EME Measurements and EMECalc

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G3LTF

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- Calculation of the received signal
- System Temperature, Spillover, Mesh Feed-through

  Where do they come from?
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- Derivation of solar flux data
- Concluding comment

The purpose of EMECalc

- Estimate SNR of own echoes and signals from other stations by entering system parameters; Antenna size and feed type, Noise figure, cable losses, Tx power
- Enables exploration of the sensitivity of an EME system to parameter changes
- Allows checking of some of the parameters by using measurements of noise power from known sources (sun, moon, radio stars, ground)

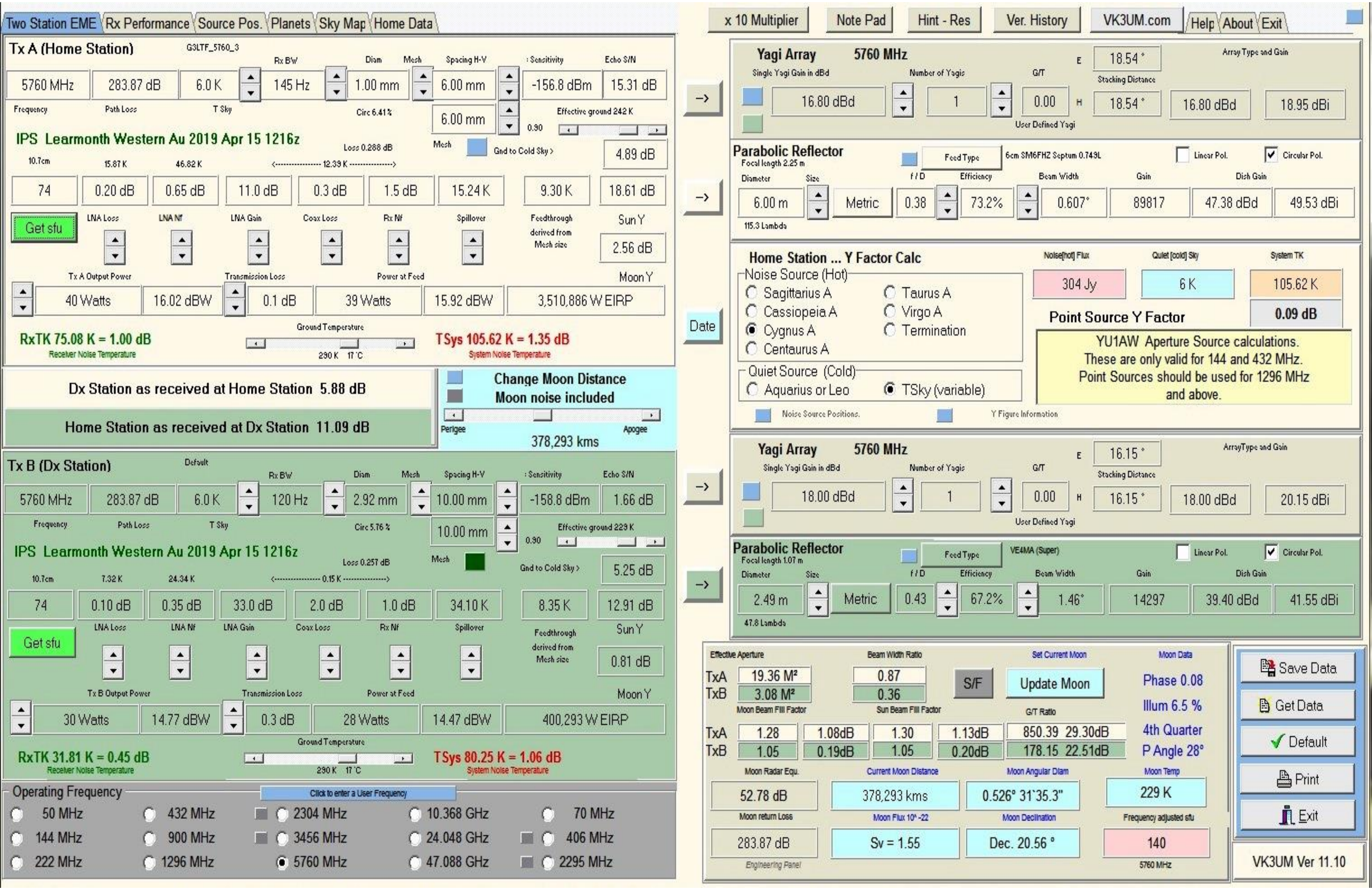
A few key points

- I will only be discussing applications at 1296MHz and above
- I will not cover yagis
- Remember that EMECalc is not a complete, comprehensive, system analysis and it contains some simplifying assumptions
- There is a wealth of detail in the Help section

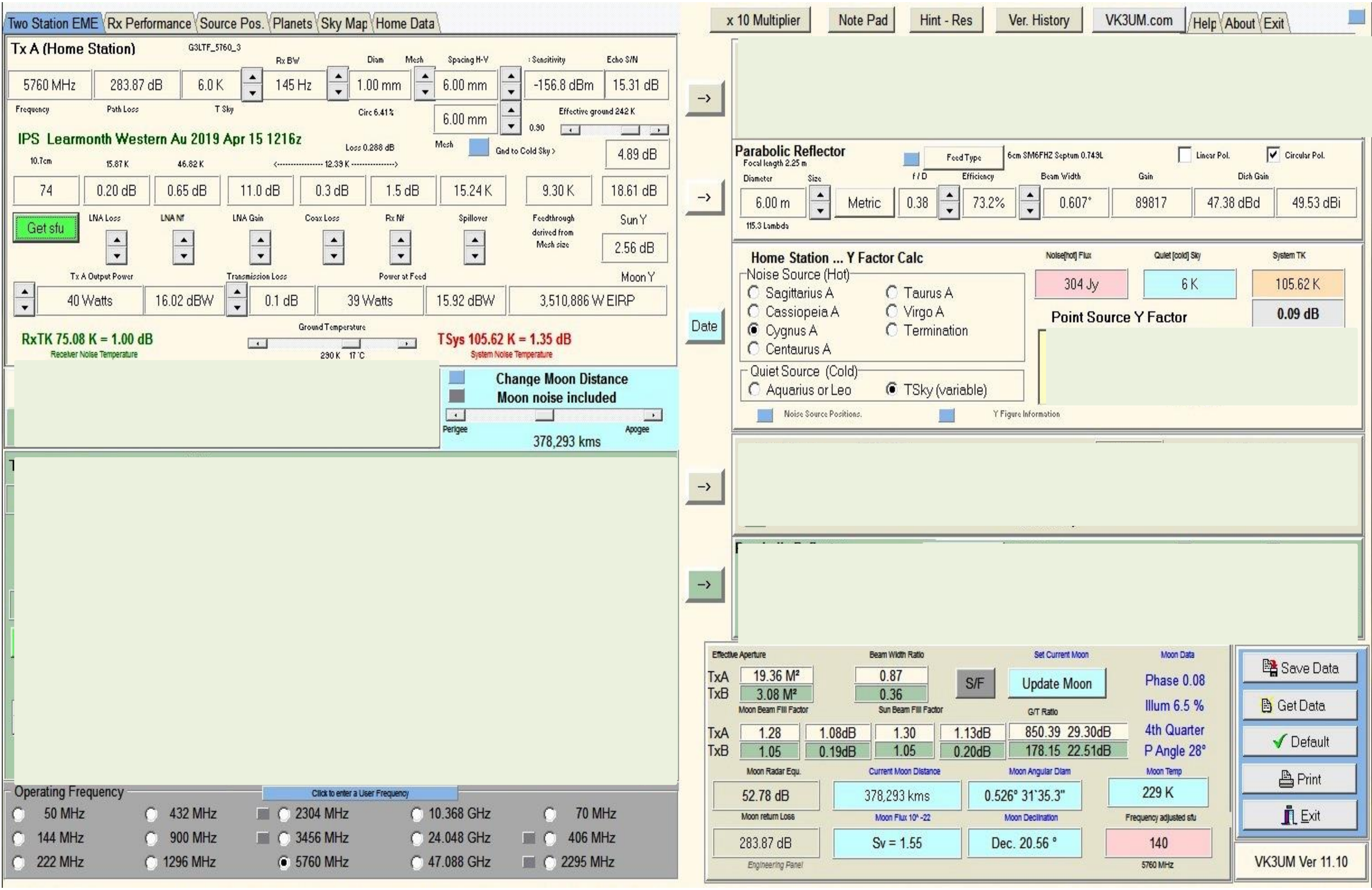
Recent History

- EMECalc was in near continuous evolution until Feb 2016 when VK3UM became SK
- Major changes to parabola performance following W1GHZ paper at EME2014
- Changes to Solar flux acquisition
- Changes to Ground/ Cold Sky prediction
- Moon temperature and Radio star flux updated

The full EMECalc screen is tightly packed because its displaying a lot of data and variables. But don’t be put off. You can start by altering the default screen to your own station.



The full EMECalc screen is tightly packed but we don't need all of it for now.
We can take out the Dx Station and Yagi sections. This is showing my 5.7GHz system.



EMECalc Key equation (1)

The radar equation for echos

$$Pr/Pt = G^2 * \lambda^2 * \rho / R^4 *(4*\pi)^3$$

G is the Antenna gain

Pt Transmitter power at the feed terminal

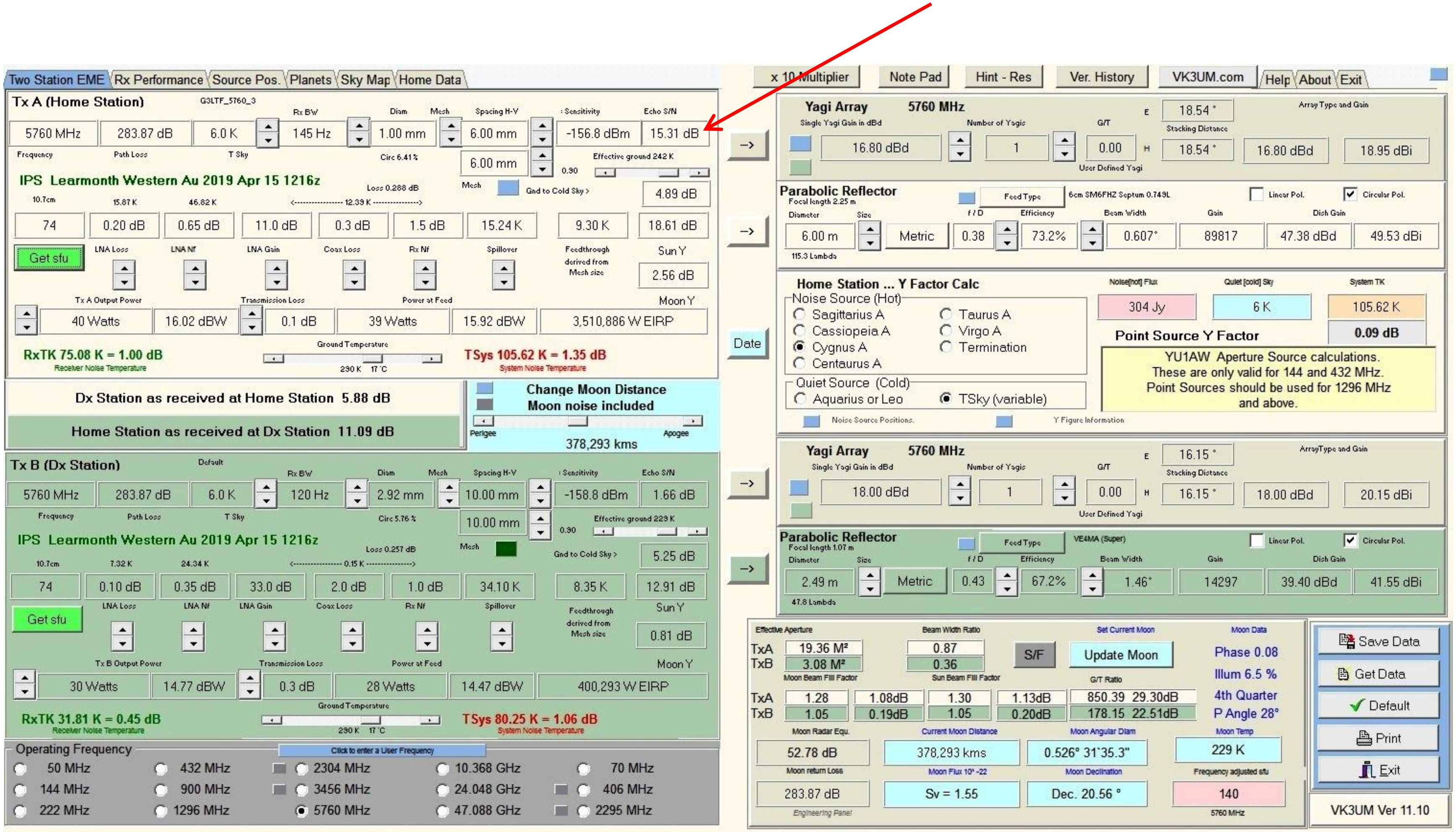
Pr Received power at the feed terminal

R moon distance

ρ Moon radar cross section

If we set G=1 (isotropic) Then Pr/Pt is called the "path loss" or the "moon return loss"

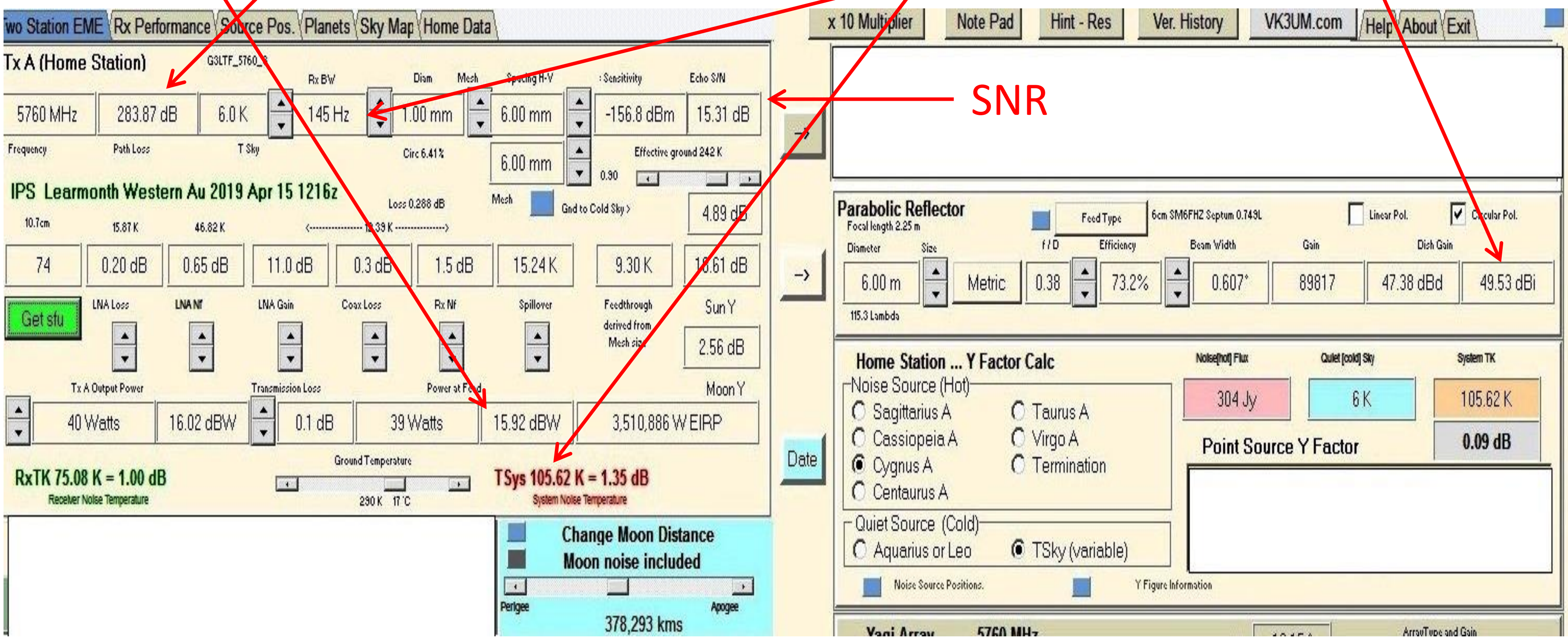
EMECalc uses Equation 1 to give the received echo SNR



Echo SNR =

Pt – Return loss +2*Antenna Gain

Noise Power =10*log (k*Tsys*B)



k is Boltzmanns constant   1.38*10^-23   joules/ kelvin

Where does EMECalc get Tsys and Antenna gain from?

