audible to the human ear.
  - Forward Error Correction (FEC) used. 5.25:1 Redundancy Ratio
  - Fixed and Expected Message, Grid and Callsign Formats
    - CQ VE2ZAZ FN25
    - K2UYH VE2ZAZ FN25
    - O, RO, RRR, 73
  - Does averaging of several Rx messages
  - Uses Deep Search table (list of stations known to do EME)

# WSJT - JT65

WSJT 6 by K1JT

File Setup View Mode Decode Save Band Help



Moon  
Az: 162.52  
El: 42.44  
Dop: 3  
Dgrd: -2.3

6.0 Time (s) UT1PA\_070514\_075500

FileID	Sync	dB	DT	DF	W			
075000	T	-7	0.3	229	1	#		
075100	4	-12	1.2	5	3	*	CQ UT1PA K021	1 0
075300	7	-11	1.2	5	3	*	CQ UT1PA K021	1 0
075500	6	-11	1.6	5	3	#	OZ1PF UT1PA K021	000 1 0

075500 2 2/2 CQ UT1PA K021 1 0

Log QSO Stop Monitor Save Decode Erase Clear Avg Include Exclude TxStop

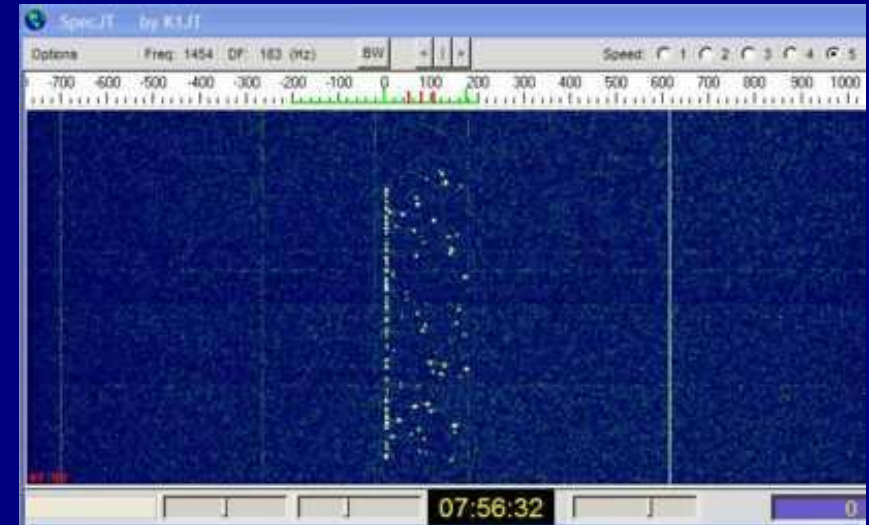
To radio: UT1PA Lookup  
Grid: K021fc Add  
Az: 116 962 km

2007 May 14  
07:56:32

Sync 0 Zap  
Clip 0 NB  
Tol 200 Freeze  
Defaults AFC  
Dsec 0.0 Shift 0.0

Tx First UT1PA OZ1PF R-11 Tx1  
 Rpt UT1PA OZ1PF J065 000 Tx2  
 Ch Msg R-11 Tx3  
TxDF = 0 RRR Tx4  
GenStdMsgs 73 Tx5  
 Auto on Off CQ OZ1PF J065 Tx6

0.9999 0.9999 JT65A Freeze DF: 0 Rx noise: 0 dB TR Period: 60 s Txing: UT1PA OZ1PF R-11

