CONF-9

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AN ICRF ANTENNA EDGE PLASMA DENSITY PROFILE DIAGNOSTIC FOR DIII-D*

T.S. BIGELOW, G.R. HANSON, R.L. LIVESEY, J.B. WILGEN
I. COLLAZO(GIT)
Oak Ridge National Laboratory

E.J. DOYLE, T. RHODES
University of California at Los Angeles

J. DEGRASSIE, R. PHELPS
General Atomics Technologies

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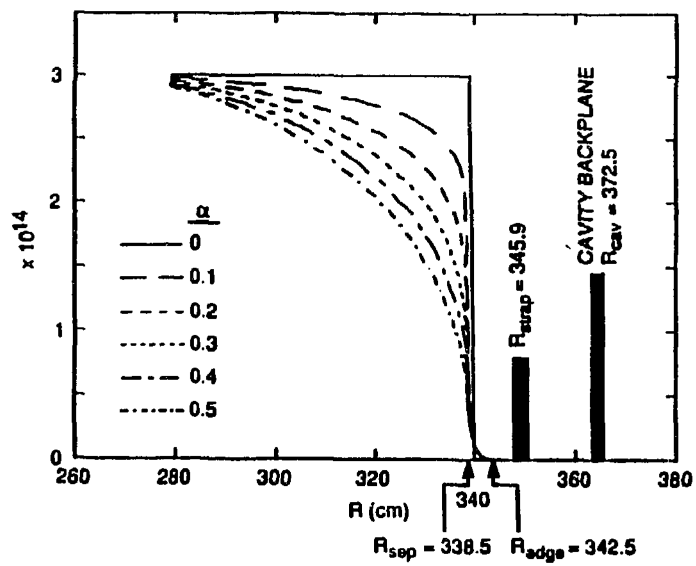
INTRODUCTION

- High power waves in the Ion Cyclotron Range of Frequencies (ICRF) are used for heating and current drive of plasmas in experimental fusion devices.
- ICRF power is launched from high current antennas located at the plasma edge. ICRF waves tunnel through the low density evanescent region at the plasma edge
- Antenna loading and antenna launch spectrum are important parameters affecting ICRF heating & current drive system performance
  - -Increasing loading reduces the antenna voltage and current
  - -Optimum launch spectrum maximizes current drive or heating efficiency
- Antenna coupling and launch spectrum are strongly influenced by the plasma edge density profile and edge location
  - -A 50% loading decrease typically results as a profile changes from gradual to steep
- There is evidence that high ICRF power levels steepen the density profile in front of the antenna due to ponderomotive and/or electric field effects driving off the plasma
- Edge density profile data is desired for ICRF antenna coupling studies
  - -Both the slope and edge location are important
  - -Measurement of the profile perturbation is desired
- ICRF heating & current drive are key experiments on the DIII-D tokamak at General Atomics
  - -A 2 MW transmitter operating from 30-60 MHz is presently available
  - -A four-strap antenna is used to couple power to the plasma
  - -Heating and current drive experiments are performed by adjusting phasing
- A microwave reflectometer system with a launcher as close as possible to the ICRF antenna is being developed for density profile measurements
  - + The experiment is a collaboration between ORNL, UCLA and GA
  - + The configuration uses existing UCLA reflectometer electronics
  - + ORNL is fabricating a new launcher mounted next to the ICRF antenna
  - + First operation with the new configuration is likely during early 1993

THEORETICAL ANTENNA LOADING CALCULATIONS

$n_e(R)$ FOR BPX (R_{axis} = 279 cm)



Power-parabolic density profiles $\{\sim |1-(r/r_{sep})^2|^{\alpha}\}$ converging to flat ($\alpha \to 0$) profile.

$\langle n_e \rangle = 2 \times 10^{20}$

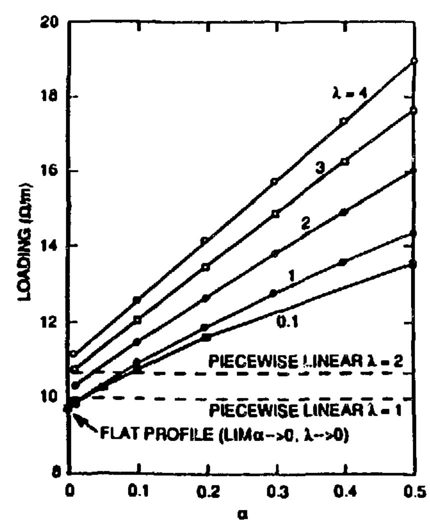


Fig. 6.26. Antenna loading, R', versus profile shape exponent, α.

BY D.B. BATCHELOR, ET AL. FOR BPX

MICROWAVE REFLECTOMETRY

- Microwave reflectometry has evolved as a successful technique for both plasma density profile and density fluctuation measurements

- A microwave reflectometer probes the location of the plasma cutoff layer
  - \+ A high frequency probe beam is launched into the plasma normal to the edge
  - \+ The beam propagates into the plasma until a density cut-off layer is reached which reflects the wave back toward the edge
  - \+ A receiving antenna collects a portion of the reflected signal
  - \+ The cutoff location is determined from the phase of the reflected signal
  - \+ Separate (bistatic) transmit & receive horns are desired to eliminate interference from transmission line reflections

- Profile measurements are performed using a swept frequency signal
  - +Phase shift vs. frequency is measured and inverted to estimate the profile

$$\phi_{measured} = \phi_{waveguide} + \phi_{vacuum} + \phi_{plasma}$$

$$\phi_{plasma}(f) = 2\, k_0 \int_{r_{edge}}^{r_{cutoff}} \mu_r(n_e, B_0, f)\, dr - \frac{\pi}{2}$$

  - +Total phase can amount to hundreds of 2π fringes
  - +The extraordinary plasma wave can measure a larger density range for a given frequency range and provide more resolution at low density

- Microwave reflectometers are ideally suited for density profile measurements near a high power ICRF antenna
  - +A true local profile measurement is obtained- not Abel-inverted cord measurements
  - +High speed, nearly continuous profile data is available
  - +The launchers are "hardened" against the plasma and high power ICRF fields

