MEMO #33

To: Bill Bruckman
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From: Heinrich Foltz

Date: November 5 1990

Subject: FURTHER REVISIONS TO REQUIREMENTS FOR BENT NASMYTH OPTICS

This document contains the results of calculations based on the revisions to the bent Nasmyth optics requirements given to me by Liz Whitbeck in October. In the previous document, titled "Revised Requirements for Bent Nasmyth Optics," I assumed a value for the distance from the third mirror (the one directing the beam downward toward the receiver) to a fourth mirror which would be located in the turret assembly (see Figure 1B). I also assumed a value for the distance from this fourth mirror to the receiver feed point (the point where the frequency independent image of the aperture is formed).

In this report, the two dimensions mentioned above are treated as variables. I have not assumed specific values but instead have done calculations over a range of values for these distances, and plotted the results, so that you will be able to see the various trade-offs involved in choosing these dimensions.

The mirrors are identified as M1, the mirror which moves with the elevation axis); M2, the mirror which reflects the beam back toward the dewar at 38.7 degrees; M3, the mirror which sends the beam down toward the receiver; and M4, an additional curved mirror in the turret assembly. The calculations are restricted to the case in which M3 and M4 only are curved. This allows the mirrors in the less accesible positions in the backup structure to be flat, while the curved mirrors are close to the receiver, which should make alignment somewhat easier. It also allows the possibility of using M1 as a wobbler, although the performance would not be as good as a wobbling the main subreflector.

The diameter of the subreflector is assumed to be fixed at 45 cm diameter and the diameter of the image is 2.18 cm, as described in the previos report.

The results are plotted as follows:

FIGURE 1A and 1B: These are drawings of the bent Nasmyth configuration simply to identify the parts and make sure there has been no misunderstanding.

FIGURE 2: This is the approximate spot size of the Gaussian beam on M1 at 230 GHz. (This is the frequency at which the spot sizes are largest, out of the frequency range 230-810 GHz). The horizontal scale is the distance from the last curved mirror, inside the turret assembly, to the feed point. The different curves are for different path lengths between M3 and M4.

FIGURE 3: This is the required diameter of the M1 surface, projected onto the beam path. The longest dimension of the mirror will be longer than what is plotted here by a factor of 1.414 because of the 45 degree angle of incidence. The required diameter was assumed to be 5.5 times the spot size at 230 GHz.

FIGURE 4: The same as Figure 2, but for M2.

FIGURE 5: The same as Figure 3, but for M2. The long dimension of the mirror

will be 1.060 times longer because of the 19.35 degree angle of incidence.

FIGURE 6: The same as Figure 2, but for M3.

FIGURE 7: The same as Figure 3, but for M3. The long dimension of the mirror will be 1.414 times longer because of the 45 degree angle of incidence.

FIGURE 8: The same as Figure 2, but for M4. There is only one curve because the spot size is independent of the M3 to M4 path length.

FIGURE 9: The same as Figure 3, but for M4. The long dimension of the mirror will be 1.414 times longer because of the 45 degree angle of incidence.

FIGURE 10: The focal length required for the curved M3.

FIGURE 11: The focal length required for the curved M4.

FIGURE 12: Focal length to spot size ratio at 230 GHz (the worst case) for M3. A higher ratio leads to less distortion, simpler fabrication, and improves the accuracy of the Gaussian beam calculations.

FIGURE 13: Distortion and asymmetry losses for a single reflection from M3, based on the results of Figure 12. These are calculated for M3 independently of the rest of the system. When operated with M4, the distortion terms may add or cancel. If they add, the loss could be as high as the square of the sum of the square roots of the losses given in Figures 13 and 15. If they cancel, the resulting loss could be as low as the square of the difference of the square roots. I am still working out the relative phases to see which effect occurs.

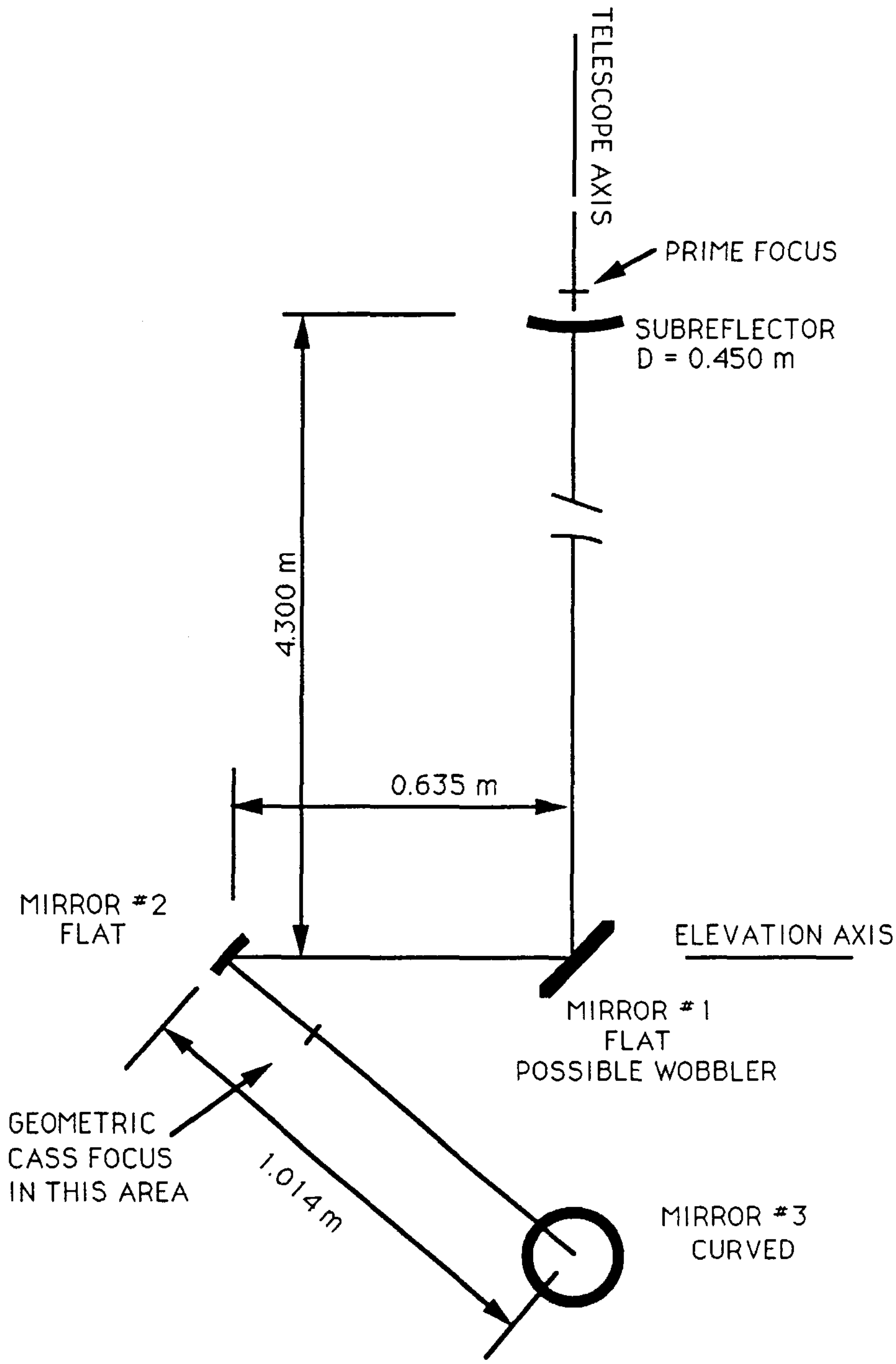
FIGURE 14: Same as Figure 12, but for M4.

