

Large Dish Cassegrain Development Using CAD & Spreadsheet For Millimetric Bands & Practical Implementation.

Martin Farmer G7MRF
Email: g7mrf@compuserve.com

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Introduction

The scope of this paper is to make available the design calculations and the spreadsheet program for which now carries out the long-winded and repetitive process to design the hyperbolic sub reflector for manufacturing, the W2IMU feed horn used and how the implementation of quick change bands on my portable set up.

After using flat plate type reflectors on both portable systems on 24GHz 47GHz band to good effect the decision was made to incorporate both of these bands into one box during a major rebuild over the winter months. The decision also included using one dish with interchangeable bands contained within a quick-change system eventually ending up with 5.7, 10, 24 & 47GHz as a possible combination on a portable expedition.

The decision to move away from the flat plate type reflectors was made by the small improvement in system gain but more importantly I wanted to use a W2IMU dual mode feedhorn using circular waveguide to feed the new dish which has a F/D ratio of 0.38.

Looking at the reference books the optimum F/D for the dual mode feedhorn is 0.8 but can be used on parabolic dishes with F/D ratios as low as 0.5. The use of a cassegrain system and in particular the ability to slightly change values in the calculation you can end up modifying the F/D ratio of the virtual parabolic dish to suit what F/D you require for your feedhorn as in my particular case from 0.38 if I used a flat plate type reflector the virtual dish would appear to be 0.38 and not suit the feedhorn type that I wanted to use.

For details of the 24GHz and the 47GHz W2IMU dual mode feed horn see figure 8.

The original flat plate reflector used on 24GHz is shown in figure 1 it was constructed from double-sided PCB material and brazing rods for the supports from the WG20 dish feed.

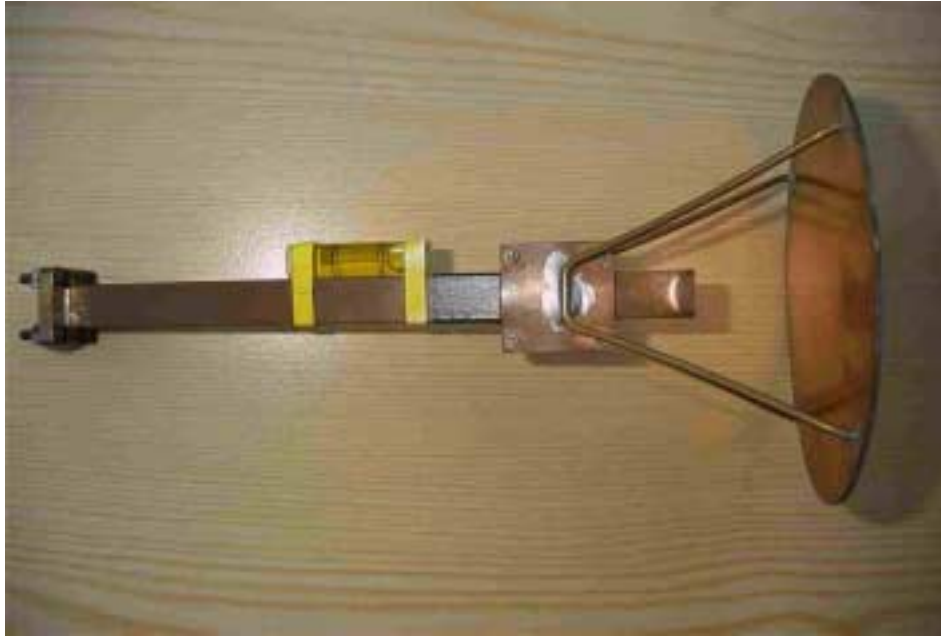


Figure 1

A similar approach was used on my original 47GHz transverter using a 60mm circular disc reflector and brazing rod supports but with a circular collar on the round 4mm tube see figure 2



Figure 2

Discussions with Dr Dennis Hawkins of Qpar Angus [1] at the end of one of the UK Microwave Round Tables during 1999 resulted in the exchange of correspondence on the subject of cassegrain feeds. Armed with this information and calculations from a paper [2] regarding Microwave antennas derived from the cassegrain telescope we started to lay out in AutoCAD the profile from the main dish that was going to be used and by using geometry we arrived at a shape for the reflector. This profile from the CAD system was sent to Dr Dennis Hawkins who compared with his commercial antenna software what we had laid out and confirmed this to be ok. It was decided to go ahead with the manufacture. I found a machine shop that was willing to make the component for me using CNC technology and they had the ability to take the CAD profile of the sub reflector in to his computer system to generate his NC code automatically. The end result is shown in figure 3.



