Measurements on OZ9AAR 70 cm EME array

OZ9AAR 2024-11-06

4 x 23 elements, 5.7 meter booms/8.2WL

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Introduction

When my new 70 cm EME system was completed, I did some preliminary sun noise measurements and the numbers I got from that did not (initially) match the predicted sun noise levels calculated by the EMECalc program by VK3UM (SK).

On the other hand, I was working stations, both dual and single yagi stations, so it could not be a complete disaster, also Frank NC1I mentioned that he thought my station performed "more or less as it should".

To gain some understanding of what could be wrong/what could be optimized, I did several measurements of the system. The results of these measurements are described in this document. I got A LOT of input from vastly more experienced EME operators, this I am VERY grateful for!).

1) The system consists of 4 antennas arranged in a typical "H" frame. The antennas are from the company "Antennas&Amplifiers" (see picture on the first page of this document).
2) Each cable from the four antennas has a measured insertion loss of 0.25 dB,
3) The antennas are combined using a single "4 to 1" combiner.
4) After the combiner (and 30 cm cable), an external preamp (NF 0.8 dB, 20 dB gain) is mounted (also from Antennas&Amplifiers). Later changed preamp to WD5AGO cavity preamp.
5) After the preamp, a cable with a loss of approx. 2.5 dB feeds the signal to an ICOM IC-9700 transceiver.

The antennas are each 23 elements (horizontal only), boom length is 5.7 meters, gain is 18.9 dBi, F/B is 40 dB, G/T (Tsky 27K) is +8.22 dB.
Four antennas have an estimated gain of 24.6 dBi / 22.4 dBd.

Further data and description of the system are available at:

https://www.moonbounce.dk/hamradio/ham-radio-current-systems/70cm-eme-system.html

Thanks for input from Frank NC1I, Nic G3YEG, Peter PA2V, Steve W5DOG, Chuck AG7CM, Peter G3LTF, Sam G4DDK, Thomas DL1VPL and many others on the moon-net email reflector!

Measurement methods

Five plus one different method was used to measure levels, "WS": WSJT (echo monitor function), "NM": Noise Meter, "AP": Audio Power, "SV": SpectraVue and a "DMM": DMM6500 (AC voltage, dB reading, Filter on). (Later on, I developed my own program, SimpleCalc, which also is able to measure the noise, results from that falls in line with the other methods shown here)

The sixth method used a step attenuator in the RF path to the radio, this gave in fact a higher sun noise measurement under certain circumstances! More on that later in this document.

For all measurements, the IC-9700 was set to:

1) FIL 1 (Bandwidth 3.6 KHz)
2) Mode USB-D
3) USB LF level = 33% (audio level to PC/soundcard)
4) Frequency 432.065 MHz (checked no spurs etc.)
5) AGC OFF

All measurements with software were done using the built-in soundcard of the IC-9700.

The DMM6500 multimeter measurements (set to AC, Filter on, readout in dB) were done using the headphone connector on the front of the IC-9700. LF level knob on IC-9700 was kept at a constant level during measurements.

The software used and the version of each:

- WSJT: By K1JT (and others) v2.7.0-rc6
- Noise Meter: By G8KBB v 0.4
- Audio Power: By SV1CAL v 1.0
- SpectraVue: By RFSPACE v 3.44 Beta 0

Generally, the five different measurement methods gave the same result in all cases, there were maybe a couple of 1/10th dB of differences, but these where probably due to the different time of measurement and did not have much (if anything) to do with what type of software/DMM was used. There was an offset between the different (software) methods used, but this was constant and did not change over the measurements.

So basically, I could have used any of the measurement tools/methods.

In the measurements below, I chose to use SpectraVue in continuum mode, this seems to give the most "quiet" and stable reading (using FFT average 20).

Measurements on my IC-9700.

First, I did a couple of measurements on my IC-9700 at 70 cm. I wanted to make sure that it was close to the different reviews out there.

First test was MDS (done at CW, 500 Hz, AGC Mid, ATT, NR, NB, IP+ all off).