FIGURE 15: Same as Figure 13, but for M4.

<u>SUMMARY (FIGURE 16):</u> The dimensions which are treated as free parameters above may be set by Ray's receiver requirements. If they are not, going to a relatively long optical path from M3 to M4 will reduce the sizes of M1 and M2 and will also reduce the distortion and asymmetry losses at M4 significantly, but will increase the size of M3.

Increasing the distance from M4 to the desired image point makes the mirrors M1 and M2 larger. However, decreasing the distance makes M3 larger, and increases the distortion at M3.

It looks like a good range of values is 60 to 70 centimeters for the M3 to M4 distance and 25 to 40 centimeters for the M4 to receiver feed point dimension.



BENT NASMYTH w/ FREQ. INDEPENDENT OPTICS
FED AT FLAT IMAGE OF SUBREFLECTOR APERTURE
VERSION (f)- MIRRORS #3 AND #4 CURVED
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6 OCTOBER 1990 H.D.FOLTZ
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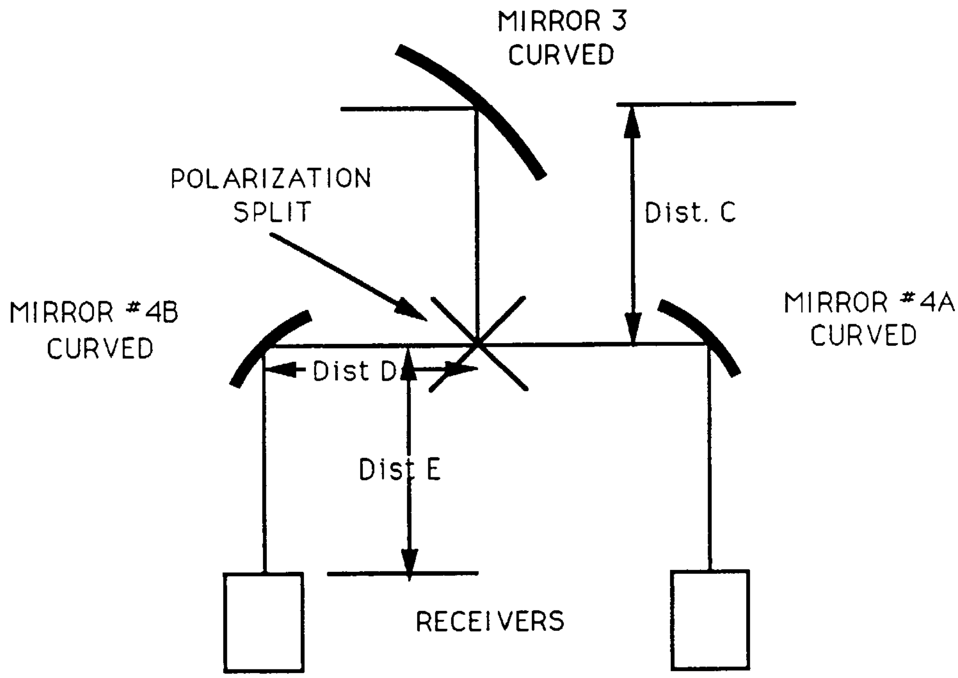
FIGURE 1A



Distance E includes path through any grids, etc., to point where feed point (waist) is located. This is called "M4 to Feed Point Distance" in remaining figures
Distance C+D is called the M3 to M4 distance in remaining figures.

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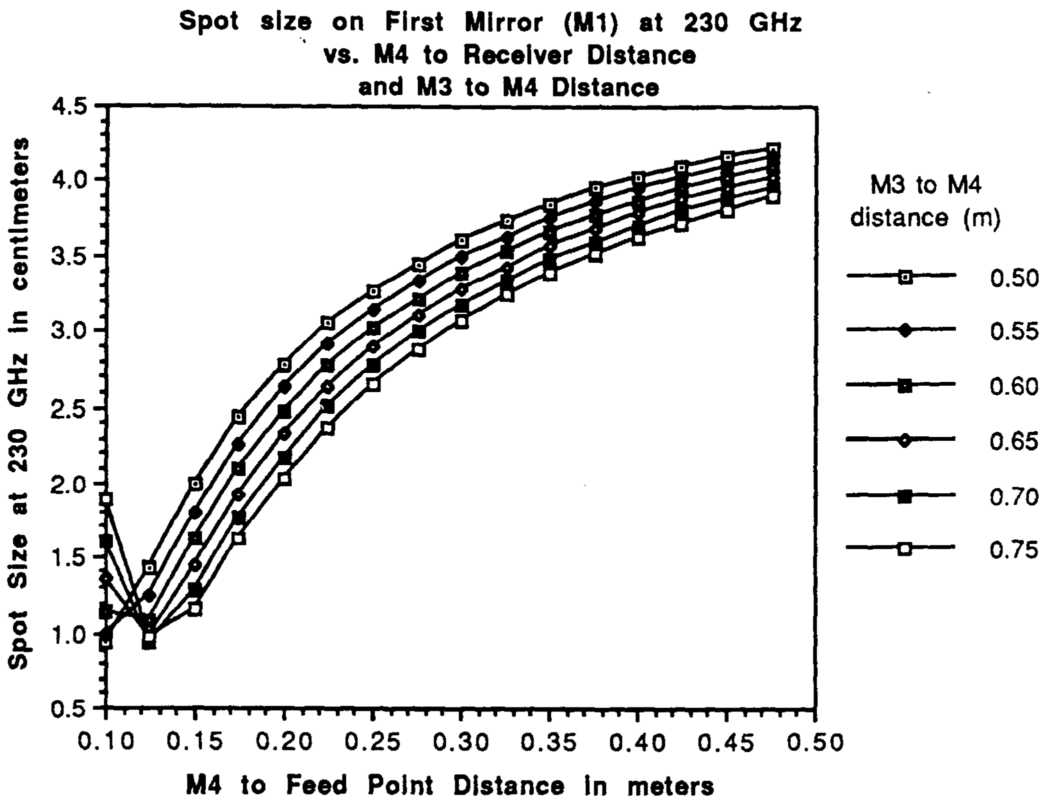
FIGURE 1B



Spot size on First Mirror (M1) at 230 GHz
vs. M4 to Receiver Distance
and M3 to M4 Distance
Spot Size at 230 GHz in centimeters
M4 to Feed Point Distance in meters
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
M3 to M4
distance (m)
0.50
0.55
0.60
0.65
0.70
0.75

