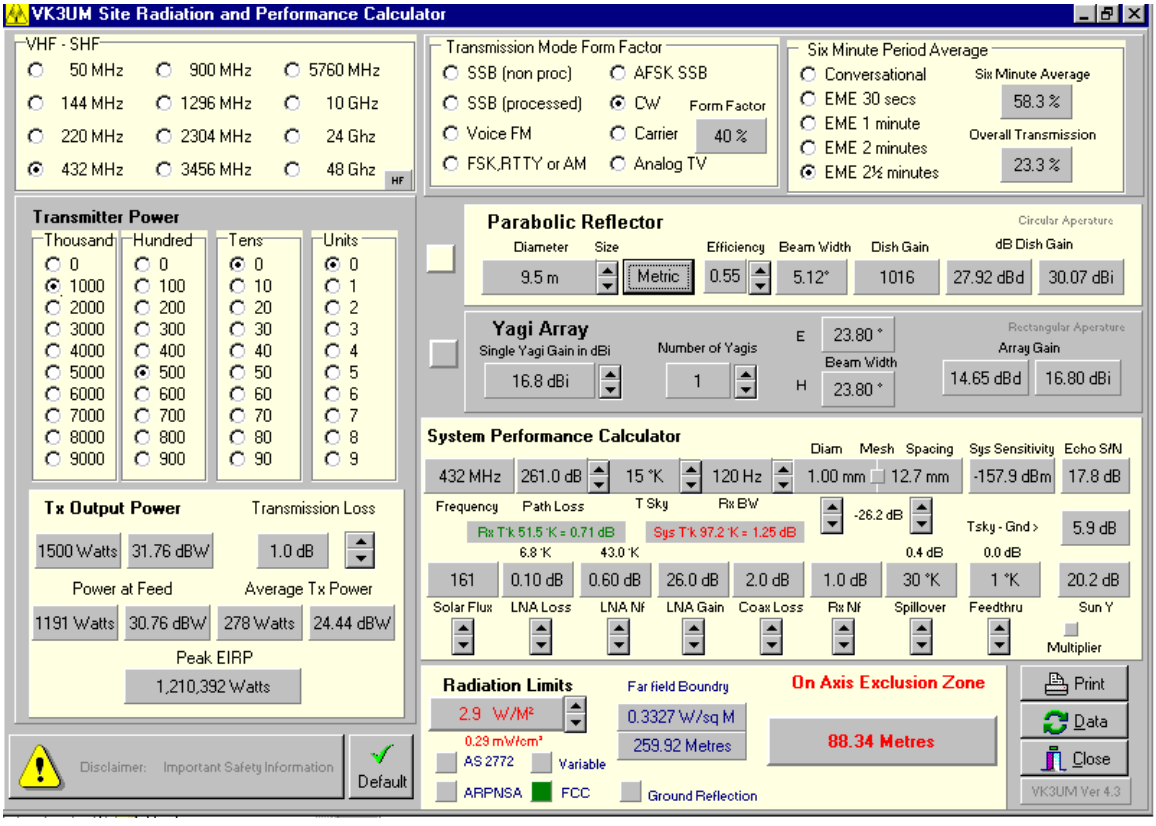
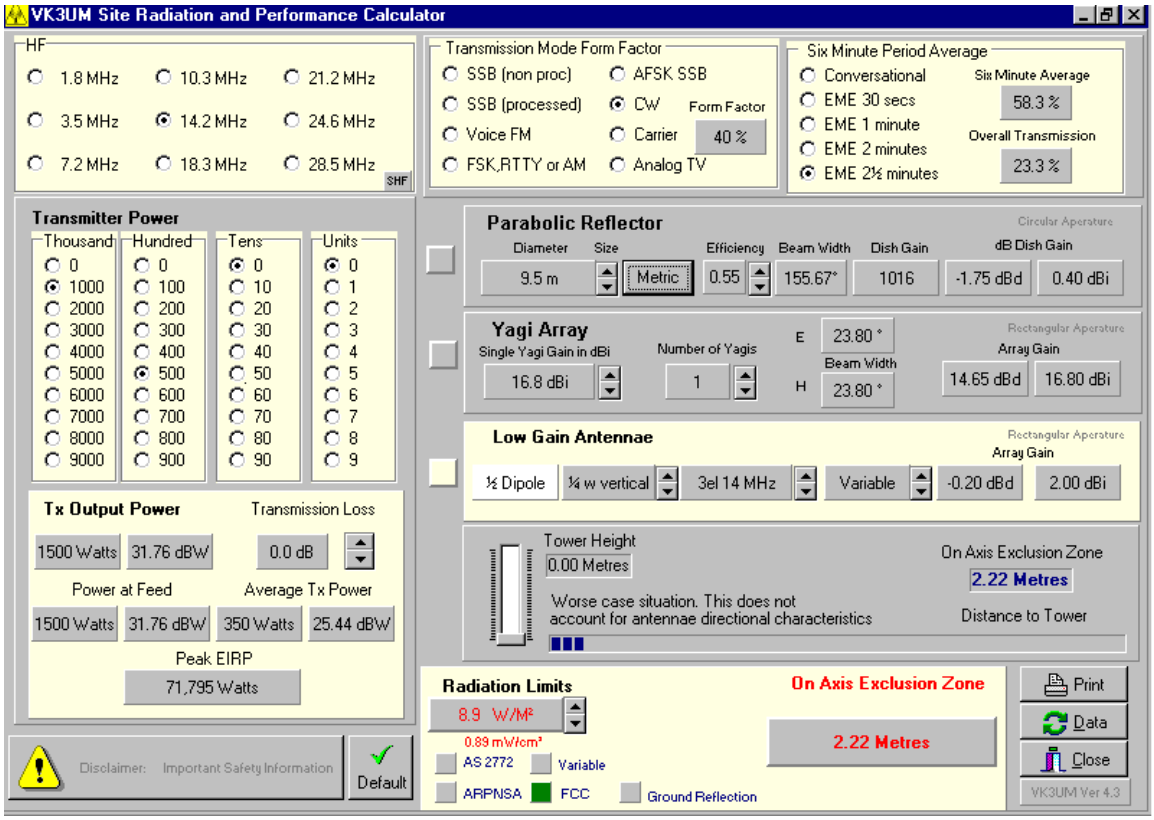
