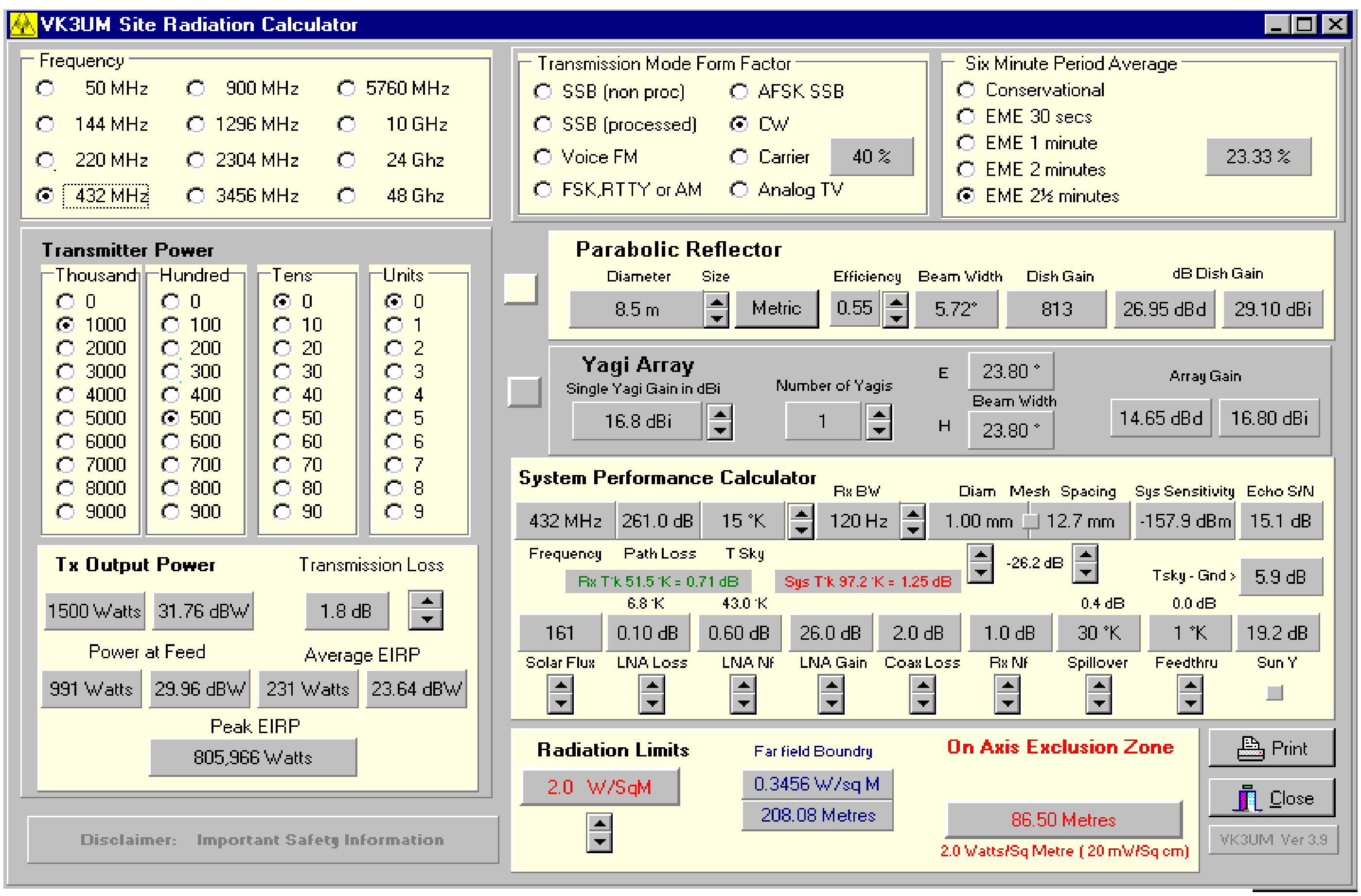
The VK3UM Radiation and System Performance Calculator



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1. Disclaimer

The accuracy of this software is in accordance with the calculation methods prescribed in Australian Standard AS 2772.

