BNL-101935-2014-TECH

AD/RHIC/23;BNL-101935-2013-IR

Beam Transfer, Capture and Acceleration in RHIC

J. G. Cottingham

January 1987

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

AD/RHIC-23

Accelerator Development Department

Brookhaven National Laboratory
Associated Universities, Inc.
Upton, New York 11973

RHIC Technical Note No. 23

Beam Transfer, Capture and Acceleration in RHIC

J. G. Cottingham

January 16, 1987

Beam Transfer, Capture and Acceleration in RHIC

J. G. Cottingham

The beam, protons or heavy ion, is accelerated in the AGS to top energy, bunched tightly by the AGS rf system and then transferred box-car wise into RHIC. During this transfer the magnetic field in RHIC is fixed but that in the AGS may be rising. Thus the beam is transferred from an accelerating rf bucket into a stationary one. The phase motion contour for an off momentum particle in these two systems are not identical (see Figures 1, 2 and 3). These figures show the phase motion contours within the stated electrical buckets. Figure 4 illustrates this shape mismatch by lifting certain constant width contour from the previous figures. Contours matched at the crest are not matched at the base. This shape mismatch results in some, although small, growth of the phase space area as a result of the transfer. As shown in Figure 4 the stationary bucket that encloses all points within a moving bucket with a 40 degree stable phase angle, has an area 29.8% larger than the accelerating bucket.

To relate the phase width of constant momentum contours to the phase space area enclosed, Figure 5 has been prepared. Plotted on the vertical axis of Figure 5 is the ratio of the enclosed area to that of a stationary bucket with the same rf voltage. The horizontal axis gives the phase width at the base and curves for various stable phase angles are shown. This normalized plot can be used to relate these parameters for any accelerator.

Figure 6 relates this same phase space area ratio to the ratio of the crest energy difference from the stable particle to the crest energy difference in a stationary bucket with the same rf voltage. Again, curves for various stable phase angles are shown defining the relationship between these three parameters. These normalized nomographs will be used to calculate the transfer, capture and acceleration rf parameters for RHIC.

Table I lists the parameters for protons and for a typical set of heavy ion species as they will be in the AGS at full energy. In preparing this table some assumptions were made. The phase space area of the populated region was assumed to be 0.3 eV-sec. for all heavy ion species. This choice is consistant with that given in the RHIC Conceptual Design. The populated phase space area for protons has been increased to 0.55 eV-sec. because this larger area appears to be manageable. Table II lists the RHIC capture parameters before acceleration. In this case the rf voltage is chosen so that one of the constant momentum contours in the stationary bucket has the correct phase width at the base and the correct energy difference at the crest to match those of the beam populated region in the AGS, as given in Table I. Note that the rf voltage required to match the shape of the proton populated region is very small, 4.6 kV. If larger voltages are used the phase space will be diluted as particles with large phase errors move out to fill the contour. If this dilution is desirable, then it is readily available. However, this analysis will attempt to minimize dilution.

Table III lists the RHIC parameters needed for acceleration just after capture. The rate of change of magnetic field (db/dt) is assumed to be 0.0418 Tesla/sec. In this case the rf voltage could be reduced until the accelerating bucket just matched the area of the beam population and this is the voltage listed in the table. But there is no necessity to use this minimum voltage and I recommend that the acceleration be accomplished with the same voltage as used to capture. The heavy ions must pass through transition which will cause some phase space area dilution. Table IV has been prepared assuming a phase space area dilution of a factor of three. Notice the large rf voltages required.

Beam interactions during storage will introduce additional momentum spread and the rf voltage must be increased so that these scattered particles are retained. This process is described in the RHIC Conceptual Design and results in the need for even higher rf voltages, 1200 kV, for gold after 10 hours.