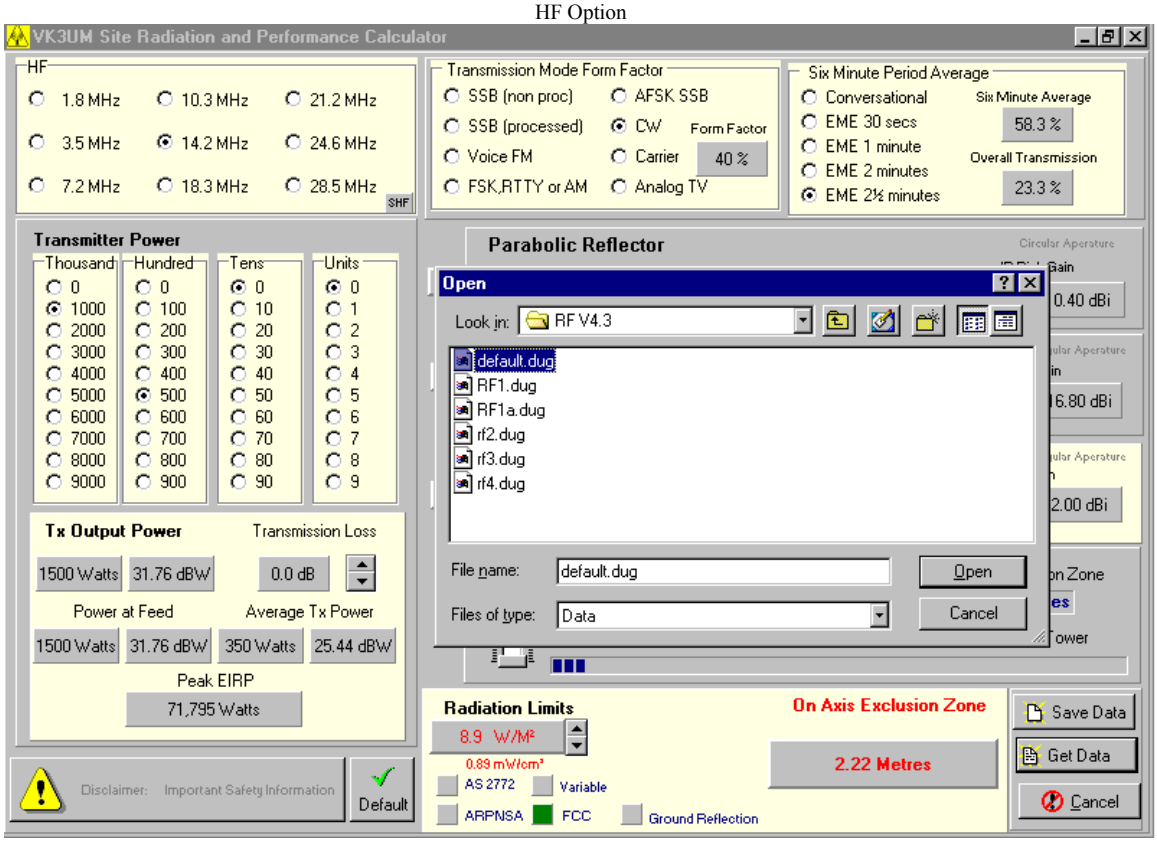
The VK3UM Radiation and System Performance Calculator