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. In Australia such standards were introduced in July 2002.

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

This software is able to predict the level of the radiation. In the author's opinion, most available software appears not to address the near field radiation characteristics of circular aperture antennae. This aspect could be significant in being able to demonstrate that an EME Station is able to meet Governing Authority's radiation limits.

3. Calculations

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 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. Features

The software provides the ability to

- vary the Radiation Limit to suit your Governing Authority's Standard.
- select the transmission frequency (50MHz to 49GHz).
- vary the transmitter output power and associated feed losses.

- select the transmission mode duty factor and averaging period characteristics.
- vary the antenna size and efficiency of a Parabolic reflector or select yagi arrays
- provide metric to imperial conversions

The calculation of the On Axis Exclusion Zone, for both near and far field radiation levels, is then displayed in both text and graphical (***RFGraph***) formats.

In addition 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.

5. 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	1.8 dB
Parabolic Reflector	8.5 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)	161
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	2 watts / square metre (20 mW /sq cm)

6. Parameter Description

6.1 Frequency. Select the frequency of operation as required. This will provide the default quiet sky temperature (T Sky). The default values have been chosen as the minimum quiet sky achievable for the frequency selected and may have to be varied to equate to the actual sky temperature behind the selected source at the time. The default Sky temperatures are as follows

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

6.2 Transmission Mode Form Factor. Choose the mode of operation. The form factor % is indicated in the associated box which, along with the 6 minute period average, will then be used to determine the average Effective Radiated Power (EIRP) in conjunction with the transmitters power and transmission loss. The figures as indicated are those as defined by the Australian Communication Authority. [1]

6.3 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.

6.4 Transmitter Power. This the output power as measured at the transmitter output.

6.5 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).

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

6.7 Yagi Array. If you are using a yagi or yagi array firstly 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 this slightly (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.

6.8 Diameter and mesh 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 temperature (eg 144 MHz yagi installation) then this can be added by the use of the adjacent button.

6.9 Receiver bandwidth. Adjust the value to suit your receiving configuration.

6.10 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]

6.11 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.

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

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

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

6.15 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.

6.16 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.

6.17 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 be added by the user when using yagi arrays as necessary. A solid dish surface can be selected by clicking on the small button between the two input values.

6.18 Radiation Limit. The default setting is 2 watts /square metre which is the Australian defined Standard . Adjust this to suit your Authorities requirement.

7. On Axis Exclusion Zone - Calculation Method and display

7.1 The on axis exclusion zone is the direct line (bore site) distance from the radiator. The distance is that where the radiation level exceeds the Radiation Limit as specified by the user (i.e. 2 Watts / square metre).

7.2 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.** [3]

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

7.4 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 $2D^2/\lambda$ where

$$PD = 26.1 [1-16x/\pi \sin \pi/8x + 128x^2/\pi^2(1 - \cos \pi/8x)]$$ [4]

7.5 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.

7.6 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.

7.7 Rectangular aperture calculations (yagi) are based upon the uniform line source power density in the near field [3 & 4]

8. System Performance Calculator

8.1 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 many dB below what the program predicts as the true 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).

The user of this software is able to vary all the parameters and compute the 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)