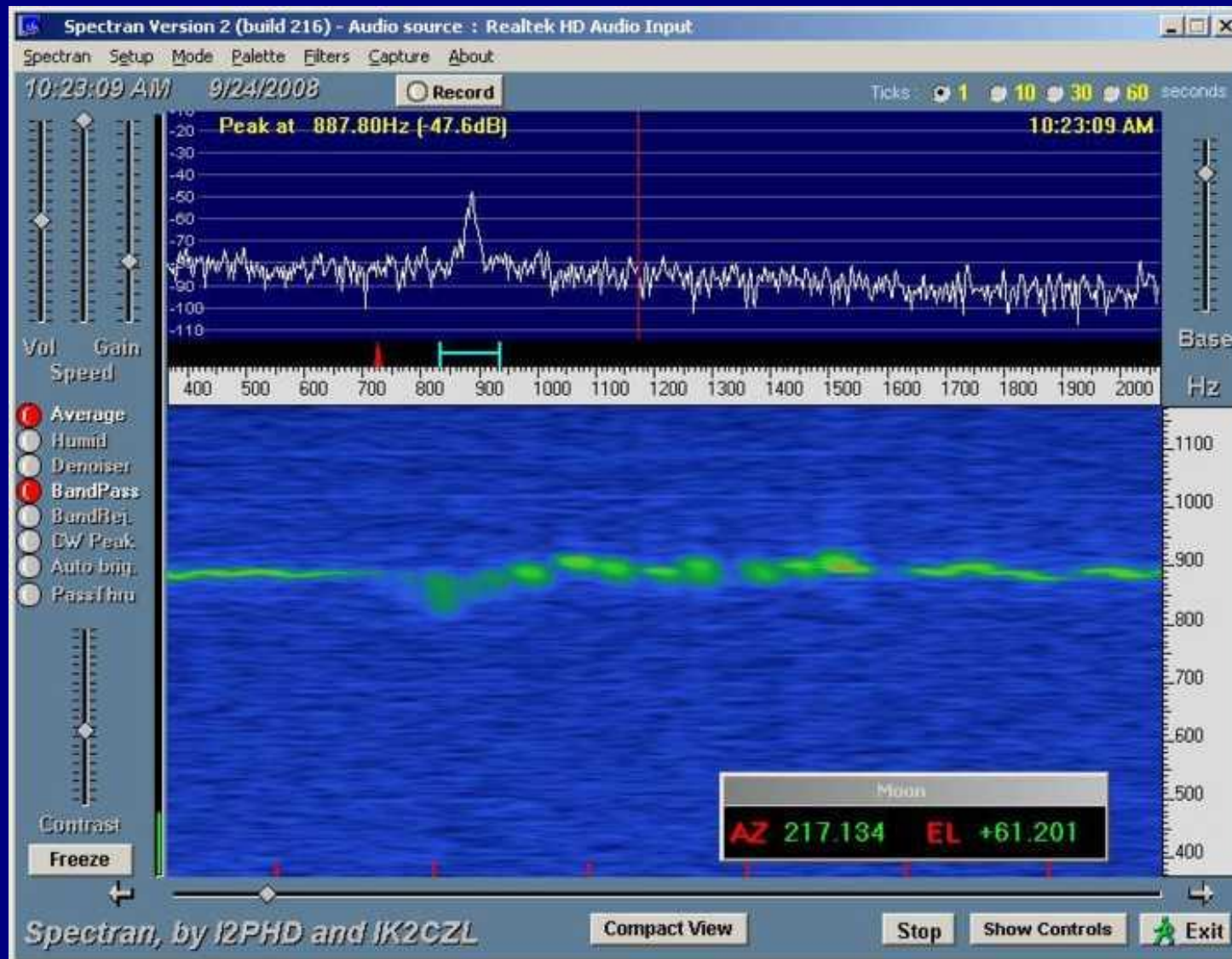




# *The JT65 Controversy...*

- “Deep Search” Lookup Controversy
  - Is it considered a complete copy of info for valid QSO?
- Not a true EME QSO? Too easy!
  - Endless Debate...
  - Solution will be to produce specific award classes for the EME digital modes

# Spectran – Audio SA and Filter SW



# MultiKeyer – Auto CW Keyer SW

The screenshot shows the MultiKeyer software interface. At the top, there is a menu bar with 'File', 'Edit', 'View', 'Setup', 'Period', 'Mode', and 'Help'. Below the menu bar is a toolbar with icons for copy, paste, save, and help. The main interface is divided into several sections:

- Start Time:** A time selection box showing '14:44:00'.
- CW WPM:** A speed selection box showing '16'.
- To Radio:** A text box containing 'K1RQG'.
- Grid (6 digit):** An empty text box.
- Report:** A text box containing 'T'.
- Duration (sec):** A text box containing '120'.
- Seq:** A text box containing '120'.
- Pause:** An empty text box.
- Gen Std Msgs:** A button.
- Auto is OFF:** A button.
- Date/Time:** A digital display showing '2008 Sep 24 14:43:12'.
- Message Queue:** A list of seven CW messages:
  - {K1RQG DE VE2ZAZ}{R:120}
  - {K1RQG DE VE2ZAZ}{R:90}{%0}{R:30}
  - {K1RQG DE VE2ZAZ}{R:90}{K1RQG}{R:30}
  - {K1RQG DE VE2ZAZ}{R:90}{VE2ZAZ}{R:30}
  - {OR }{R:120}
  - {R }{R:120}
  - {CG DE VE2ZAZ VE2ZAZ VE2ZAZ}{R:120}
- TX Selection:** A vertical list of radio buttons labeled TX1 through TX7. TX1 is selected.
- TX First:** A checkbox.
- SO2R:** A button with a blue 'A' icon.
- TX Stop:** A button.
- Type:** A button with a green 'CW' icon.
- Filters:** Checkboxes for 'FIR Filter' and 'FFT Filter', both unchecked.
- Filter Freq:** A text box containing '1230'.
- Filter Width:** A text box containing '100'.
- Width @ -60 dB:** A text box containing '200'.
- Display Controls:** Three sliders for 'Display Gain', 'Display Contrast', and 'Display Averaging'.
- Status Bar:** Text 'For Help, press F1' and a 'NUM' indicator.

# NOUK JT-65 EME Logger

- A Must for both Skeds and Random QSOs
- Mostly 144MHz activity, but all bands are seen
- Other Logger Sites available
  - HB9Q EME Logger
  - ON4KST EME Chat

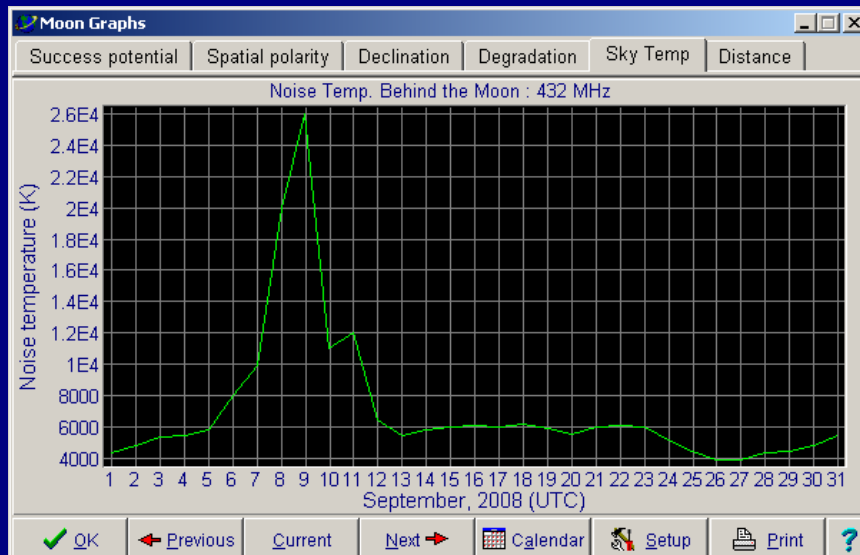
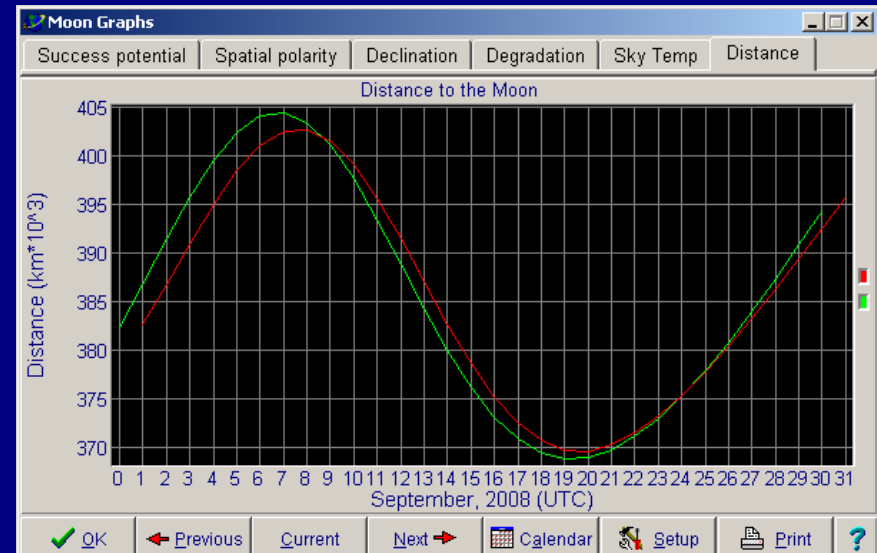