Opening Screen



HF Option



Open File option (Get Data)

1. Disclaimer

The accuracy of this software is in accordance with the calculation methods prescribed in the Standard chosen in the software.

The On Axis Exclusion Zone value calculated in this Software is the exposure limit that applies to the General Public for the Standard selected. (Uncontrolled environment)

The calculated Safety Exclusion Zones should only be taken as a guide and must not be relied upon as safe for human exposure. External influences can cause significant variations to predicted values.

The Exclusion Zone should be accurately measured in the prescribed manner and the readings thus obtained treated as absolute with respect to safety matters and not those predicted by this software.

2. Background

Through out the World many Government Authorities have indicated that they are proposing to implement, or are in the process of implementing mandatory standards of radiation limits pertaining to the Radio Amateur Service.

Because of the nature of EME (Earth-Moon-Earth) and other Amateur communications, radiated power levels can be quite high and may, under certain situations, pose a radiation hazard.

This software calculates the level of RF Radiation and specifically addresses the near field radiation characteristics of a circular aperture radiating antennae. ***(RFGraph.exe)***. This characteristic could be most significant in being able to demonstrate that an EME Station is able to meet Governing Authority's radiation limits.

3. Program Aim.

The *prime* purpose of the software is to define the ***Radiation Level*** of the *On Axis Exclusion Zone*, commensurate with the stations effective radiated power, mode of operation and antennae gain.

The *secondary* purpose is to provide the most accurate calculations for the ***EME budget, Sun Y factor (relative to the solar flux), and Sky (Cold) to ground Y factor.***

The user has the ability to vary all or any of the interacting factors and determine, with a high degree of accuracy, your system's performance.

4. Screen Options.

- The first time the program is run the default parameters as listed in Part 6 of this document will be displayed.
- The ***VHF-SHF*** *Screen* provides access to the Parabolic Reflector (default) and the yagi Array. To select the yagi array click on the button to the left of the display. Similarly to reselect the Parabolic Reflector display click on its button.
- The ***HF Screen*** may be selected by clicking on the small button (HF) in the bottom right hand corner of the frequency panel. The options available within this screen may be selected by clicking one of the available options (Low Gain Antennae, Yagi Array or Parabolic Reflector). Access to all the Low Gain Antennae options may be gained by clicking on the associated panel (it will high light in white) and further choose other options by use of the up/down arrows . To return to VHF-SHF screen click on the SHF button.
- ***Transmission Mode Form Factor*** options should be selected in accordance with the Standard chosen. In the case of the FCC OET Bulletin 65 they select Carrier or 100%.
- ***Six Minute Period Average*** options should also be selected in accordance with the Standard chosen. In the case of the FCC OET Bulletin 65 they select Conversational or 100%.
- ***Ground Reflection.*** Select his option where required. This will depend upon the situation under question and should be applied as appropriate. In the case of the FCC OET Bulletin 65 they stipulate this option (in most instances) as a worse case scenario.
- ***RF Radiation Standards***. Three are provided as indicated plus a variable facility to allow for any other Radiation Limit. Many Countries have as yet to define their Standard and the variable option is provided for such eventualities.
- ***Transmitter Power***. Levels from 1-9999 are provided to cover most Amateur situations.
- ***Transmission Loss***. Actual power measured at the radiator. Adjust to suit your particular situation. Remember to include all feed, relay, balun, and divider losses as appropriate.
- ***Metric/Imperial Button***. Selecting either will reflect on all displayed calculations. Note that this function is a '*stored parameter*'.
- ***System Performance Calculator***. There are 14 variables that the user may adjust to suit their situation. The ability to 'reverse engineer' your results provides the user with a system analysis tool of considerable effectiveness.
- ***File Handling Options***