And what is Tsys?

System Noise Temperature, Tsys, definition

Tsys = Trx + Tsky + Tspill +Tft

Trx Receiver noise temperature contribution from line losses, LNA and following stages

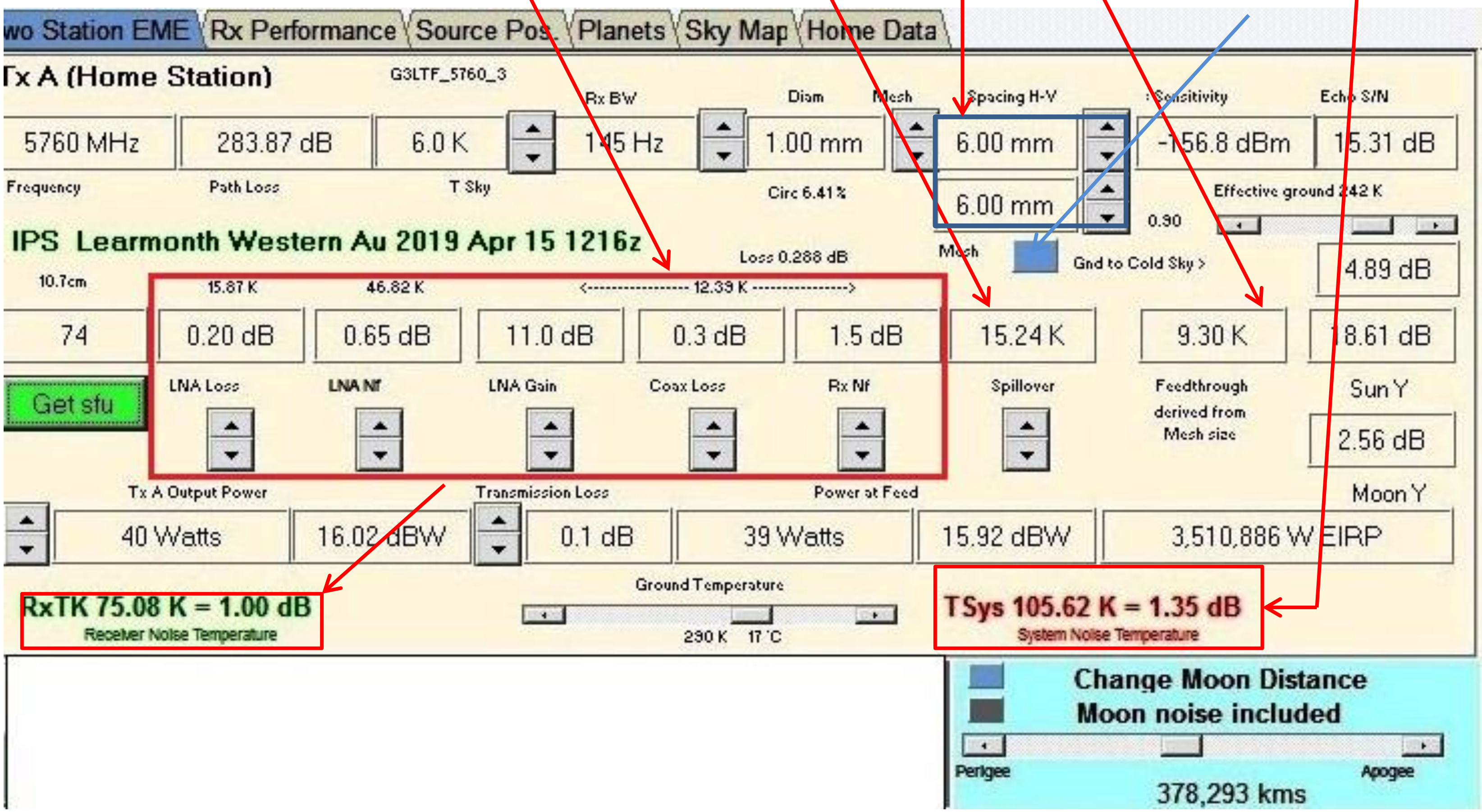
Tsky Sky temperature

Tspill noise temperature contribution from spillover and sidelobes

Tft noise temperature contribution from any mesh transparency

Trx + Tspill + Tft = Tsys

Solid dish
Tft =Zero



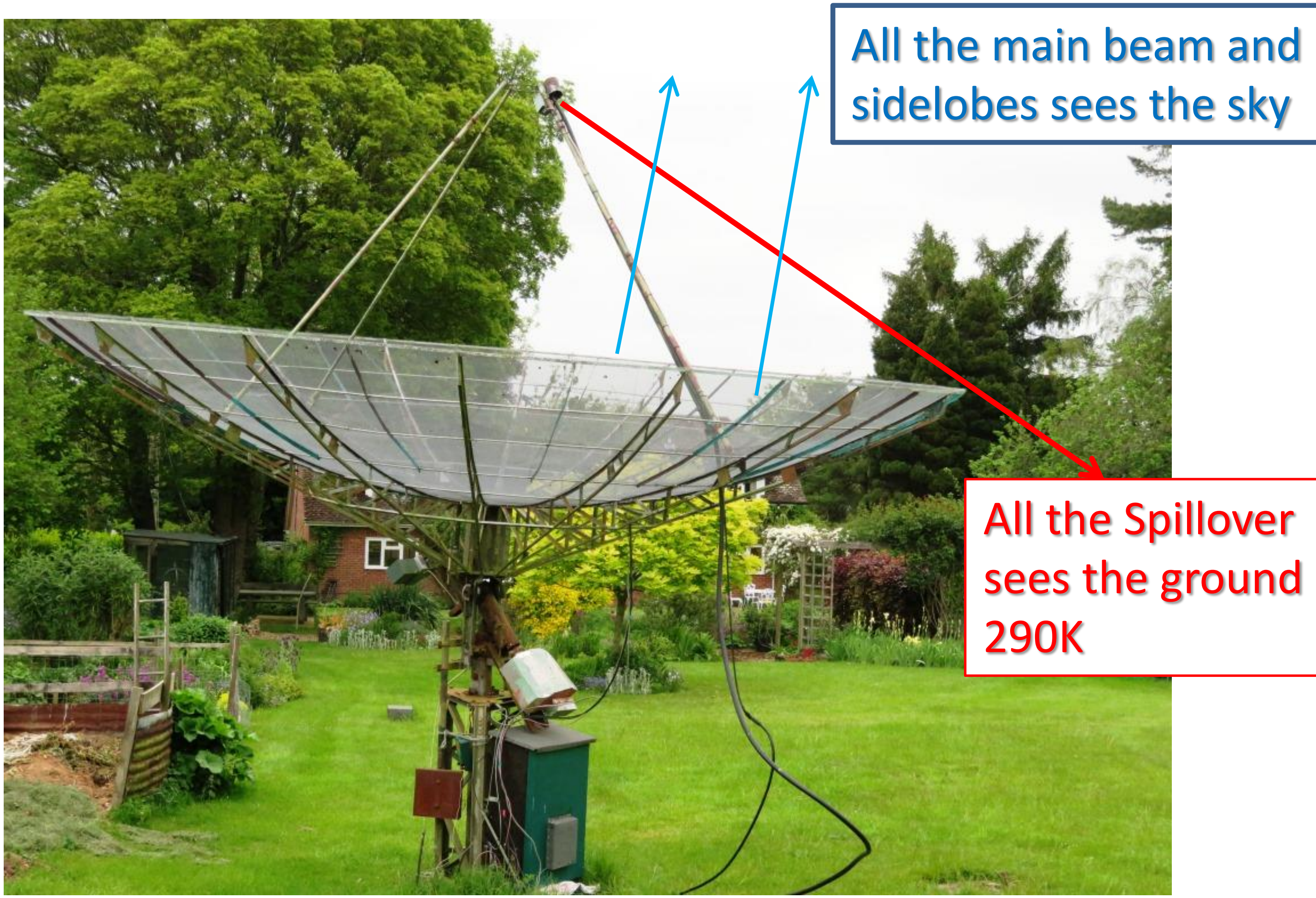
Spillover

- Solid dish + perfect receiver means….

Tsys = ~~Trx~~ + Tsky + Tspill + ~~Tft~~

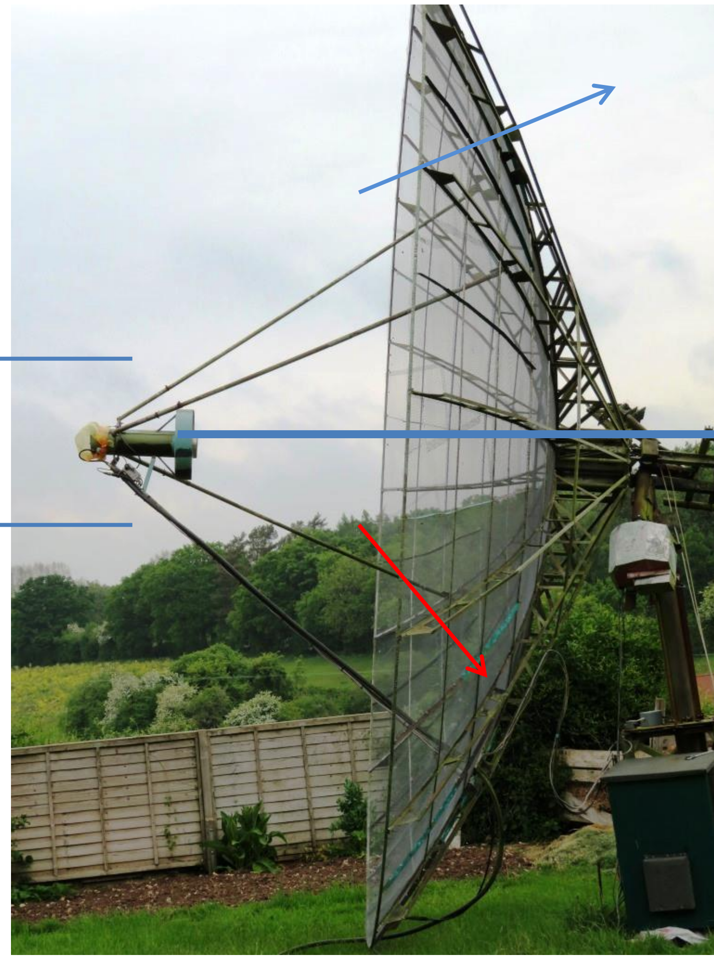
- In the limit the Antenna determines the system performance.
- Putting an excellent VLNA on a poor antenna is a waste of time.
- Calling this quantity in EMECalc “Spillover” is not strictly correct but it’s historical and cant be changed now!

Dish pointing to Zenith (almost)



Dish pointing horizontal (almost!)

Main beam and sidelobes see part sky and part ground



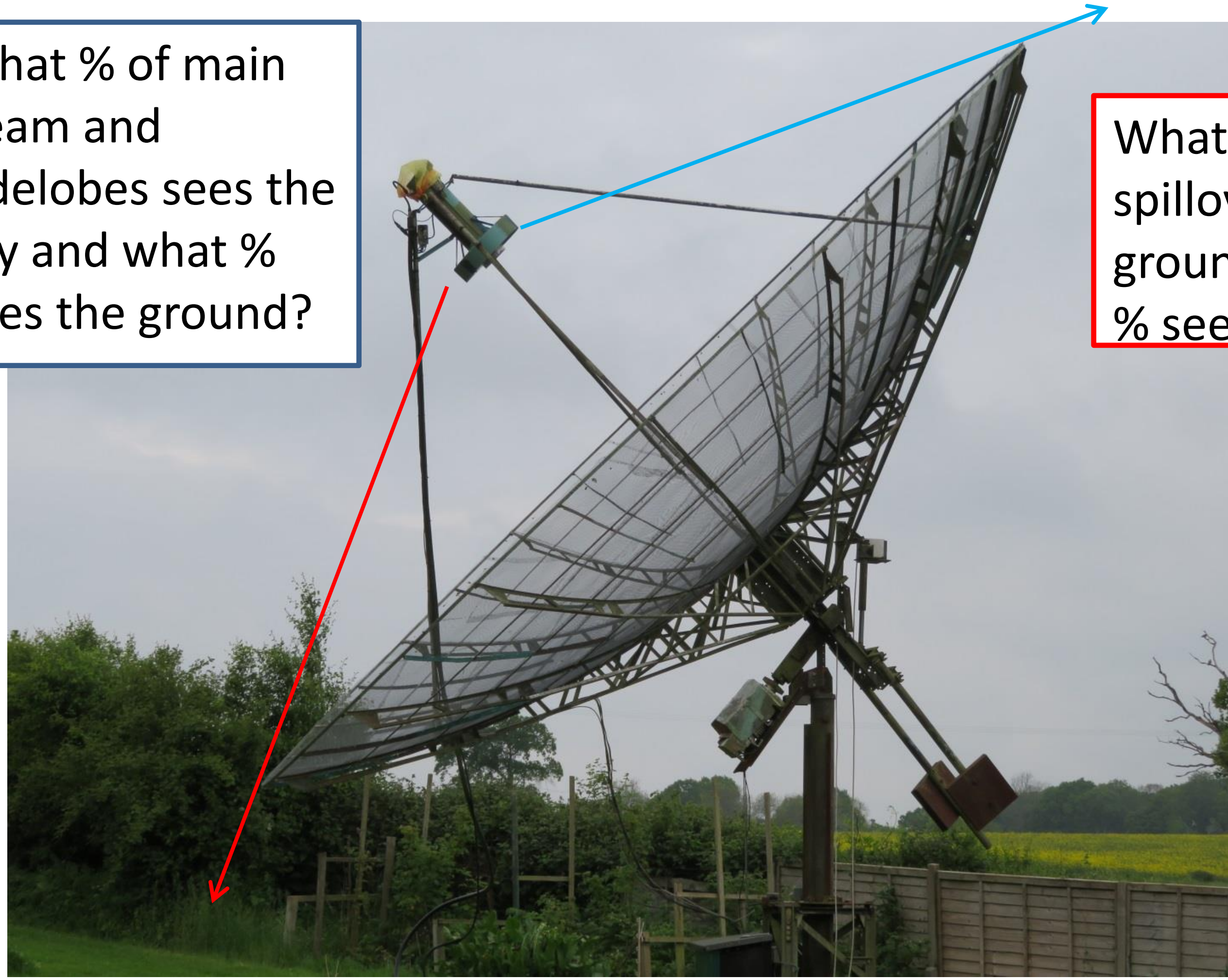
Spillover above horizontal sees the sky

Spillover below horizontal sees the ground

Dish pointing at 45 degrees

45 degrees is the standard elevation in EMECalc

What % of main beam and sidelobes sees the sky and what % sees the ground?

