To: Associated Universities, Inc., Committee on Radio Astronomy
From: R. H. Dicke
Subject: 3 Dish Interferometer

JUN 7 1954

It will be recalled that at the afternoon meeting of May 20 I suggested that it was premature to decide on a large dish as the principle antenna of the proposed new radio observatory. I suggested that a three dish interferometer had advantages of both the interferometer and the large dish. It could be used to give a pencil beam or alternately it could be used to give a sharp multilobed beam. This flexibility is particularly important if the antenna is to be used at longer wave lengths in addition to the 21.cms. band.

Having climbed way out on an interferometric limb I felt that I should justify some of my remarks, and the purpose of this memorandum is to present the results of some recent deliberation on the antenna problem. It should be indicated that since I am not a radio astronomer I have no ax to grind, but am only interested in seeing that all the reasonable possibilities are considered before a cost estimate is made.

Given unlimited resources, it is reasonable to say that the one antenna which would please everyone would be an arbitrarily large dish. The beam would be arbitrarily narrow at all wavelengths. On the other hand, with a fixed finite number of dollars available the type of antenna desired would depend gratly on the wavelength and on the nature of the source. For example, isolated point sources would require a large interferometer. By making measurements at several interferometric spacings the ambiguity from the many lobed pattern can be removed. On the other hand, an extended source can be handled with a large dish, but not by the usual interferometer.

Before discussing the advantages of the three dish interferometer I should like to make a few general remarks about a single dish antenna. First as to mounting, I think that it is clear that an equitorial mounting for a large dish would be much more expensive than a computor-servo direction system. Also as an alternative to building a mounting system for a very large dish sufficiently rigid to withstand wind induced flexure one might consider a servo system to stabilize the support. For a several hundred foot dish this would probably be the least expensive.

A large dish should preferably be uniformly illuminated. A uniformly illuminated dish has the maximum antenna gain attainable, namely an absorption cross section equal to its area, and has 85% of its integrated intensity in its main lobe. The 15% of the intensity in side lobes can be strongly reduced by not illuminating the edges of the dish. However, this reduces the effective area by a large factor, and it does not seem reasonable to work so hard to build a large antenna if one is to use only part of it. In any case it is clear that considerable attention should be given to the question of side lobe power remembering that the penalty for its reduction is severe.

Antenna pattern of three dish interferometer.

Fig. 1 shows the antenna pattern of a uniformly illuminated 150 ft. single dish (21 cm). In Fig. 2 and 3 antenna patterns of an equivalent three dish interferometer are given for two different spacings of the dishes. The dish diameter for the interferometer was chosen to be such as to give a total area equal to that of the 150 ft. single dish. Assuming uniform dish illumination, this gives a peak absorption cross section equal to that of the big dish. The solid curves are for close spacing of the three dishes. The central lobe has essentially the same width as that of the equivalent large single dish. Also, the integrated intensity in the central lobe is nearly equal to the 85% characteristic of the large dish. The antenna pattern has a 6-fold symmetry axis and Figs. 2 and 3 give the patterns in the symmetry planes "A" and "B", shown in the diagrams.

The first conclusion that one can draw is that with close spacing the antenna pattern of a three dish interferometer is not noticeably worse than that of an equivalent uniformly illuminated dish.

The dotted curves are for a wider spacing of the interferometer. This gives a central peak width equal to that of a 195 foot dish but without excessive side lobes. A greater spacing would give a sharper main lobe but with stronger side lobes. It is suggested that one of the chief advantages of the interferometer would result from its versatility in being capable of giving a pencil beam or a sharp many lobed pattern.

Information rates.

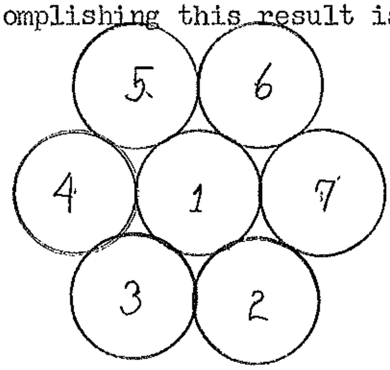
A second advantage of the close-spaced interferometer over the equivalent single dish is connected with the speed of data taking. The three antennas can be interconnected to define not one, but three, separate, but slightly overlapping, sharp beams provided three separate detecting apparatuses are used. It must be emphasized that each of these beams is equivalent to that of a 150 ft. dish. Consequently, data can be accumulated at 3 times the rate of a large single dish.