# *Moon Prediction*

- **Software (Current Position, Prediction, Sked planning, Mutual Visibility)**
  - MoonSked \$
  - Nova \$
  - EME Systems
  - SatTrack (Linux)
  - Winorbit
  - ...
- **Internet Applets (Current Position)**
  - Sun, Earth and Moon Applet
    - <http://www.jgiesen.de/SME/>
  - Sun & Moon Position Calculator
    - <http://www.satellite-calculations.com/Satellite/suncalc.htm>
  - ...



# Moon Prediction – Nova



**Listing Data for Sun**

Date (Z)	One Observer			One Observer AOS/LOS		Two Observers Az/El		
	Start (Z)	End (Z)	Duration	Between	Az/El@Start	Az/El @ End	Az/El@Start	Az/El @ End
Sun position on Tuesday, September 23, 2008 (UTC)								
9/23/08	11:01:17	22:52:41	11:51:23	-----	091°/001°	269°/000°	090°/000°	268°/001°
Sun position on Wednesday, September 24, 2008 (UTC)								
9/24/08	11:02:12	22:50:45	11:48:33	12:09:31	092°/001°	269°/000°	091°/000°	268°/001°
Sun position on Thursday, September 25, 2008 (UTC)								
9/25/08	11:03:07	22:48:50	11:45:43	12:12:21	092°/001°	268°/000°	091°/000°	267°/001°
Sun position on Friday, September 26, 2008 (UTC)								
9/26/08	11:04:02	22:46:55	11:42:53	12:15:11	093°/001°	268°/000°	092°/000°	267°/001°
Sun position on Saturday, September 27, 2008 (UTC)								
9/27/08	11:04:57	22:45:00	11:40:02	12:18:02	093°/001°	267°/000°	092°/000°	266°/001°
Sun position on Sunday, September 28, 2008 (UTC)								
9/28/08	11:05:52	22:43:05	11:37:12	12:20:52	094°/001°	267°/000°	093°/000°	266°/001°
Sun position on Monday, September 29, 2008 (UTC)								

Close ReCalc Stop Visible? Setup Print ?

# QSLs are a Must for EME

- Get your QSL design refreshed!
- Paper QSLs are still very popular within EME community.
- Nice trophies for a Small Station!
- QSL is normally sent Direct, not Via Buro.





# Some References

- Moon-Net Email Reflector
  - [http://list-serv.davidv.net/mailman/listinfo/moon-net\\_list-serv.davidv.net](http://list-serv.davidv.net/mailman/listinfo/moon-net_list-serv.davidv.net)
- 144MHz EME Newsletter
  - <http://www.df2zc.de/newsletter/index.html>
- 432 and Above EME Newsletters by K2UYH.
  - <http://www.nitehawk.com/rasmit/em70cm.html>
- DUBUS EME Moon Calendar
  - <http://www.marsport.org.uk/dubus/eme.htm>
- JT-65 Protocol Description
  - <http://www.physics.princeton.edu/pulsar/K1JT/JT65.pdf>

The WWW IS FULL OF EME STUFF!