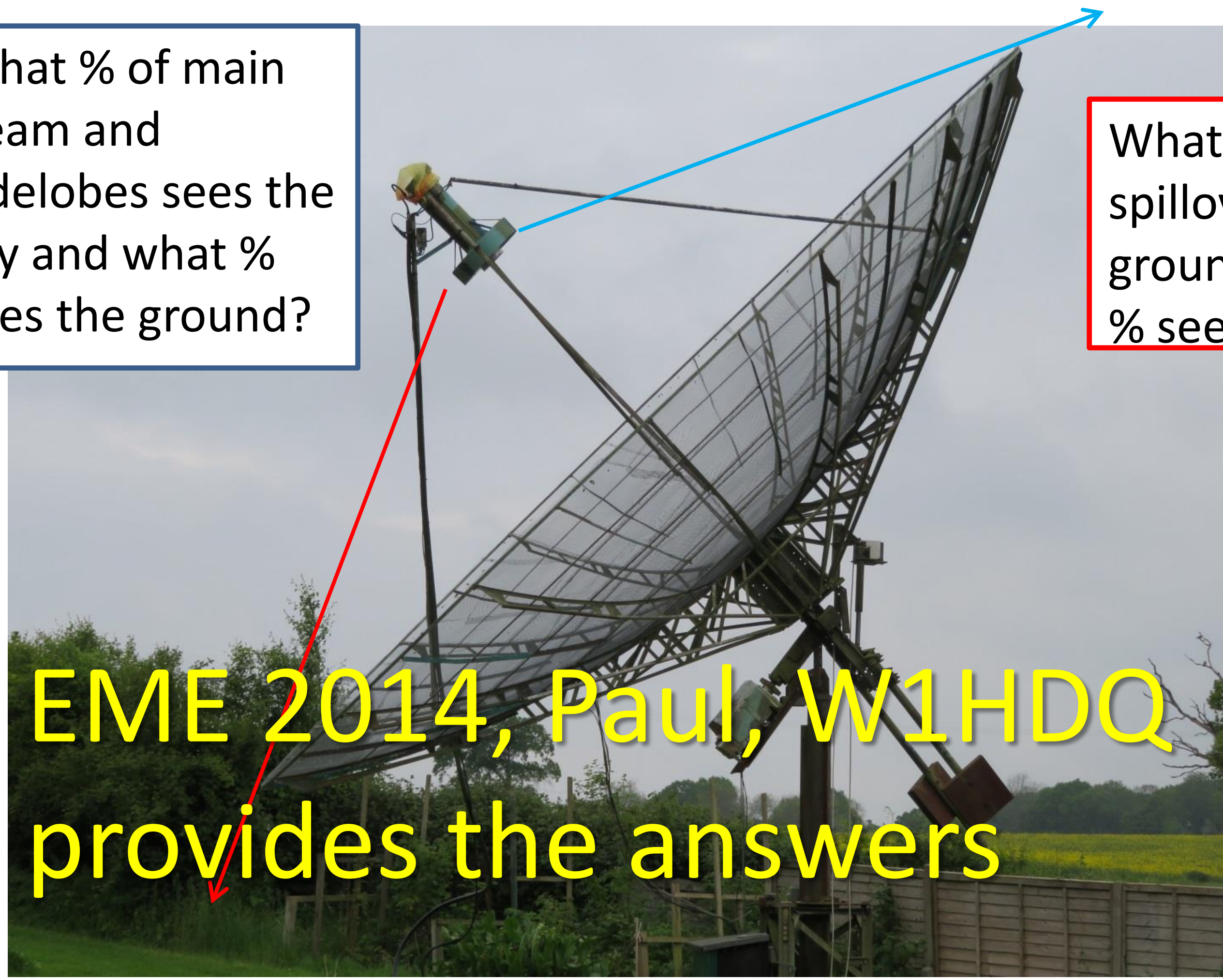


What % of spillover sees ground and what % sees the sky?

Dish pointing at 45 degrees

45 degrees is the standard elevation in EMECalc

What % of main beam and sidelobes sees the sky and what % sees the ground?



What % of spillover sees ground and what % sees the sky?

EME 2014, Paul, W1HDQ provides the answers

W1GHZ and SM6FHZ analysed a range of feeds with a dish and this was incorporated into EMECalc. (2015 SM meeting) For each feed, the Gain, G, and T (Tspill) are obtained from this analysis

A1 — f_x N2UO septum with W2IMU dual-mode horn

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
8	HalfAngle	f/D	EdgeIllum	XPOLtotal	Gain	Gain	Elevation=	10	10	20	20	30	30	40	40	45	45	50	50	
9	degrees		dB	Eff %	ratio	dBi		T (K)	G/T (dB)	T	G/T	T	G/T	T	G/T	T	G/T	T	G/T	T
10																				
11	WARNING: Edge Diffraction not accounted for																			
12	G/T at f/D < 0.3 may be optimistic																			
13																				
14	90	0.25	-27.06	35.52	1402.38	31.47		6.86	23.1	6.84	23.12	6.73	23.19	6.55	23.31	6.45	23.37	6.35	23.44	
15	89	0.254	-26.79	36.44	1438.61	31.58		6.91	23.18	6.89	23.2	6.78	23.27	6.6	23.39	6.5	23.45	6.4	23.52	
16	88	0.259	-26.51	37.37	1475.46	31.69		6.96	23.26	6.94	23.28	6.83	23.35	6.65	23.46	6.55	23.53	6.45	23.59	
17	87	0.263	-26.22	38.32	1512.94	31.8		7.02	23.34	7	23.35	6.88	23.42	6.7	23.54	6.6	23.6	6.51	23.67	
18	86	0.268	-25.92	39.78	1570.4	31.96		7.08	23.46	7.05	23.48	6.94	23.54	6.76	23.66	6.66	23.72	6.57	23.79	
19	85	0.273	-25.62	40.77	1609.69	32.07		7.14	23.53	7.12	23.54	7.01	23.61	6.83	23.73	6.73	23.79	6.63	23.85	
20	84	0.278	-25.31	41.78	1649.59	32.17		7.21	23.59	7.19	23.61	7.07	23.68	6.89	23.79	6.79	23.85	6.7	23.91	
21	83	0.283	-24.99	42.81	1690.11	32.28		7.28	23.66	7.26	23.67	7.15	23.74	6.97	23.85	6.87	23.91	6.77	23.97	
22	82	0.288	-24.66	43.85	1731.2	32.38		7.36	23.71	7.34	23.73	7.23	23.79	7.05	23.9	6.95	23.97	6.85	24.03	
23	81	0.293	-24.32	44.91	1772.84	32.49		7.45	23.77	7.42	23.78	7.31	23.85	7.13	23.95	7.03	24.02	6.93	24.08	
24	80	0.298	-23.97	45.97	1814.99	32.59		7.54	23.82	7.51	23.83	7.4	23.89	7.22	24	7.12	7.86	7.03	24.12	
25	79	0.303	-23.6	47.05	1857.61	32.69		7.64	23.86	7.61	23.87	7.5	23.94	7.32	24.04	7.22	7.96	7.13	24.16	
26	78	0.309	-23.22	48.14	1900.62	32.79		7.75	23.9	7.72	23.91	7.61	23.97	7.43	24.08	7.33	8.06	7.23	24.2	
27	77	0.314	-22.82	49.79	1965.61	32.93		7.86	23.98	7.84	23.99	7.73	24.05	7.55	24.16	7.45	8.2	7.35	24.27	
28	76	0.32	-22.41	50.91	2009.88	33.03		7.99	24	7.97	24.02	7.86	24.08	7.68	24.18	7.58	8.3	7.48	24.29	
29	75	0.326	-21.99	52.04	2054.36	33.13		8.14	24.02	8.11	24.04	8	24.1	7.82	24.2	7.72	8.39	7.62	24.31	
30	74	0.332	-21.57	53.17	2098.99	33.22		8.29	24.03	8.27	24.05	8.15	24.11	7.97	24.2	7.87	8.48	7.78	24.31	
31	73	0.338	-21.14	54.3	2143.68	33.31		8.46	24.04	8.44	24.05	8.32	24.11	8.14	24.2	8.04	8.57	7.95	24.31	
32	72	0.344	-20.7	55.43	2188.34	33.4		8.65	24.03	8.62	24.05	8.51	24.1	8.33	24.19	8.23	8.66	8.13	24.3	
33	71	0.35	-20.26	56.56	2232.9	33.49		8.85	24.02	8.83	24.03	8.71	24.09	8.54	24.18	8.44	8.74	8.34	24.28	
34	70	0.357	-19.82	57.68	2277.25	33.57		9.08	23.99	9.05	24.01	8.94	24.06	8.76	24.15	8.66	8.82	8.56	24.25	
35	69	0.364	-19.38	58.8	2321.3	33.66		9.32	23.96	9.3	23.97	9.19	24.03	9.01	24.11	8.91	8.9	8.81	24.21	

N2UO_dualmode_GT

f/D

Gain dBi

T and G/T at 45deg

Edge diffraction is not included.

EMECalc allows a wide range of feeds to be examined in dishes with a range of f/D

Click on “Feed Type” to get this table

Feed Types .. Prime Focus .. Linear .. Offset

Feed Type	Direct Link	Link Reference	Feed Type
W2IMU dual-mode	Select	Fig 6.5-1 Page 2	70cm XE1XA Loop
VE4MA (Super .71L)	Select	Fig 7 Page 7	70cm Dipole reflector
VE4MA (Original -0.15L rim)	Select	Fig 3 Page 3	70cm Dipole reflector BFR
VE4MA (Smalll flush rim)	Select	Fig 17 Page 12	70cm ES5PC Patch
OK1DFC Septum (with choke ring)	Select	Fig 13 Page 10	70cm PY2BS Patch
OK1DFC Septum (no choke ring)	Select	Fig 5 Page 4	70cm PY2BS modified Patch
Chaparral 3 rings 0.20λ W x 0.33λ D, back 0.25λ	Select	Fig 39 Page 17	70cm DL4MEA Loop
RA3AQ Stepped Dual mode Septum (improved)	Select	Page 1 -7	70cm OK1DFC Loop
RA3AQ 2L dia .6L deep flush	Select	Fig 2 Page 2	70cm Dual Dipole square reflector
RA3AQ 2L dia .375L deep .175L back	Select	Fig 10 Page 8	70cm Dual Dipole circular reflector
Chaparral 3 rings 0.20λ W x 0.33λ D, back 0.05λ	Select	Fig 17 Page 25	70cm Dual Dipole in VK3UM dish
EIA Dual - Dipole (reference)	Select	Fig 6.2-6 Page 7	70cm CT1DMK Annular Ring
NBS Dual - Dipole (KF4JU)	Select	Fig 6.2-9 Page 11	
Dual Patch linear (W0LMD)	Select	Fig 2 Page 3	23cm G3LTF Dual feed
Dual Patch LHCP (W0LMD)	Select	Fig 4 Page 5	13cm G3LTF Dual feed
Dipole Splashplate (RSGB)	Select	Fig 6.2-2 Page 2	24 GHz W5LUA feed horn
Dipole rod reflector 0.24L	Select	Fig 6.2-1 Page 1	
Dipole over 1.25L sqr refl.	Select	Fig 6.2-3 Page 4	23cm SM6FHZ Patch feed with BFR
Quad Loop opt. (KF4JU)	Select	Fig 6.2-14 Page 17	23cm SM6FHZ Patch feed without BFF
N2UO Septum in W2IMU	Select	Fig 6	23cm SM6FHZ 5 step Septum 0.710L
Optimum dual-mode, flare 2L x 3.10L long	Select	Fig 8	23cm SM6FHZ 5 step Septum 0.795L
Optimum dual-mode, flare 3L x 4.85L long	Select	Fig 6	9cm SM6FHZ 5 step Septum 0.748L
Optimum dual-mode, flare 4L x 6.55L long	Select	Fig 9	6cm SM6FHZ 5 step Septum 0.749L
Optimum dual-mode, flare 5L x 8.25L long	Select	Fig 10	3cm SM6FHZ 5 step Septum 0.692L
Optimum dual-mode, flare 6L x 10.0L long	Select	Fig 11	3cm SM6FHZ 5 step Septum 0.795L
70cm SM6FHZ BFR Loop	Select	Item 10	
70cm SM6FHZ BFR Loop with Choke	Select	Item 9	

Table Colour coding

Red ..fully known feed characteristics computed by Paul W1GHZ and Ingolf SM6FHZ.

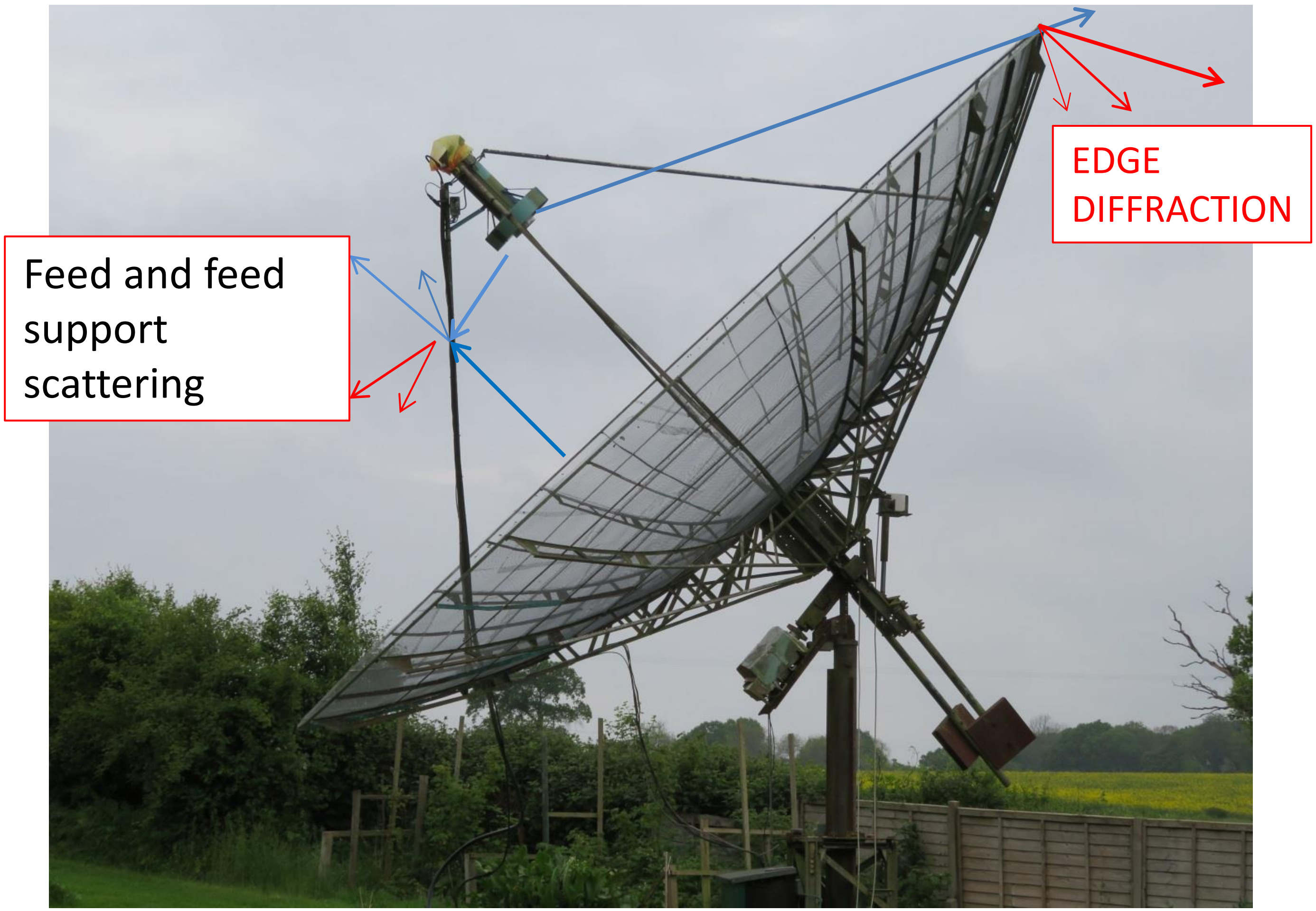
Grey .. off set feeds where spill over is assumed to be 20% of that if installed in a prime focus dish.