Figure 2

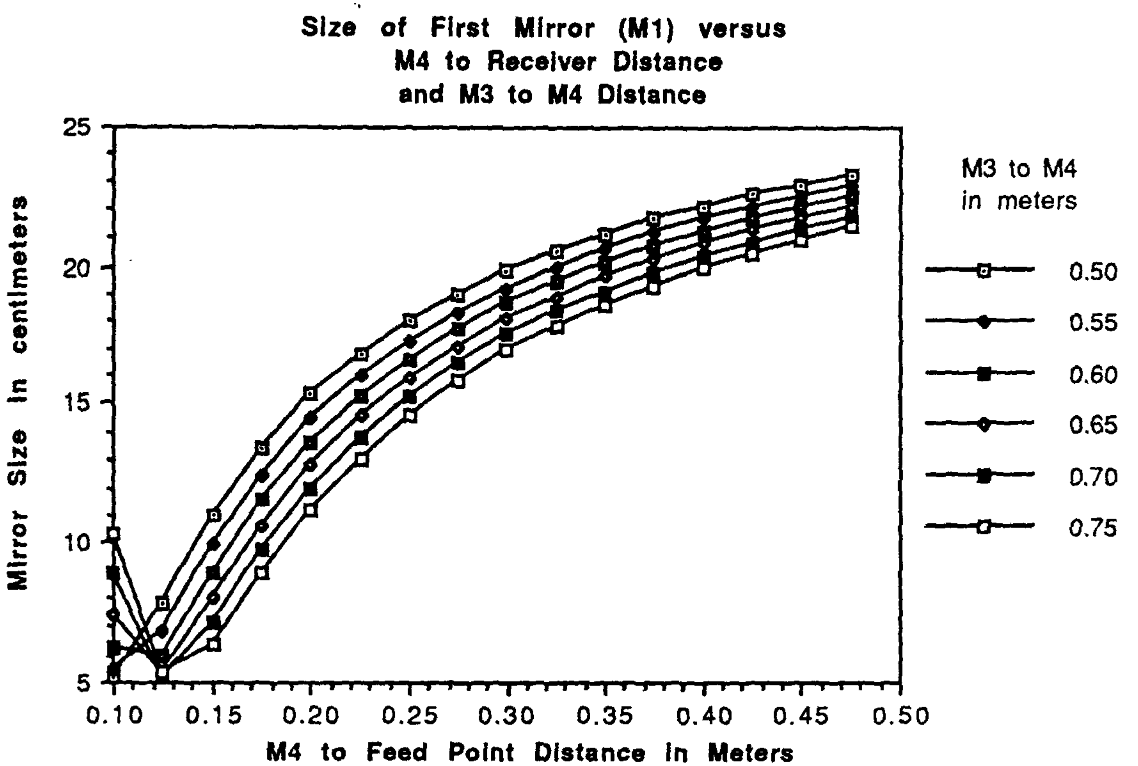

Size of First Mirror (M1) versus
M4 to Receiver Distance
and M3 to M4 Distance
Mirror Size in centimeters
25
20
15
10
5
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
M4 to Feed Point Distance in Meters
M3 to M4
in meters
0.50
0.55
0.60
0.65
0.70
0.75

Figure 3

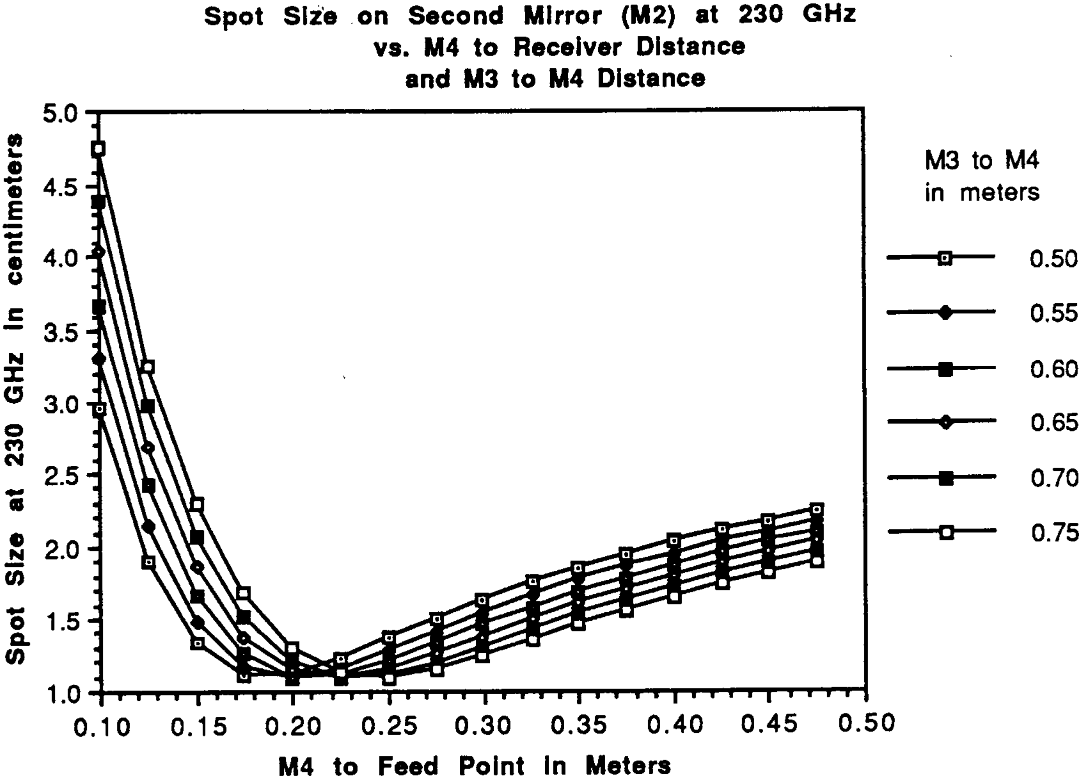

Spot Size on Second Mirror (M2) at 230 GHz
vs. M4 to Receiver Distance
and M3 to M4 Distance
Spot Size at 230 GHz in centimeters
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
M4 to Feed Point in Meters
M3 to M4
in meters
0.50
0.55
0.60
0.65
0.70
0.75