Figure 3

Above figure shows the 100mm-diameter sub reflector and support boss that is used on my new portable system.

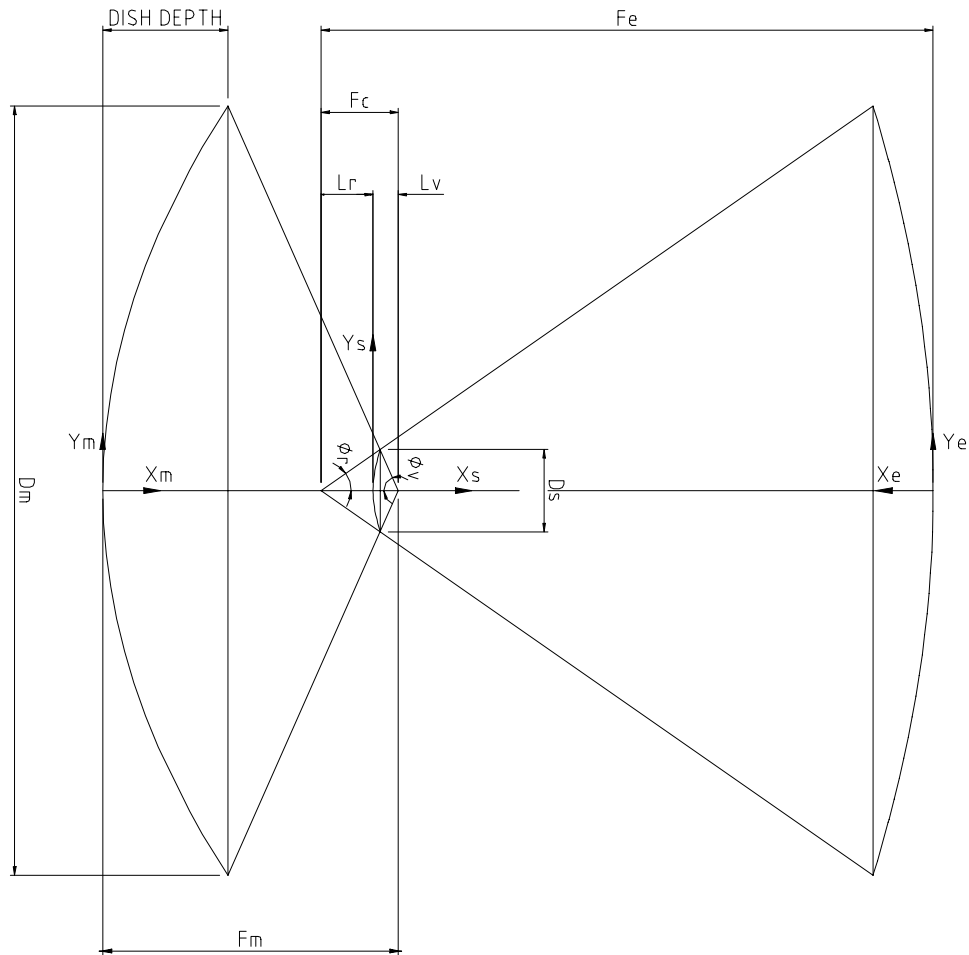


Figure 4

D_m = EFFECTIVE DIAMETER OF CIRCULAR MAIN DISH (TO EDGE RAYS).

D_s = EFFECTIVE DIAMETER OF CIRCULAR SUB DISH (TO EDGE RAYS).

F_m = FOCAL LENGTH OF MAIN DISH.

F_c = DISTANCE BETWEEN FOCI OF SUB DISH.

F_e = EQUIVALENT FOCAL LENGTH OF CASSEGRAIN SYSTEM.

L_v = DISTANCE FROM VIRTUAL FOCUS (OR MAIN DISH FOCUS) TO SUB DISH.

L_r = DISTANCE FROM REAL FOCUS (OR FEED) TO SUB DISH.

ϕ_v = ANGLE BETWEEN AXIS AND EDGE RAY, AT VIRTUAL FOCUS.

ϕ_r = ANGLE BETWEEN AXIS AND EDGE RAY, AT REAL FOCUS.

E = ECCENTRICITY OF CONIC SECTION.

A = TRANSVERSE HALF-AXIS OF CONIC SECTION.