The *Data button* provides access to data file management options.

Save data allows the user to store as many files, with whatever file name you choose (extension is set to *.dug) .
Get Data allows the user to recall the file as stored above.

Cancel aborts the process and returns the user to the main screen.

Note.
1 All the screen variables available to the user are stored.
2. You may also cancel the save or get file options by using the cancel option when in these screens.

Default Option allows for the retrieval of user defined set up parameters. When the program is first initiated the parameters displayed should be changed to suit the users preferred options. They should be stored as '***default.dug***'. This file will be recalled automatically when clicking on the default button. If the file has not been created then the user will receive an error message warning of the requirement.

5. Features

The software provides the ability to

- select the Radiation Limit to suit your Governing Authority's Standard.
- select the transmission frequency (1.8MHz to 49GHz).
- vary the transmitter output power and associated feed losses.
- select the transmission mode duty factor and averaging period characteristics.
- select ground reflection factor if required
- vary the antenna size and efficiency of a Parabolic reflector or select single or multiple yagi arrays
- select pre programmed rectangular aperture antennae types for HF (High Frequency) calculations or adjust antennae gain as necessary.
- vary the height of the HF antennae and display the resultant on axis *Exclusion Zone*. (bore sight direct line distance)
- select metric or imperial display presentation.
- save and recall user specific preference configurations as required.

The ***RF Radiation Calculator*** provides the *On Axis Exclusion Zone* (General Public), for both near and far field radiation levels, is displayed in both text and graphical (**RFGraph**) formats.

The ***System Performance Calculator*** will simultaneously display both S/N of the Moon Echo and the Sun and Cold Sky to Ground Y factor levels for variables generally not provided in other calculators. These include the added ability to vary;

- 10.7cm Solar flux.
- dish mesh characteristics.
- derived spill over and feed through values.
- Preamplifier and pre first amplifier gain and loss characteristics.

as well as all the other variables of frequency, sky temperature, LNA, receiver noise figure, band width and system loss factors. The calculator will provide most accurate data for typical installations and allow the user to define and analyse the operational capabilities of the station.

6. Default Parameters

The default parameters are as follows and should be changed to suit your installation

Frequency	432 MHz
Transmission mode duty factor	CW
Six Minute average period	EME 2½ minutes
Transmitter power	1500 watts
Transmission loss	1.0 dB
Parabolic Reflector	9.5 metre
Efficiency	55%
Single yagi gain	16.8 dBi
Number of yagis	1
Diameter of mesh	1.0 mm
Mesh spacing	12.7 mm
Feed thru	1 °K or -26.2dB (derived from mesh size)
Receiver bandwidth	120 Hz
Solar Flux (10.7 cm)	160
LNA Loss (preamp – antennae)	0.10 dB
LNA Noise figure	0.60 dB
LNA Gain	26.0 dB
LNA – Rx Loss (next stage)	2.0 dB
Rx NF (next stage following LNA)	1.0 dB
Spill over	30 °K
Radiation Limit Standard	FCC OET-65 (without Ground Reflection).
Transmission Mode Form Factor	CW (40%) note .. FCC = 100%
Six Minute Period Average	EME 2½ min. (58.3%) note .. FCC = 100%

The **FCC OET Bulletin 65 Supplement B (Amateur Stations)** calculations are based on ground Reflection and 100% Form and Time factors. These parameters should be set as required noting the default is set for CW and 2½ minute EME sequence and without Ground reflection. The transmission Loss is initially set to –1.0dB and should be adjusted as required.