- Density fluctuations in the plasma make profile measurements difficult
  - -Large fluctuation levels cause unrealistic fringe jumps
  - \- Fluctuations cause random refractive effects which lead to amplitude fading
  - +High speed frequency sweep reduces the interference
  - +A dual-frequency differential-phase reflectometer with high dynamic range has been developed to reduce the fringe count and eliminate some of these effects

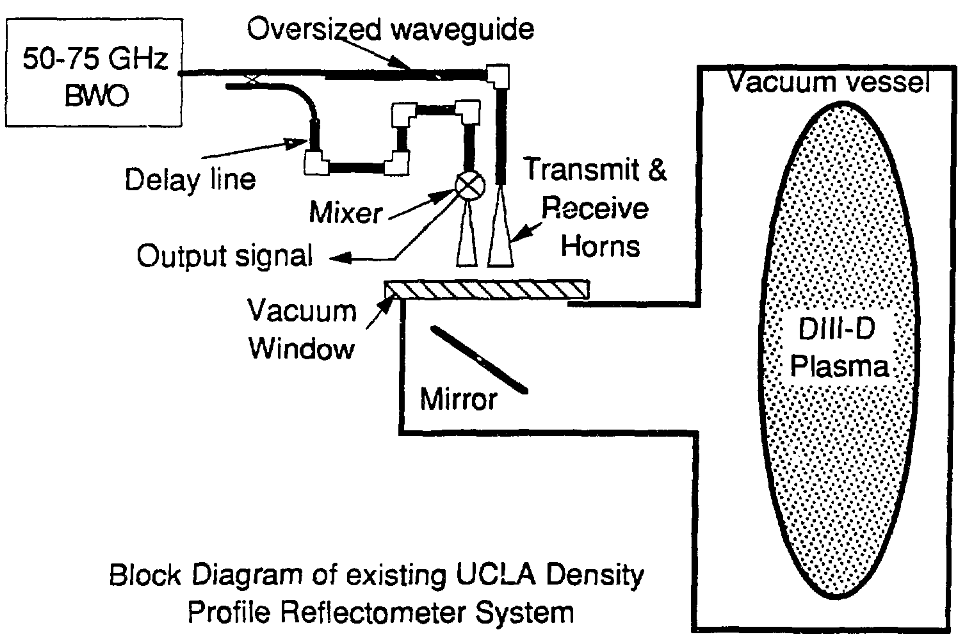
REFLECTOMETRY ON DIII-D

• Several successful reflectometer systems have been built and operated on DIII-D by UCLA

+Fixed and swept frequency types
+Profile measurements
+Fluctuation measurements
+High field launch system

• Profile measurements performed in 1990 using Q & V-band systems (Ref. E. J. Doyle, et al RSI**61**)

+47-75 GHz sweep for 2.1 T operation
+BWO source swept in 500 μsec
+Phase detector and delay line for reference
+Density range 0.2 to 4 x10^{19} m^{-3}
+Ohmic, L- and H-mode discharge profiles were successfully measured



Block Diagram of existing UCLA Density Profile Reflectometer System

A ICRF ANTENNA MOUNTED REFLECTOMETER ANTENNA SYSTEM FOR DIII-D

- A program was initiated on 2 tokamaks in 1991 to measure the plasma density profile in front of ICRF antennas to assist in improving their performance and modeling the results
  - +The existing ORNL antenna on DIII-D was being modified and it was convenient to add reflectometer antennas
  - +A differential reflectometer was developed for TFTR for use with a launcher mounted inside a new antenna

- A dual frequency system was designed to match the existing UCLA reflectometer
  V-band: 50-75 GHz
  Q-band: 33-50 GHz

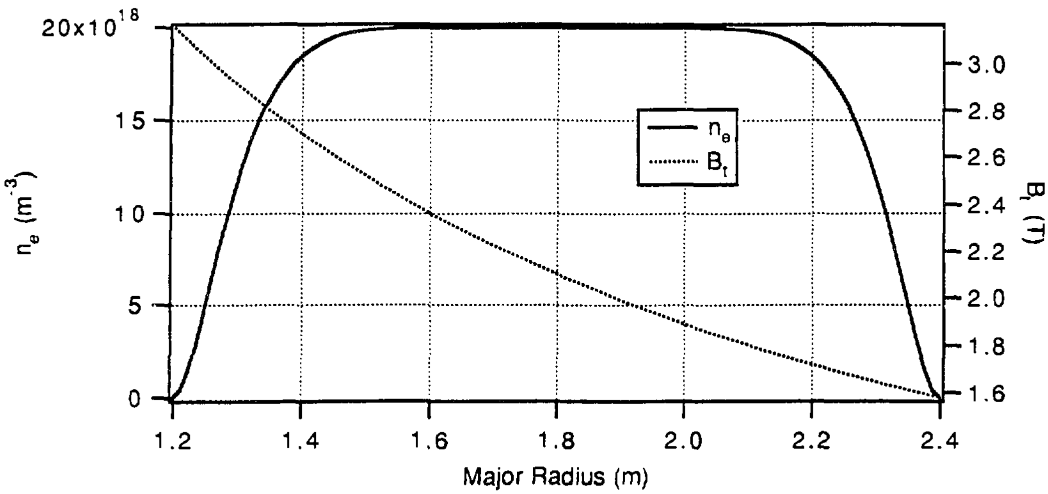
- Dual horn launchers are required to eliminate spurious response from waveguide reflections (windows, flanges, etc.)