B = CONJUGATE HALF-AXIS OF CONIC SECTION.

X_m = AXIAL CO-ORDINATES OF MAIN DISH.

Y_m = RADIAL CO-ORDINATES OF MAIN DISH.

X_s = AXIAL CO-ORDINATES OF SUB DISH.

Y_s = RADIAL CO-ORDINATES OF SUB DISH.

X_e = AXIAL CO-ORDINATES OF VIRTUAL DISH.

Y_e = RADIAL CO-ORDINATES OF VIRTUAL DISH.

Manual Calculation Method

Below is a worked example based on the following data:

$$D_m = 935 \text{ mm}$$

$$\text{MAIN DISH DEPTH} = 152 \text{ mm}$$

$$D_s = 100 \text{ mm}$$

$$F_c = 94 \text{ mm}$$

CALCULATING F/D RATIO

$$\begin{aligned} \text{F/D RATIO} &= D_m / (16 \times \text{DISH DEPTH}) \\ &= 935 / (16 \times 152) \\ &= 935 / 2432 \\ &= 0.3845 \end{aligned}$$

CALCULATING MAIN DISH FOCAL LENGTH

$$\begin{aligned} F_m &= D_m \times \text{F/D RATIO} \\ &= 935 \times 0.3845 \\ &= 359.5 \text{ mm} \end{aligned}$$

CALCULATING ANGLE ϕ_v

$$\begin{aligned} \phi_v &= \text{INV TAN} [(D_m \div 2) \div (F_m - \text{DISH DEPTH})] \\ &= \text{INV TAN} [(935 \div 2) \div (359.5 - 152)] \\ &= \text{INV TAN} [(467.5) \div (207.5)] \\ &= 66.0659^\circ \end{aligned}$$

CALCULATING ANGLE ϕ_r

$$\begin{aligned} (1 \div \text{TAN } \phi_v) + (1 \div \text{TAN } \phi_r) &= 2 (F_c \div D_s) \\ (1 \div \text{TAN } 66.0659^\circ) + (1 \div \text{TAN } \phi_r) &= 2 (94 \div 100) \\ 0.4439 + (1 \div \text{TAN } \phi_r) &= 2 (0.94) \\ (1 \div \text{TAN } \phi_r) &= 1.88 - 0.4439 \\ \phi_r &= \text{INV TAN} (1 \div 1.4361) \\ \phi_r &= 34.85^\circ \end{aligned}$$

CALCULATING DISTANCE L_v

$$\begin{aligned} 1 - [\text{SIN } \frac{1}{2} (\phi_v - \phi_r) \div \text{SIN } \frac{1}{2} (\phi_v + \phi_r)] &= 2 (L_v \div F_c) \\ 1 - [\text{SIN } \frac{1}{2} (66.0659 - 34.85) \div \text{SIN } \frac{1}{2} (66.0659 + 34.85)] &= 2 (L_v \div 94) \\ 1 - (0.269 \div 0.771) &= 2 (L_v \div 94) \\ 0.651 &= 2 (L_v \div 94) \\ L_v &= (0.651 \div 2) \times 94 \\ L_v &= 30.597 \text{ mm} \end{aligned}$$

CALCULATING ECCENTRICITY 'E'

$$E = \text{SIN } \frac{1}{2} (\phi_v + \phi_r) \div \text{SIN } \frac{1}{2} (\phi_v - \phi_r)$$
$$E = \text{SIN } \frac{1}{2} (66.0659 + 34.85) \div \text{SIN } \frac{1}{2} (66.0659 - 34.85)$$
$$E = \text{SIN } \frac{1}{2} (100.9159) \div \text{SIN } \frac{1}{2} (31.2159)$$
$$E = 0.771 \div 0.269$$
$$E = 2.866$$

CALCULATING VALUE 'A'

$$A = Fc \div 2E$$
$$A = 94 \div 2 \times 2.866$$
$$A = 16.4$$

CALCULATING VALUE 'B'

$$B = A \sqrt{E^2 - 1}$$
$$B = 16.4 \sqrt{(2.866)^2 - 1}$$
$$B = 16.4 \sqrt{7.213956}$$
$$B = 16.4 \times 2.6859$$
$$B = 44.05$$

CALCULATING CONTOUR OF MAIN DISH (PARABOLA)

$$X_m = Y_m^2 \div 4 (F_m)$$

FOR $Y_m = 50$

$$X_m = (50)^2 \div 4 (359.5)$$
$$X_m = (50)^2 \div 1438$$
$$X_m = 2500 \div 1438$$
$$X_m = 0.017$$

REPEAT FOR VARYING VALUES OF Y_m TO CALCULATE CORRESPONDING VALUE OF X_m .