Interferometer mounting.

Fig. 4 shows one way in which a three dish interferometer could be mounted to provide the flexibility and mobility needed. It is suggested that the mobile dishes be each mounted on 4 standard railway trucks with the springs removed. Standard rails and switching gear would be used. Instead of building good mechanical tolerances into the equipment, the antennas would be located and directed automatically in response to position and angle sensing servo equipment. Fig. 5 shows a possible track layout.

Ultra sharp pencil beam.

To come now to the third advantage, a three dish interferometer can be used to give a ncil beam equivalent to that of a very large single dish. This result is accomplished at considerable expense in electronics and for some cases at an expense in observation time. The procedure for accomplishing this result is illustrated with reference to Fig. 6, showing a



7 dish interferometer

Dish diameter = 86.5 feet

Diameter of single equivalent dish = 230 feet

Fig. 6

hypothetical seven dish interferometer equivalent to a single dish 230 feet in diameter. It is possible to produce the pencil beam of this seven dish array by using only three dishes (in principle two dishes are enough). The seven dishes have been numbered and the voltage developed at the output of the jth dish will be designated $V_j(t)$. These voltages are combined, amplified, squared and a time average is taken to give the output of the detector as

$$S = \overline{\left(\sum_{j=1}^{7} V_j\right)^2} = \sum_{j=1}^{7} \overline{V_j^2} + 2\sum_{i>j} \overline{V_j V_i}$$

The average $\overline{V_j^2} = \overline{V^2}$ is independent of j and $\overline{V_j V_i} = \overline{V_i V_j}$ depends only on the location of i relative to j.

Consequently:

$$S = 2\overline{(V_1 + V_2 + V_3)^2} + 2\overline{(V_2 + V_4 + V_6)^2} + \overline{(V_2 + V_1 + V_5)^2} + \overline{(V_7 + V_1 + V_4)^2} + \overline{(V_3 + V_1 + V_6)^2} - 14\overline{V^2}$$

Since $\overline{V_1V_2} = \overline{V_6V_7}$ etc.

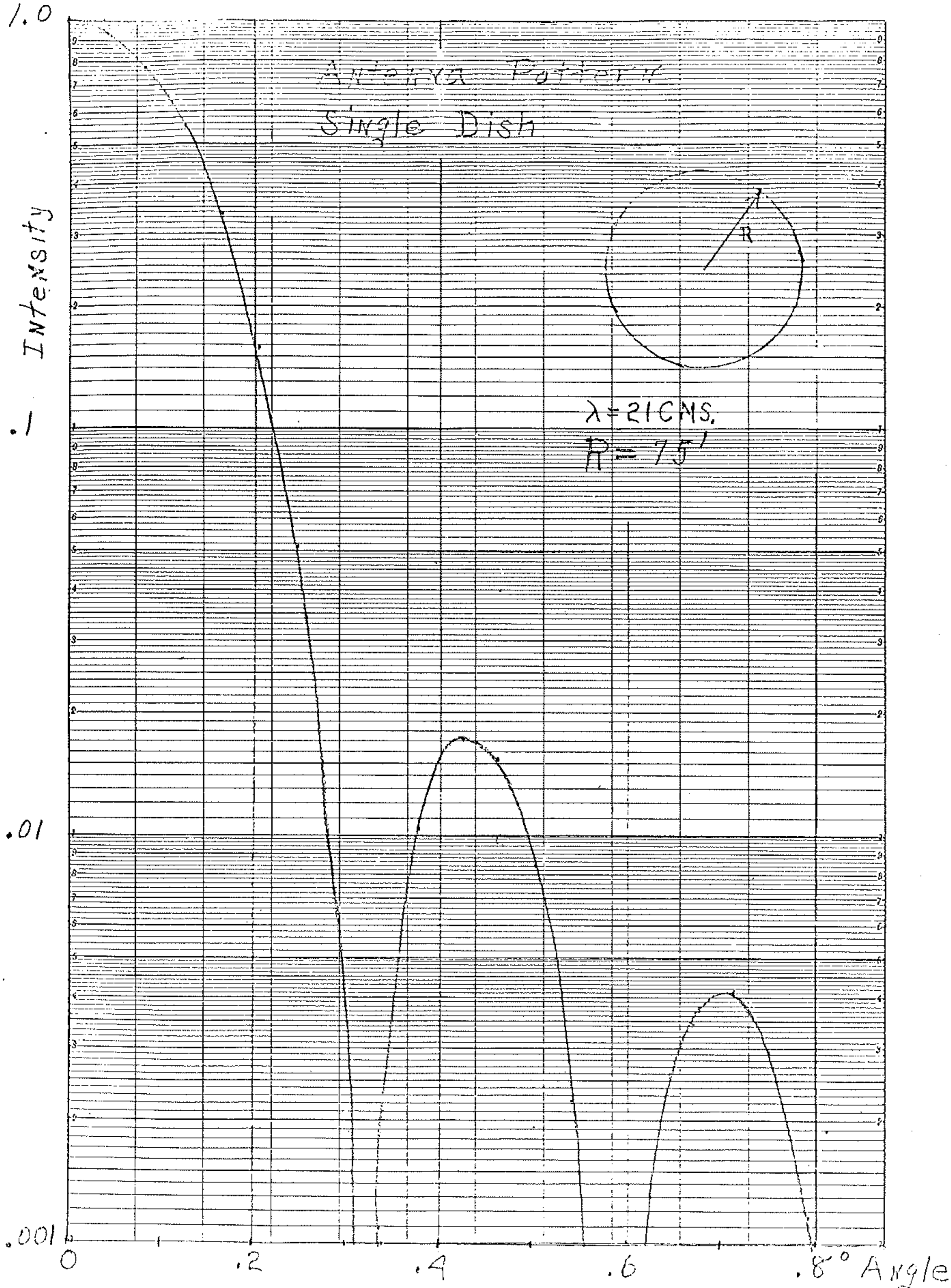
$\overline{V_3V_7} = \overline{V_4V_6}$ etc.