TABLE I

AGS Ejection Bp = 96.5 T-M (dB/dt = 2.5 T/sec)

		Protons	Deuterons	Carbon	Sulfur	Copper	Iodine	Gold
Mass/charge ratio		1.007	2.014	2.000	1.998	2.170	2.394	2.493
R.F. Volts	(KV)	440	440	440	440	440	440	440
Frequency	(MHz)	4.45	4.45	4.45	4.45	4.45	4.44	4.44
Kenetic energy/charge	(Gev)	28.0	27.4	27.1	27.1	27.0	26.8	26.7
Stationary Bucket Area	(eV-sec)	66.9	39.0	39.1	39.1	37.6	36.5	36.4
Stationary Bucket $\Delta E/E$	(10^{-4})	80.8	47	47	47	45	44	44
Populated area	(eV-sec)	0.55	0.3	0.3	0.3	0.3	0.3	0.3
Area ratio*		.0082	.0077	.0077	.0077	.0080	.0082	.0082
Populated phase width	(deg)	23.3	22	22	22	23	23	23
Bunch width	(10^{-9}sec)	14.5	13.7	13.7	13.9	14.3	14.4	14.4
Δ E/E ratio**		.101	.099	.099	.099	.1	.101	.101
Populator $\Delta E/E$	(10^{-4})	8.1	4.6	4.6	4.6	4.5	4.4	4.4

* Populated area/area stationary Bucket

** Populated Δ E/E / stationary Bucket $\Delta E_{max}/E$

TABLE II

RHIC Injection Bp = 96.5 T-M (dB/dt = 0)

		Protons	Deuterons	Carbon	Sulfur	Copper	Iodine	Gold
R.F. Crest V	(KV)	4.6	135	131	130	179	257	308
Population phase width	(deg)	140	132	132	132	138	138	138
Populated $\Delta E/E$	(10^{-4})	8.1	4.6	4.6	4.6	4.5	4.4	4.4
Area ratio*		.275	.247	.247	.247	.268	.268	.268
$\Delta E/E$ ratio**		.58	.55	.55	.55	.57	.57	.57
Stationary Bucket $\Delta E/E$	(10^{-4})	14.0	8.36	8.36	8.36	7.89	7.72	7.72
Stationary Bucket area	(eV-sec)	2.0	1.16	1.16	1.16	1.12	1.07	1.07
Populated width	(10^{-9} sec)	14.6	13.7	13.7	13.7	14.4	14.4	14.4
R.F. frequency	(MHz)	26.7	26.7	26.7	26.7	26.6	26.6	26.6

* Populated area/area stationary Bucket

** Populated $\Delta E/E$ / stationary Bucket $\Delta E/E$

TABLE III
RHIC Acceleration (dB/dt = .0418 T/sec)
Acceleration Below Transition

		Protons	Deuterons	Carbon	Sulfur	Copper	Iodine	Gold
R.F. Crest V	(KV)	49	88	87	87	99	117	125
Populated area	(eV-sec)	.66	.36	.36	.36	.36	.36	.36
Stable phase	(deg)	52.8	26.3	26.6	26.6	23.2	19.5	18.2
Stationary Bucket $\Delta E/E$	(10^{-4})	47.3	6.7	6.82	6.84	6.00	5.21	4.92
Stationary Bucket area	(eV-sec)	6.51	.934	.944	.947	.831	.723	.682
Populated width	(deg)	102	196	194	194	206	225	230
Populated width	$(10^{-9}$ sec)	10.6	20.4	20.4	20.4	21.4	23.4	23.9
Populated $\Delta E/E$	(10^{-4})	14.7	4.36	4.23	4.25	3.96	3.75	3.64

TABLE IV
RHIC Acceleration (dB/dt = .0418 T/sec)
Acceleration After Transition

		Protons	Carbon	Sulfur	Copper	Iodine	Gold
R.F. Crest V	(KV)	242	237	237	302	412	470
Populated area	(ev-sec)	1.1	1.1	1.1	1.1	1.1	1.1
Stable phase	(deg)	9.3	9.5	9.5	7.4	5.4	4.8
Stationary Bucket $\Delta E/E$	(10^{-4})	11.19	11.26	11.29	10.48	9.78	9.54
Stationary Bucket area	(eV-sec)	1.55	1.56	1.56	1.45	1.35	1.32
Populated width	(deg)	248	248	248	261	274	278
Populated area	(10^{-9} sec)	25.8	25.8	25.8	27.1	28.5	28.9
Populated $\Delta E/E$	(10^{-4})	9.84	9.91	9.93	9.43	9.10	8.97
Transition Energy	(Gev/charge)	52.6	52.2	52.1	56.6	62.5	65.1
Transition Field	(Tesla)	.745	.740	.739	.803	.886	.923

Fig 1.