EG. FOR $Y_m = 50$ $X_m = 1.739$
 $Y_m = 100$ $X_m = 6.954$
 $Y_m = 150$ $X_m = 15.647$ Etcetera

CALCULATING CONTOUR OF SUB DISH (HYPERBOLA)

$$X_s = A [\sqrt{1 + (Y_s \div B)^2} - 1]$$

FOR $Y_s = 5$

$$X_s = 16.4 [\sqrt{1 + (5 \div 44.05)^2} - 1]$$
$$X_s = 16.4 [\sqrt{1 + 0.01288} - 1]$$
$$X_s = 16.4 (0.006419)$$
$$X_s = 0.105$$

REPEAT FOR VARYING VALUES OF Y_s TO CALCULATE CORRESPONDING VALUES X_s .

EG. FOR $Y_s = 5$ $X_s = 0.105$
 $Y_s = 10$ $X_s = 0.417$
 $Y_s = 15$ $X_s = 0.925$ Etcetera

CALCULATING EQUIVALENT FOCAL LENGTH F_e

$F_e \div F_m = (E + 1) \div (E - 1)$
 $F_e \div 359.5 = (2.866 + 1) \div (2.866 - 1)$
 $F_e \div 359.5 = 3.866 \div 1.866$
 $F_e \div 359.5 = 2.072$
 $F_e = 2.072 \times 359.5$
 $F_e = 744.88$

CALCULATING CONTOUR OF VIRTUAL DISH (PARABOLA)

$X_e = Y_e^2 \div 4F_e$
FOR $Y_e = 50$
 $X_e = (50)^2 \div 4 (744.88)$
 $X_e = 2500 \div 2979.52$
 $X_e = 0.839$

REPEAT FOR VARYING VALUES Y_e TO CALCULATE CORRESPONDING VALUES OF X_e .

EG. FOR $Y_e = 50$ $X_e = 0.839$
 $Y_e = 100$ $X_e = 3.356$
 $Y_e = 150$ $X_e = 7.552$ Etcetera

After going through the above set of calculations a series of X, Y points are obtained, with this the shape of the sub reflector could be laid out onto paper to produce a template. This could then be used to check profile accuracy if manually turning the reflector in a lathe.

After searching the Internet for any programs to calculate the reflectors profile nothing could be found and also not everybody has access to a CAD workstation on their desk so the decision was made to make the calculations available to other amateurs by writing a simple Microsoft Excel spreadsheet to do this task.

Figure 5 shows the layout of the Excel screen and user data input is on the left hand side moving to the right the data tables for the sub reflector, actual dish parabola and virtual dish parabola profiles are given. The dish and virtual dish profiles tables are given to allow the user to draw out the whole scheme if required. I am currently writing an AutoCAD Lisp program to take this data and draw a 1:1 layout within the CAD system.

The Excel program is available to download from [3] but we are getting close to the limits of what we as a group are able to do within Excel. Please feel free to play with the routine and comment.