With radio terminated in 50 ohms (levels measured on SpectraVue):

Preamp off: -61.6 dB
Preamp on: -62.3 dB

Measurement of MDS (+3 dB above noise floor).

Preamp off: -131.9 dBm (0.057uV) **(with SSB SP-70 preamp: 144.6 dBm)**
Preamp on: -143.1 dBm (0.016 uV) **(with SSB SP-70 preamp: 144.8 dBm)**

Just to get another number to compare with reviews, I measured the level needed for S9 indication:

Preamp off: -87 dBm
Preamp on: -95 dBm

Calculation of Noise Factor from MDS.

Using the calculator at: https://owenduffy.net/calc/mds2nf.htm it is possible to calculate the Noise Figure based on the MDS value. If I use -131.9 dBm and -143.1 dBm, I arrive at Noise figures of 15.09 dB and 3.89 dB. (with SSB Electronics SP-70 preamp in line, NF is 2.41 and 2.21 dB).

(doing the same measurements at 1.2 KHz BW yielded MDS of -127.7 and -139.0 dBm / NF 15.5 and 4.2 dB)

These (500 Hz BW) numbers fit perfectly with numbers in the reviews I found online. Especially the one from Adam Farson VA7OJ/AB4OJ, in his review both the MDS and NF are mentioned. Adam measures the MDS to be:

Preamp off: -132 dBm
Preamp on: -143 dBm

Which is the same as I measured. This makes me believe that the Noise Figure I use in the following calculations is pretty accurate (**15 dB NF with preamp off, and 4 dB NF with preamp on**).

Table 5: Noise figure in dB.

Band	Preamp	Meas. NF dB	NF calc. from MDS dB
144 MHz	off	16	16
	on	3	4
432 MHz	off	15	15
	on	4	4
1.2 GHz	off	8	7
	on	4	3

Figure 1 From Adam Farson VA7OJ/AB4OJ review

He also measured the Noise Figure separately, and this match the numbers when using MDS to calculate NF.

Measurements without connection to antennas

First, I did four measurements without the antennas connected. I tested with a 50 ohm termination on the input of the external LNA, made two measurements, one with the internal preamp on and one with it off.

Then I connected the 50 ohm termination to the radio (at the output cable on the external LNA), measured again with the internal preamp off and on.

Int preamp off, radio terminated in 50 ohms.

-53.0 dB

Int preamp on, radio terminated in 50 ohms.

-54.3 dB

Int preamp off, ext. preamp on, (50 ohm termination instead of antenna).

-48.8 dB

Int preamp on, ext. preamp on, (50 ohm termination instead of antenna)

-40.1 dB

Measurements of "cold sky".

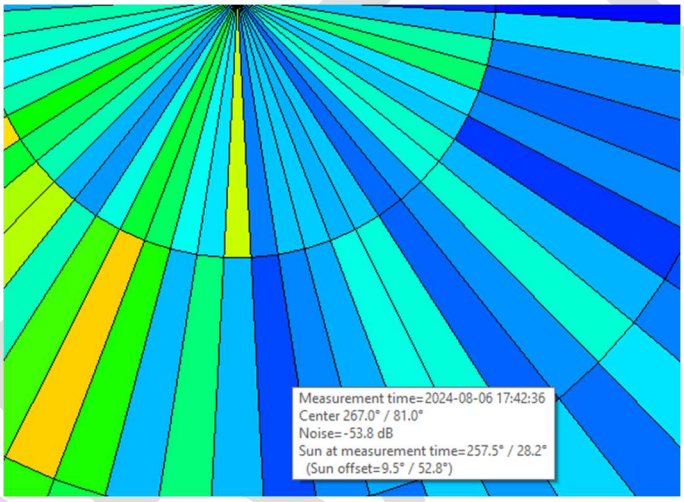
I tried using Leo as "cold sky", it turns out that sometimes I was able to find an even "colder spot" on the sky, probably because of local noise that would creep into the antennas when pointing to Leo.