Blue .. Optimised feed spill over value computed from best available data.

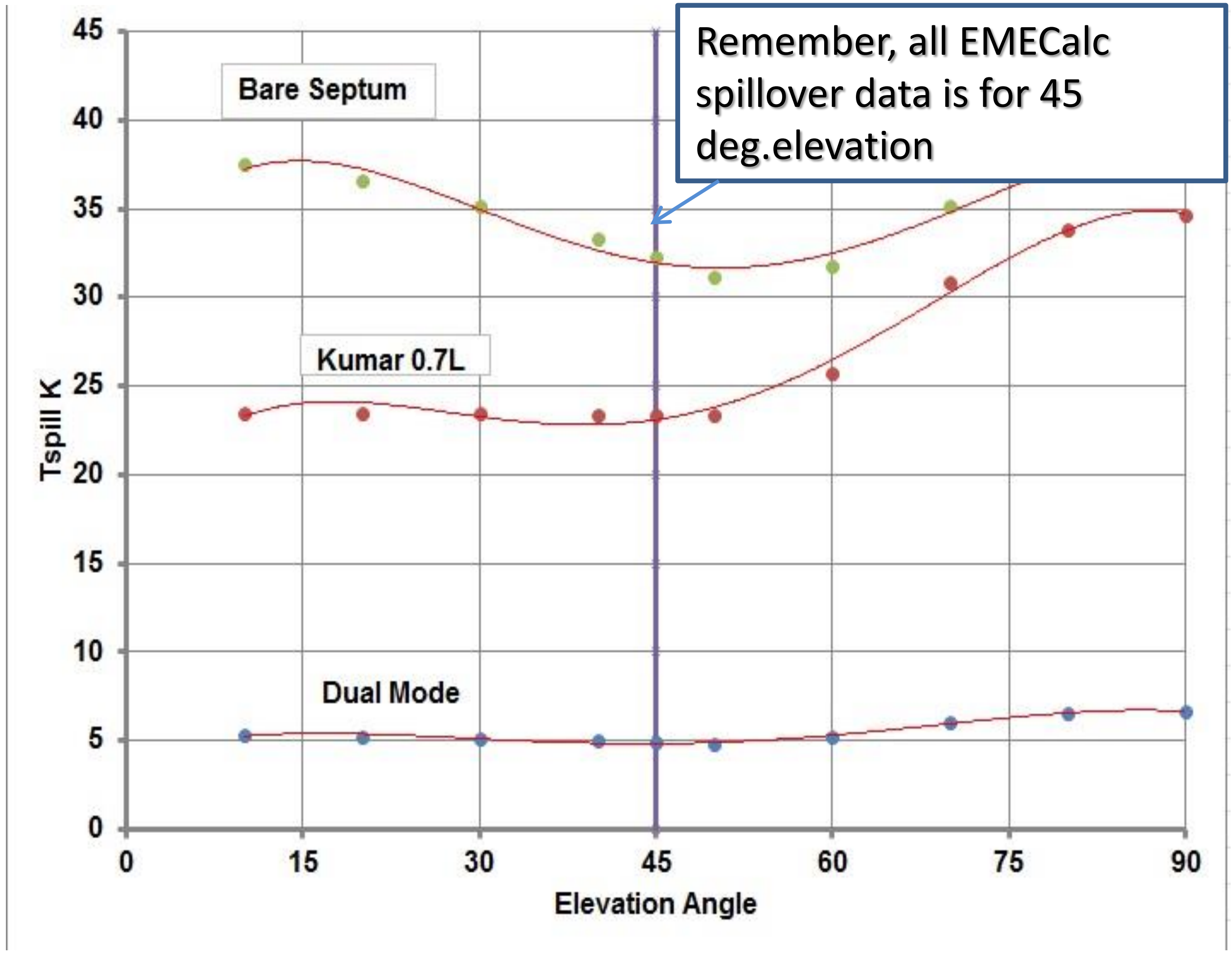
No colour .. values derived from polar plots.

Dish at 45 degrees elevation with edge diffraction

Also missing from “Spillover” is feed support scattering and feed support shadowing



Spillover contribution varies with Elevation Examples at 0.4 f/D. 290K ground, 5.7K sky



Mesh Feed-through, Tft

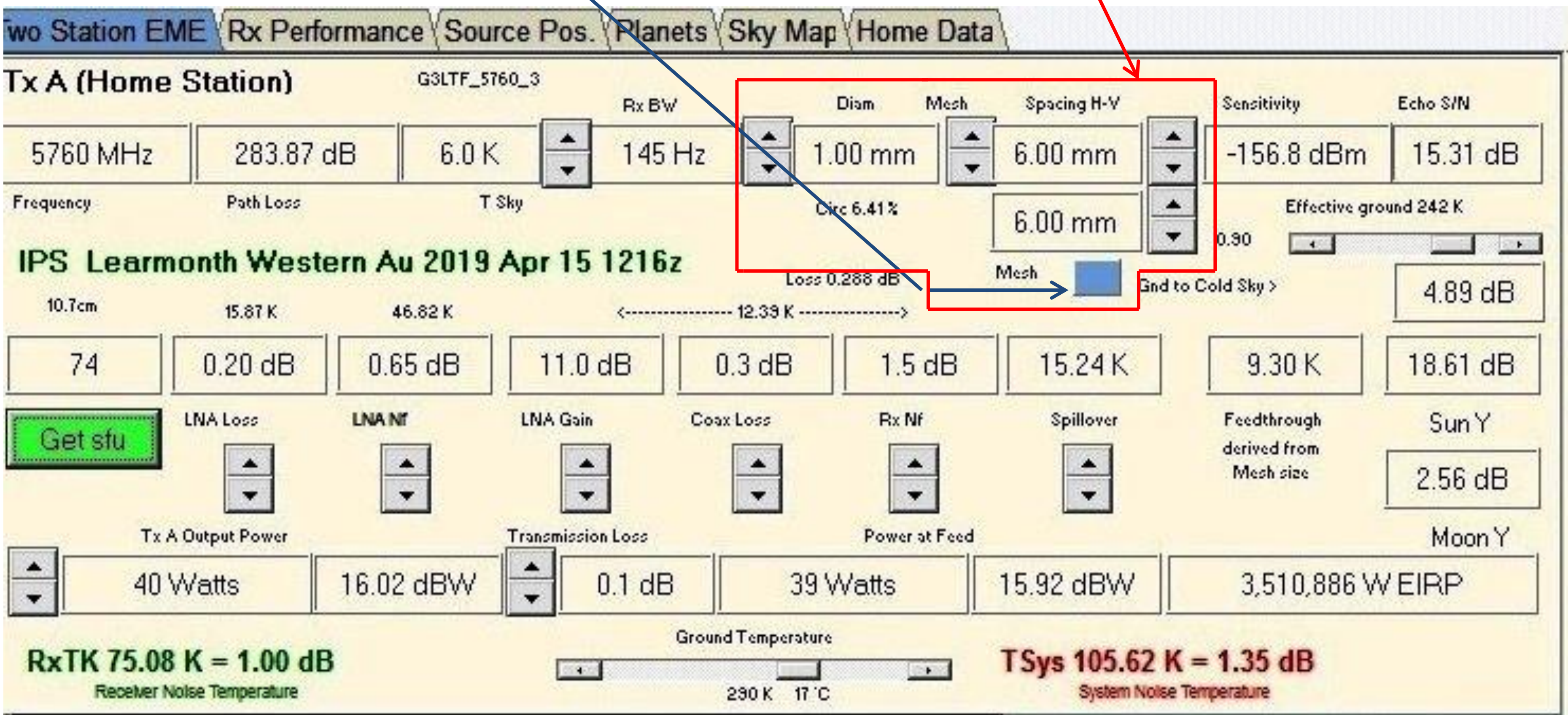
- Mesh feed-through is calculated from the book by Otoshi,

"Noise temperature theory and applications for deep space communications antenna systems". P275 This is also in a spread sheet on the W1HDQ website

- The small gain loss is applied to the dish gain G.
- When the dish is at Zenith the feed horn sees the hot ground through the mesh and if the transparency is x% then Tft is (x/100)*Tg where Tg is set by the ground temperature slider.
- When the dish is at 45 degrees this changes so that the horn sees some cold sky through the mesh and less hot ground and this is taken into account in the estimate.

Mesh Feedthrough controls

Press for solid dish



Y factor measurement

- If we point the antenna at the cold sky and then at a known source, the sun, moon, or radio star or the ground, then the power ratio observed is known as the Y factor.
- If we know the flux (or the temperature) of the source then we can derive G/Tsys.
- In EMECalc we can insert the parameters we believe we have and see if the measurement gives the predicted result.

Y factor measurement

- Accurate measurement requires widest bandwidth, B and long integration time, T

  The smallest temperature change, Tmin, that you can detect is.

$$T_{min} = T_{sys} / (B*T)^{0.5}$$

- Several analogue meter designs available.
- For measurement I use Spectravue in Continuum mode.

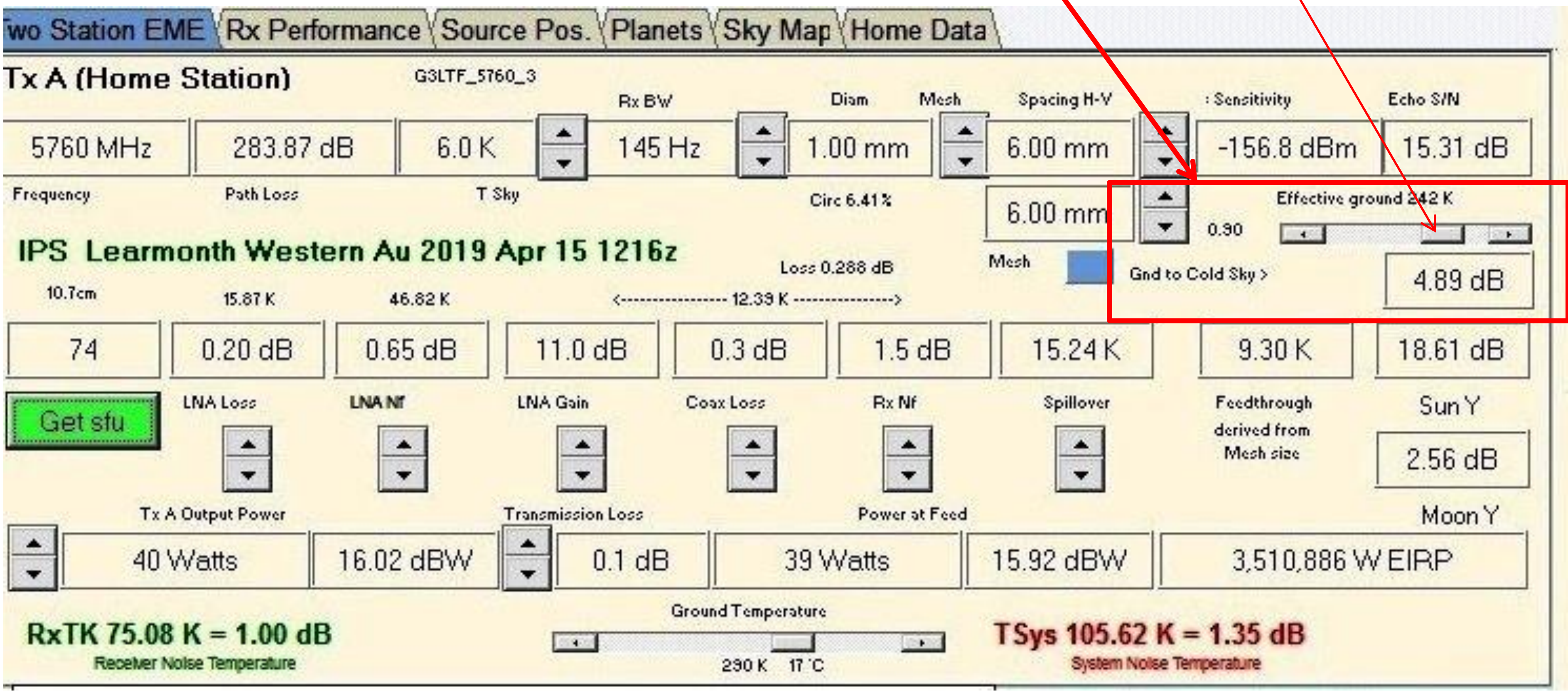
Ground / Cold Sky ratio measurement is different from Y factor measurement of sun, moon and star measurement

We will describe Ground / Cold Sky next

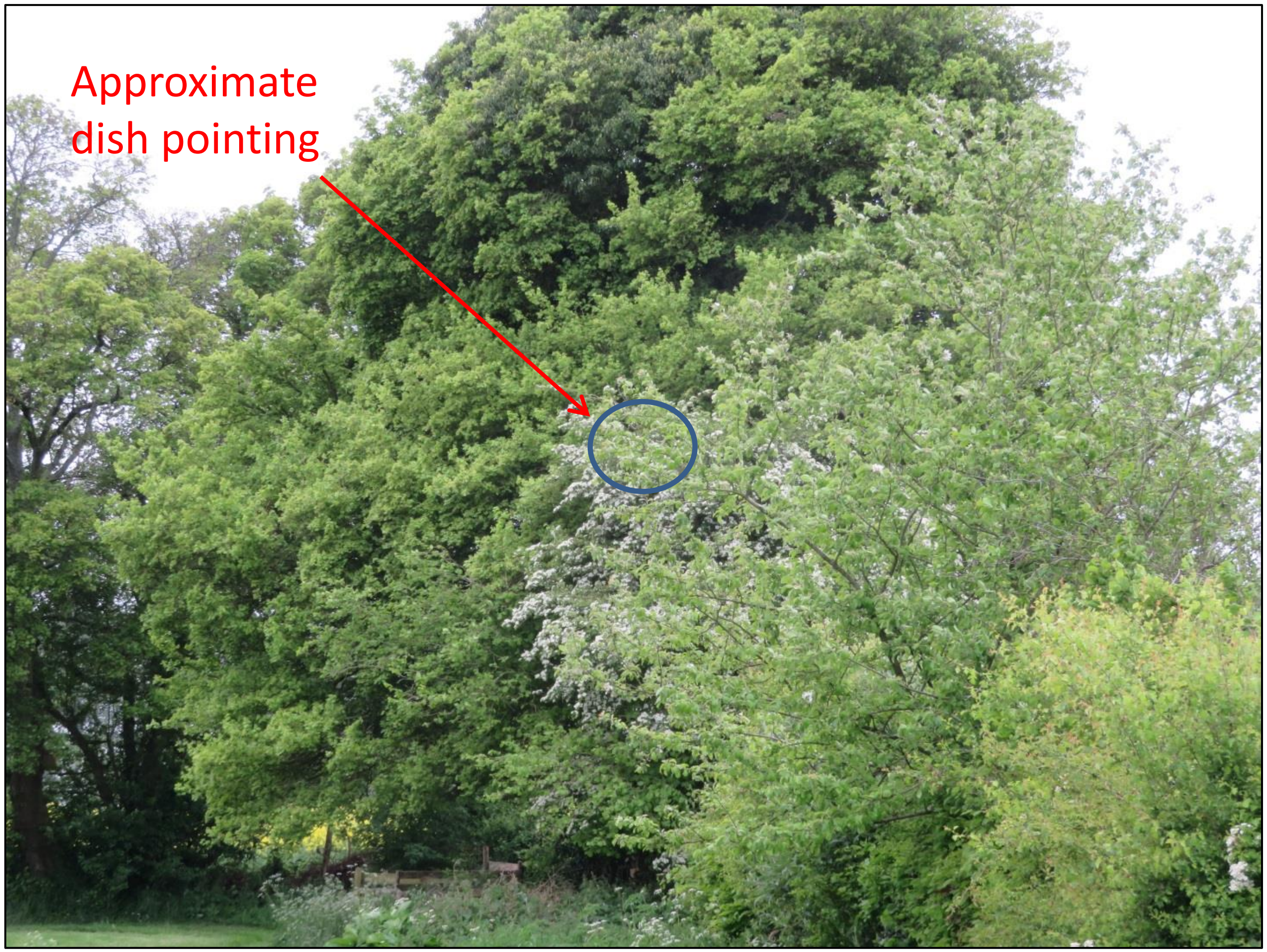
Ground / Cold Sky ratio measurement

- A useful measurement as a reference but not easy to make. The target must fill at least the projected area of the dish inside the near field, $2*D^2/\lambda$ where D is dish diameter.
- The formula used in EMECalc again takes account of the fact that a portion of both the feed-through and spillover sees cold sky.
- The target should ideally be a rough absorber otherwise the incident wave will reflect (reciprocity invoked). It should also not reflect the cold sky back to the dish. Trees in full leaf seem to work fairly well.
- A Slider is provided to adjust for target quality, Q.