- High quality horn radiation patterns are desired
  - -Low sidelobe levels and high polarization purity
  - -E-plane tilted ~12° to match X-mode polarization at the plasma edge

- Mechanical restrictions around the antenna made the launcher design difficult
  - -Small space for horns and transitions: broadband corrugated horns ruled out
  - -Feed waveguides insulated and braced for plasma disruptions
  - -Small port size for waveguide entry
  - -Wide band vacuum windows which meet bake-out requirements

- A graphite shield is desired for all plasma facing components

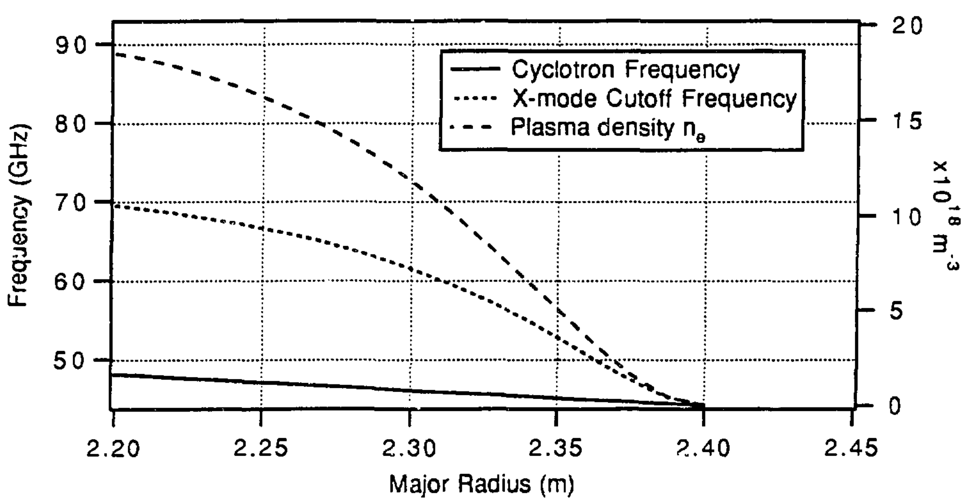
D-IIID Plasma Profile Simulation



H-mode parabolic density profile $n_e = n_{eo}\,(1-\rho^8)^2$

B_o on axis = 2.1 T

$n_{eo} = 2 \times 10^{13}\ cm^{-3}$



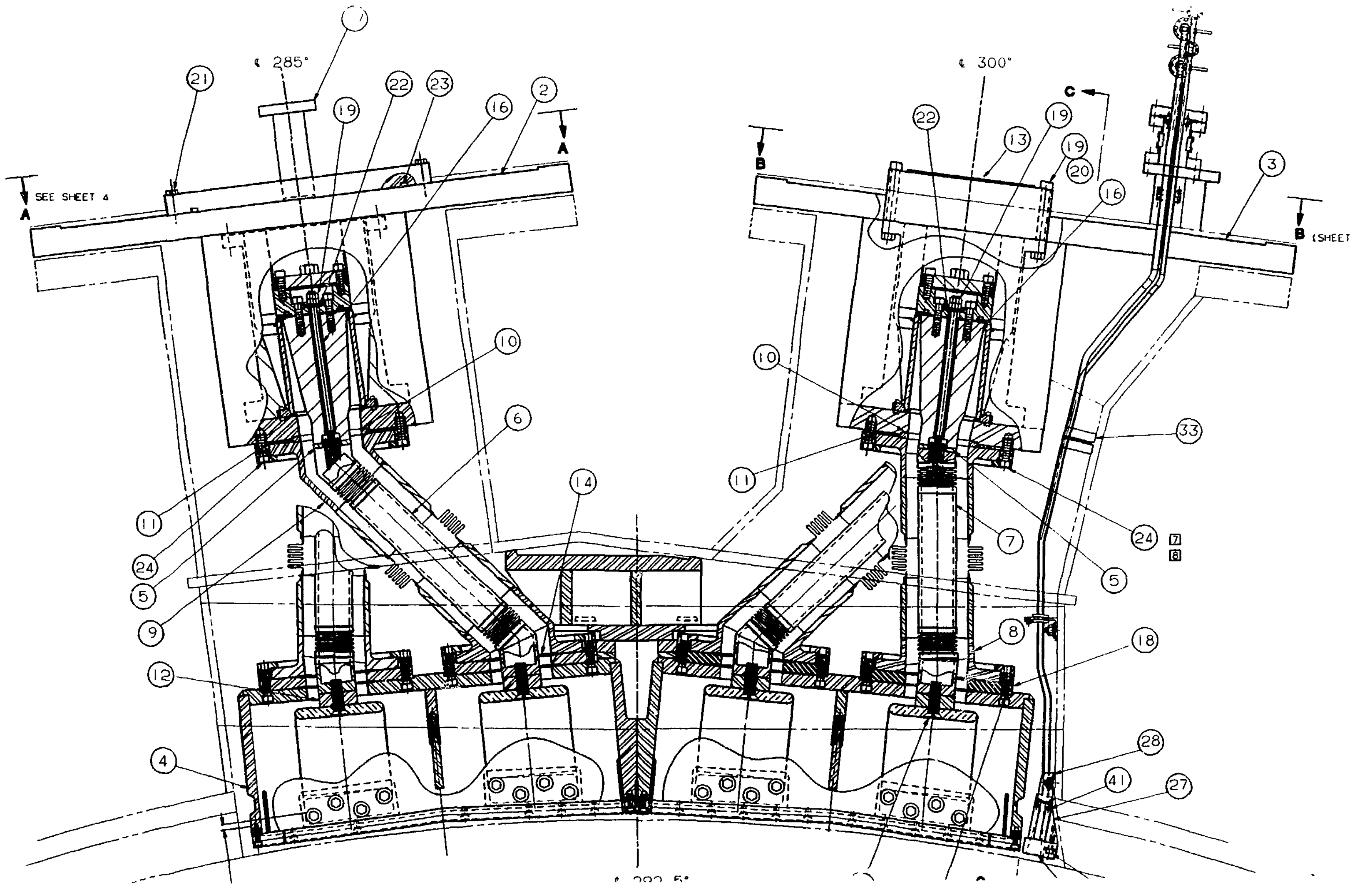
R_o=1.8m a=0.6m B_o=2.1T $n_{eo}=2\times10^{13}\ cm^{-3}$

