VLA SCIENTIFIC MEMORANDUM NO. 102

PRELIMINARY RESULTS OF A STUDY OF A COMPACT SPECTRAL LINE CONFIGURATION FOR THE VLA

I. General Considerations

Whereas the VLA as it presently stands has been configured for high resolution and very low sidelobe levels, these criteria, while generally desirable for continuum observations, may be relatively less desirable or attainable in line work. In particular, many objects of interest for line synthesis are of low surface brightness and low resolution is needed for low brightness temperature detectability.

The performance of the VLA in the four wye configurations and a possible compact configuration with a nominal system is shown in Table I. The apparent gain in sensitivity of a factor seven in signal to noise over the 0.7 km wye

TABLE I

Brightness Temperature Sensitivity of the VLA (21 cm)

	Configuration				
	21 km	7 km	2.1 km	0.7 km	Compact
Beamwidth	1".3	4".0	12"	36"	95"
ΔT_b (5 rms)	1020°	113°	12°.6	1°.4	0°.20

Assuming:
- Dual polarization 50° receivers
- 12 hours of integration
- 100 kHz bandwidth
- 50% dish efficiency
- 70% array efficiency

configuration is impressive and many more astronomical phenomena could be investigated. Also the resolution of the compact array, corresponding to ∿ 400 meter filled aperture, is a convenient step from that of existing filled apertures of about 100 meters.

However, we find the difference in performance between a heavily tapered 0.7 km wye and the compact array differ only by less than a factor of 2 in sensitivity. With further optimization perhaps a factor of three improvement could be obtained. The major question then is whether the increased cost is worth the increase in sensitivity.

II. The Compact Array

In Figure 1 we show a sample of a compact array utilizing 22 antennas. The over-all size of the array fits into a 350 meter by 500 meter box as compared with the smallest wye which fits into a 1200 meter by 1200 meter box. This particular array has been "eyeball engineered" to have good u-v coverage with low redundency at 0° declination, while utilizing as many as possible of the present VLA stations. A concern for keeping the cost down for the array was also used in its design. The compact array has not been subject to computerized optimization procedures for maximum coverage in the u-v plane and minimum shadowing and is not intended to be considered as a final design. It does, however, satisfactorily demonstrate the amount of sensitivity gain to be expected from a compact array.

It is not worthwhile analyzing any particular array in detail at the present time. The exact location of the other 99 stations, the placement of the transporter rail lines, the location of the extra 400 meters of rail, etc. will greatly limit the availability of sites for the additional 20 stations. However, since the array will need to fill only 25 x 25 resolution cells in the primary beam, such could be accomplished with the expected constraints dictated by the other wye configurations.

The practical limit on the size of such an array is set by shadowing. This is defined to occur when the projected baseline between two antennas is less than a dish diameter. Note that when this takes place, all correlations with the shadowed antenna are lost (i.e. n-1, when n is the number of array elements). The most severe shadowing occurs at low declination (where the array will be most useful). At present the compact array suffers a loss of 30 percent in correlation time at -30° declination. This loss could probably be dropped to 20 percent with better optimization, but the array is near the limits of compactness.

The beam patterns for δ = +30°, 0° and -30° for the compact array using a taper of 10 dB are given in Figure 2. The grid spacing is 21" and the synthesized HPBW and primary HPBW are shown. The cross hatched area in the δ = 0° and δ = -30° plots show areas of sidelobes greater than -13 dB (5%). A few interesting points are:

1) Since there are only 25 x 25 resolution cells in the primary beam, it is relatively easy to design an array with a transfer function with few holes.

2) The inner sidelobe level is necessarily increased compared with the wye having about 100 x 100 resolution cells.

3) Since spacings closer than 25 meters are lost due to shadowing, the compact array approximates a 300 meter filled aperture with a 25 meter diameter hole in the center. This causes a low level baseline drift in the beam.

4) The array has been designed at δ = 0° with a stepping interval of ∿ 8 meters producing to a grating ring at a distance of 2.5 times the half power radius of a 25 m dish, i.e. well outside the primary response.

A cost estimate for the compact array is as follows:

1)	20 new stations (4 crossings @ 20 K; 1 station 12K)	92 K each	1840 K
2)	∿ 1 km of rail ($45 per foot)		150 K
3)	Special crossings, bends, etc.		200 K
		TOTAL	2190 K

The cost should be compared with 9200 K which is the total cost of the wye construction.