Ground / Cold Sky ratio location.   Q slider



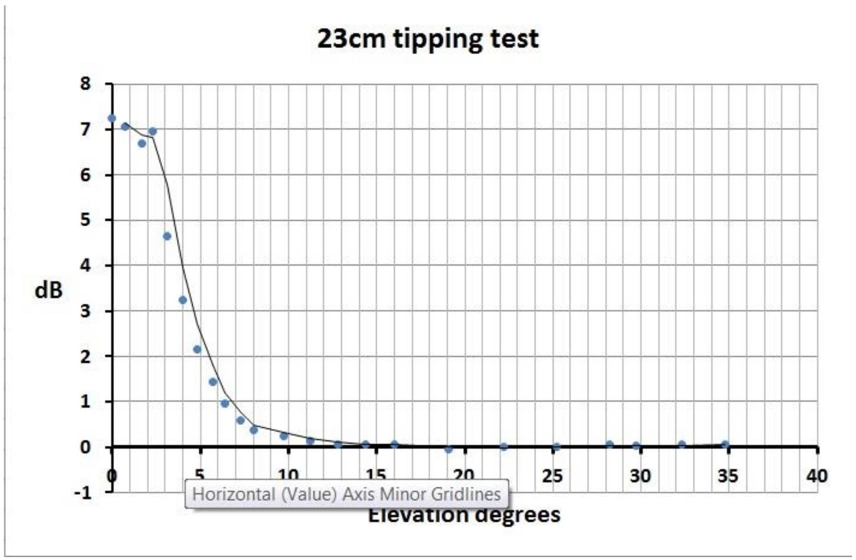
Target used for Ground/Cold Sky tests
Clump of trees at 50m



Ground / Cold Sky measurements at 23 and 6cm with the tree target

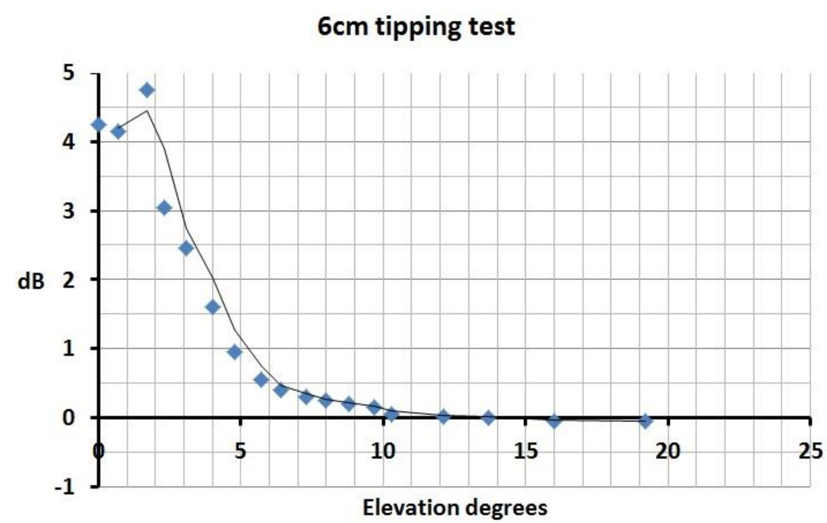
7.25dB. Prediction 7.3dB

Q 0.8 Tg 220K Tsky 10K

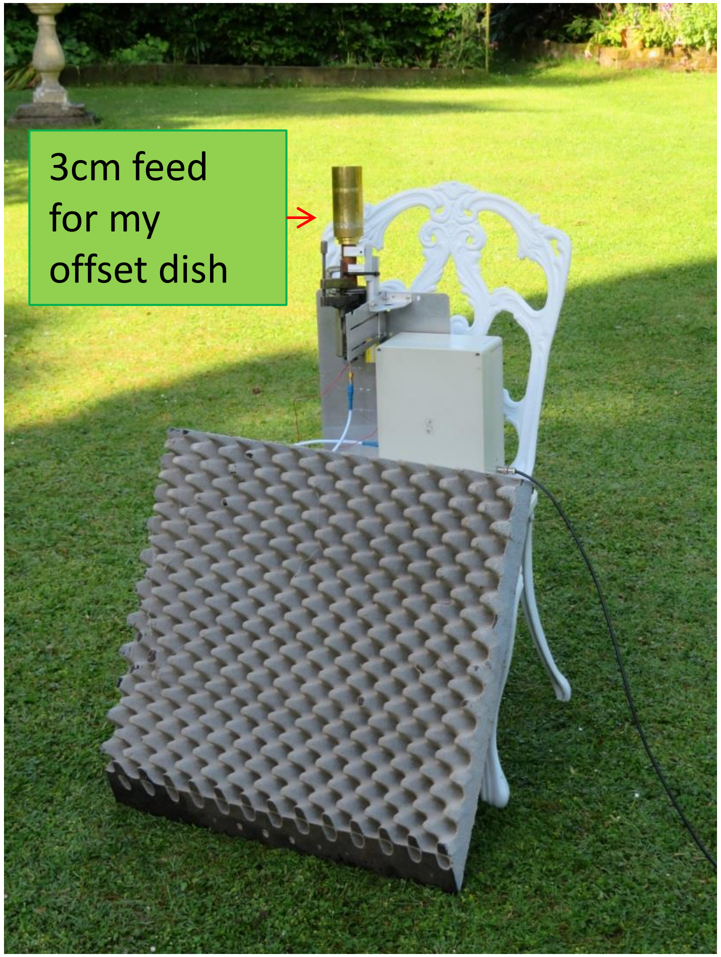


4.75dB. Prediction 4.9dB

Q 0.9 Tg 242K Tsky 7K



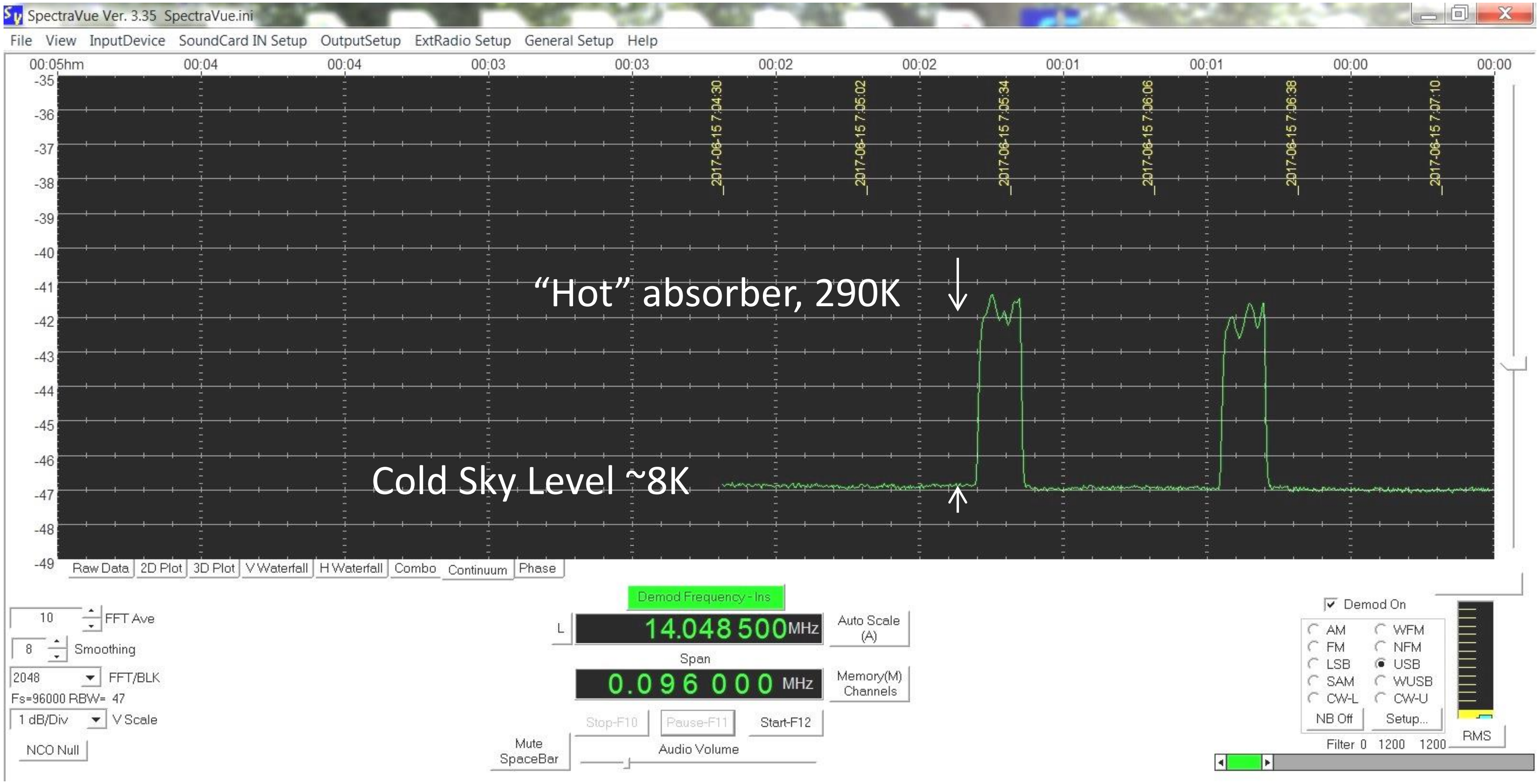
NF estimation using cold sky to ground. In this case a piece of X-band absorber is used at the "hot" ground



Y= [Trx +Thot] / [Trx +Tcold]

Gives result Trx = 105-120K

(More attention to detail needed for a definitive and more accurate result)



How EMECalc calculates Y factor from Sun, Moon and Stars

EMECalc Key equation (2)