$B=B_o{*}\,R_o/R \quad f_b=28*B$

$n_e = n_{eo}\ \times10^{19}(1-\rho^8)^2$

$f_{co} = 8.98{*}\mathrm{sqrt}(n_e)/10^9$

$f_{cx} = (f_b+\mathrm{sqrt}(f_b^2+4*f_{co}^2))/2$



℄ 285°
℄ 300°
SEE SHEET 4
A
A
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(SHEET
C
21
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6
11
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9
14
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13
19
19
20
3
16
10
11
33
7
24
5
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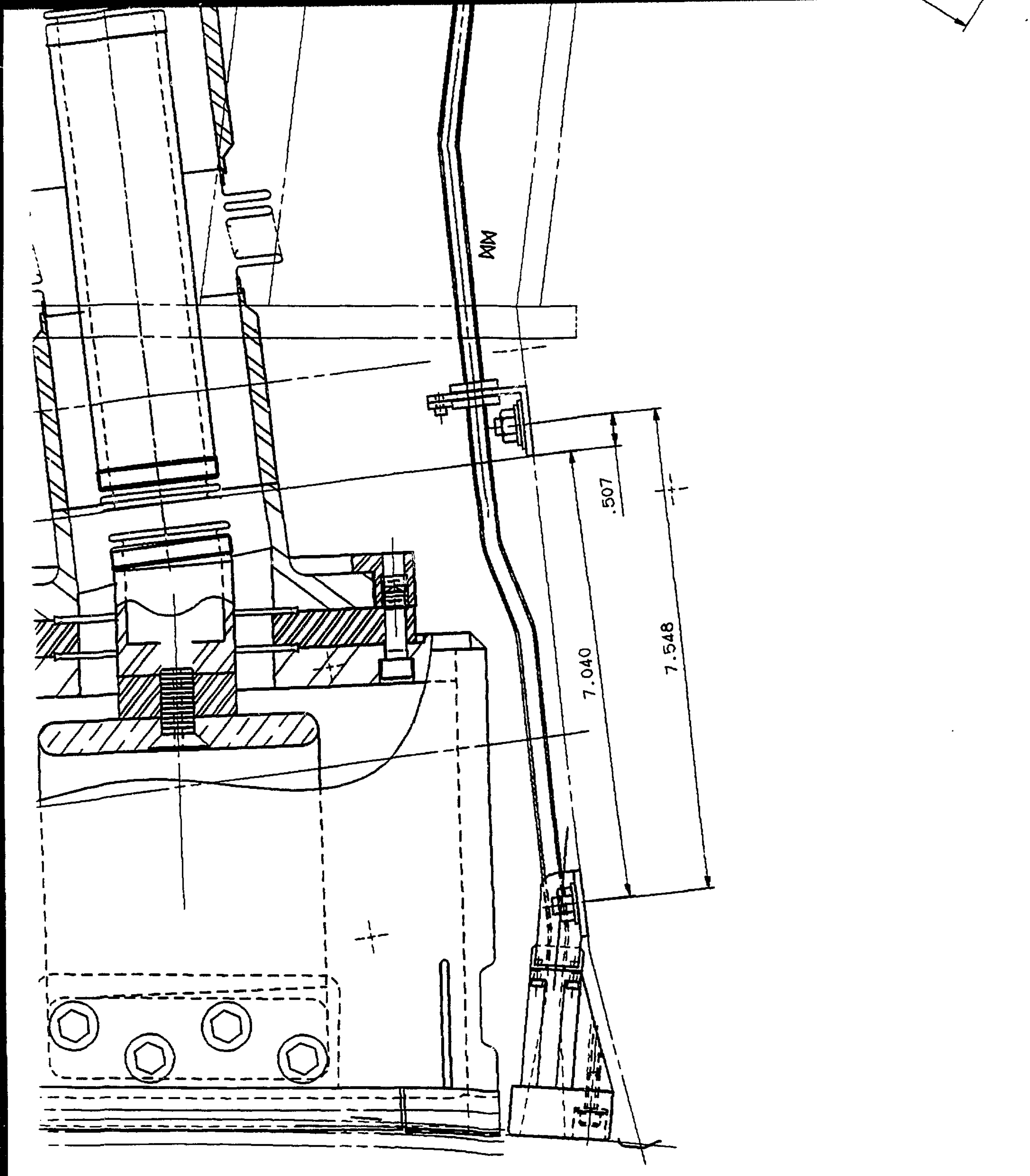
8
8
18
28
41
27

REFLECTOMETER ANTENNA AND WAVEGUIDE FABRICATION

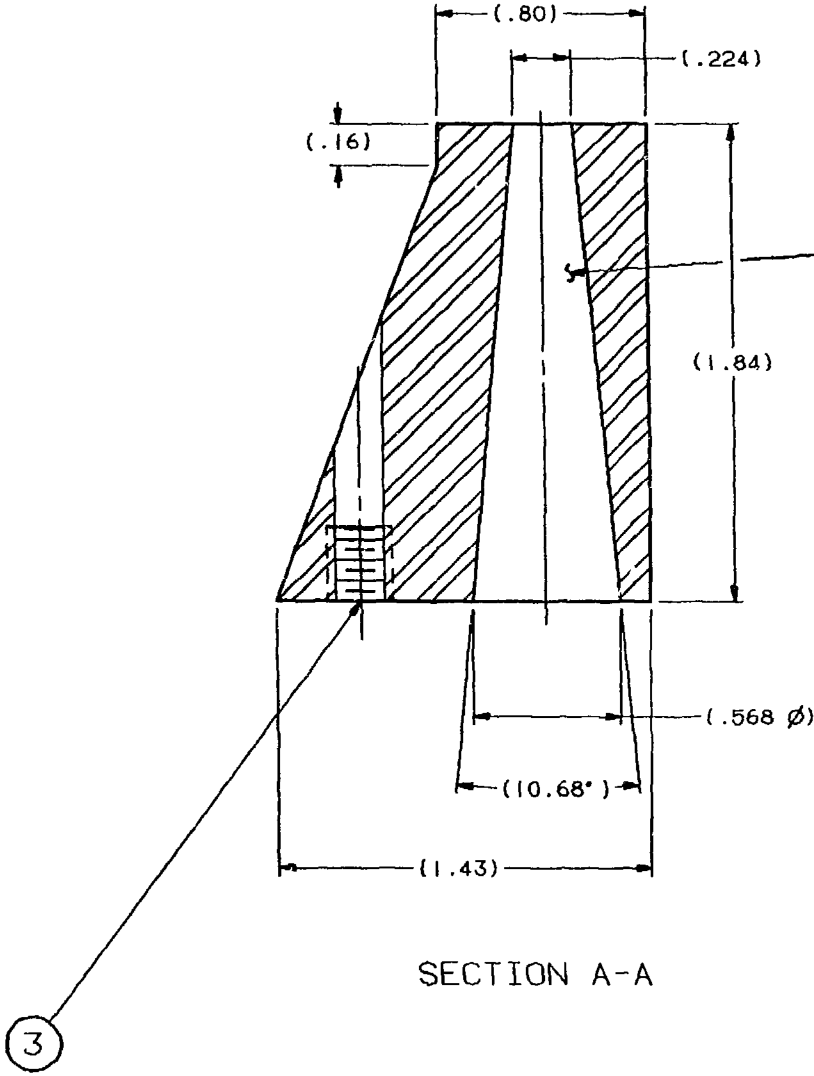
- Waveguide horns and transitions were formed in a single stainless steel block
  - +Wire electro-discharge machining (EDM) of rectangular to circular transition
  - +Outer 2-cm of the horns formed into a graphite block with a slight flare
  - +V-band circular apertures 1.6 cm diameter with 10.6° flare
  - +Q-band circular apertures 1.8 cm diameter with 10.6° flare
  - +Horn assembly attached to the DIII-D vessel wall with a bracket & studs