Figure 4

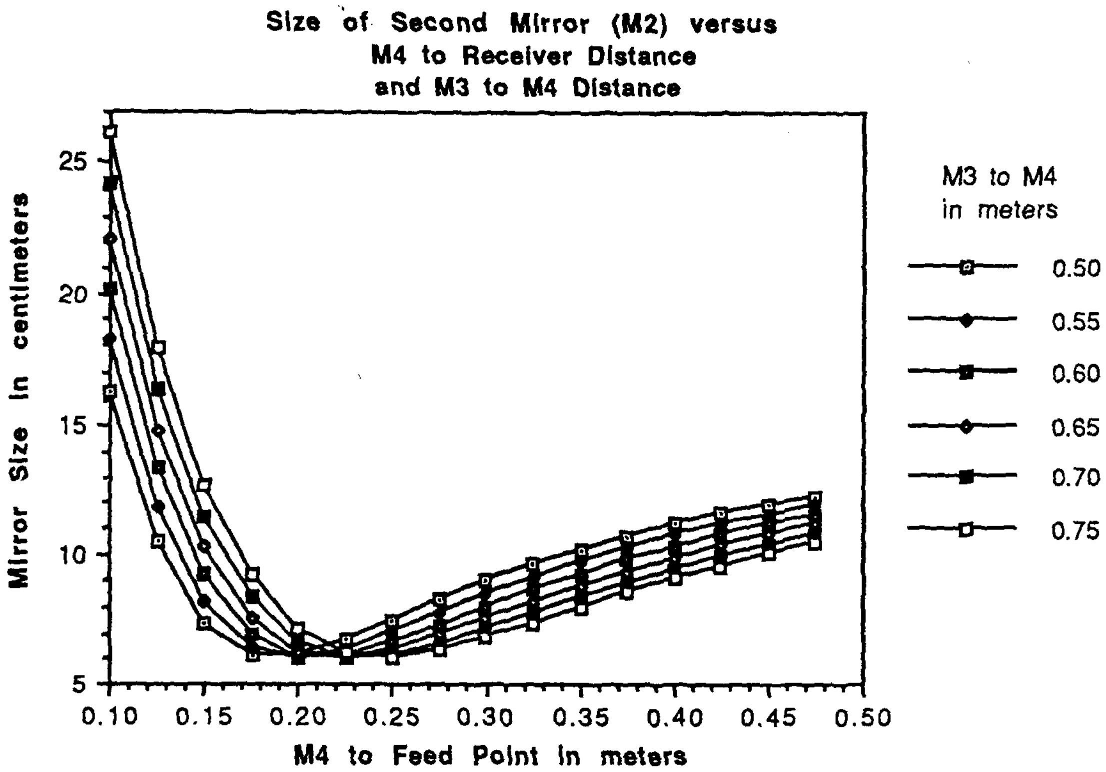

Size of Second Mirror (M2) versus
M4 to Receiver Distance
and M3 to M4 Distance
Mirror Size in centimeters
5
10
15
20
25
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
M4 to Feed Point in meters
M3 to M4
in meters
0.50
0.55
0.60
0.65
0.70
0.75

Figure 5

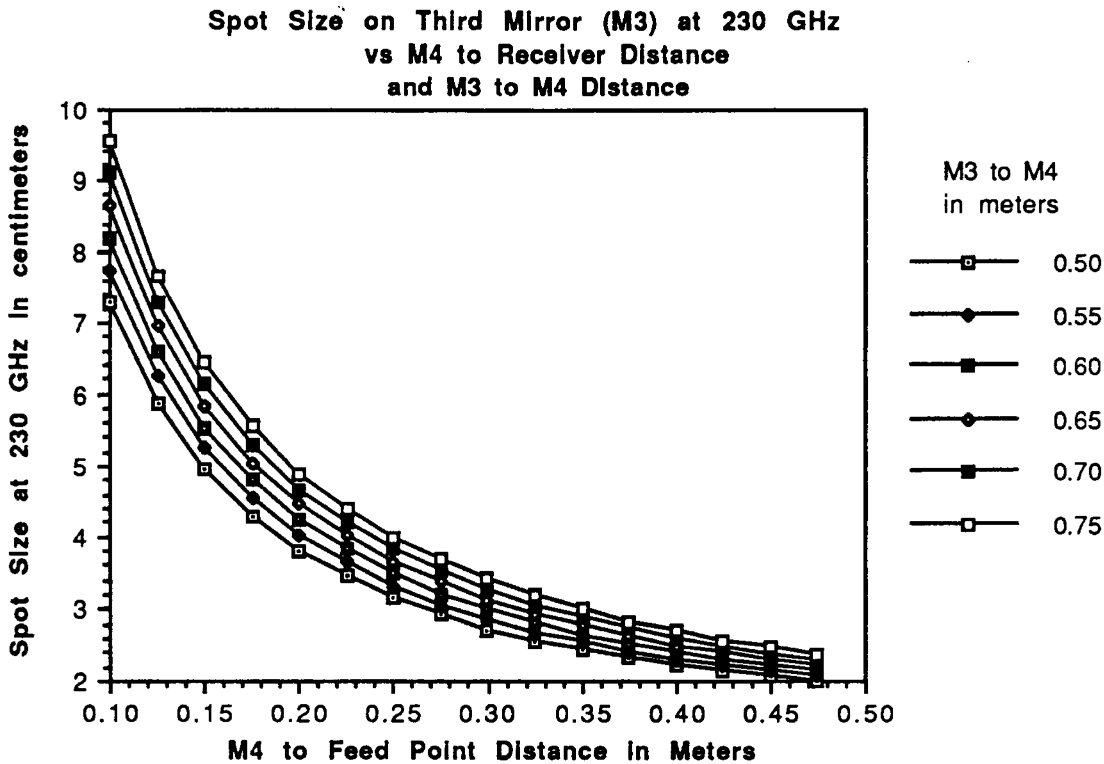
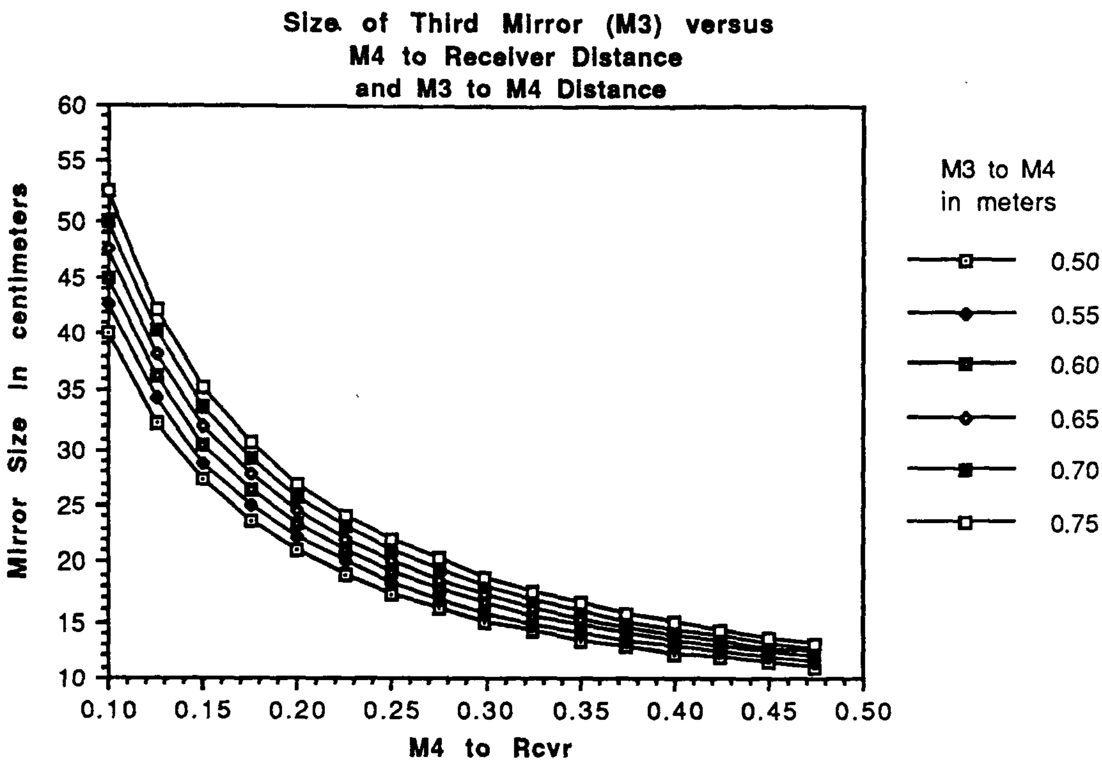