Cold spot (Az 267, El 81), Int preamp off, ext. preamp on

-50.7 dB

Cold spot (Az 267, El 81), Int preamp on, ext. preamp on

-43.6 dB
This position fits fine with the scan from my SkyScanner program (note there is approx. a 3 dB (constant) offset between SkyScanner and SpectraVue):



IC-9700 Noise Figure

According to a review (and my own measurements) of the IC-9700 by Adam Farson VA7OJ/AB4OJ, the noise figure of the IC-9700 is:

Table 5: Noise figure in dB.

Band	Preamp	Meas. NF dB	NF calc. from MDS dB
144 MHz	off	16	16
	on	3	4
432 MHz	off	15	15
	on	4	4
1.2 GHz	off	8	7
	on	4	3

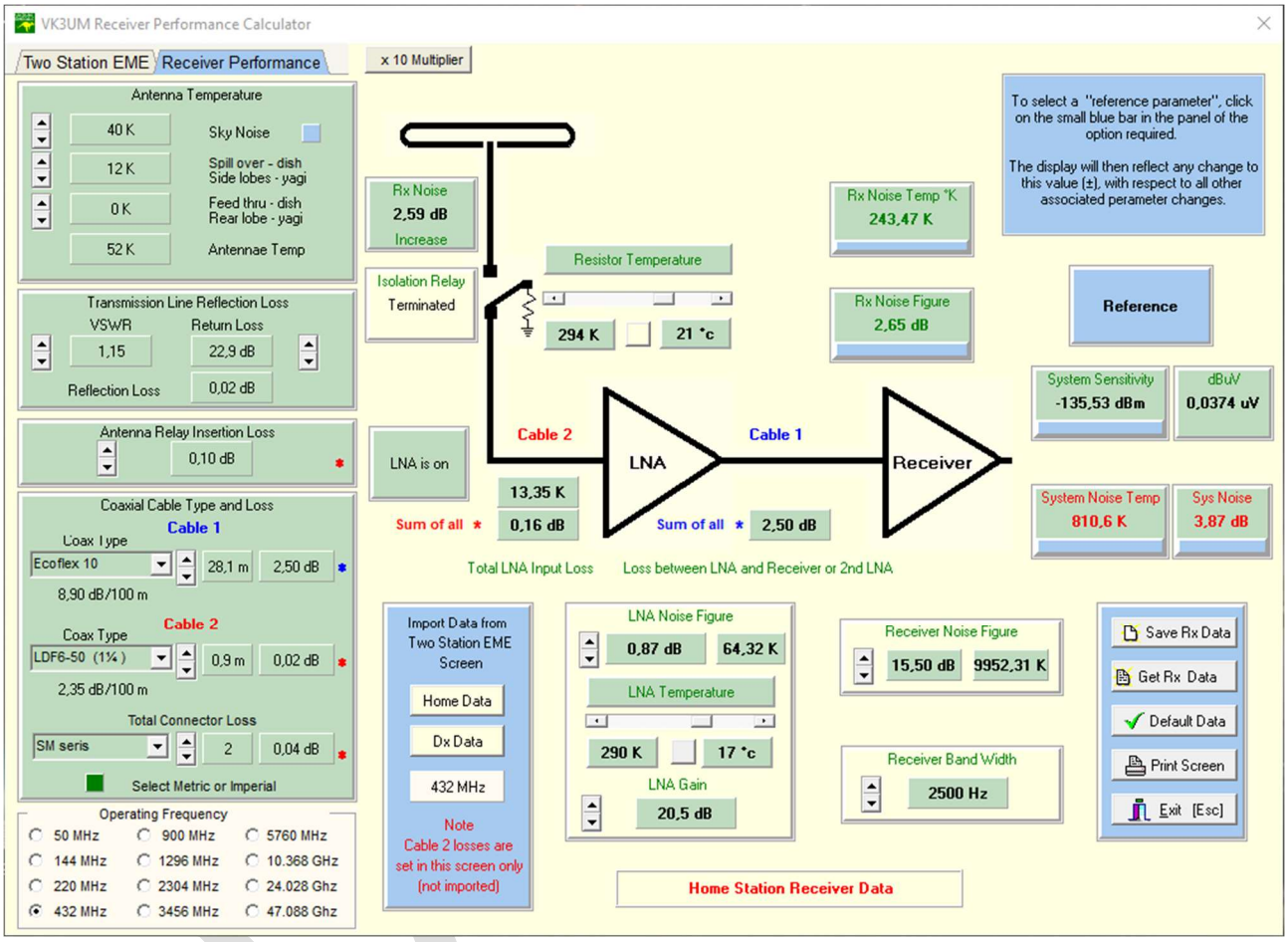
According to this, the IC-9700 has a **Noise Figure of 15 dB with the internal preamp off, and 4 dB with the internal preamp on**, in the 70cm band.