- Coin silver waveguide used to connect horns to outside the vacuum vessel
  - +Silver is preferred for forming complicated routes
  - +Low temperature ~600°C braze used to preserve temper
  - +Special "quad" flanges used for joints with raised bosses to minimize signal cross-coupling
  - +Waveguide insulated at the port end with a vacuum break and with BN bushings at a support bracket

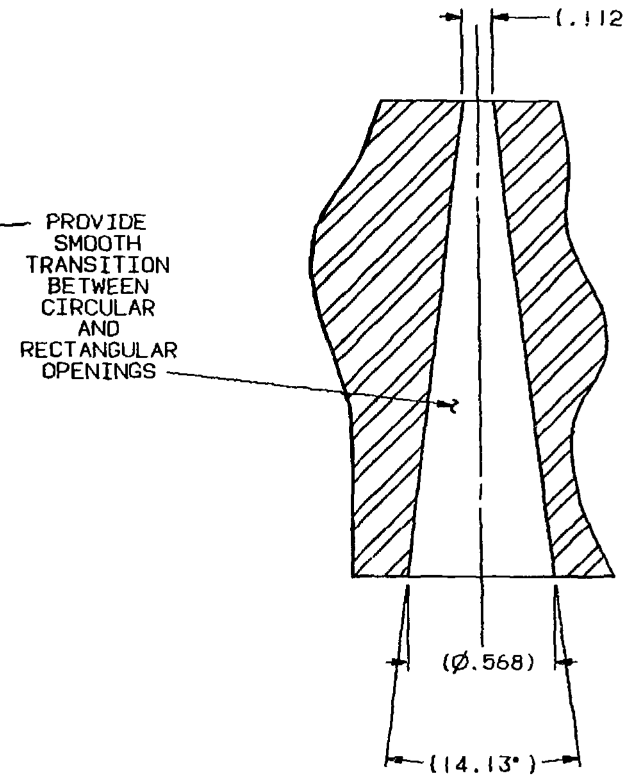
- Waveguide vacuum windows
  - +Thin mica used to reduce reflections (0.076 mm or 0.003" thick)
  - +Dual windows not used due to excessive frequency variation in VSWR
  - +Viton O-rings for vacuum seal
  - +Temperature rating to 150°C
  - +Back-up vacuum can designed to cover up window assembly if a leak occurs


XIX
.507
7.040
7.548

H
G
F
E



SECTION A-A



SECTION D-D

PERFORMANCE MEASUREMENTS

- Antenna patterns closely match predictions
  - V-band @ 62.5 GHz: ~18° HPBW
  - Q-band @ 40 GHz: ~30° HPBW

- Reflections from windows
  - V-band: ~-10dB RL = 1.9:1 VSWR
  - Q-band: ~-10dB RL = 1.9:1 VSWR

- Waveguide loss (total R+T)
  - V-band: 4dB
  - Q-band: 3dB

- Cross coupling between horns minimized
  - Slots used to reduce direct signal further
  - V-band: <-53dB
  - Q-band: <-45dB

- Signal vs. distance from horn aperture using a flat plate reflector
  - V-band: 10-20dB as plate varies from 5-55 cm
  - Q-band: 10-25dB as plate varies from 5-55 cm

- Small second order interference seen from 2-bounce signals. Graphite face beveled to reduce the effect