$$Y = [G * \Psi * \lambda^2 / T_{sys} * K] - 1$$

G Antenna gain

Ψ Flux of the object being observed

λ Wavelength

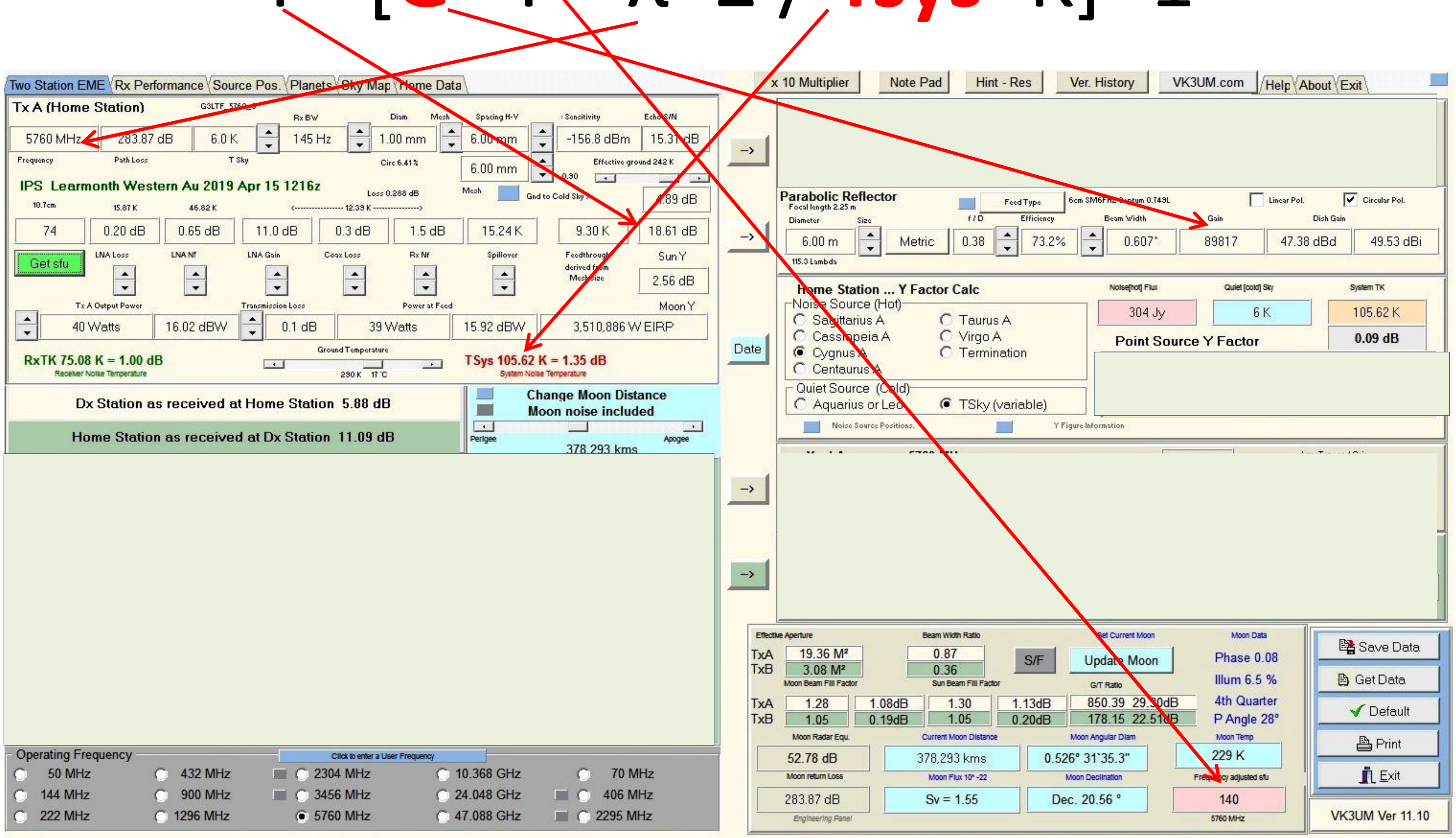
Tsys System temperature

K contains the constants. $8*\pi*k$

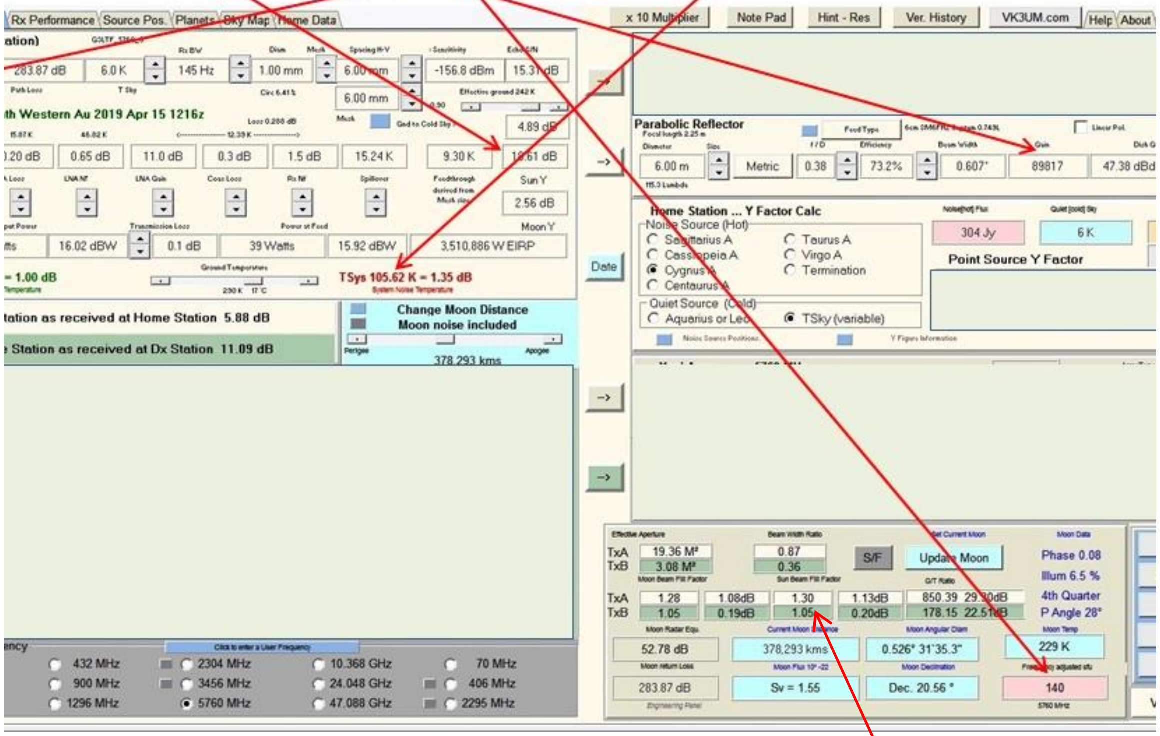
This formula is used for sun , moon and radio star measurements

Sun noise

$$Y = [G * \Psi * \lambda^2 / Tsys * K] - 1$$



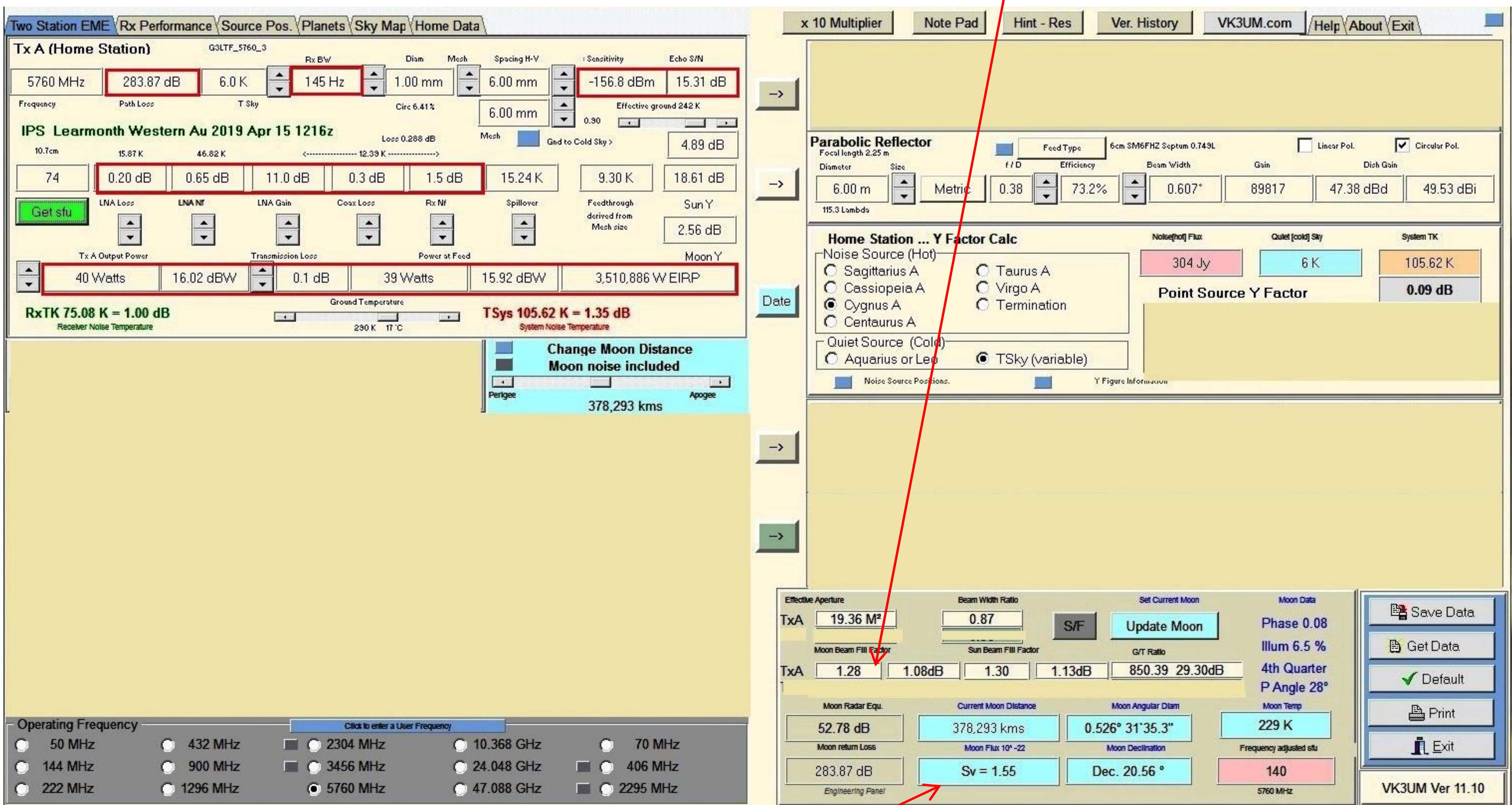
$$Y = [G * \Psi * \lambda^2 / T_{sys} * K] - 1$$



Correction for an extended source

If the source has a comparable or greater angular extent than the antenna beamwidth then not all the flux will be collected by the antenna and a correction is made to reduce the flux value, in this case 1.3

Moon Noise uses the same equation with an appropriate correction



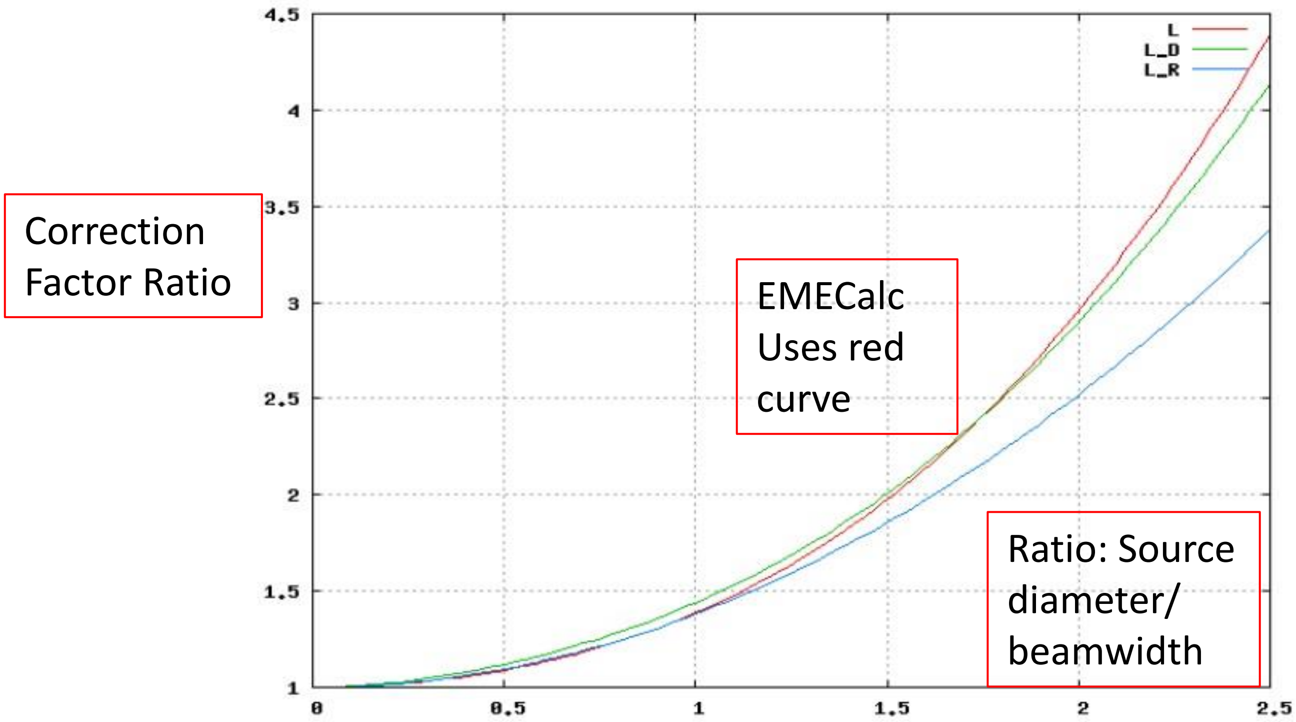
For derivation of moon temperature see my 2013 paper at this conference.

Moon temperature is converted into flux

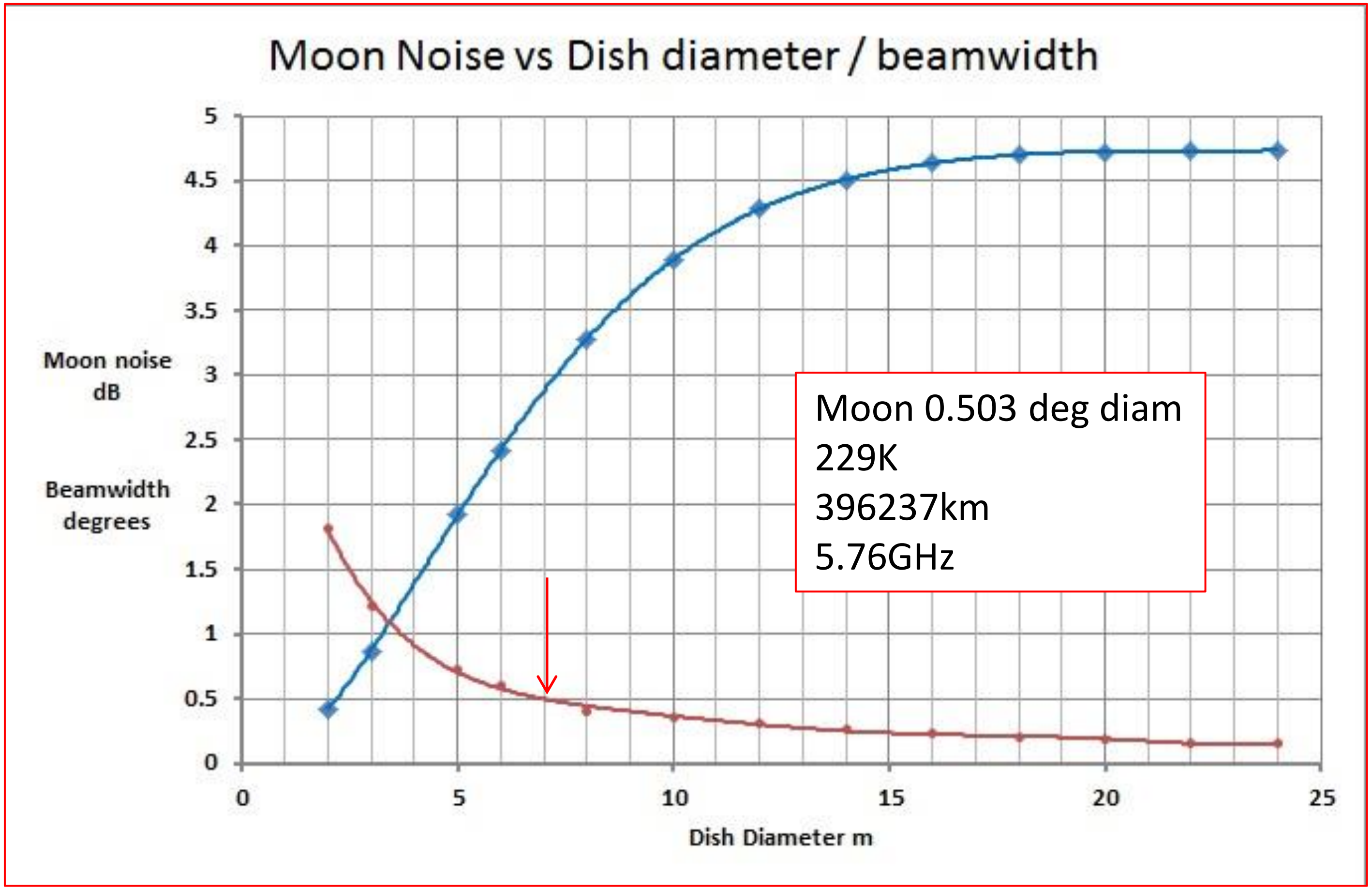
When the source has an angular extent larger than the beamwidth then less of the total flux is collected.

The flux value used in the Y factor equation has to be modified.