The first parenthesis represents the output of the detector with a three dish interferometer occupying positions 1, 2 and 3, with similar meanings for the other brackets. Assuming stationary random time series, the five observations represented by the five parentheses can be taken sequentially. Consequently all five parentheses can be evaluated with a single three-dish interferometer. The last term may be a separate observation, but preferably it is the average of information obtained from the separate dishes concurrent with the observations represented by the parentheses.

Five separate scans or observations of a particular direction in space are required to calculate S. However, with proper electronics the observations are sufficient to establish seven independent sharp beams. Actually the observation time is essentially the same as that of an equivalent single large dish to obtain the same signal to noise. However, to synthesize a very much larger antenna would require a payment in signal to noise or the equivalent observation time.

Costs.

There may be some advantage of the three dish interferometer over the single large dish on grounds of economics. If one argues that the cost per pound is the same for each and that the dishes can be scaled, the single large dish would cost 4.8 times as much as one of the interferometer dishes. This might be compensated, however, by the increase in costs resulting from the complexity of controls for the interferometer.



Antenna Pattern
Single Dish
Intensity
1.0
.1
.01
.001
R
λ = 21 CMS.
R = 75'
0
.2
.4
.6
.8°
Angle

Fig. 1

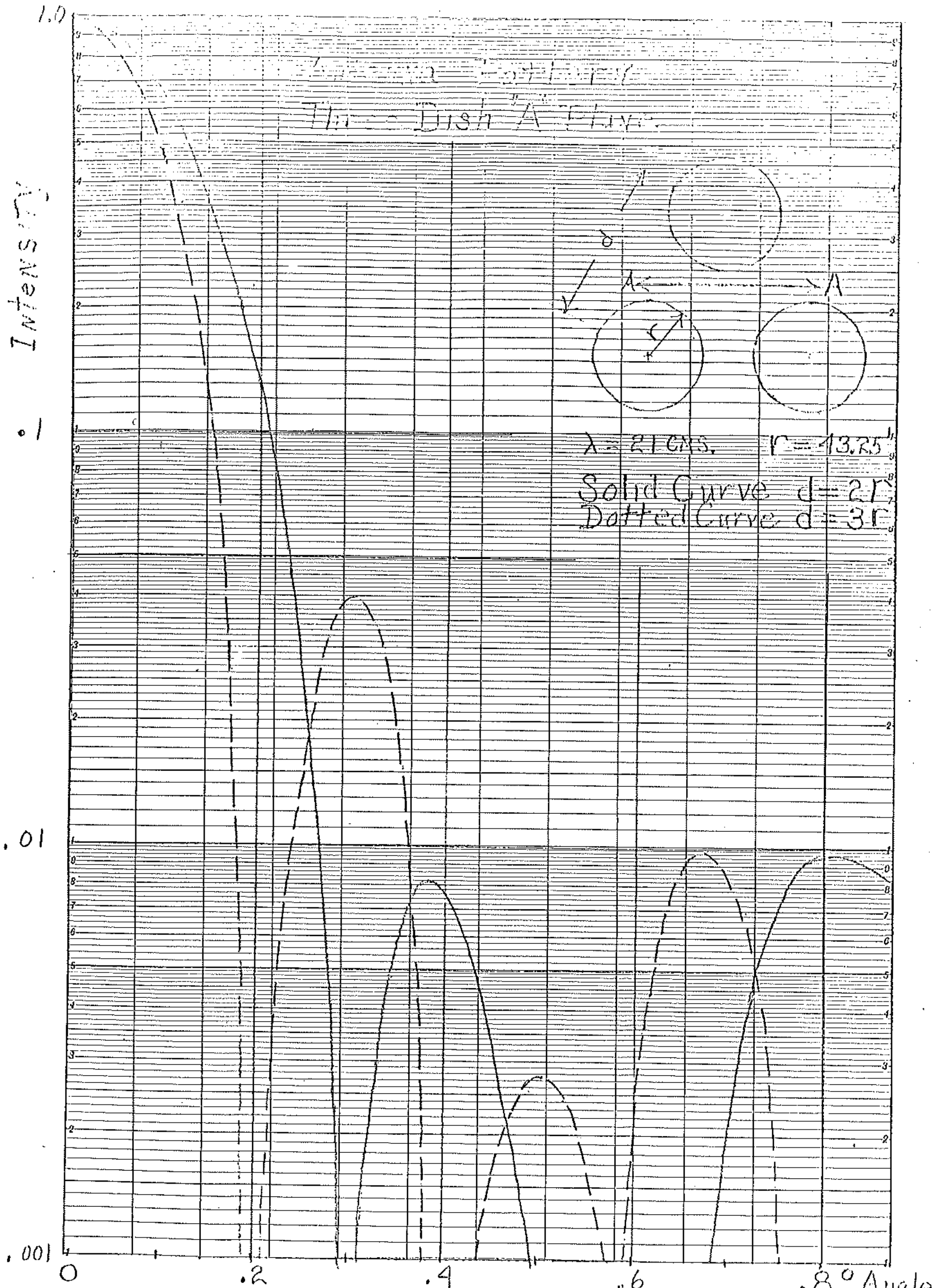

Three Dish "A" Array
Intensity
1.0
.1
.01
.001
0
.2
.4
.6
.8° Angle
d
r
A
A
λ = 21 CMS.
r = 13.25"
Solid Curve d = 2r
Dotted Curve d = 3r