7. Parameter Descriptions

- ***Frequency.*** Select the frequency of operation as required. This will define the default quiet sky temperature (T°K Sky). The default values have been chosen as the minimum quiet sky achievable for the frequency selected. It will most likely

have to be varied to equate to the actual sky temperature behind the selected source at the time of measurement. The default T°K Sky temperatures provided are as follows

50MHz	2200 °K	
144 MHz	250 °K	
220 MHz	150 °K	
432 MHz	15 °K	
900 MHz	10 °K	
1296 MHz	5 °K	and above

- ***Transmission Mode Form Factor.*** (TMFF) Choose the mode of operation. The form factor % is indicated in the associated box which, and along with the 6 minute period average, is used to calculate the average *Effective Radiated Power* (EIRP) (minus the *transmission Loss*). The figures as indicated are those as defined by the *Australian Communication Authority* and *FCC OET Bulletin 65 Standards.* [1 & 4]

  Note The examples provided in the FCC OET Bulletin 65 Standard Supplement B utilize a 100% TMFF. (Carrier)

- ***Six-Minute average period.*** Choose the six-minute period average commensurate with your operation. This figure will be used to calculate the average EIRP as stated above. *Note. The examples provided in the FCC OET Bulletin 65 Standard Supplement B utilize a 100% Six Minute average period. (Conservational)*

- ***Transmitter Power.*** This is the RMS output power as measured at the transmitter output.

- ***Transmission loss.*** Adjust the value to equal to the total transmission loss between the transmitter output and the radiating element. (include any switching relays where used).

- ***Parabolic Reflector.*** Adjust for the size you are using and adjust the efficiency to reflect the characteristic of the reflector. *Note this is reflector efficiency and not f/d.*

- ***Yagi Array.*** If you are using a single yagi or yagi array, first select the button adjacent to the Yagi array. This will highlight the Yagi Array box and darken the Parabolic reflector area. Adjust the Single Yagi dBi gain and the number of yagis to match your installation. You may wish to vary the single yagi figure to reflect your realised array gain. This can vary depending upon the stacking distances chosen and the cumulative losses of your system. This program has chosen a stacking gain of 2.85 dB. The default yagi configuration, if 4 are selected, equates to 4 x 5λ M ² on 144MHz.

- ***Mesh diameter and spacing.*** If you are using a parabolic reflector, with mesh as the reflector, then adjust these parameters to suit your installation. If you are using

a solid dish click on the small button between the two values. The program will automatically calculate the *feed thru loss* and it is displayed in both °K and dB. Should your situation require the addition of higher impinging ground or other adjacent temperature sources, then this can be added by the use of the associated button. (eg 50/144 MHz yagi installations) Refer also *Feed thru* in part 6.

- ***Receiver bandwidth.*** Adjust the value to suit your receiving configuration.

- ***Solar Flux. (10.7 cm)*** Adjust to the Solar Flux for the time of the measurement. The program extrapolates the value to the frequency of operation as based upon the IPS Learmonth figures. [2]

- ***LNA Loss*** (preamp – antennae). Set the value to the loss between the preamplifier input and the radiator. This should include connectors, coax and relay insertion losses.

- ***LNA Noise figure.*** This is the measured or theoretical noise figure of the preamplifier.

- ***LNA Gain.*** This is the measured gain of the preamplifier in dB.

- ***Cable Loss*** (next stage). This is the loss in dB between the pre amplifier output and the next stage input.

- ***Rx Nf (next stage).*** This is the nose figure of the following stage. The overall receiver noise temperature is derived from the above parameters by utilising the cascade amplifier method.

- ***Spill over.*** This value is adjusted to the set position of your feed. The value can be set as the level at the dish rim in dB which is subsequently converted to °K. The default is –9.9dB or 30°K but can be varied in 1°K increments to reflect under or over illuminating the dish.

- ***Feed thru.*** This value is automatically calculated from the mesh dimensions of your antennae and the frequency of operation. The computed value is in dB and converted to °K for overall system performance calculations. Additional feed thru loss can also be added by the user when using yagi arrays as necessary. (refer part 8). A solid dish surface can be selected by clicking on the small button between the two input values.

- ***Radiation Limit.*** The default setting is the FCC nominated level as defined in OET Bulletin 65. If this does not equate to your requirement adjust this to suit your Authorities requirement by selecting the variable option provided..