Sam, G4DDK also did measurements on the IC-9700 (reviews in Practical Wireless magazine), he measured 15.9 dB with internal preamp off, and 4.8 dB with internal preamp on, so a little higher than Adam Farson measured.

RX performance calculator in EMECalc

When using the "RX performance" tab in EMECalc, it is possible to calculate the effect of connecting a 50 ohm termination to the preamp instead of the antenna (on 70cm, noise is expected to increase with the termination resistor).

I entered the known data, for the NF of the radio, **I first chose 15.4 dB** as that was in the middle of the two reviews.



According to this, I should see an increase in noise by 2.59 dB when connecting a 50 ohm terminal instead of the antenna to the preamp.

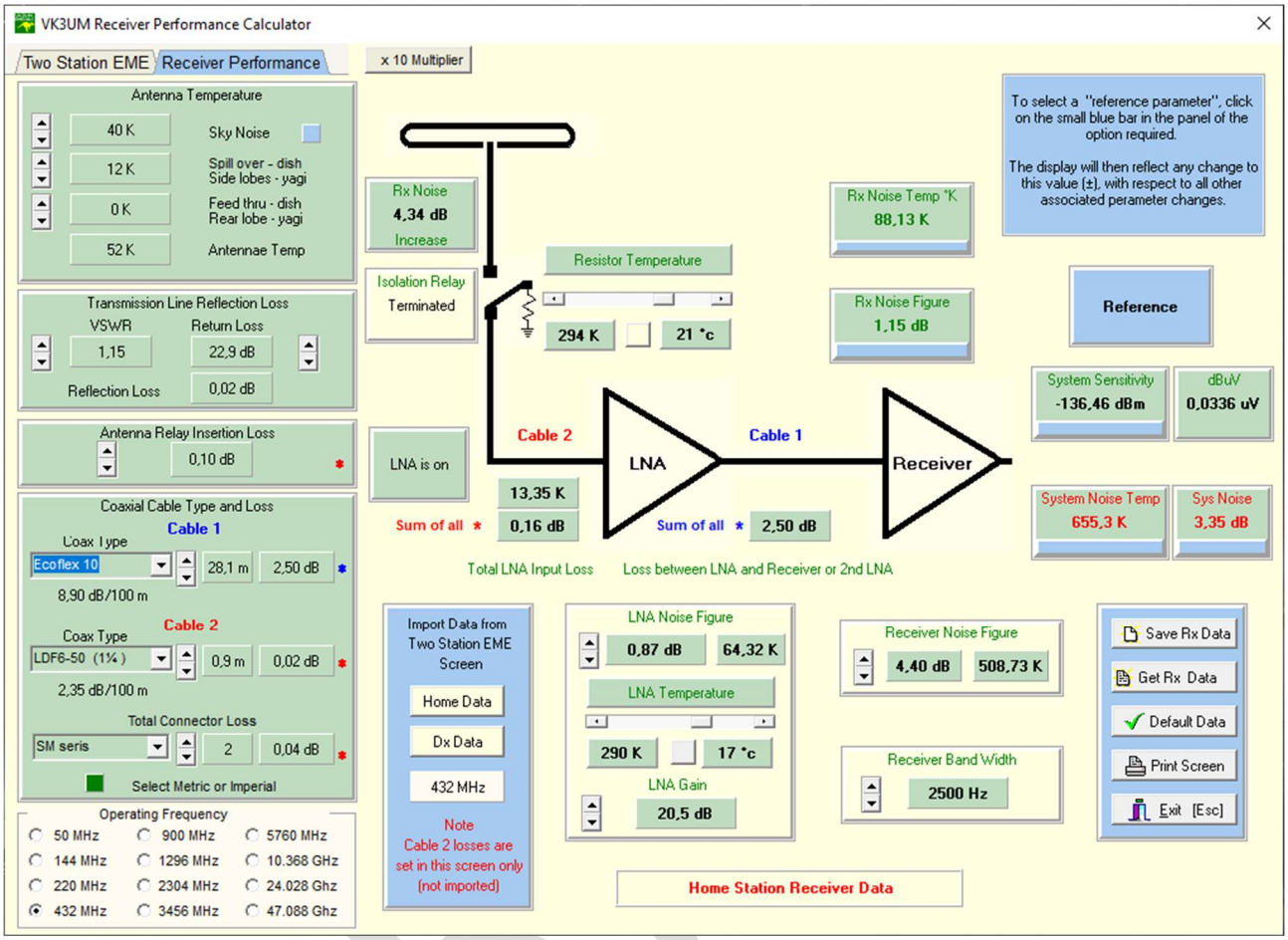
If I compare the "cold sky" value of -50.7 dB (with intern. Preamp off) and the -48.8 dB (with intern. Preamp off) with 50 ohm termination instead of antenna, I arrive at 1.9 dB.