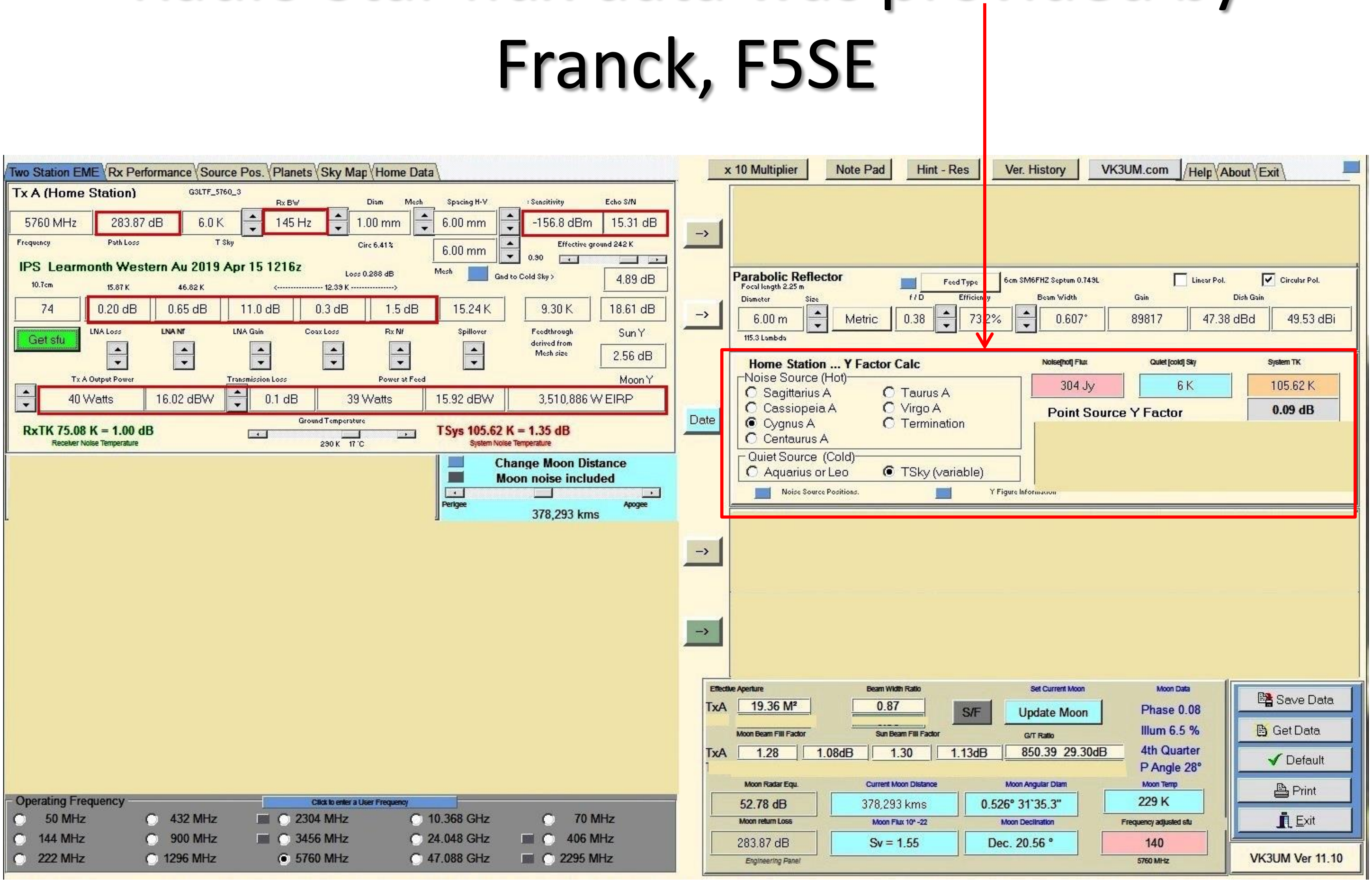
The correction is affected by beam shape and source shape



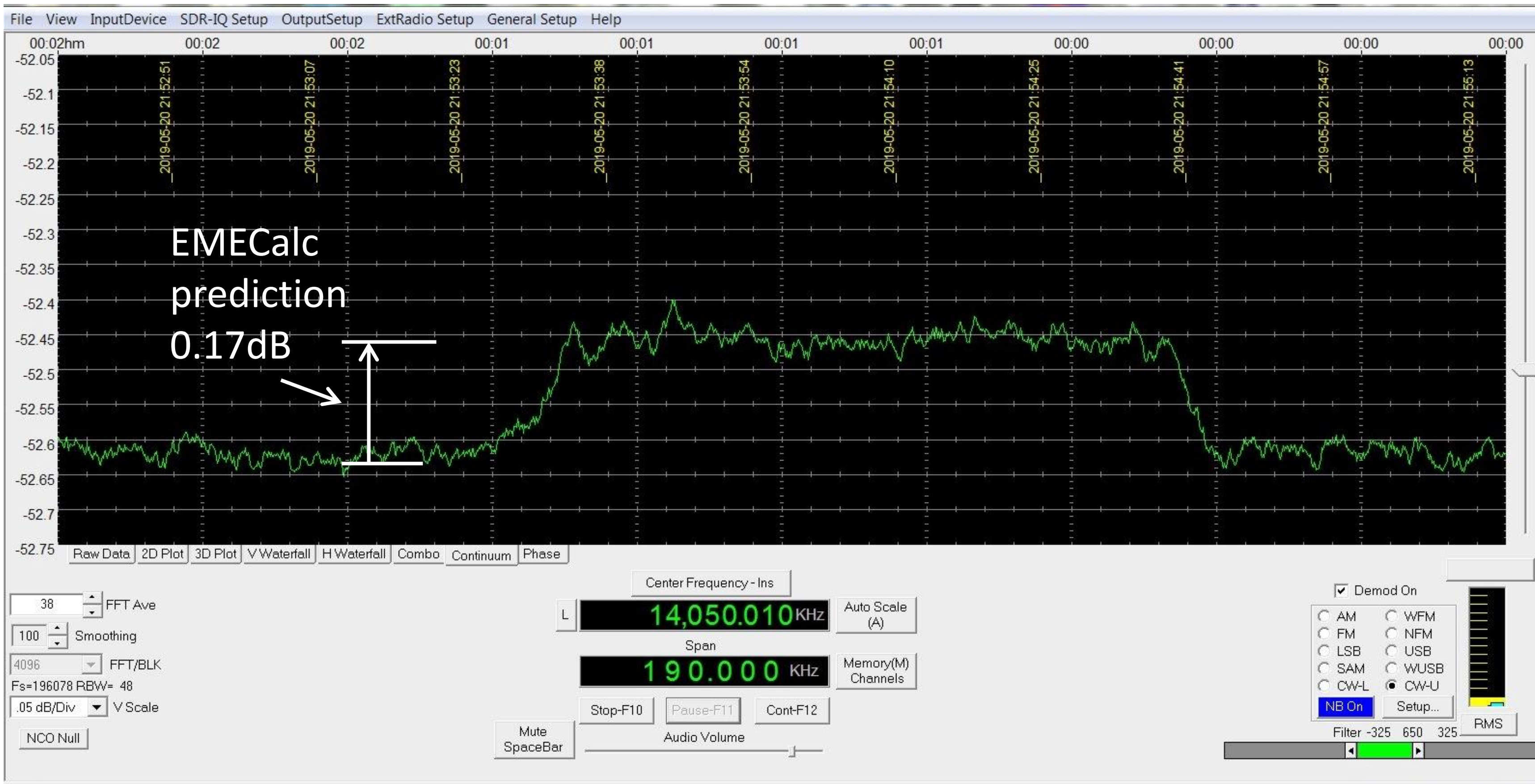
Moon noise and sun noise limits as dish size increases



Radio Star flux data was provided by Franck, F5SE



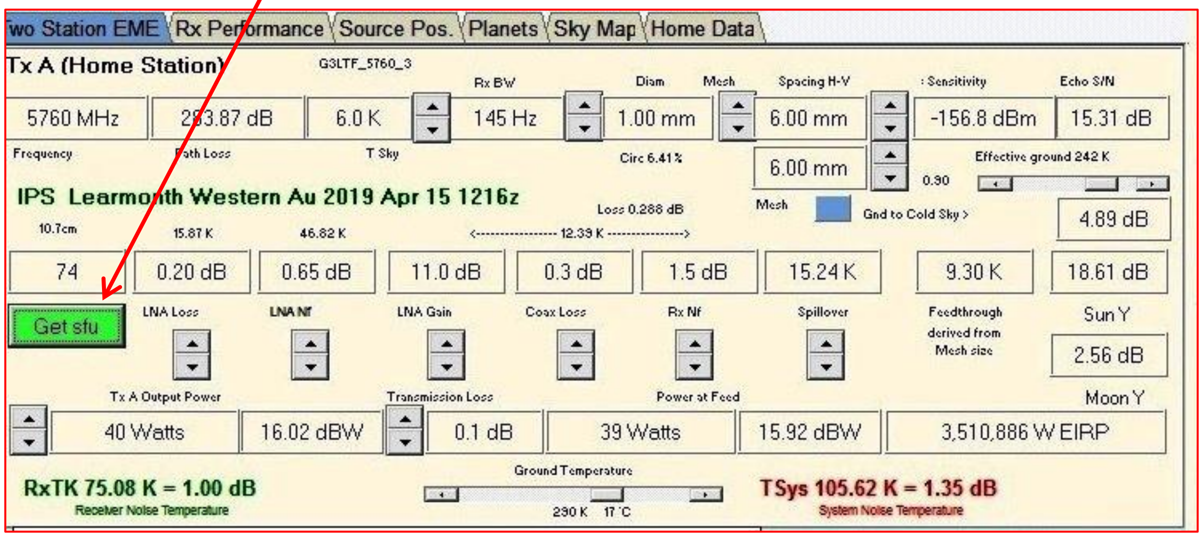
Virgo A (M87) measured at 23cm with 6m dish and SM6FHZ Kumar feed. Tsys 44.4K



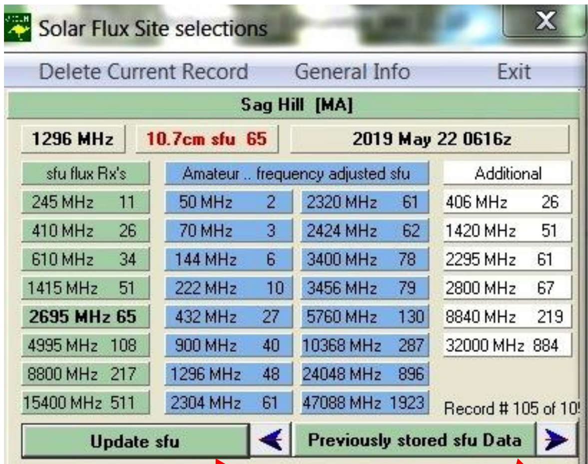
Derivation of Solar Flux in EMECalc

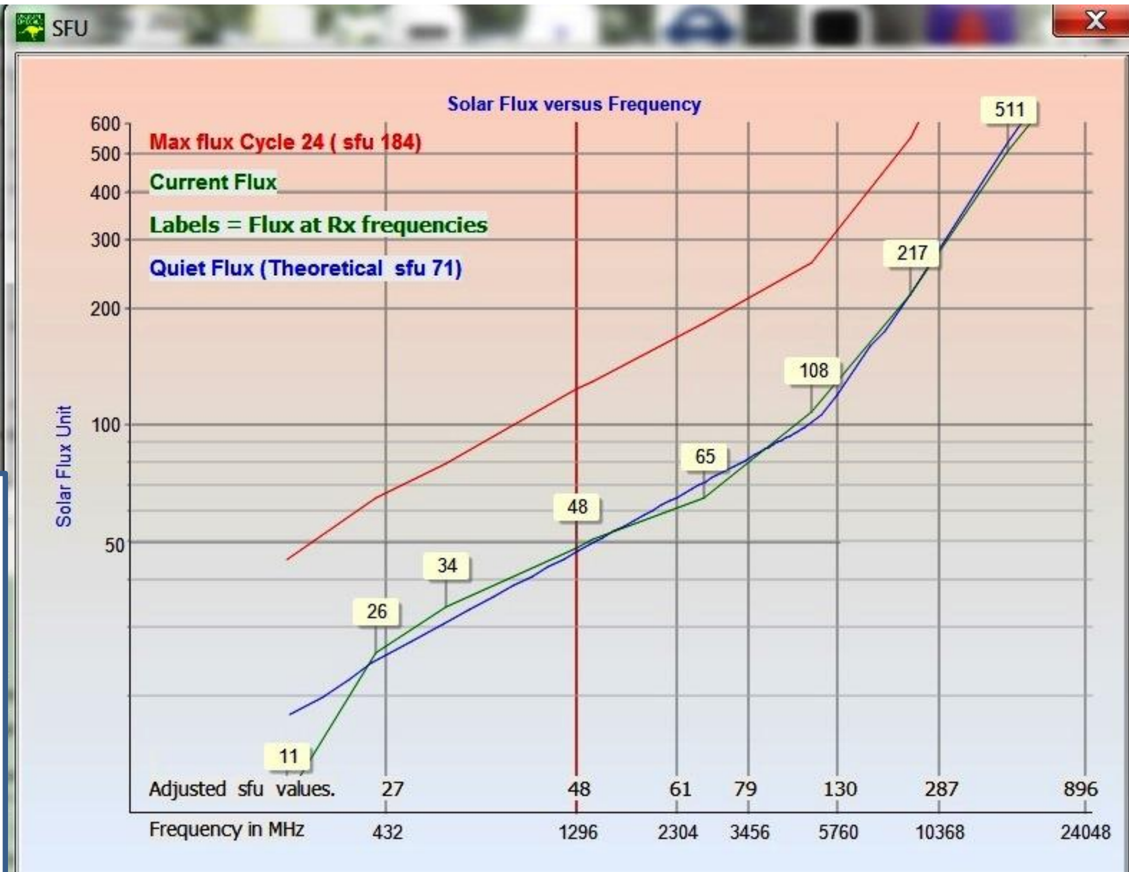
Updates from the NOAA database from world wide stations with multiple frequency measurements

Click “ Get SFU”



Derivation of Solar Flux in EMECalc

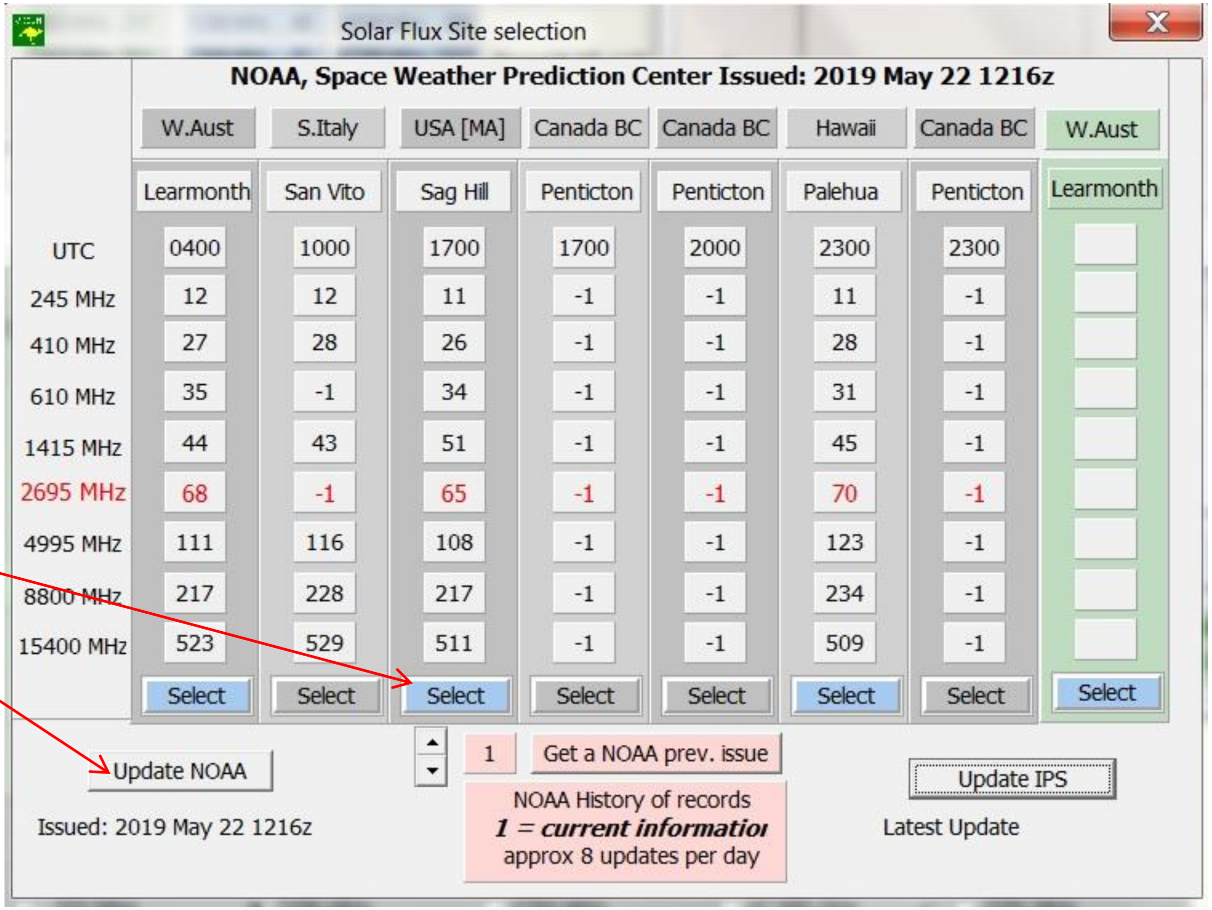




Last screen loads, so to update, click "Update SFU" Or use historical, previously stored data.