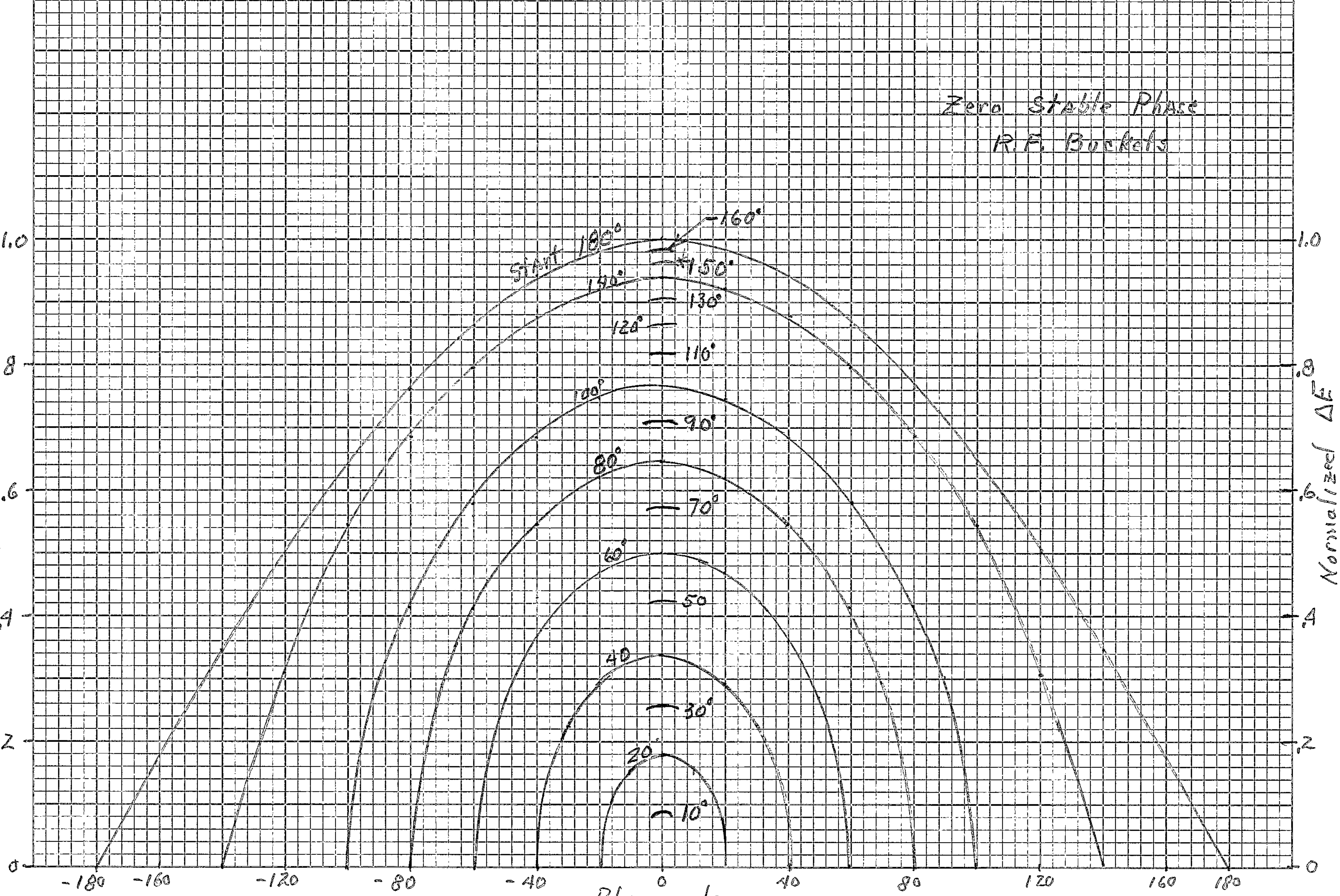

Zero Stable Phase
R.F. Buckets
Start 180°
160°
150°
140°
130°
120°
110°
100°
90°
80°
70°
60°
50
40
30°
20°
10°
1.0
.8
.6
.4
.2
0
-180
-160
-120
-80
-40
0
40
80
120
160
180
Normalized ΔE