This is 0.69 dB lower than predicted.

This could possibly indicate that "cold sky" is influenced by some (local) noise.

The cable losses and the LNA NF/G I have measured and I'm confident that these are correct.

Next, I switched on the internal preamp of the IC-9700 and changed the **NF in EMECalc to 4.4 dB** (middle of the two reviews).



According to this, I should see an increase in noise by 4.34 dB when connecting a 50 ohm resistor instead of the antenna to the preamp.

If I compare the "cold sky" value of -43.6 (with intern. Preamp on) dB and the -40.1 dB (with intern. Preamp on) with 50 ohm termination instead of antenna, I arrive at 3.5 dB.

This is 0.84 dB lower than predicted.

These two results depend on the quality of the 50 ohm termination, the LNA NF/G and the NF of the IC-9700.

Measurements of sun noise.

A measurement was done using the sun as a noise source. The amount of noise that is being received from the sun depends on several factors. One of them is the "SFI" (Solar Flux Index) at the time the measurement was taken. In this case, the 10.7 cm SFI index is noted at each measurement.

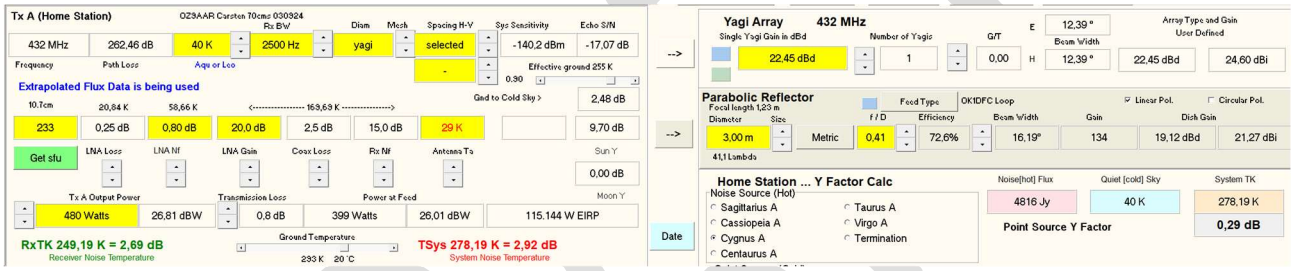
Sun (SFI 233) 2024-09-04 14:25 UTC

Sun was at azimuth 235, elevation 29 (a bit low due to the "late" time of day).