III. The 0.7 km "wye" VLA

Since the 0.7 km wye, when heavily tapered may perform adequately, its properties were investigated in some detail. This was done by generating beam patterns using different tapers at several declinations, thus allowing a determination of beamwidths, sidelobe levels, efficiency and shadowing. Because of its heavy sampling redundancy at short baselines, the efficiency of the 0.7 km wye remains reasonable even with severe taper. Consequently, it may be used to synthesize a 3 to 1 range of beamwidths (30" to 90" at 21 cm) while maintaining at least half of its maximal efficiency. When used with a hard taper of 120 dB, the sensitivity of the wye is about 0°8 K. Therefore, we conclude that the present VLA configuration is capable of performing all of the 21 cm observations listed in M. Roberts' memorandum of March 13. A compact array, however, may be needed for higher frequency lines.

IV. Detailed Comparison of the 0.7 km Wye and the Compact Array

Sensitivity

The minimum detectable brightness temperature ΔT_b (5 rms) is given by

$$\Delta T_b = \frac{0^\circ 7}{\beta^2} E \qquad (5 \text{ rms})$$

where β is the half power beamwidth of the synthesized beam in arc minutes and E is the efficiency of the array. We have assumed the same system given for Table 1. For any array β can be decreased by tapering the array and increasing ΔT_b. The efficiency increases until the natural taper of the u-v coverage is approximated (15 dB for the wye and 10 dB for the compact array). Further tapering causes E to decrease but ΔT_b generally decreases until almost all of the spacings are tapered out of existence. Thus a direct comparison of the two arrays can be made by looking at their efficiencies at equal beam-widths.

A plot of the efficiency E versus beamwidth β for the 0.7 km wye and the compact array is given in Figure 3. The array efficiency as expressed as the equivalent area of a filled aperture is given to the right and the brightness temperature sensitivity corresponding to 100 percent efficiency is given at the top of the diagram. The tapering used for each array is shown along the curves. The declination chosen for the comparison is 30°, however, no substantial changes occur for other declinations.

THE MOST IMPORTANT RESULT IN THE ANALYSIS IS THAT IN THE RANGE 90" to 200" RESOLUTION, THE COMPACT ARRAY IS ONLY A FACTOR 2 MORE SENSITIVE THAN THE 0.7 km WYE. EVEN IF A PERFECT COMPACT ARRAY COULD BE BUILT WITH A 150" RESOLUTION, ITS EFFICIENCY WOULD ONLY BE A FACTOR OF 3 BETTER. IN ADDITION, THE SIDELOBE LEVELS ARE MORE ACCEPTABLE WITH THE WYE CONFIGURATION THAN THE COMPACT ARRAY.

Sidelobe Levels

A detailed comparison of the two arrays are shown in Table II for a 90" synthesized beam. Although only 22 telescopes were used for the compact array, no significant change is expected for 27 elements. Only the sensitivity has been calculated assuming 27 elements. Some comments are:

1) The inner sidelobe are 5 dB better in the wye. The inner sidelobes are predominently caused by a sharp antenna (filled or unfilled) edge. Since the wye is heavily tapered, there is essentially no edge diffraction.

2) The mean near and far sidelobe levels are about the same for the two arrays. These sidelobes depend mainly on the number of telescopes and coverage in the u-v plane.

3) The wye array does not foreshorten for southern declination because of the severe tapering while the compact array produces elliptical beams for southern declination. However, the increase north-south beamwidth produces better sensitivity.

Shadowing

The shadowing time of the compact array is less than the 0.7 km wye north of -20° declination. However, shadowing will be a problem at = -30°. The shadowing time probably could be made less than 20 percent with optimization.