Fig 2

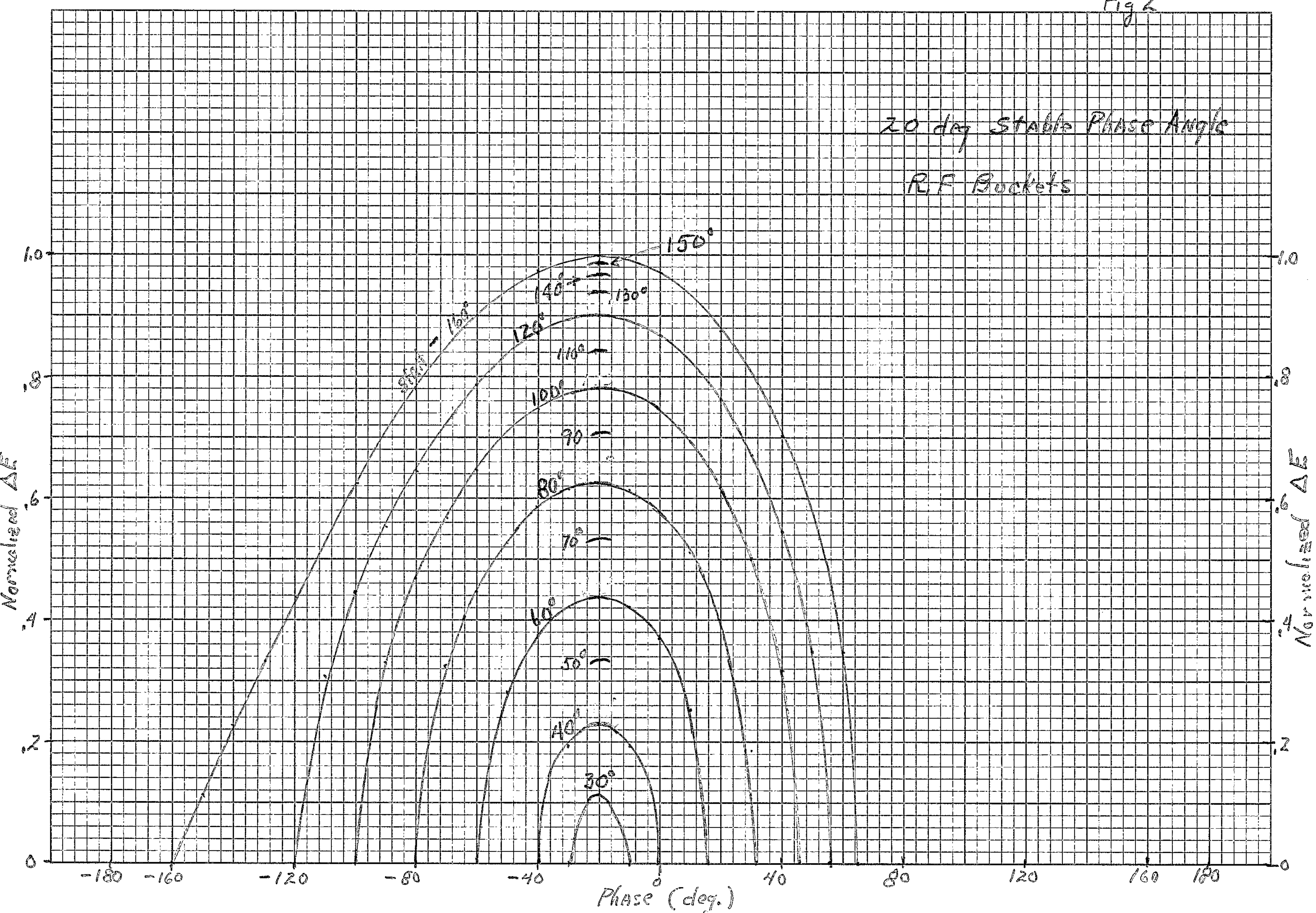