- ***Multiplier Button.*** Clicking this button provides a faster (x10) increment or decrement of the following parameters. Path Loss, T Sky, Rx BW, Spill over and

Feed thru. The associated boxes will be high lighted in yellow when the button is selected.

8. Calculation Methods and display presentation.

The *On Axis Exclusion Zone* is the direct line (bore sight) distance from the radiator. The distance is that where the radiation level exceeds the Radiation Limit as specified by the Standard chosen. In most Standards this will vary with frequency in accordance with the requirement. The actual level will be displayed in both Watts/metre² and mW/cm².

The calculation method used by this software is that as detailed in the ***Australian Standard AS 2772-2-1988 Radiofrequency radiation - Principles and methods of measurement – 300 kHz to 100 GHz*** and those similarly described in ***FCC OET Bulletin 65.*** [3 &4]

The program calculates the near field values for both circular and rectangular apertures depending upon the user selecting either a Parabolic reflector (circular aperture) or a Yagi, dipole or vertical radiator. (rectangular aperture)

In the case of a Parabolic reflector the near field correction follows the (1-q ²) taper curve where q is the radial distance from the centre of the circular aperture, normalised to the aperture radius. The program utilises the power density (PD) in the Near Field Normalised to unity at 2D ²/λ where

$$PD = 26.1\ [1\text{-}16x/\ \pi \sin \pi/8x + 128x\ ^2/\pi^2(1 - \cos \pi/8x)] \quad [5]$$

The above curve is displayed in **RFGraph** and highlights the near field radiation characteristic. This characteristic, where the radiation level falls below the *Exclusion Zone* within the near field, may of significance when establishing safe distances from antennae installations. The near field safe distance characteristic may permit operation as result of the height separation of the antennae or the elevation of the antennae. This may not be the case if the Exclusion Zone alone were the sole determining factor.

It should be noted that in the **RF program**, only the 'first near field' curve is calculated and displayed whilst the **RFGraph program** displays all near field curves and their distances.

- ***Rectangular aperture*** calculations (yagi) are based upon the uniform line source power density in the near field. [3 & 5]

- ***Ground Reflection*** is as detailed in the FCC Standard. This is derived by multiplying the power density by a factor of 2.56 to equate to the predicted ground reflection as stipulated in the Standard. This option may be turned on or off as required.

- ***Tower Height.*** An option is provided to vary the tower height (click on the track bar and move the bar with the mouse or roller) and observe the *On Axis Exclusion Zone* height separation effect. Note this calculation is purely a trigonometry calculation and does not take in to account any additional loss that may be present from the radiation characteristics of the antennae. It is a worst-case scenario with respect to Radiation Levels.

9. System Performance Calculator

- ***Echo S/N.*** This value is computed from the following fixed and variable parameters.

- ***Antennae gain*** is determined by the operating frequency, dish size, and efficiency.

- ***Path loss*** (aperture loss) is a fixed value derived from the free space loss, distance to and from the Moon, reflective index of the Moon, and the frequency of operation. The value equates to the Moon at Perigee (minimum loss).

- ***Receiver bandwidth.*** It should be noted that the human ear can act as a narrow band filter and the discernable echo can be several dB below what the program predicts as the actual S/N.

- ***System sensitivity.*** This value is the combination of the receivers total noise temperature that includes feed losses, receiver overall noise temperature, sky temperature, feed thru and spill over losses. It should be noted that the default sky temperature may require changing to equate to the actual temperature at the time of measurement. The value is the generally accepted minimum value for the frequency chosen and not that behind the Moon at the time of measurement. Care should be exercised when using the calculator with yagi arrays on 144MHz as 'spill over', 'feed thru' and sky temperatures can be quite high. (eg 254 °K is accepted as typical for 4 x 5λ M ² on 144MHz).