Spot Size on Third Mirror (M3) at 230 GHz
vs M4 to Receiver Distance
and M3 to M4 Distance
Spot Size at 230 GHz in centimeters
M4 to Feed Point Distance in Meters
M3 to M4
in meters
0.50
0.55
0.60
0.65
0.70
0.75
10
9
8
7
6
5
4
3
2
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50

Figure 6



Size of Third Mirror (M3) versus
M4 to Receiver Distance
and M3 to M4 Distance
Mirror Size in centimeters
60
55
50
45
40
35
30
25
20
15
10
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
M4 to Rcvr
M3 to M4
in meters
0.50
0.55
0.60
0.65
0.70
0.75

Figure 7

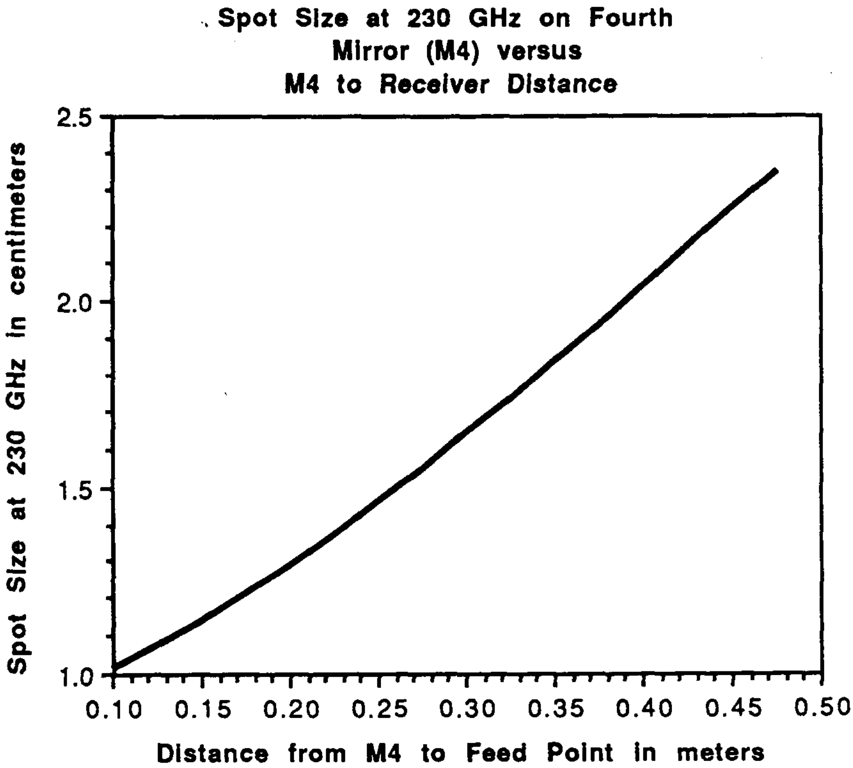
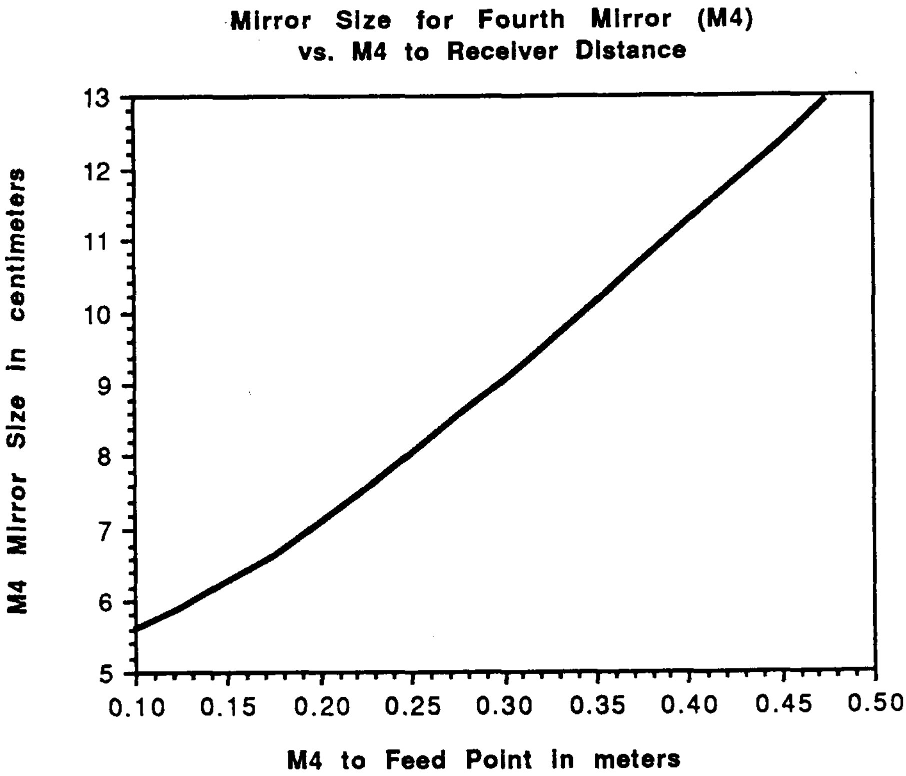

Spot Size at 230 GHz on Fourth
Mirror (M4) versus
M4 to Receiver Distance
2.5
2.0
1.5
1.0
Spot Size at 230 GHz in centimeters
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Distance from M4 to Feed Point in meters

Figure 8



Mirror Size for Fourth Mirror (M4)
vs. M4 to Receiver Distance
13
12
11
10
9
8
7
6
5
M4 Mirror Size in centimeters
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
M4 to Feed Point in meters