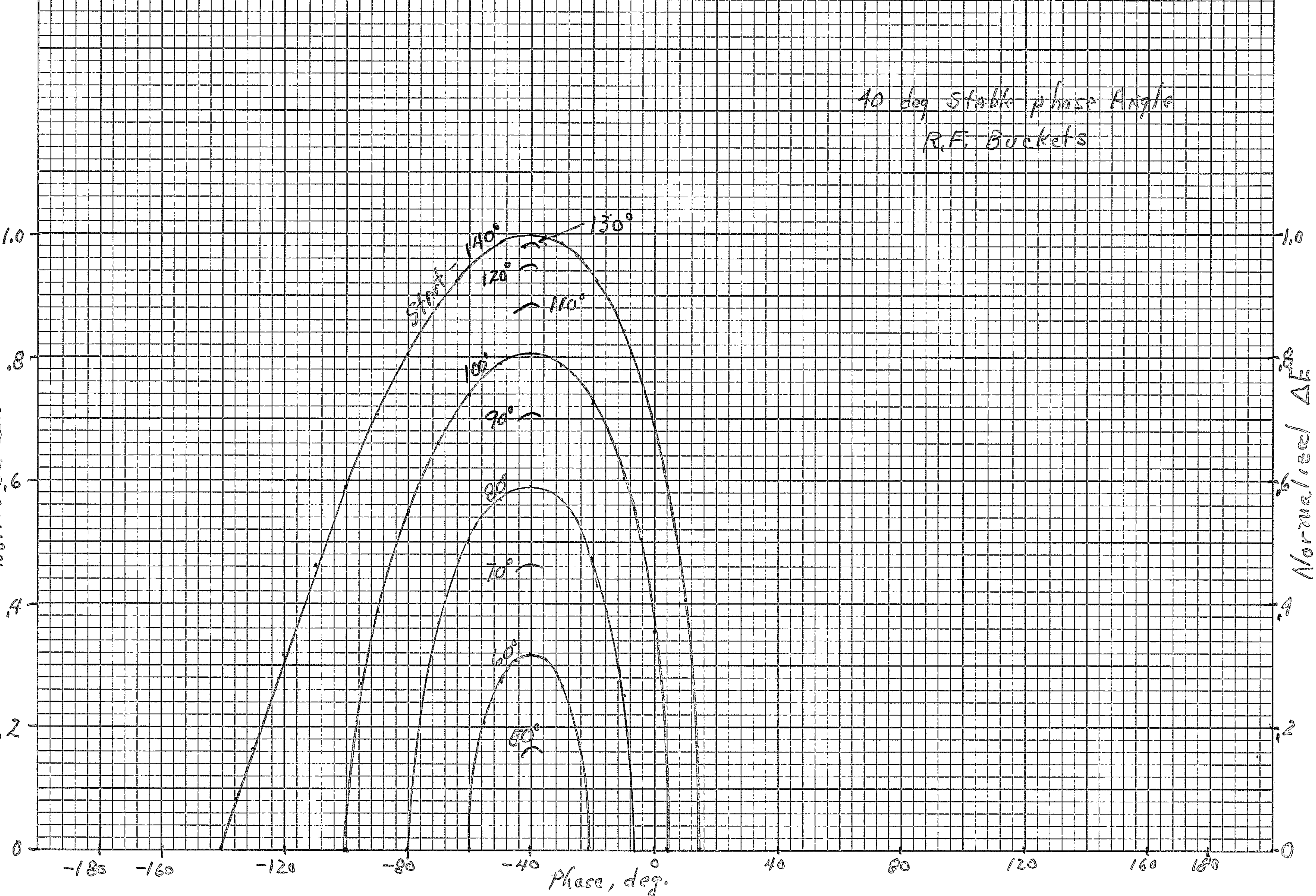