Internal preamp off.

Using SpectraVue, 7.6 dB
Using step attenuator, 10.0 dB

Prediction from EMECalc

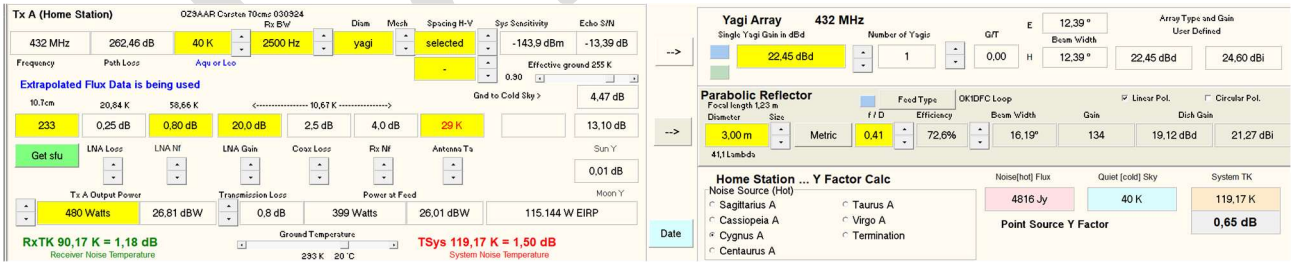


This fits almost perfectly with the predicted sun noise from EMECalc when using the step attenuator.

Internal preamp on.

Using SpectraVue, 10.0 dB
Using step attenuator, 10.0 dB

Prediction from EMECalc



In this case we see a rather large difference from the predicted (13.10 dB) to the measured (10.0 dB)

Lack of LNA gain.

When doing calculations in EMECalc, it becomes obvious that the gain of my Preamp (20 dB) is not enough when running without the internal preamp of the IC-9700!

If I do the calculations with a RX NF of 15 dB (IC-9700 internal preamp off), LNA NF of 0.8 and LNA gain of 20 dB, the prediction (SFU 233) for sun noise is 9.7 dB, and my own echoes are predicted at -17.08 dB.

If I then increase the LNA gain from 20 dB to 40 dB, the sun noise increases from 9.7 to 13.42 dB and own echoes are predicted at -13.33 dB.

This is natural as it takes a lot of (extra) gain to overcome the high noise figure of the IC-9700 of 15 dB.

If I reduce the RX NF in EMECalc to 4 dB (as it should be with the internal preamp on), it seems that an LNA with a gain of approx. 30 dB would be a better match for my system.

Preamp from WD5AGO

I ordered a new preamp from Tommy WD5AGO. Tommy makes some very nice preamps for the various bands, he offers them in different configurations, cavity input, helix inputs, single, dual stage etc.

The preamp I ordered was a silver plated cavity dual stage preamp. The first stage of the preamp has an NF of 0.22 dB and the second stage 0.7 dB. The P1out is +12 dBm.

The combination of the two stages gives a total noise figure of 0.27 dB and 37 dB gain.

To this I then need to add the loss of the high power relay in front of the preamp, the CZX3500 relay was measured to have a loss of 0.08 dB. This means that the total loss in front of the preamp is 0.25 (cable loss) + 0.08 (relay) = 0.33 dB in total.

After installing the WD5AGO preamp, my measured sun noise is getting closer to the predicted numbers. The preamp has a higher gain than the previous ones I used (and lower NF), also there are filtering on both the input and output that might help the system.

So far, this setup is what I'm using. The internal preamp of the IC-9700 is off, there were some theories that it somehow has problems with overdrive. I have quite a lot of "out of band" noise sources where I am located.