V band, 62.5 GHz 1.65cm ϕ

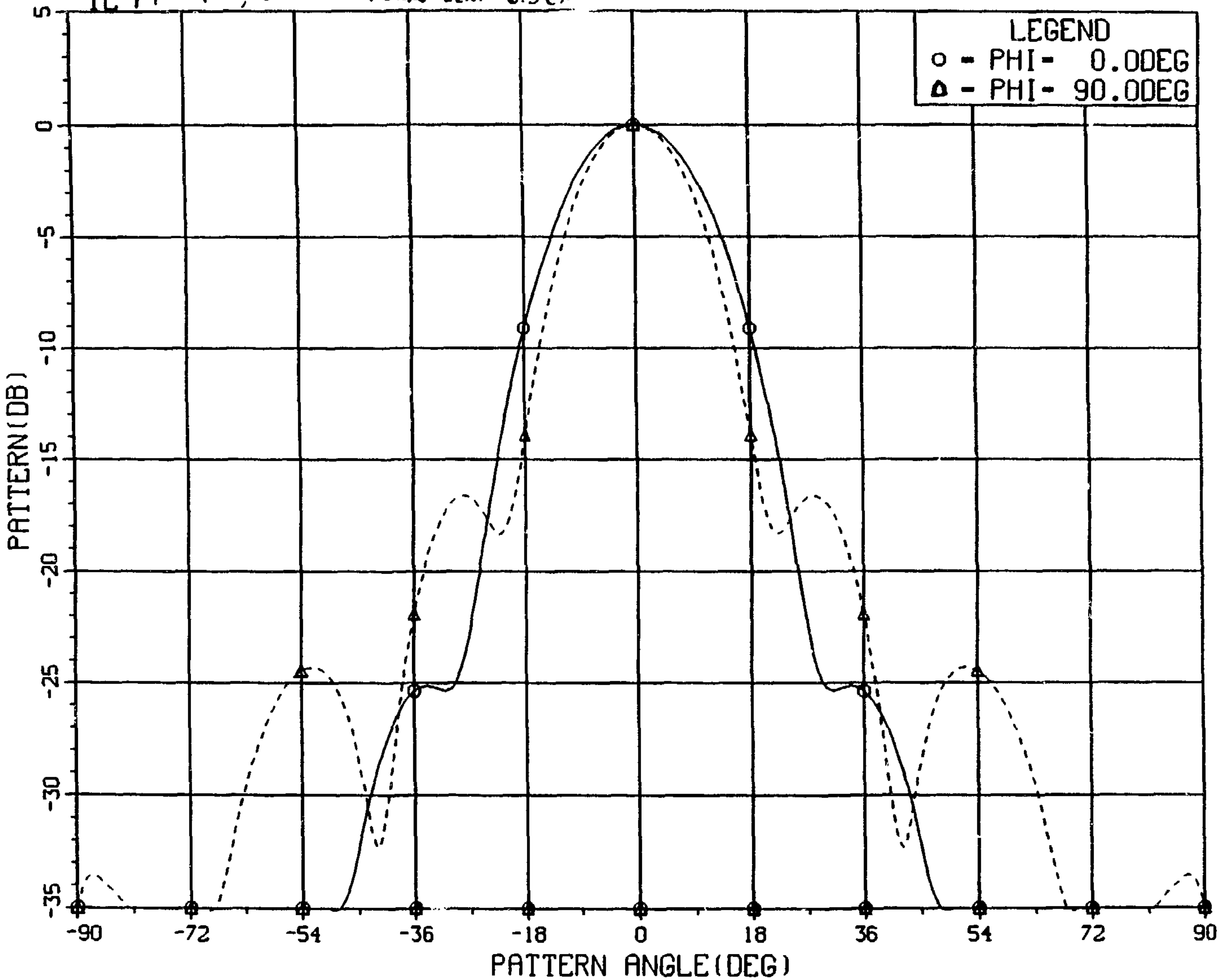
Smooth Wall Horn
20 cm range length

NEAR FIELD PATTERN

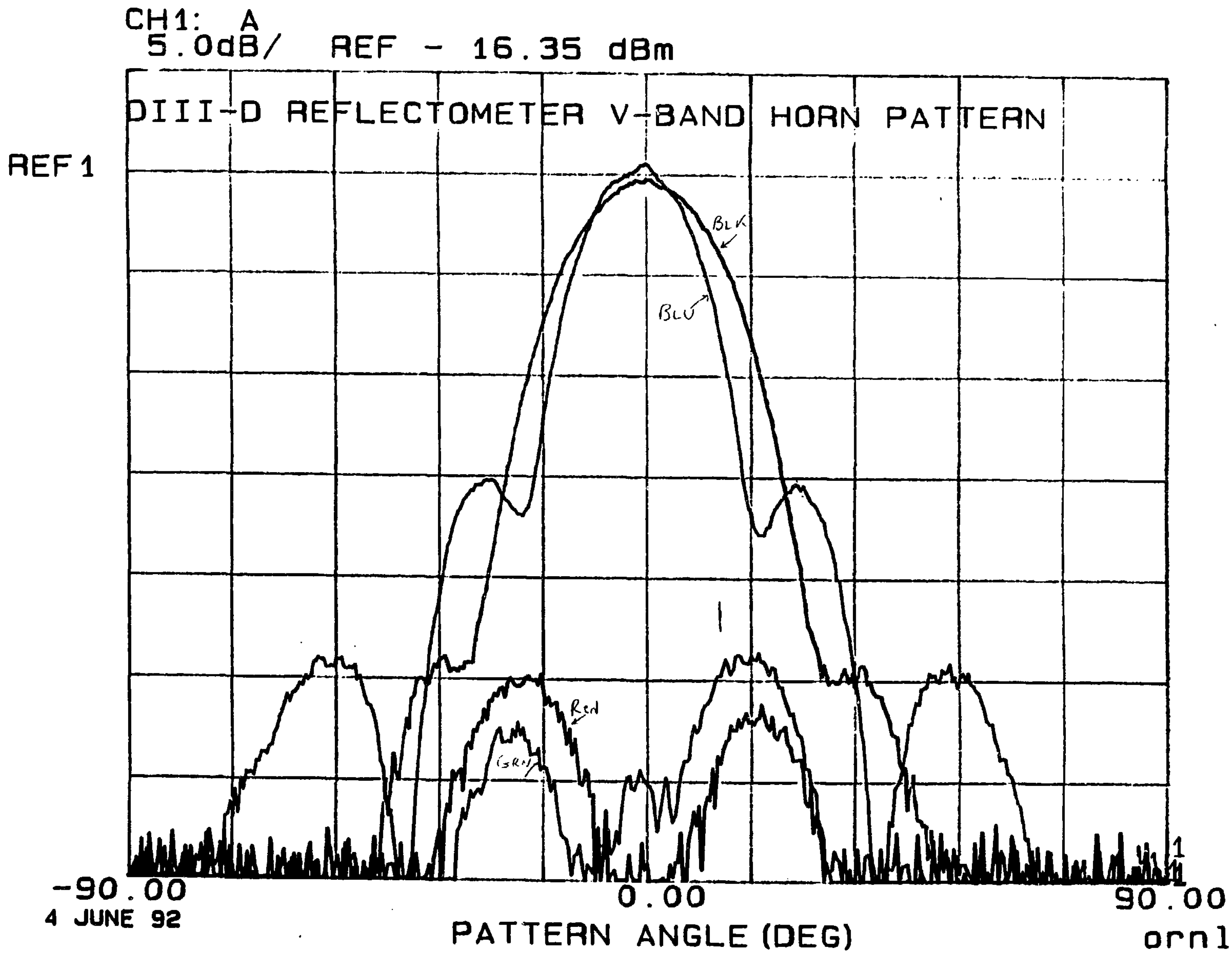
——EPHI ---ETHETA

F= 62.5 G=87.09 EM=.223E+02 R= 20.0 PHO= 0.000 THO= 0.000
NAPTS=1257 ATILT= 0.00 NX= 20 NY= 20 WX= 0.825 WY= 0.8

TE 11 1.0, 0.0 HORN LEN. 6.5cm



PLOT 1 14.32.58 THUR 31 OCT, 1991 JOB=TBI , MARTIN MARIETTA ENERGY SYSTEMS DISSPLA 10.5



30 cm range

Horn rotated ≈12° for max or min signal

≈ H plane (horiz)