20 deg Stable Phase Angle
R.F. Buckets
Normalized ΔE
Phase (deg.)
150°
140°
130°
120°
110°
100°
90
80°
70°
60°
50°
40°
30°
1.0
.8
.6
.4
.2
0
-180
-160
-120
-80
-40
0
40
80
120
160
180

Fig 3


10 deg Stable phase Angle
R.F. Buckets
Start
140°
130°
120°
110°
100°
90°
80°
70°
60°
50°
1.0
.8
.6
.4
.2
0
-180
-160
-120
-80
-40
0
40
80
120
160
180
Phase, deg.
Normalized ΔE

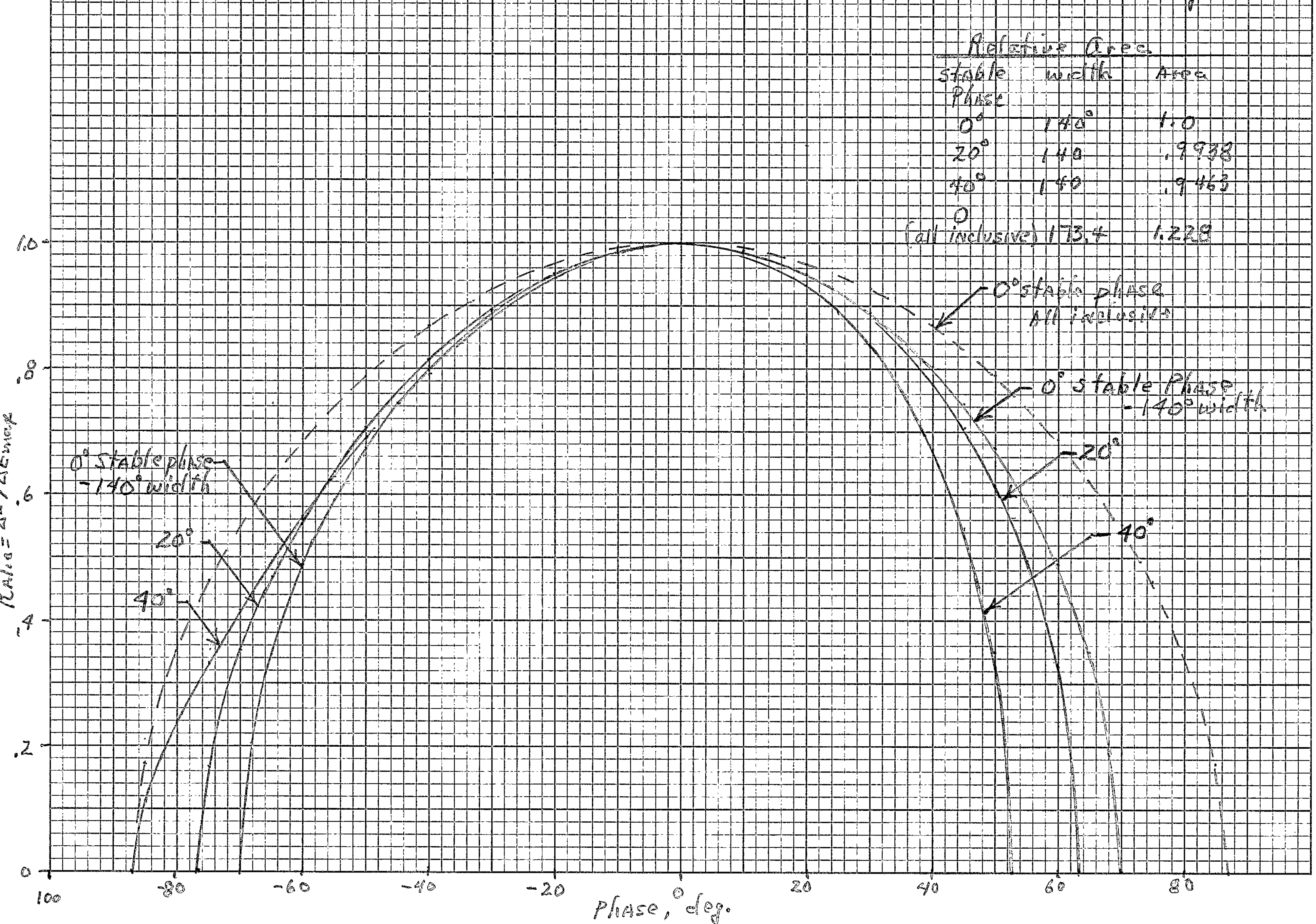

Relative Area
stable Phase | width | Area
0° | 140° | 1.0
20° | 140 | .9938
40° | 140 | .9463
0 (all inclusive) | 173.4 | 1.228
0° stable phase All inclusive
0° stable Phase -140° width
20°
40°
0° stable phase -140° width
20°
40°
1.0
.8
.6
.4
.2
0
Ratio = ΔE/ΔEmax
100
-80
-60
-40
-20
0
20
40
60
80
Phase, ° deg.