Derivation of Solar Flux in EMECalc

Click “Update NOAA” and select the most relevant site.



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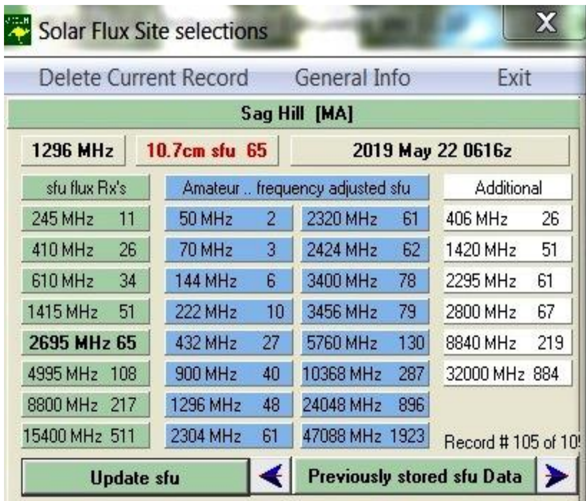
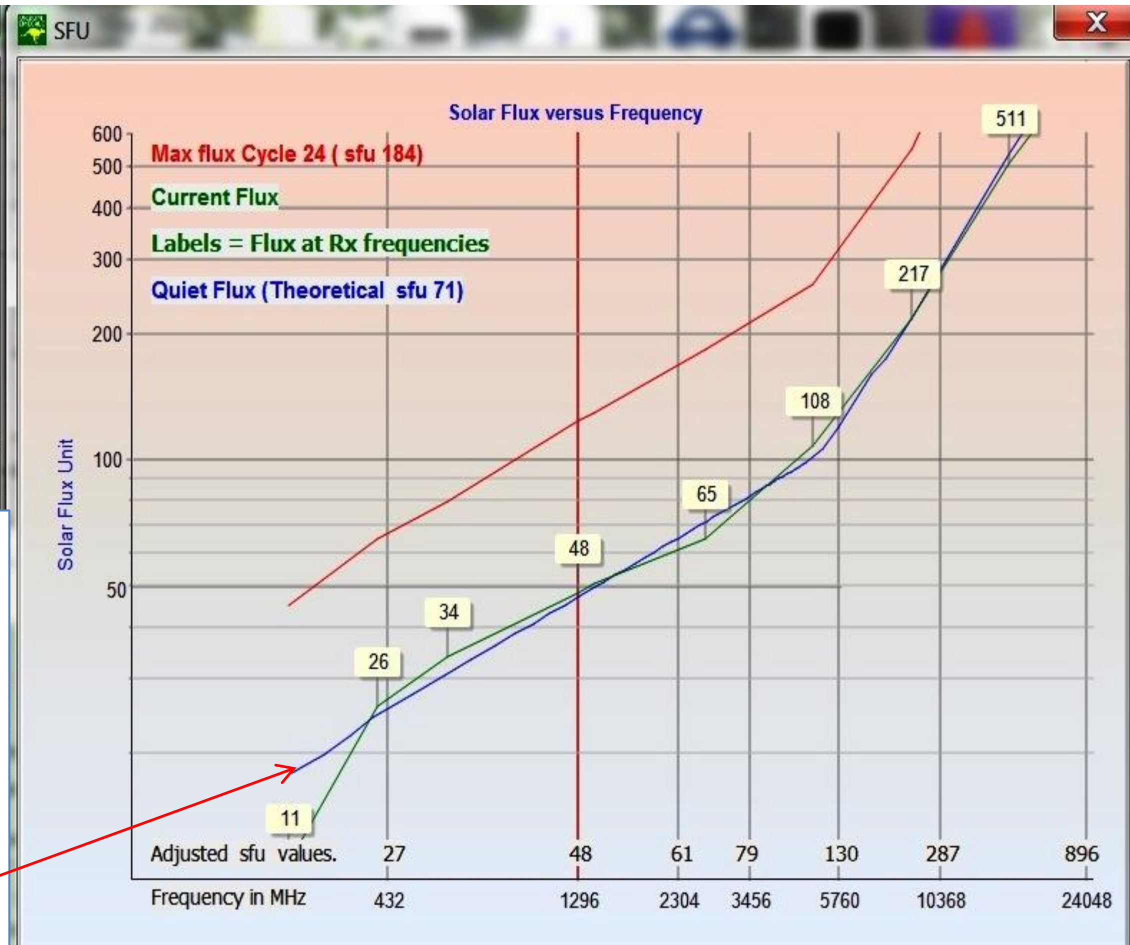


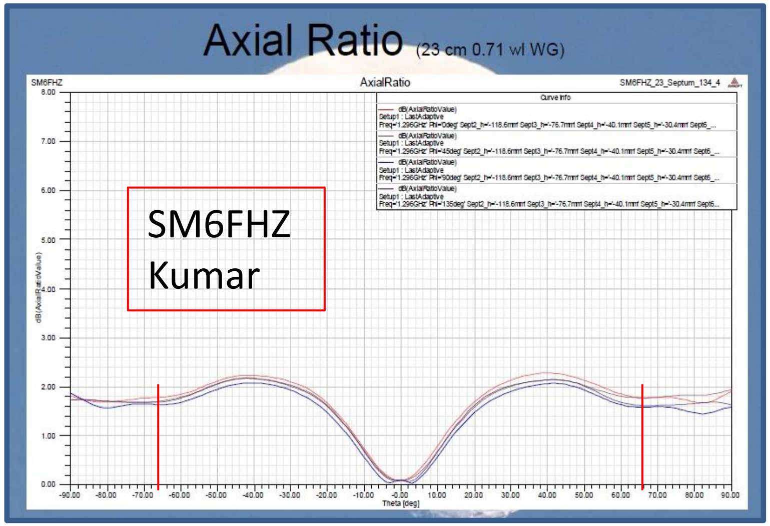


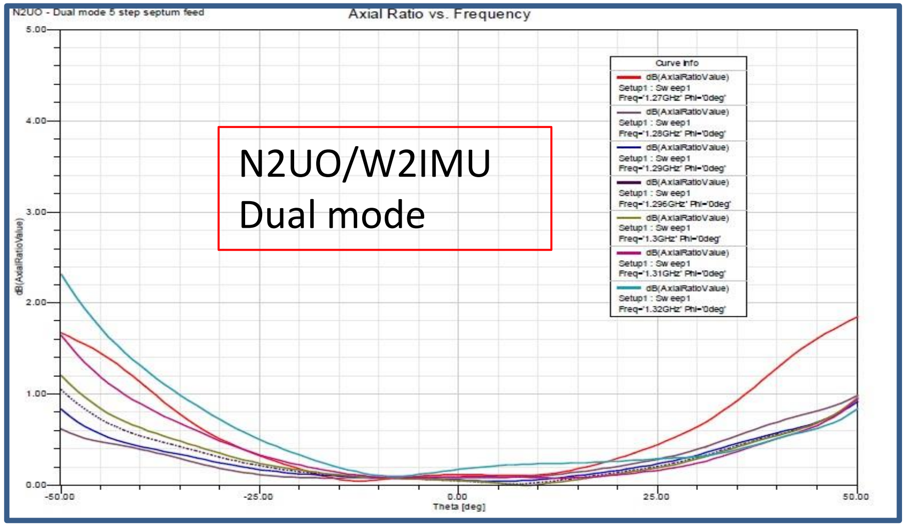
Updated curve of Solar Flux vs Frequency is now displayed with extrapolated values for the amateur frequencies. Note the close alignment with the theoretical quiet sun curve

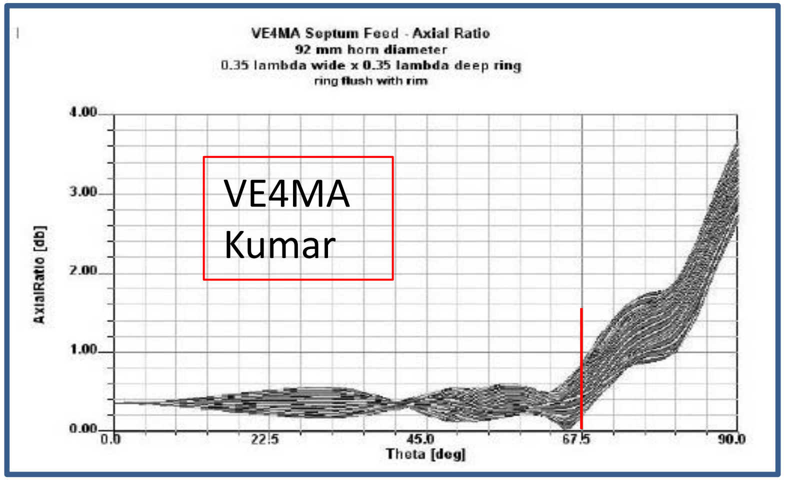
Finally, a comment on measurement and actual operation

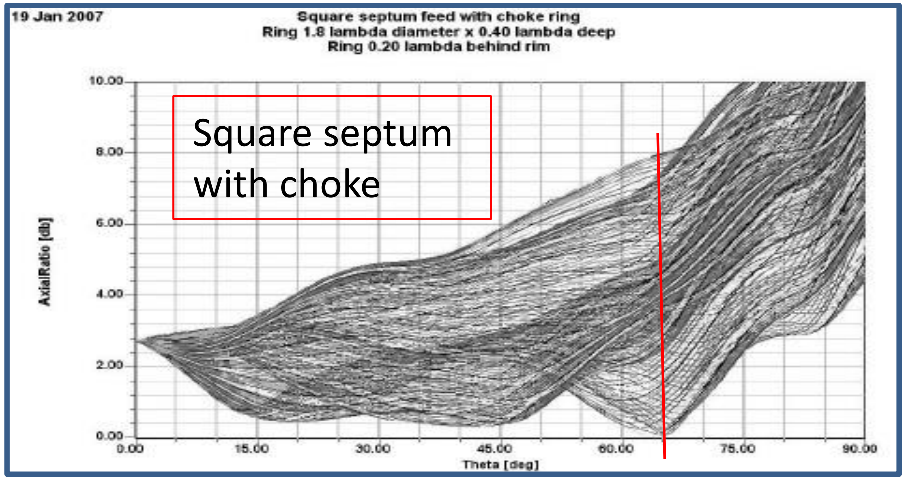
Cross-polar performance is important and mostly negleced

All our sun, moon, star measurements are using noise as the signal, but we communicate with coherent signals. Good CP across the whole aperture is important. Circular feeds are significantly better than square ones.





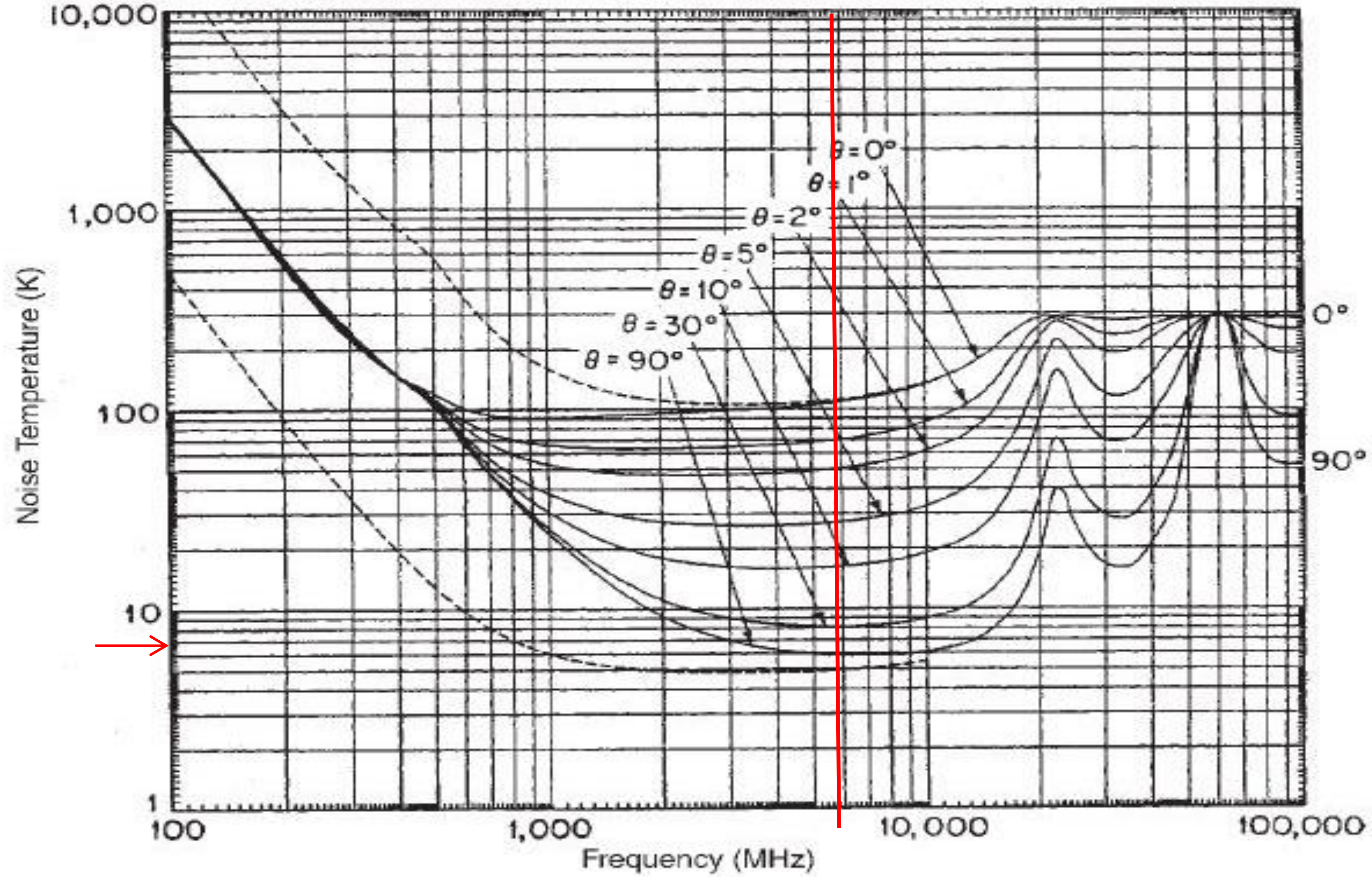




Acknowledgements

- To Doug, VK3UM (RIP) who created this wonderful toolset.
- To Paul W1GHZ and Ingolf SM6FHZ for their feed analysis.
- To the many others who gave Doug help, advice and suggestions.

Thank you for listening



Sky Noise Temperature

5.7GHz 45 deg. Elevation Tsky = 7K

At 10 deg. Elevation it is 14K