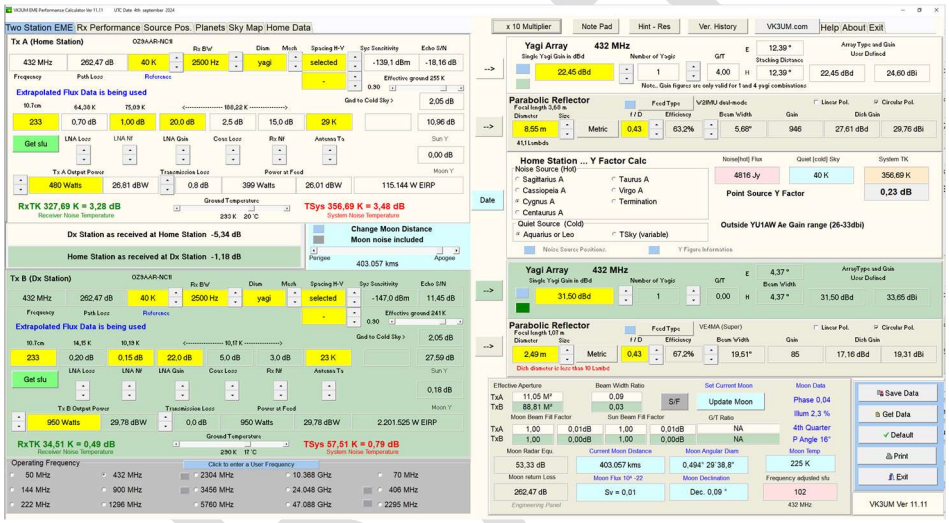
EMECalc data for OZ9AAR and NC1I

I entered data for both my own station as well as for Frank NC1I massive antennas. I have worked Frank several times and have some data collected from these contacts. Note that the predicted signal strengths by EMECalc is under optimum conditions, correct polarization etc., this might not always be the case!

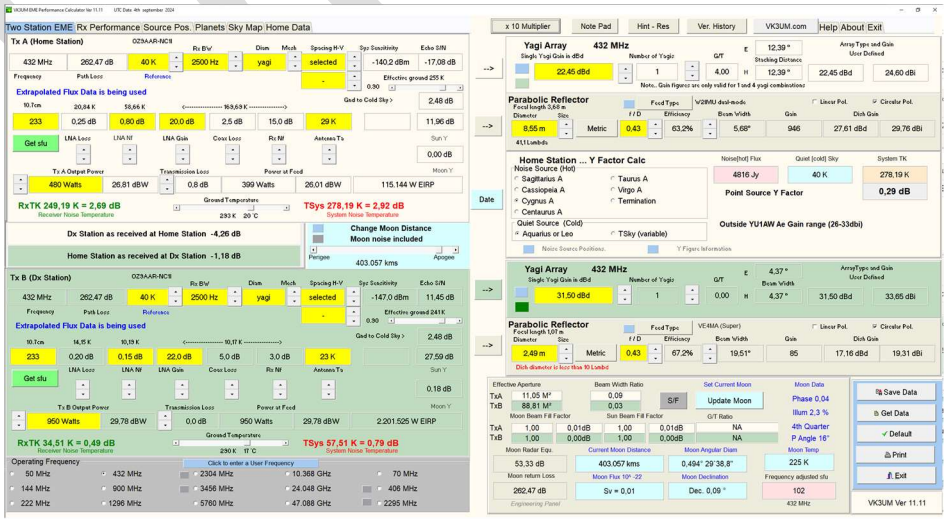
Home = OZ9AAR (old preamp/diplexer: SSB SP-70 preamp 1 dB NF, 20 dB G, Loss 0.7 dB (diplexer))
DX = NC1I

This was my setup using my "old" preamp (and a diplexer as a filter). According to the data, I should be able to receive frank at around -5 dB (BW 2500 Hz/WSJT). In real life, I have received Frank at -4 dB in WSJT.

Frank should be able to receive me at -1 dB, he has seen me with -3 dB so again close to the predicted values.