Fig 4

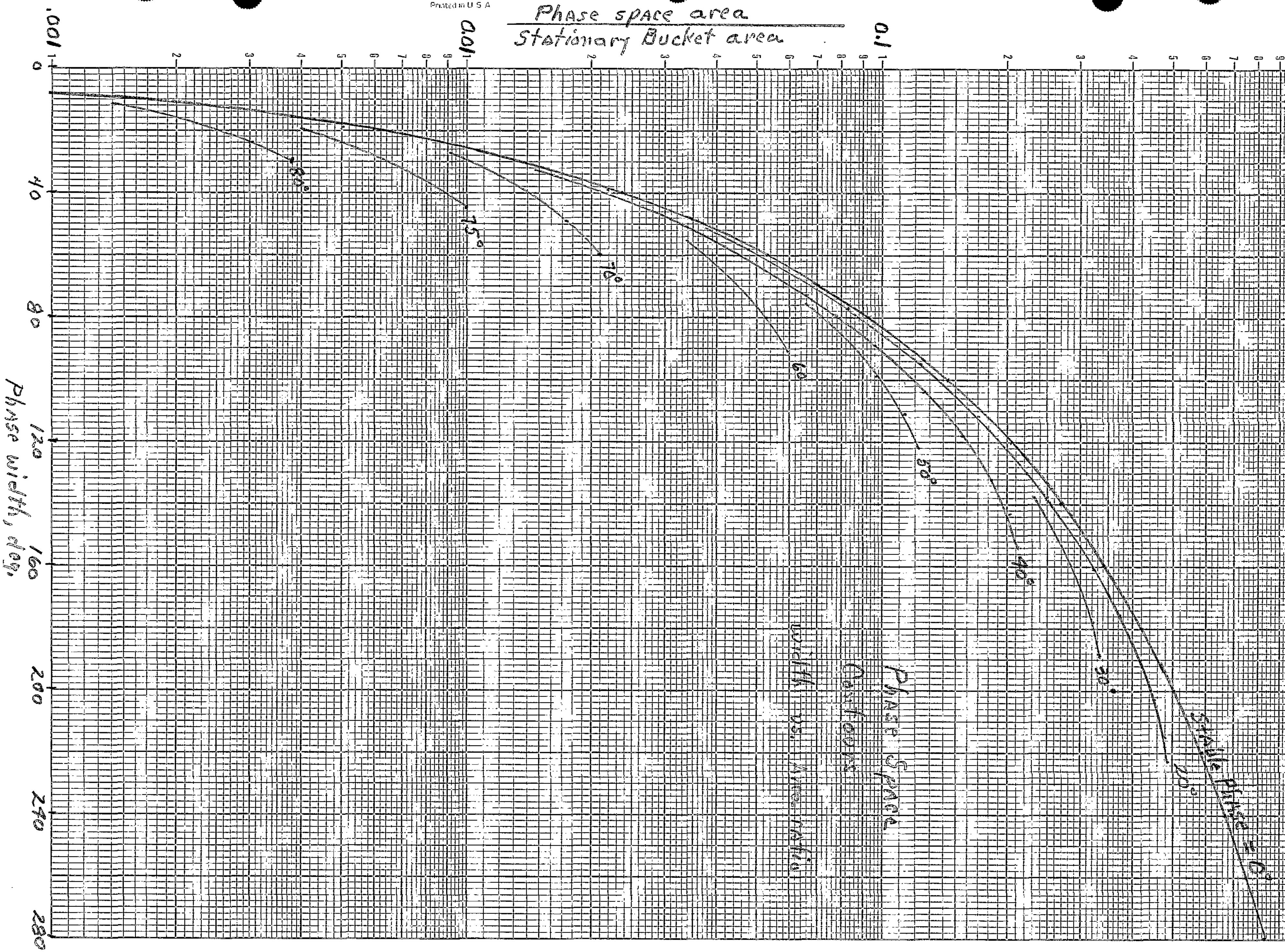
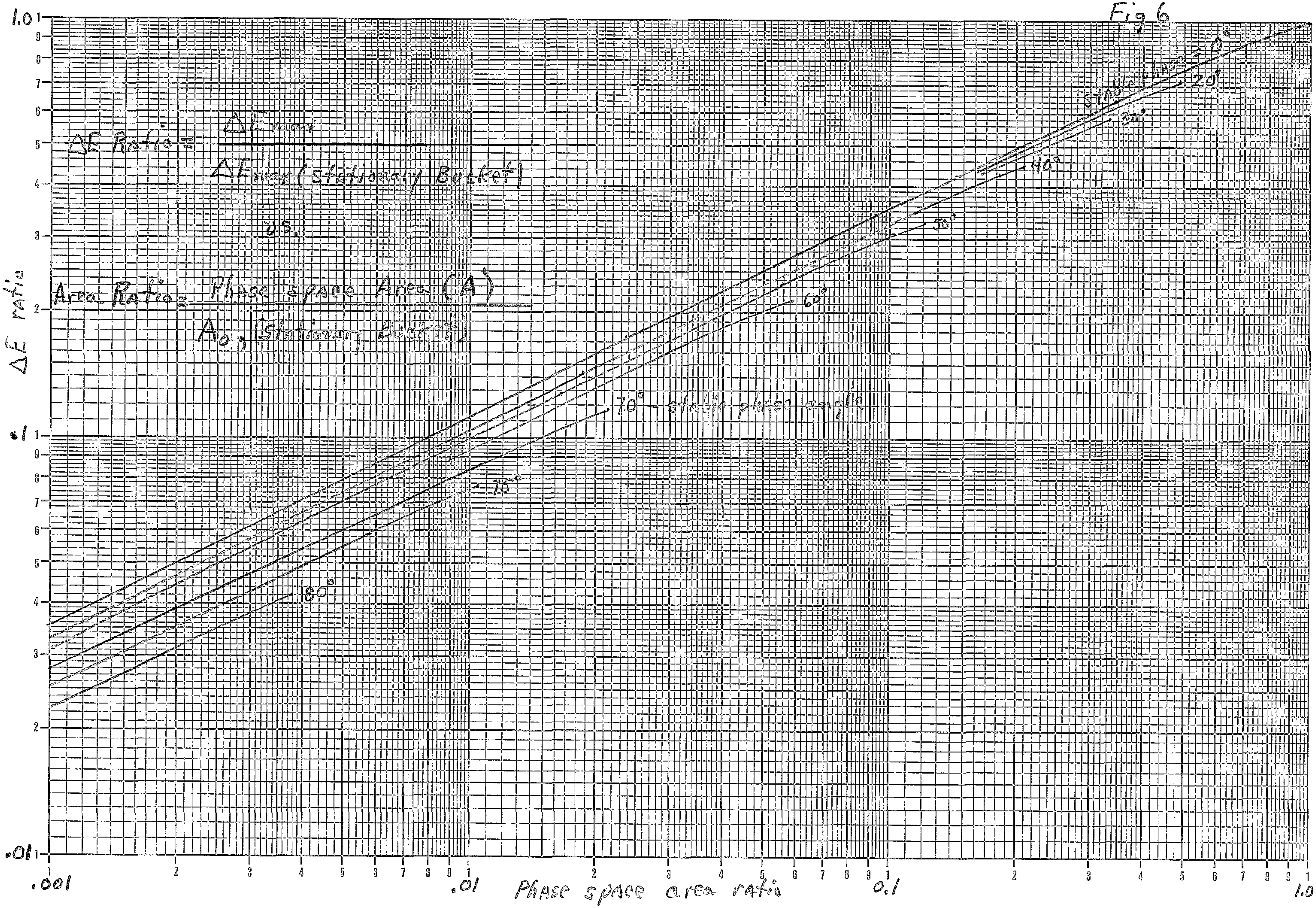

Phase space area
Stationary Bucket area
.001
0.01
0.1
1.0
0
40
80
120
160
200
240
280
Phase width, deg.
80°
75°
70°
60
50°
40°
30°
20°
Stable Phase = 0°
Phase Space Contours
width vs. Area ratio

Fig. 5

Fig 6


ΔE Ratio = ΔE max / ΔE max (stationary Bucket)
vs.
Area Ratio = Phase space Area (A) / Ao, (Stationary Bucket)
synch phase = 0°
20°
30°
40°
50°
60°
70° — stable phase angle
75°
80°
ΔE ratio
Phase space area ratio
1.0
.1
.01
.001
.01
0.1
1.0