Figure 9

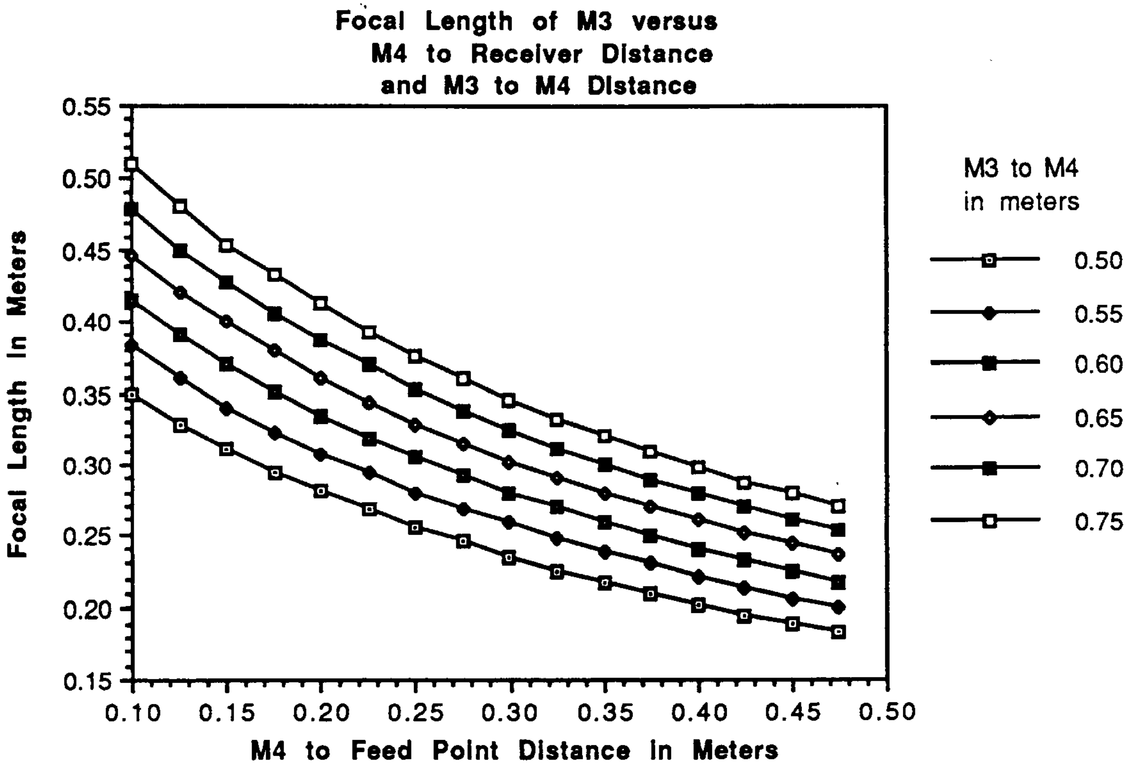
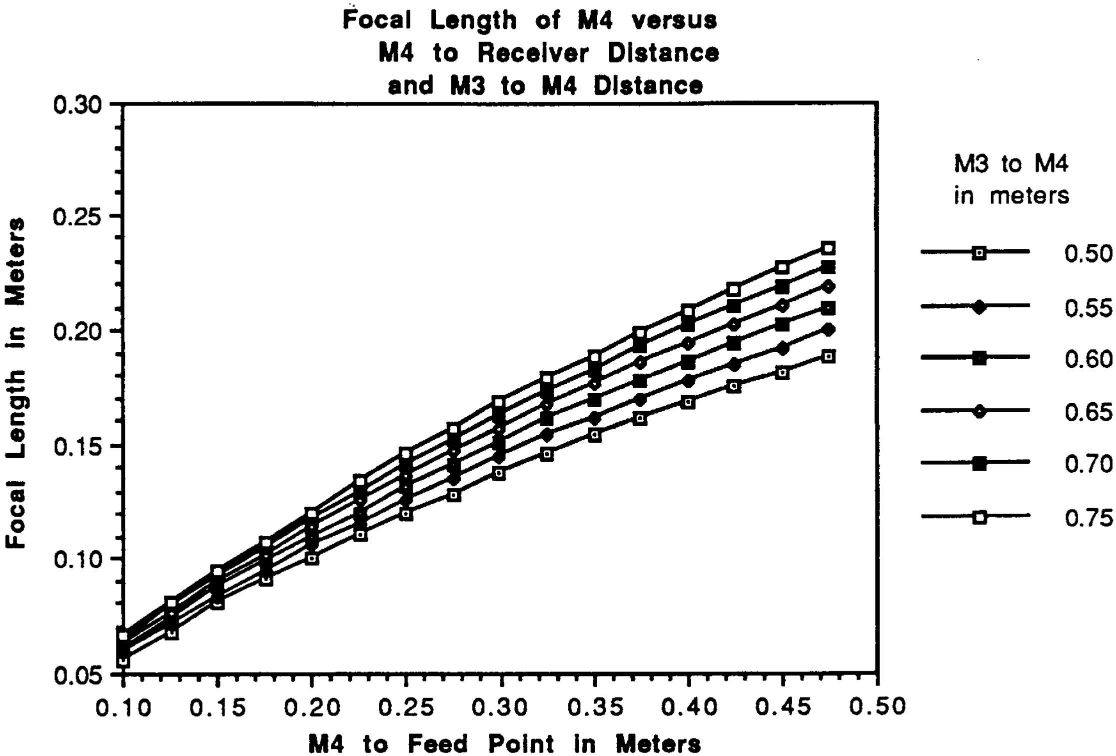

Focal Length of M3 versus
M4 to Receiver Distance
and M3 to M4 Distance
Focal Length in Meters
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
M4 to Feed Point Distance in Meters
M3 to M4
in meters
0.50
0.55
0.60
0.65
0.70
0.75

Figure 10



Focal Length of M4 versus
M4 to Receiver Distance
and M3 to M4 Distance
Focal Length in Meters
0.30
0.25
0.20
0.15
0.10
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
M4 to Feed Point in Meters
M3 to M4
in meters
0.50
0.55
0.60
0.65
0.70
0.75

Figure 11

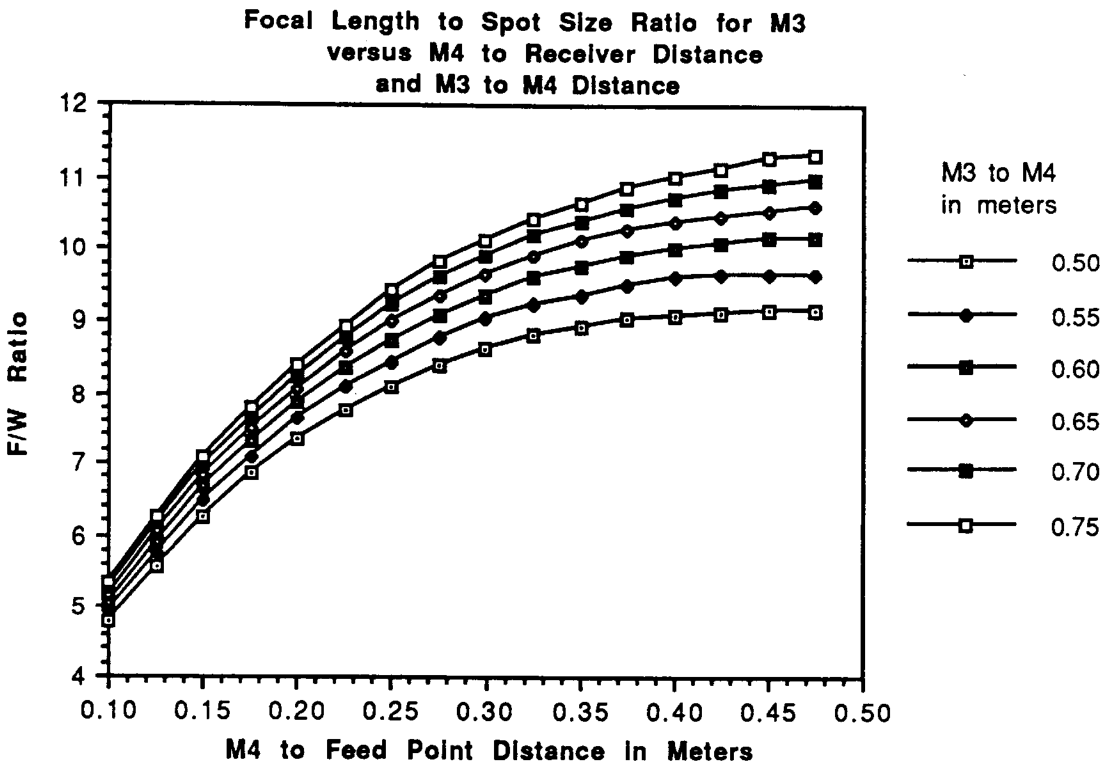

Focal Length to Spot Size Ratio for M3
versus M4 to Receiver Distance
and M3 to M4 Distance
F/W Ratio
12
11
10
9
8
7
6
5
4
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
M4 to Feed Point Distance in Meters
M3 to M4
in meters
0.50
0.55
0.60
0.65
0.70
0.75