I	A	B	F	G	H	SUB REFLECTOR		J	K	L	M	N	O	P	VIRTUAL DISK PROFILE		R
						A	B								F _u	F _v	
1																	
2																	
3																	
4	Fc (mm)	24.0000		9.4004	44.0452	9.2041	Z0 (microns)	Tr (microns)		Fw Feed L (Max Disk) (mm)	Zm	Ym		Fu	Zu	Yu	
5	Dr. Sub ref. dia (mm)	30.0000		9.4004	44.0452	9.2041		-60.0000		353.4615	95.391826	-475		144.2500	25.24004175	-475	
6	Dr. Dia. (mm)	30.0000		9.4004	44.0452	9.2041		-50.0000		353.4615	140.82323	-450		144.2500	61.87852029	-450	
7	Fw Feed L (Max Disk) (mm)	353.4615		9.4004	44.0452	9.2041		-45.0000		353.4615	95.419375	-425		144.2500	68.46496619	-425	
8	Disk Depth	192.0000		9.4004	44.0452	9.2041		-40.0000		353.4615	110.82323	-400		144.2500	53.30612500	-400	
9	Fkr (Dish)	1.9500		9.4004	44.0452	9.2041		-35.0000		353.4615	37.60000084	-375		144.2500	41.20304831	-375	
10	Fkr (Dish)	66.9853		9.4004	44.0452	9.2041		-30.0000		353.4615	37.60000084	-350		144.2500	85.1926268	-350	
11	Ums Ply	54.562		9.4004	44.0452	9.2041		-25.0000		353.4615	37.60000084	-325		144.2500	75.40444329	-325	
12	Fkr (Dish)	0.8282		9.4004	44.0452	9.2041		-20.0000		353.4615	52.358072	-300		144.2500	50.20717384	-300	
13	Fkr (Dish)	34.8484		9.4004	44.0452	9.2041		-15.0000		353.4615	45.4617028	-275		144.2500	29.32442021	-275	
14	Fkr (Dish)	8.0219		9.4004	44.0452	9.2041		-10.0000		353.4615	55.2803274	-250		144.2500	20.35586058	-250	
15	Fu	344.0250		9.4004	44.0452	9.2041		-5.0000		353.4615	37.60000084	-225		144.2500	15.42923477	-225	
16	Fw Disk Main Disk	0.2045		9.4004	44.0452	9.2041		0.0000		353.4615	20.2406643	-200		144.2500	10.47964069	-200	
17	Fw Disk Equidist. Disk	0.1285		9.4004	44.0452	9.2041		5.0000		353.4615	6.4818455	-175		144.2500	3.55848251	-175	
18	Fw Disk Equidist. Disk	2.3959		9.4004	44.0452	9.2041		10.0000		353.4615	19.8887671	-150		144.2500	3.244740746	-150	
19	Fu (mm)	50.3356		9.4004	44.0452	9.2041		15.0000		353.4615	8.58473133	-125		144.2500	5.26613383	-125	
20	Fu (mm)	62.4034		9.4004	44.0452	9.2041		20.0000		353.4615	3.25202658	-75		144.2500	1.685106453	-75	
21				9.4004	44.0452	9.2041		25.0000		353.4615	1.71991813	-50		144.2500	0.833915423	-50	
22				9.4004	44.0452	9.2041		30.0000		353.4615	0.43462071	-25		144.2500	0.202112626	-25	
23				9.4004	44.0452	9.2041		35.0000		353.4615	0	0		144.2500	0	0	
24				9.4004	44.0452	9.2041		40.0000		353.4615	0.43462071	25		144.2500	0.202112626	25	
25				9.4004	44.0452	9.2041		45.0000		353.4615	1.71991813	50		144.2500	0.833915423	50	
26				9.4004	44.0452	9.2041		50.0000		353.4615	3.25202658	75		144.2500	1.685106453	75	
27				9.4004	44.0452	9.2041		55.0000		353.4615	6.4818455	100		144.2500	3.26613383	100	
28				9.4004	44.0452	9.2041		60.0000		353.4615	19.8887671	125		144.2500	3.244740746	125	
29				9.4004	44.0452	9.2041		65.0000		353.4615	37.60000084	150		144.2500	3.26613383	150	
30				9.4004	44.0452	9.2041		70.0000		353.4615	52.358072	175		144.2500	3.244740746	175	
31				9.4004	44.0452	9.2041		75.0000		353.4615	66.9853	200		144.2500	3.244740746	200	
32				9.4004	44.0452	9.2041		80.0000		353.4615	81.6658	225		144.2500	3.244740746	225	
33				9.4004	44.0452	9.2041		85.0000		353.4615	96.3463	250		144.2500	3.244740746	250	
34				9.4004	44.0452	9.2041		90.0000		353.4615	111.0268	275		144.2500	3.244740746	275	
35				9.4004	44.0452	9.2041		95.0000		353.4615	125.7073	300		144.2500	3.244740746	300	
36				9.4004	44.0452	9.2041		100.0000		353.4615	140.3878	325		144.2500	3.244740746	325	
37				9.4004	44.0452	9.2041		105.0000		353.4615	155.0683	350		144.2500	3.244740746	350	
38				9.4004	44.0452	9.2041		110.0000		353.4615	169.7488	375		144.2500	3.244740746	375	
39				9.4004	44.0452	9.2041		115.0000		353.4615	184.4293	400		144.2500	3.244740746	400	
40				9.4004	44.0452	9.2041		120.0000		353.4615	199.1098	425		144.2500	3.244740746	425	
41				9.4004	44.0452	9.2041		125.0000		353.4615	213.7903	450		144.2500	3.244740746	450	
42				9.4004	44.0452	9.2041		130.0000		353.4615	228.4708	475		144.2500	3.244740746	475	
43				9.4004	44.0452	9.2041		135.0000		353.4615	243.1513	500		144.2500	3.244740746	500	