The next screenshot is with another new preamp and no diplexer (Ant&Amp preamp NF 0.8 dB, G 20 dB, loss 0.25). The prediction is that I should be able to receive Frank at -4 dB which I have done many times. Frank should (under optimum conditions) be able to see me at close to -1 dB.



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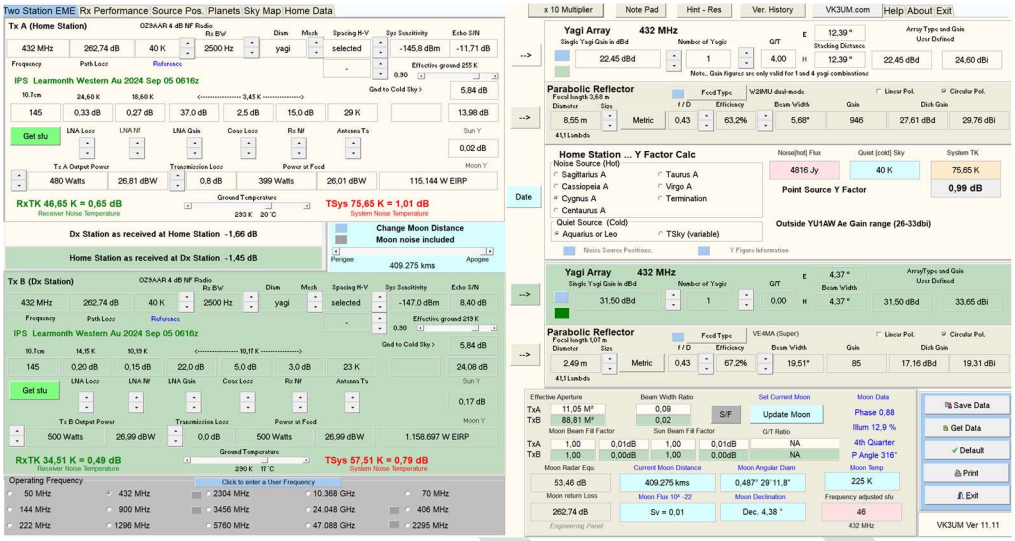
The last screenshot is with the WD5AGO preamp, NF 0.27, gain 37 dB. With this I should receive Frank at -1.7 dB (this is with reduced power at Frank), with this setup I have seen Frank at -3 dB, again pretty close.



Conclusions so far.

When comparing the predicted results from EMECalc when working Frank NC1I, the difference does seem to be as expected (+/-).

Another VERY important thing is according to Frank and his vast experience on 70 cm (digital) EME, he thinks that my station performs as he would expect. Frank has worked a very large number of stations and has a VERY good knowledge of "how a 4 yagi station should perform".

One thing that is still to be figured out, is why there is no difference in measured sun noise when the IC-9700 has its internal preamp switched on or off. Only with the internal preamp switched off, I measure what EMECalc has predicted. When switching the internal preamp on, I measure no difference in sun noise (there should in one of the sun noise measurements be around 3 dB increase in sun noise with the internal preamp on). The lack of "extra sun noise" also influences the signal strength I receive stations (and echoes) with.

So, I'm nowhere near finished with this, I will do further tests and measurements in the coming weeks/months and update this document accordingly.

Also, there is a separate problem measuring the sun noise using SpectraVue (and the other tested software tools) when the internal preamp is off, resulting in "too little gain" from LNA to radio (a difference of 2.4 dB compared to using a step attenuator). Only if the internal preamp is on, does SpectraVue measure the same sun noise as using step attenuators does.

In order to gain some understanding, and also have a easy to use tool for calculating cascaded NF/G, prediction of sun noise, measurement of noise etc., I developed a PC application, SimpleCalc that is available from my webpage www.moonbounce.dk/hamradio/simplecalc.html

SimpleCalc lets you do a small subset of the calculations that EMECalc gives you, it allows you to measure and compare the noise level from the radio (somewhat similar to SpectraVue). It also contains a "comment" window where you can record your measurements, comments etc.