Fig. 2

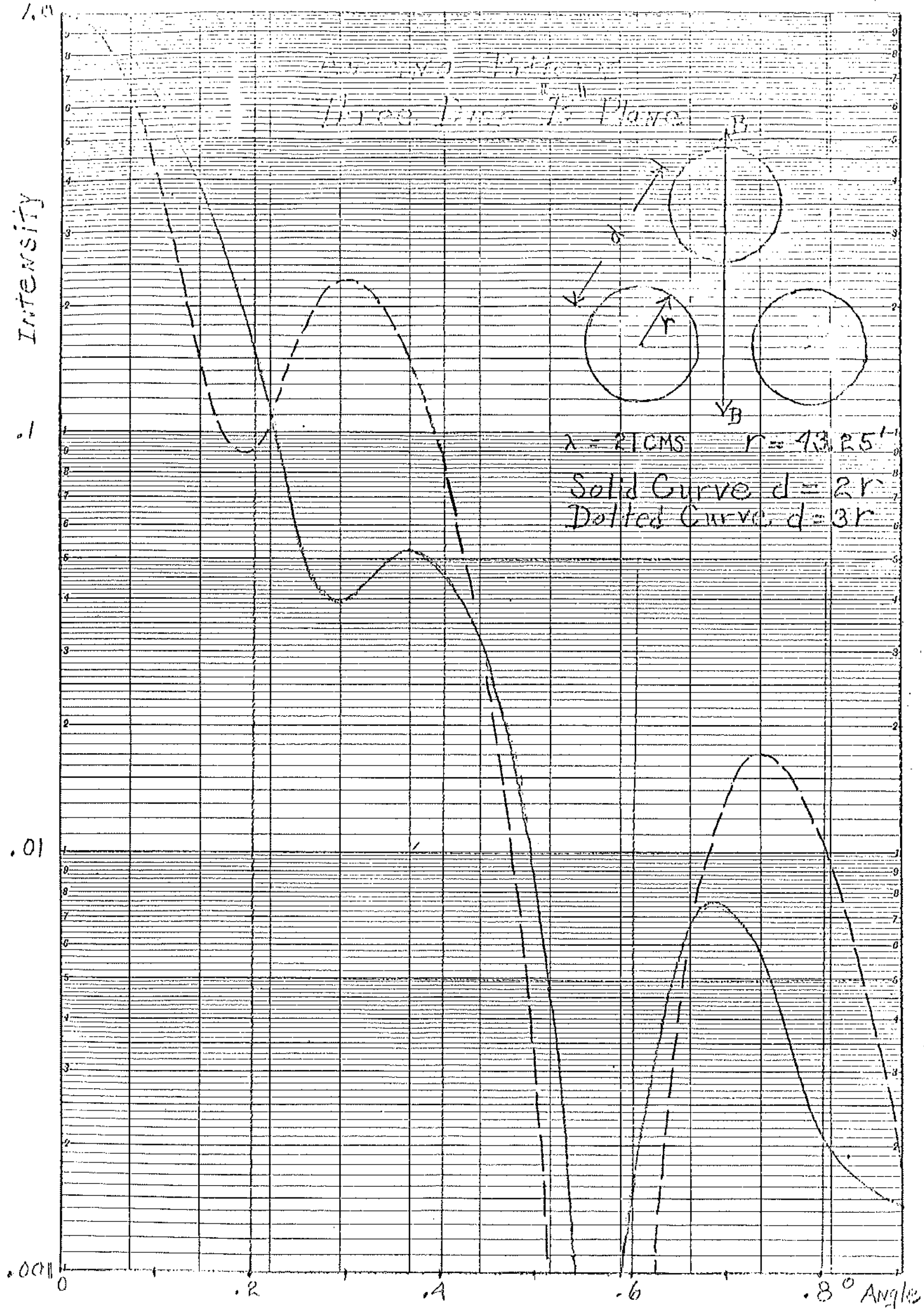

1.0
.1
.01
.001
Intensity
B
d
r
B
λ = 21 CMS r = 13.25'
Solid Curve d = 2r
Dotted Curve d = 3r
0
.2
.4
.6
.8° Angle

Fig. 3

Three dish interferometer.
Each peripherical dish mounted on 4 standard roller bearing railroad trucks with springs removed.
Dish diameter 86.5 ft.