Figure 12

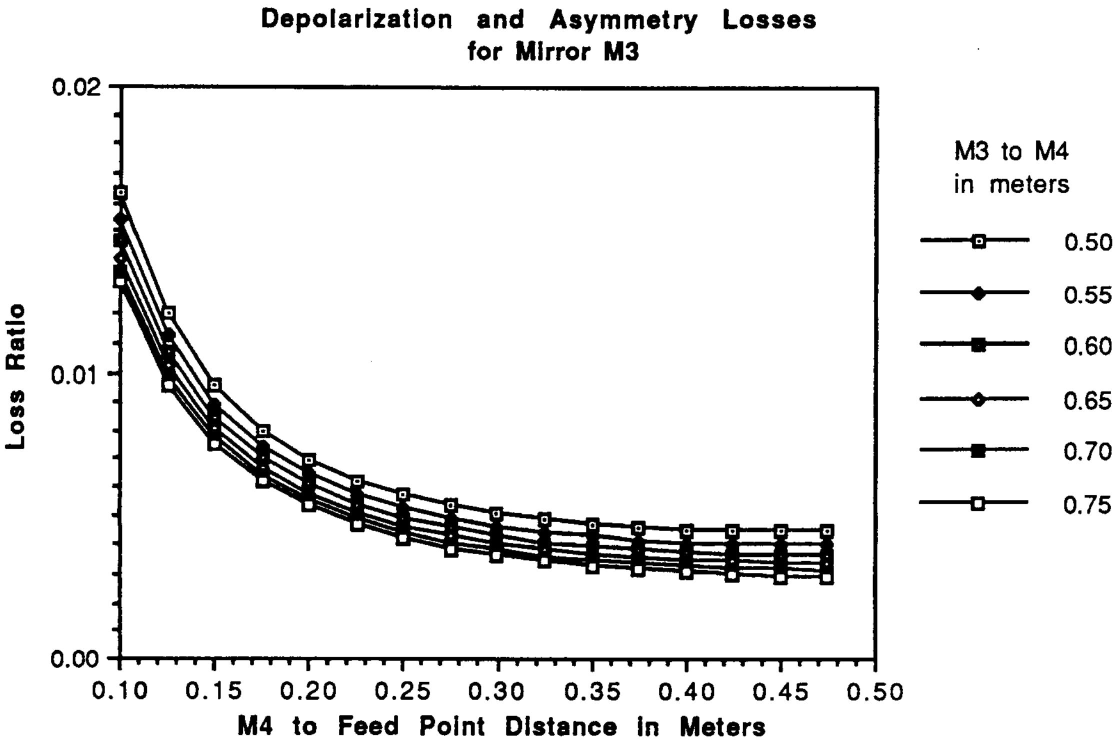
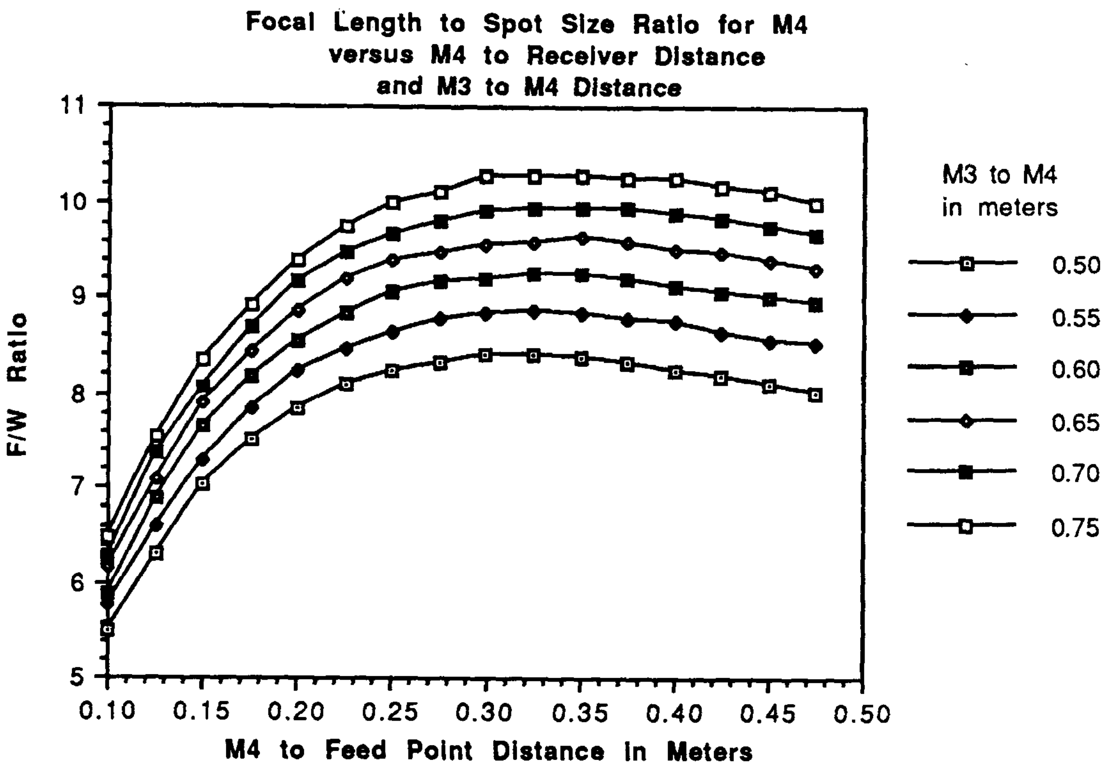
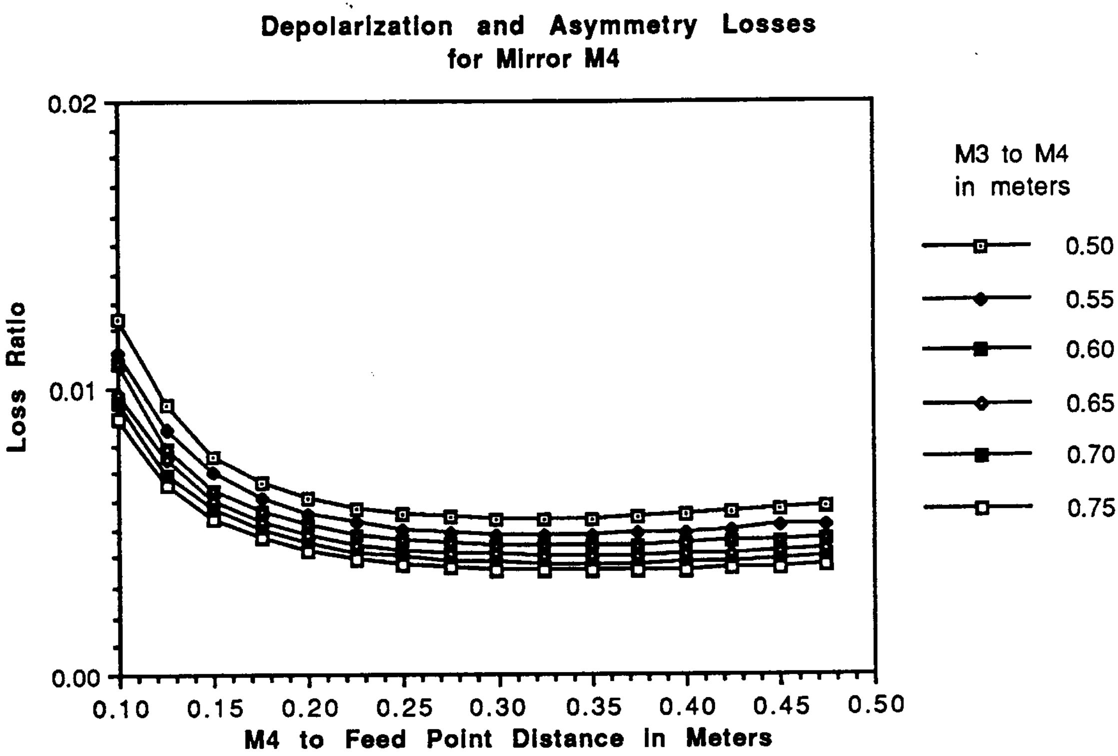