62.5GHz

BLK Emax

Red X-Pole

≈ E plane (vert)

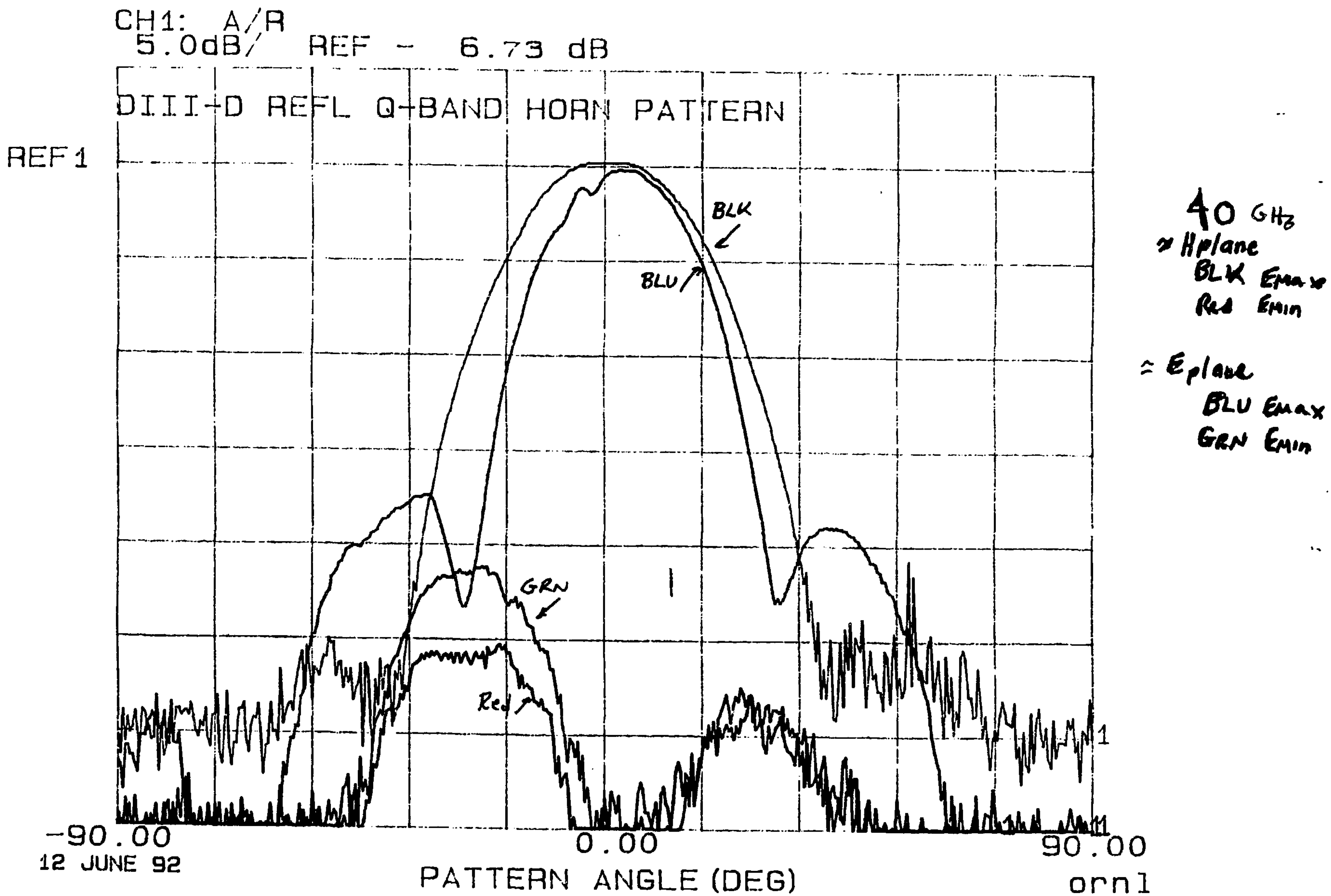
BLU Emax

Grn Xpol