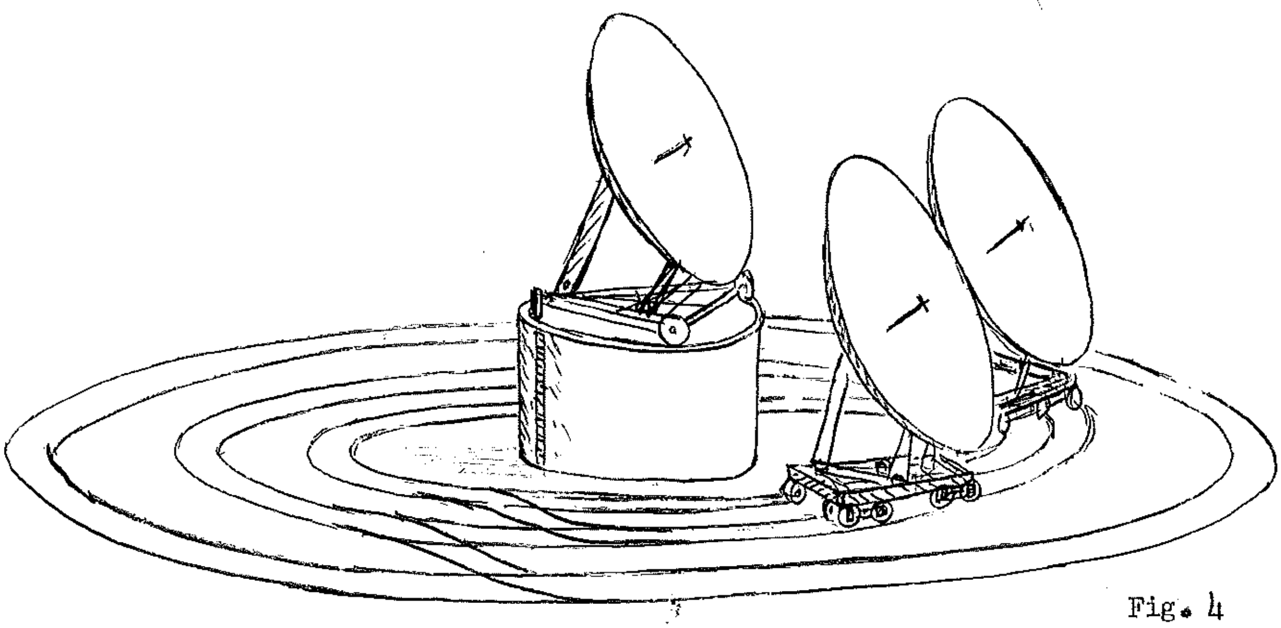
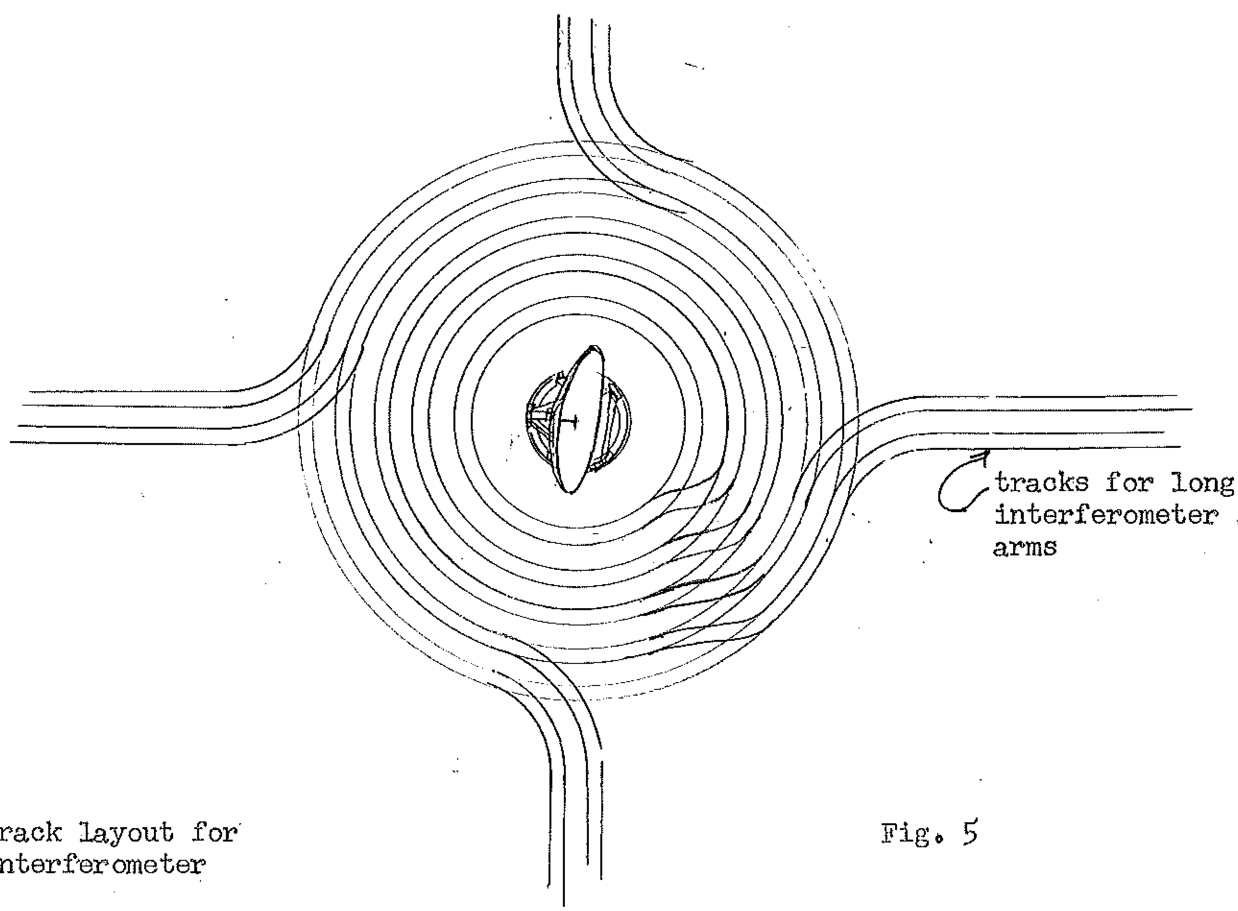


Fig. 4



track layout for interferometer

Fig. 5