It is possible to vary all the variable interacting parameters and compute the resultant Echo S/N. In this way, the factors that affect the magnitude of the end result become clearly evident and can be to optimised to improve system performance. (note some have a much greater affect than others and all interact)

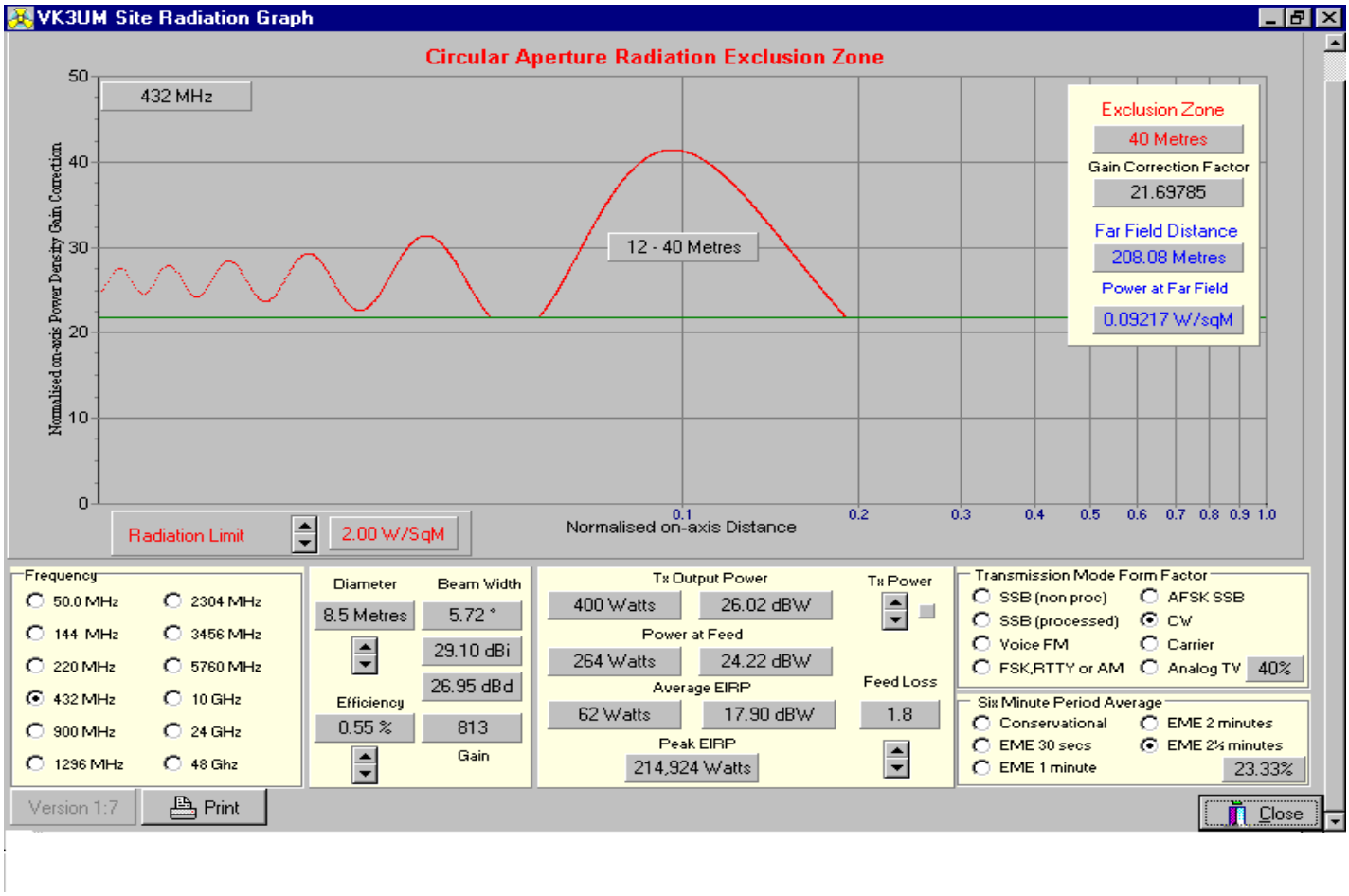
- ***Solar Flux.*** This value is computed from the all the above (8.1) parameters as related to the noise power of the 10.7 cm Solar Flux . The relationship between the received Sun power and that of cold sky is the Sun Y factor.

As with the calculation of the Moon Echo S/N the interaction between all the associated parameters may be varied and analysed to obtain an understanding of what is required to optimise your system.

- ***Cold Sky to Ground.*** This value is computed from the all the above (8.1) parameters and computes the relationship between the Ground (accepted as 290 °K) and that of cold sky. This is the Cold Sky to Ground Y factor.