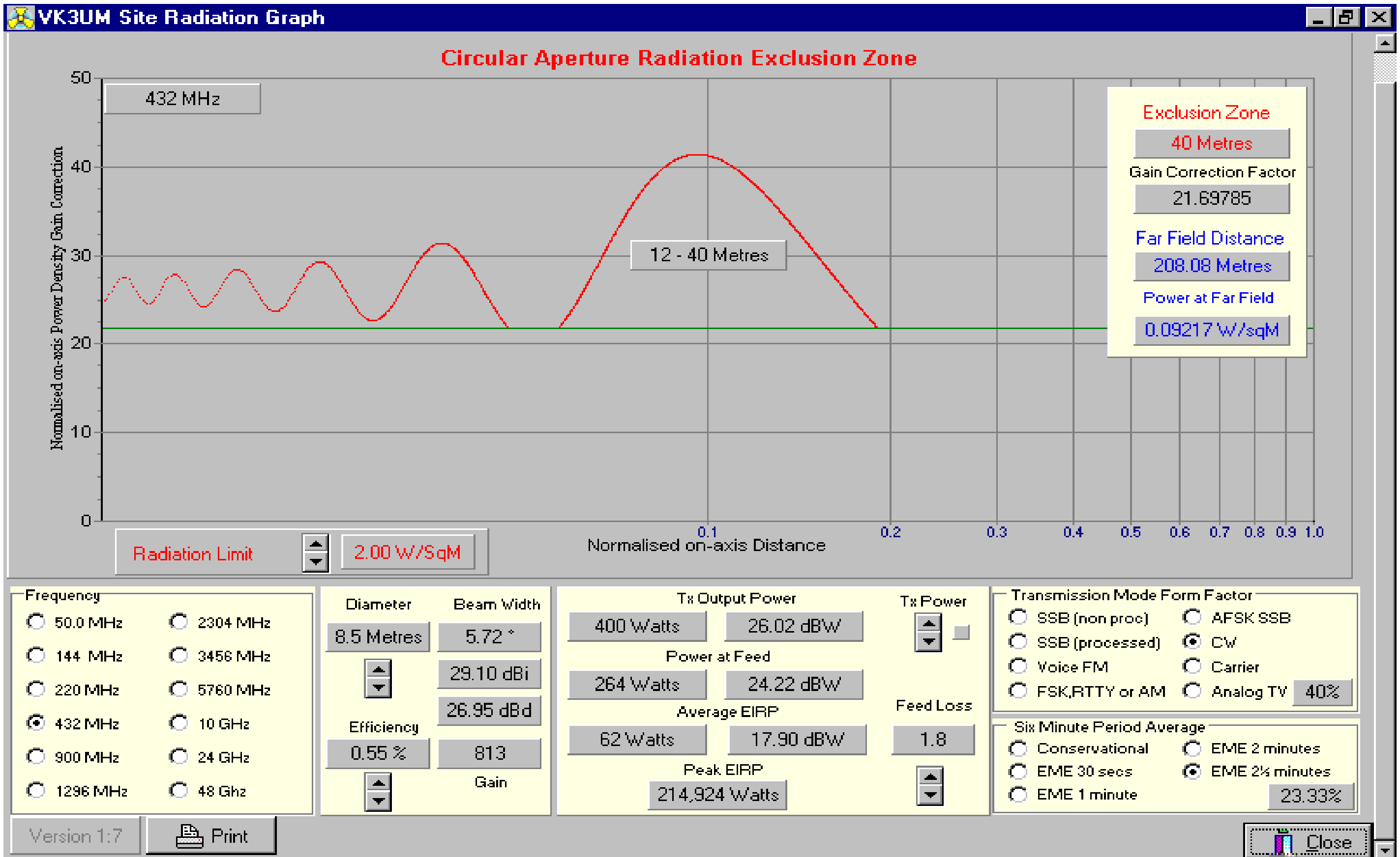
8.1 Sun Y Factor. This value is computed from the all the above (8.1) parameters as related to the noise power of the 10.7 cm Solar Flux . The relationship between the received Sun power and that of cold sky is the Sun Y factor.

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.

8.2 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) maybe reflective and there for affect the measured value. Care should also be exercised in the measurement of Cold Sky.

9. 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.
- 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).

10. 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] Microwave Engineers Handbook – Volume 2

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

- Mr Graham Daubney (G8MBI)
- Mr Lyle Patison (VK2ALU)
- Mr Peter Blair (G3LTF)
- Mr Peter Sundberg (SM2CEW)
- Mr Peter Freeman (VK3KAI)