Depolarization and Asymmetry Losses
for Mirror M3
0.02
0.01
0.00
Loss Ratio
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
M4 to Feed Point Distance in Meters
M3 to M4
in meters
0.50
0.55
0.60
0.65
0.70
0.75

Figure 13



Focal Length to Spot Size Ratio for M4
versus M4 to Receiver Distance
and M3 to M4 Distance
F/W Ratio
M4 to Feed Point Distance in Meters
M3 to M4
in meters
0.50
0.55
0.60
0.65
0.70
0.75
11
10
9
8
7
6
5
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50

Figure 14



Depolarization and Asymmetry Losses
for Mirror M4
Loss Ratio
0.02
0.01
0.00
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
M4 to Feed Point Distance in Meters
M3 to M4
in meters
0.50
0.55
0.60
0.65
0.70
0.75

Figure 15

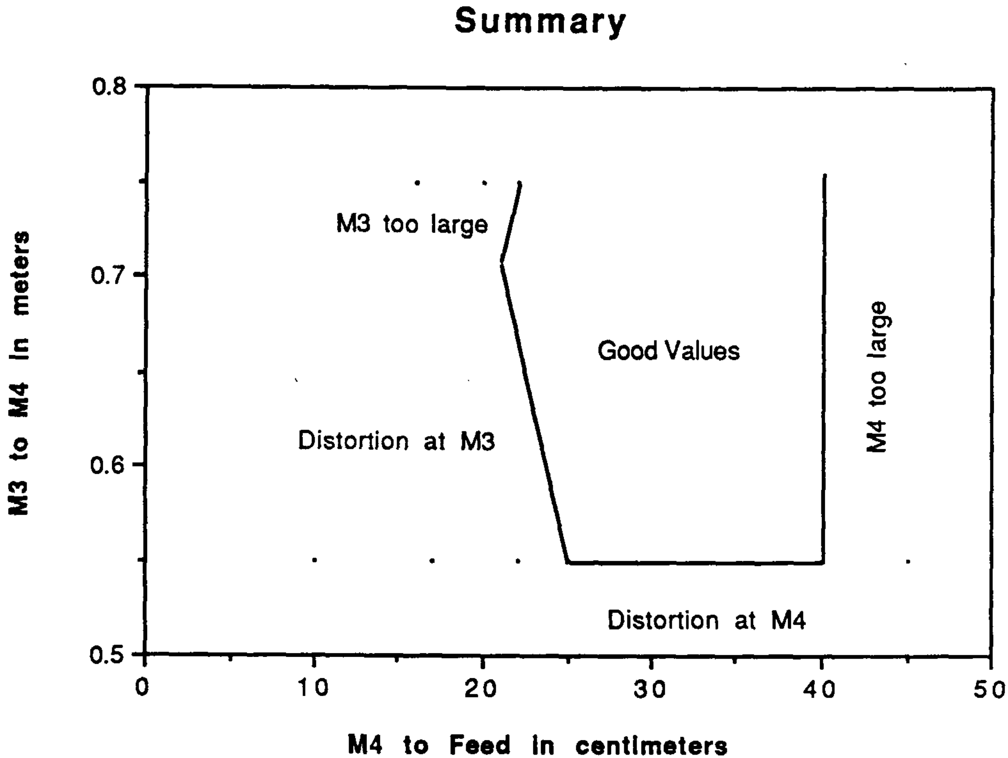

Summary
0.8
0.7
0.6
0.5
M3 too large
Good Values
Distortion at M3
M4 too large
Distortion at M4
0
10
20
30
40
50
M3 to M4 in meters
M4 to Feed in centimeters

Figure 16

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6 October 1990

Bill:

This letter accompanies a revised version of the last report, with changes appropriate to the drawings of a bent Nasmyth which you faxed last week. As before, two curved mirrors are required to obtain a frequency independent image while letting the mirror positions be specified by other constraints. Since the mirror positions in the sample design included in this document are the same as in your drawing, this system would be interchangeable with an "all-flat" non-frequency independent, non-aperture image system, simply by exchanging the third mirror in your drawing as well as a smaller mirror in each polarization path with curved reflectors.

I used some "wild guess" numbers for dimensions of the optical path between the polarization split and the dewar. When these numbers are better known I can recalculate the focal lengths and mirror sizes required. It looks like the largest mirror would have to be about 25 cm by 35 cm.

If you are fairly certain that the bent Nasmyth will be the final configuration I can start setting up the code for the more detailed analysis; leaving the exact dimensions as input parameters.

With regard to your questions about phase error, I have several questions/comments of my own:

(1) Does the r.m.s. number your program gives include any sort of illumination weighting? If not, and your primary forms of error are large scale bending like astigmatism and spherical aberration, then the effective r.m.s. will be substantially lower than what the program gives, since these forms of error grow toward the edges while the illumination is tapering off.

(2) Your program measures r.m.s. deviations from a best fit paraboloid. Are these deviations measured along the axis, normal to the surface, or do they already take into account the angle of the optical path? If the deviations do not take into account the optical path then again the effective r.m.s. will be substantially lower than what the program gives.

If your program does not take the above two factors into account, I am preparing some graphs giving effective r.m.s. versus untapered, uncompensated r.m.s. for various forms of aberration, which I can fax to you. If your program does take the above into account then the ordinary Ruze or small-phase formulas for gain loss should work well.

Heinrich Foltz