Figure 5

Figure 6 shows the completed portable transverter in use. With using such a large dish initial alignment when arriving onto the portable site is done by fitting into the sub reflector boss on the front of the dish a rifle site that looks back though a hole where the feed fits and by optically aligning the dish onto a visible landmark (180 degrees out) then working out the beam heading to this point and altering the compass on the neck of the tripod to suit. After an initial contact refinement to the compass can be made.



Figure 6

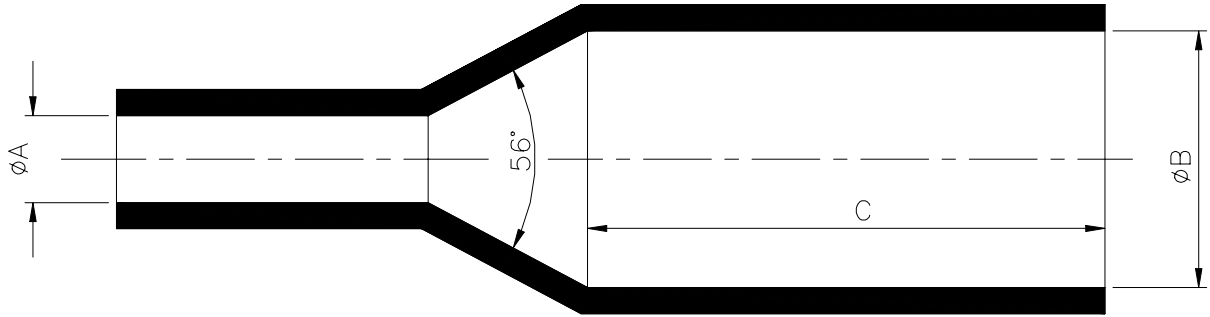
After working somebody with the 24GHz transverter the head unit can be replaced with the 47GHz transverter whilst still maintaining the correct beam heading by the following method

I start with standard type die-cast boxes for the equipment and a three-point female conical mounting on the lid of every box that is to be used. This is done before any equipment is installed & the position of the waveguide feed is marked using a laser pen innards mounted inside a machined cylinder that is slid into position where the sub reflector is located. The laser light beam projects through a very small hole in the cylinder and marking of the box entry are quite straightforward. Mounted on the metal framework that supports the dish is three male conical points that allow the boxes to be repeatedly positioned with good accuracy.

Figure 7 shows the 24/47GHz transverters mounted on the metal frame that holds the dish onto the tripod.



Figure 7



BAND	DIMENSION A	DIMENSION B	DIMENSION C
24GHz	8.73	23.06	46.50
47GHz	4.0	11.81	23.81

W2IMU Dual Mode feedhorns for 24GHz and 47GHz

Dimension A in the table above shows the inside diameter of K&S modelmakers brass tubing that is being used for circular waveguide. For 24GHz K&S Number 135 and for 47GHz K&S Number 129. Figure 8 shows the completed W2IMU dual mode feed horns.



Figure 8

Conclusion

After initial outings with the system I feel it was worth the effort to go to the trouble of researching and wading through the calculations. The ability to change the parabolic dish F/D ratio to suit a particular type of feed horn in my circumstance will only be proven in time but at the moment the 24GHz system is not yet near its path potential and the 47GHz has worked 140Km without much problem.

As seen the calculations for the sub reflector are long but with the use of the spreadsheet it was easy to nudge figures one way then the other to see the effects of what if.

The spreadsheet is available to anybody to use and I welcome comments and improvements to it

Acknowledgments

I would like to thank Dr Dennis Hawkins of [1] for assistance at the early stages of this project and confirming our profile results David Woodward G0IVA for his assistance in locating [2] and for his assistance with the calculations. Simon John Pritchard for help with the understanding of the manual calculations and work done on the spreadsheet [3] alongside John McNeil who co-wrote the routine. It was a team effort on this project.

References

1. Qpar Angus Limited, Barons Cross Lodge, Leominster, Herefordshire, HR6 8RS
2. Microwave Antennas Derived from the Cassegrain Telescope by Peter W Hannan
3. <http://www.qsl.net/g3pho/cassdesign.xls>