Care should be taken in the interpretation of the results. The computed figure is theoretical and can be realised in ideal conditions but, adjacent objects found in typical installations (trees houses etc) may be reflective and there-for affect the measured value. Care should also be exercised in the measurement of Cold Sky.

10. RFGraph Calculator (Circular Apertures only)



This software provides all the RF *Exclusion Zone* calculations as described earlier but it is now displayed in a graphical format. Note the default is 2W/M².
As with the other version set the Radiation Limit, operating frequency, Dish Diameter and efficiency, transmission Mode Duty factor and 6 minute period average.

Finally the *Feed Loss* should then be set to reflect your station losses. The transmitter power can then be varied and the Exclusion will be displayed.

The level of radiated power with in the Near field region will displayed.
This characteristic and the predicted *Exclusion Zone* could, in some circumstances, permit operation where space or elevation separation can take advantage of the safe area within the Near Field.

Explanation. The X axis of the graph is the normalised on–axis distance where 1.0 equates to the Far field distance. The 0.1 point is the transition point between the near and far field. The X base line is logarithmic. The Y axis is the normalised on-axis power density gain correction. The curve depicted in red is the on-axis power flux density curve for a circular aperture ($1-q^2$) taper. The near-field power density is determined by calculating the far-field distance ($r = 2D^2/\lambda$) and the power flux density at this point [$S = GP/(4\pi r^2)$] and multiplying this power flux by the gain correction factor. [3 page 28].
Example. Given a 2 W/square metre radiation limit, a frequency of 432 MHz, 8.5 metre dish, efficiency 55%, 1.8dB transmission loss, 400 watts Tx O/P, a CW Transmission Mode Form Factor with a 2½ minute EME 6 minute Period Average then the display will show :=
An Exclusion Zone of 12 – 40 metres and a Far Field Distance of 208.08 metres. This can be interpreted as the distance from the radiator up to a distance of 12 metres is below the radiation limit. The Exclusion Zone extends from 12 metres to 40 metres. As the power is further reduced, additional safe areas (below the set radiation level) are revealed. The green horizontal line is the graphical representation of the radiation level in Watts/square metre as set by the user. Below this green line is below the radiation limit (default is 2 W/square metre or what ever is chosen).

11. References and Acknowledgements

[1] Australian Communication Authority
Self –Assessment Supplement 5: Amateur Services
(Revised Addition 4 December 2000)
Supp5.pdf http://www.aca.gov.au/

[2] International Prediction Service http://www.ips.gov.au/learmonth

[3] Australian Standard AS 2772-2-1988 Radiofrequency radiation- Principles and methods of measurement – 300 kHz to 100 GHz. http://www.standards.com.au/

[4] FCC OET Bulletin 65 http://www.fcc.gov/oet/rfsafety/

[5] Microwave Engineers Handbook – Volume 2

I wish to make specific acknowledgement and thanks to the following persons that provided most valuable suggestions and beta tested versions of the software.

Mr Graham Daubney (G8MBI)
Mr Lyle Patison (VK2ALU)

Mr Peter Blair (G3LTF)
Mr Peter Sundberg (SM2CEW)
Mr Peter Freeman (VK3KAI)
Mr David Tanner (VK3AUU)

12. Updates and Version Numbers

RF.exe

4.0 Original release ..... Prague August 2002.

4.1 Following items amended ..... October 2002

- *On Axis Exclusion Zone* display not present when Imperial selected.
- Peak EIRP was not correct for Yagi arrays.
- Added Overall Transmission Display % allowing Six Minute Average to reflect that value more correctly.
- Circular Aperture and Rectangular Aperture designations added to emphasise the mode of calculation used.

4.2 Additional feature added ..... November 2002

- Ability to vary the Path loss value.
  Note the value will change to green when it does not equate to the Perigee value for the frequency selected.

4.3 Additional features added ..... December 2002

- ARPNSA and FCC Standards included with FCC as the default selection
- Ground Reflection added as an option.
- Frequency range extended to cover Amateur HF Bands (1.8 MHz to 28 MHz)
- Tower height / *Exclusion Zone* simulator added.
- The ability to store and retrieve all variable set up parameters. (endless multiple files)
- mW/cm² display corrected to reflect correct conversion value as well as other minor cosmetic changes. (eg Disclaimer logo)