Ed Fomalont, Seth Shostak
June 28, 1972

TABLE II

Comparison of the 0.7 km Wye and the Compact Array

	0.7 km wye (120 dB taper)				Compact (10 dB taper)			
	Declination				Declination			
	60°	30°	0°	-30°	60°	30°	0°	-30°
21 cm Beam								
E/W	86"	86	87	84	91"	94	106	81
N/S	86	86	83	91	91	97	120	173
Efficiency %*	.47	.44	.34	.42	.75	.68	.66	.56
ΔT_b °K	0.72	0.77	1.10	0.95	0.40	0.40	0.33	0.43
Inner sidelobe	-19 dB	-18	-11	-14	-14	-13	-10.6	-9.6
Mean Sidelobe								
Near	-22	-22	-19	-17	-22	-21	-19	-17
Far	-27	-26	-24	-24	-29	-28	-26	-24
Tracking Time	12^h	12^h	$10^h.4$	$6^h.6$	12^h	12^h	$10^h.4$	$6^h.6$
Shadowing %	5	9	15	22	1	4	9	30

* Includes Shadowing

COMPACT ARRAY

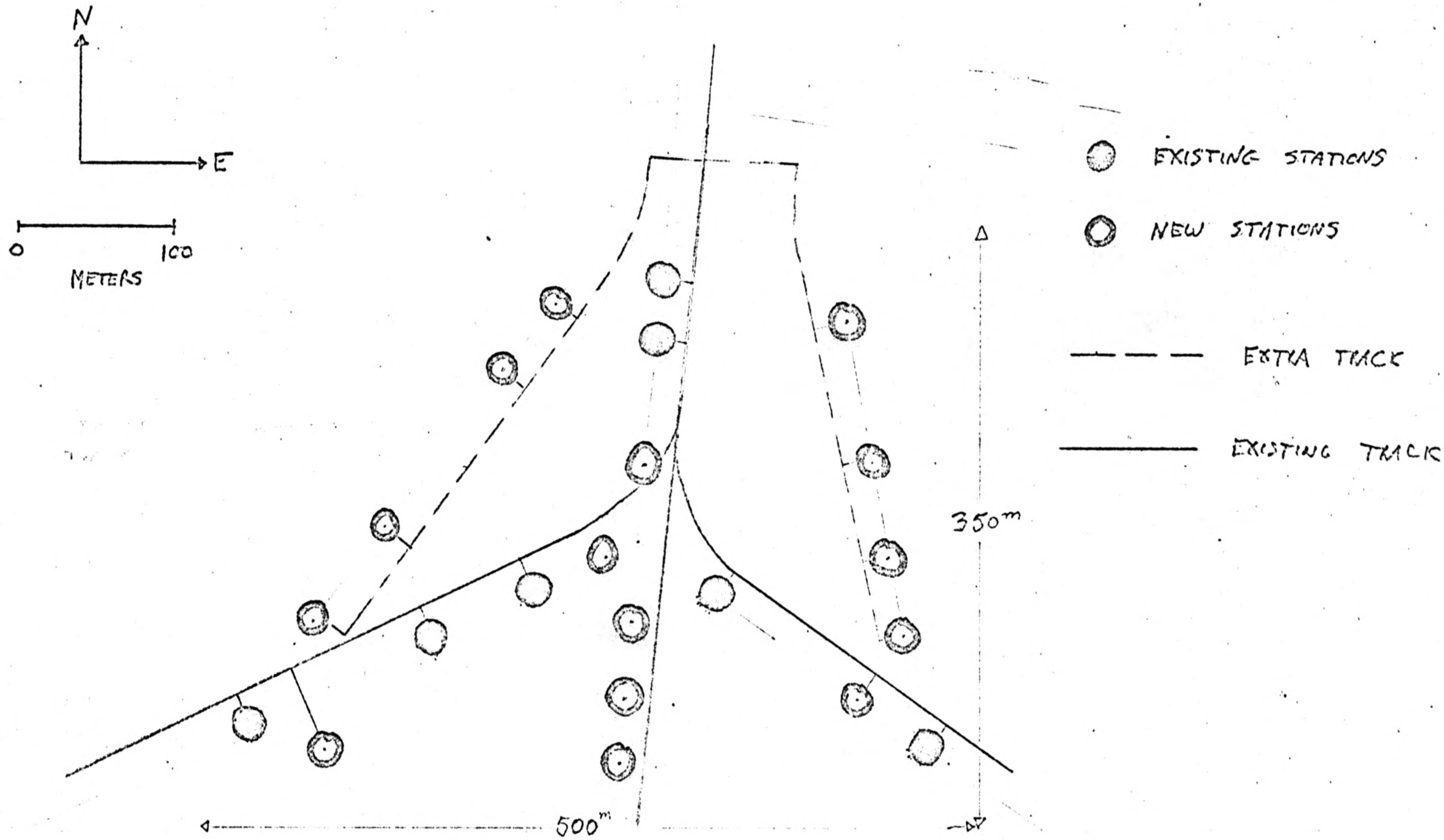


FIG 1

Fig 2a

$\delta = 0^\circ$

21" GRID

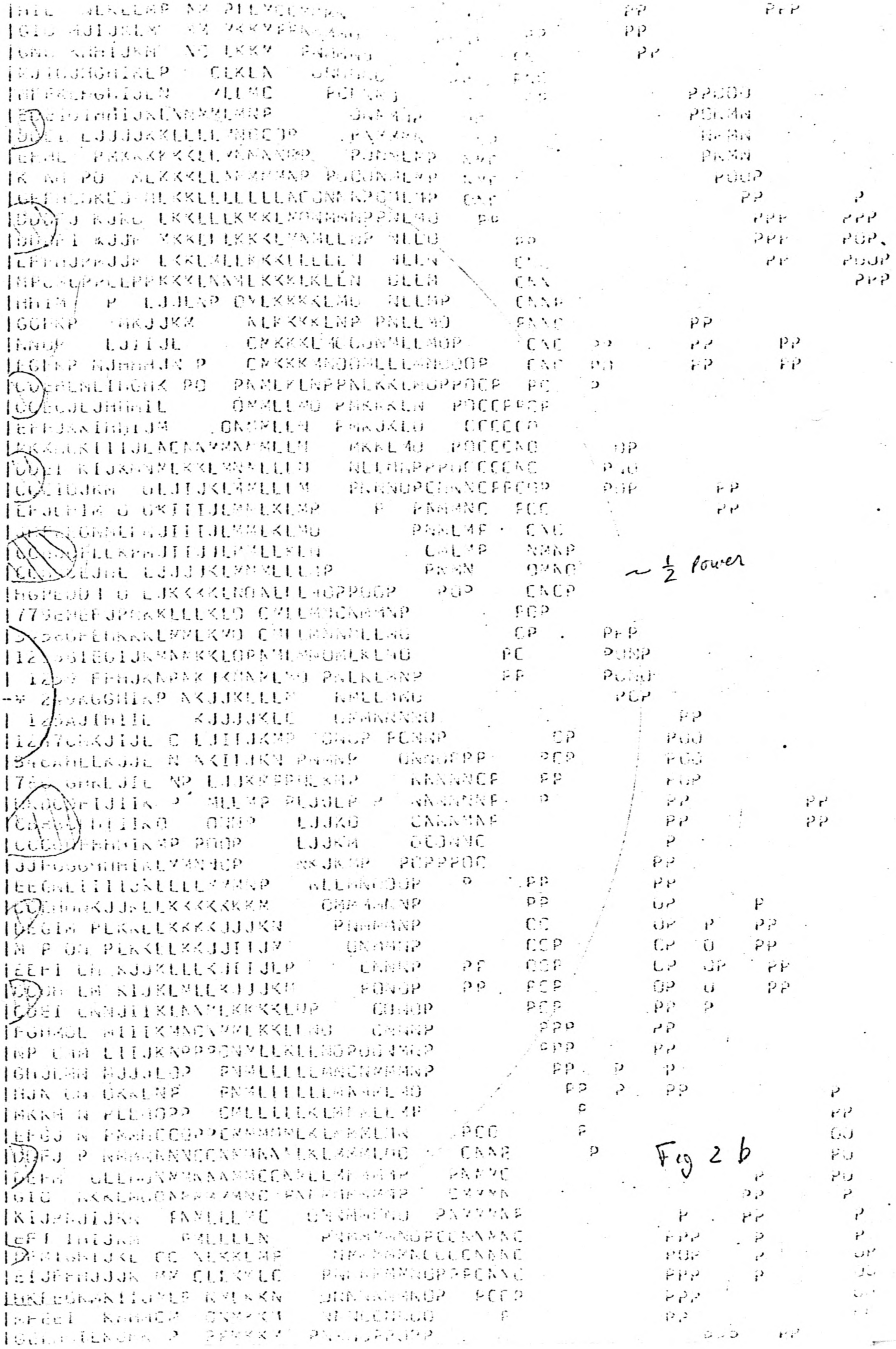


Fig 2 b

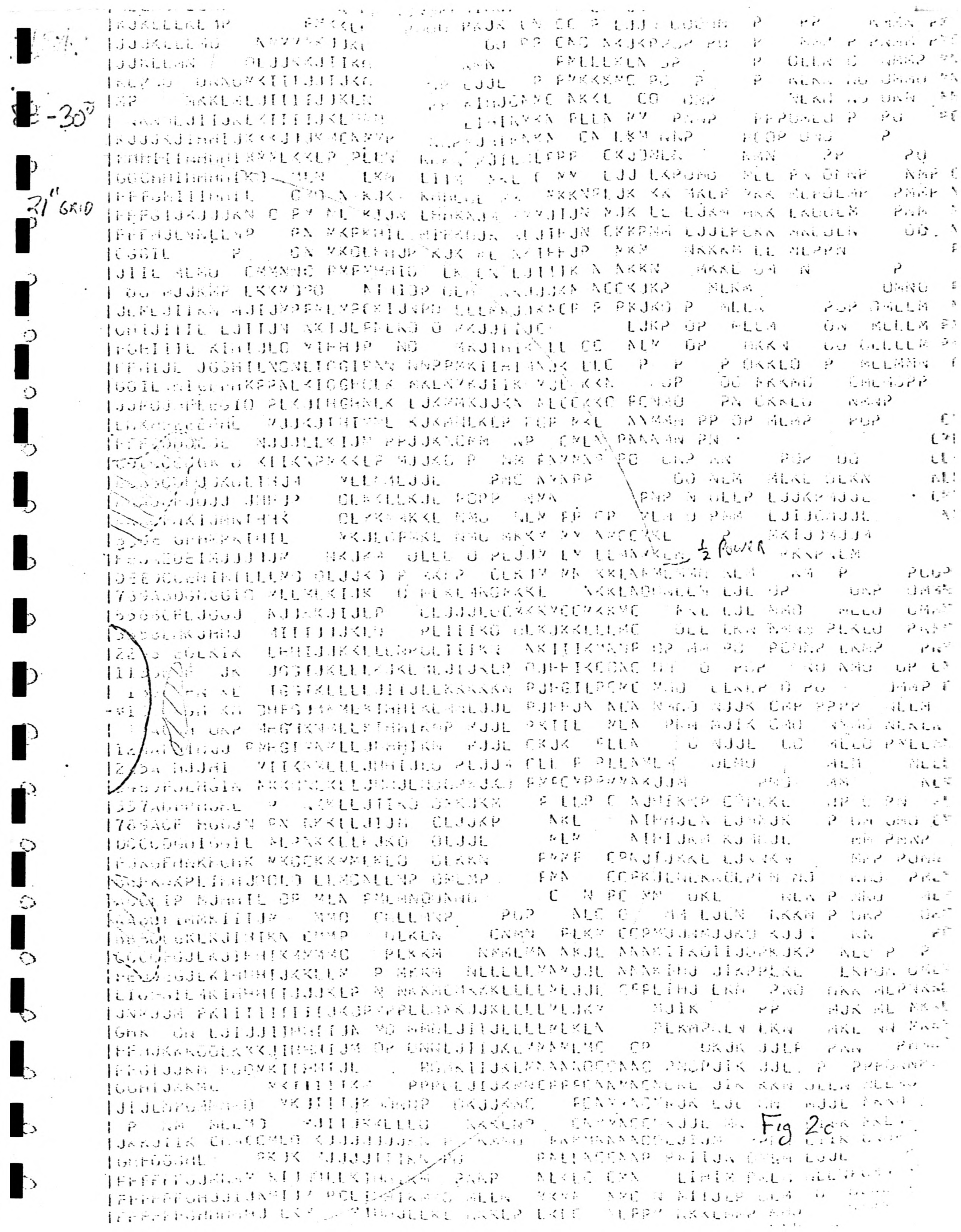
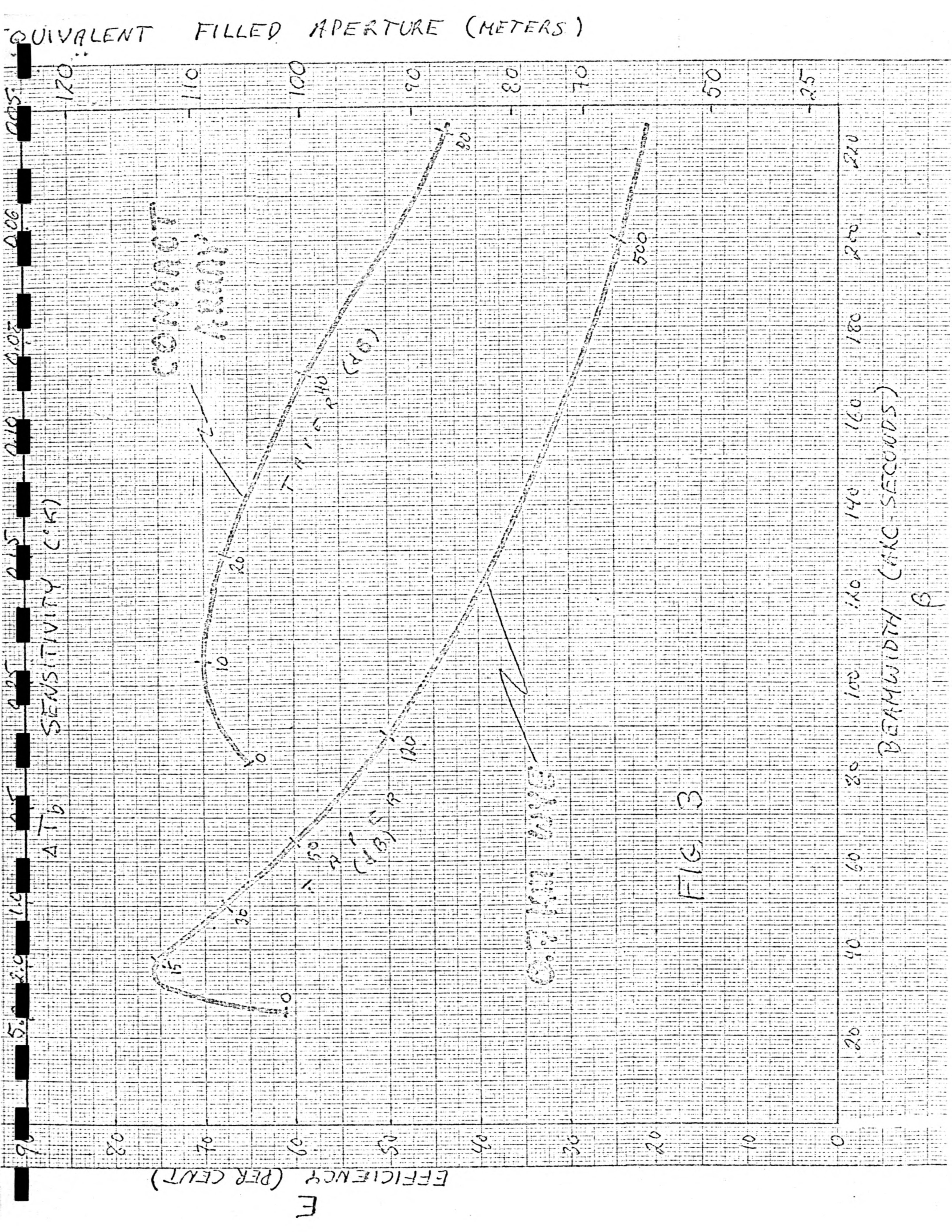


Fig 2c


EQUIVALENT FILLED APERTURE (METERS)
120
110
100
90
80
70
50
25
ΔT_b SENSITIVITY (°K)
.005
0.06
0.07
0.10
0.15
0.25
0.5
1.0
2.0
5.0
COMPACT ARRAY
T (R6)
C.G. MILLS WYE
(R3)
FIG. 3
BEAMWIDTH (ARC SECONDS) β
220
200
180
160
140
120
100
80
60
40
20
EFFICIENCY (PER CENT)
E
90
80
70
60
50
40
30
20
10
0
500