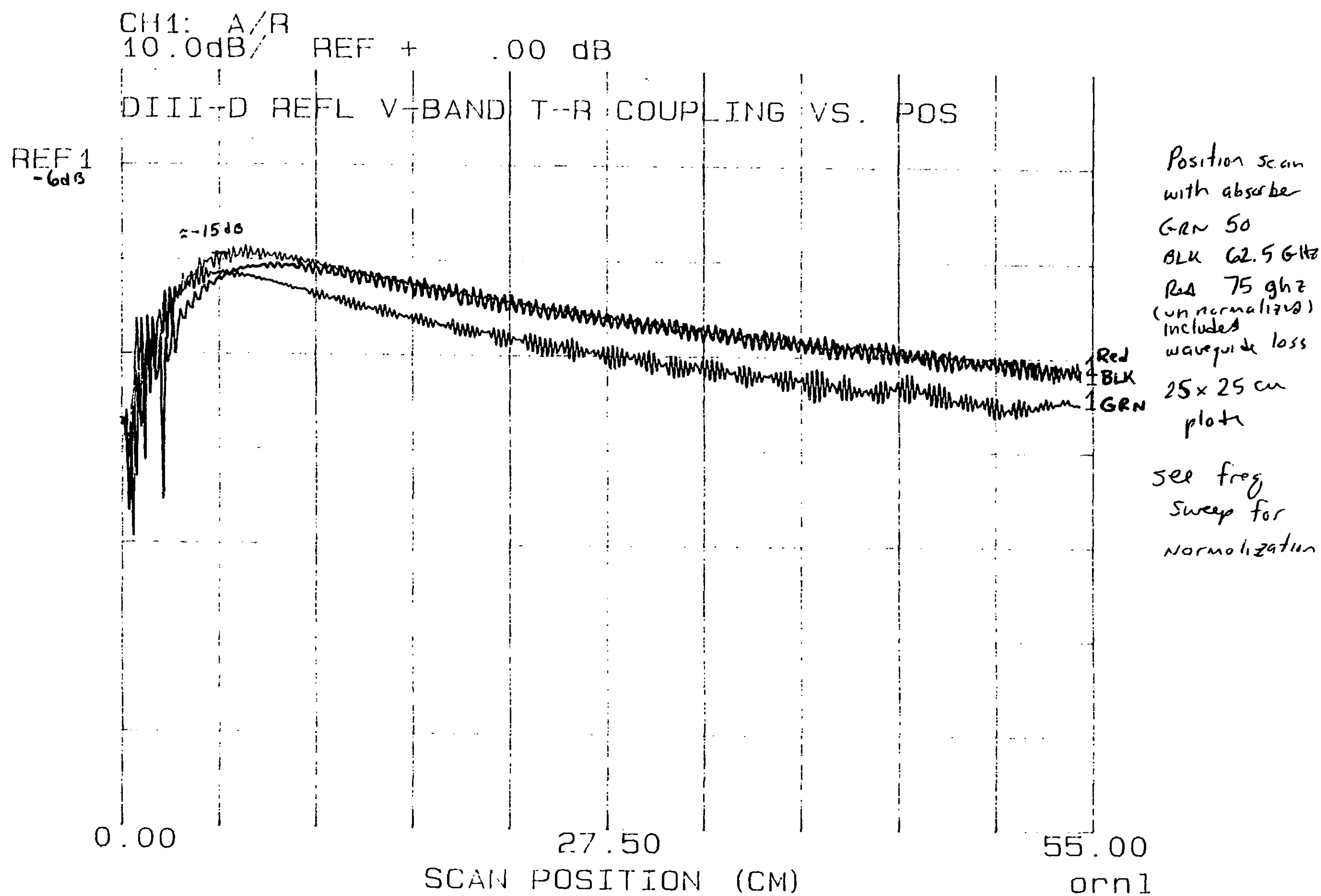
Hplane

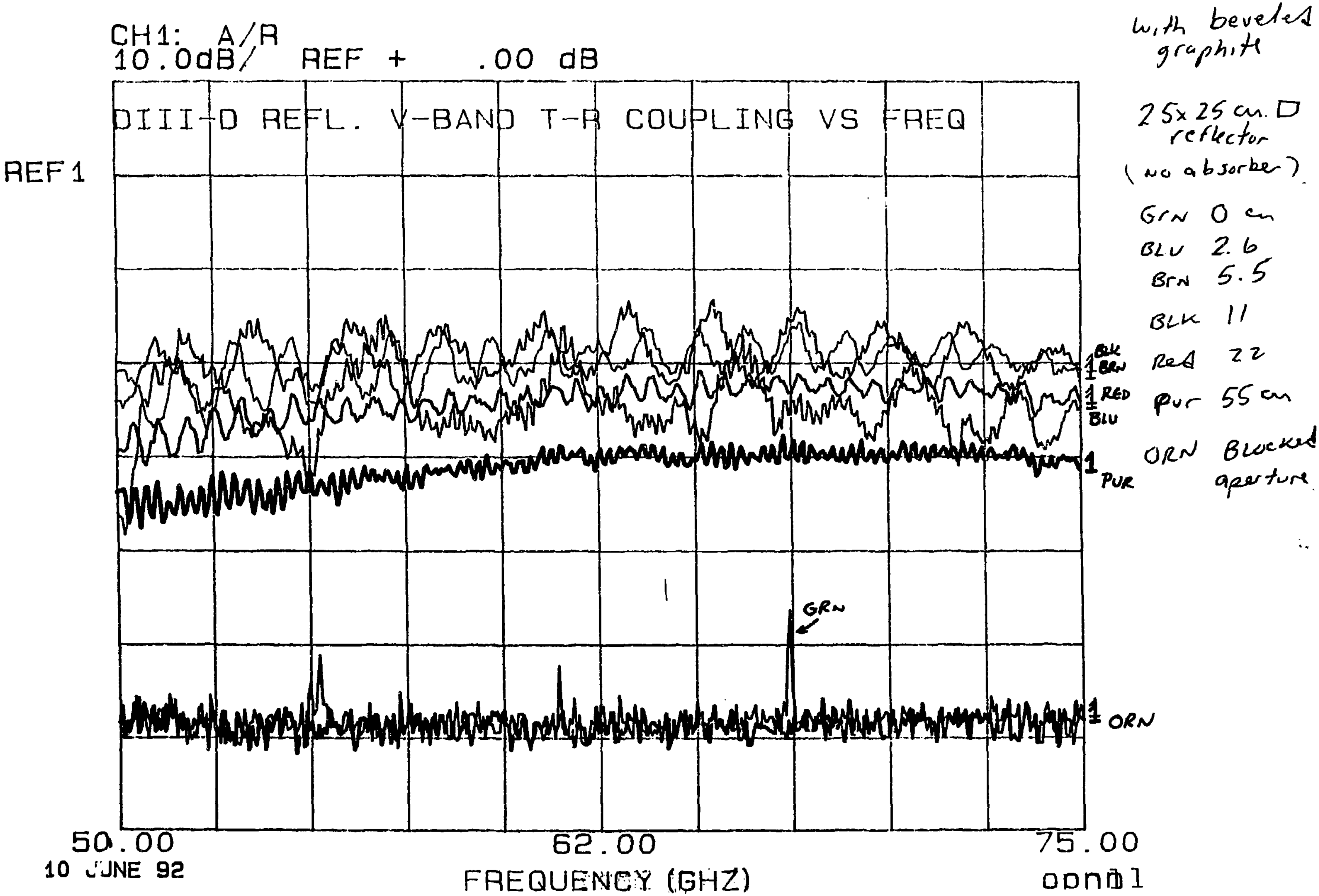
Eplane

1.3 X 0.8 cm receiving horn

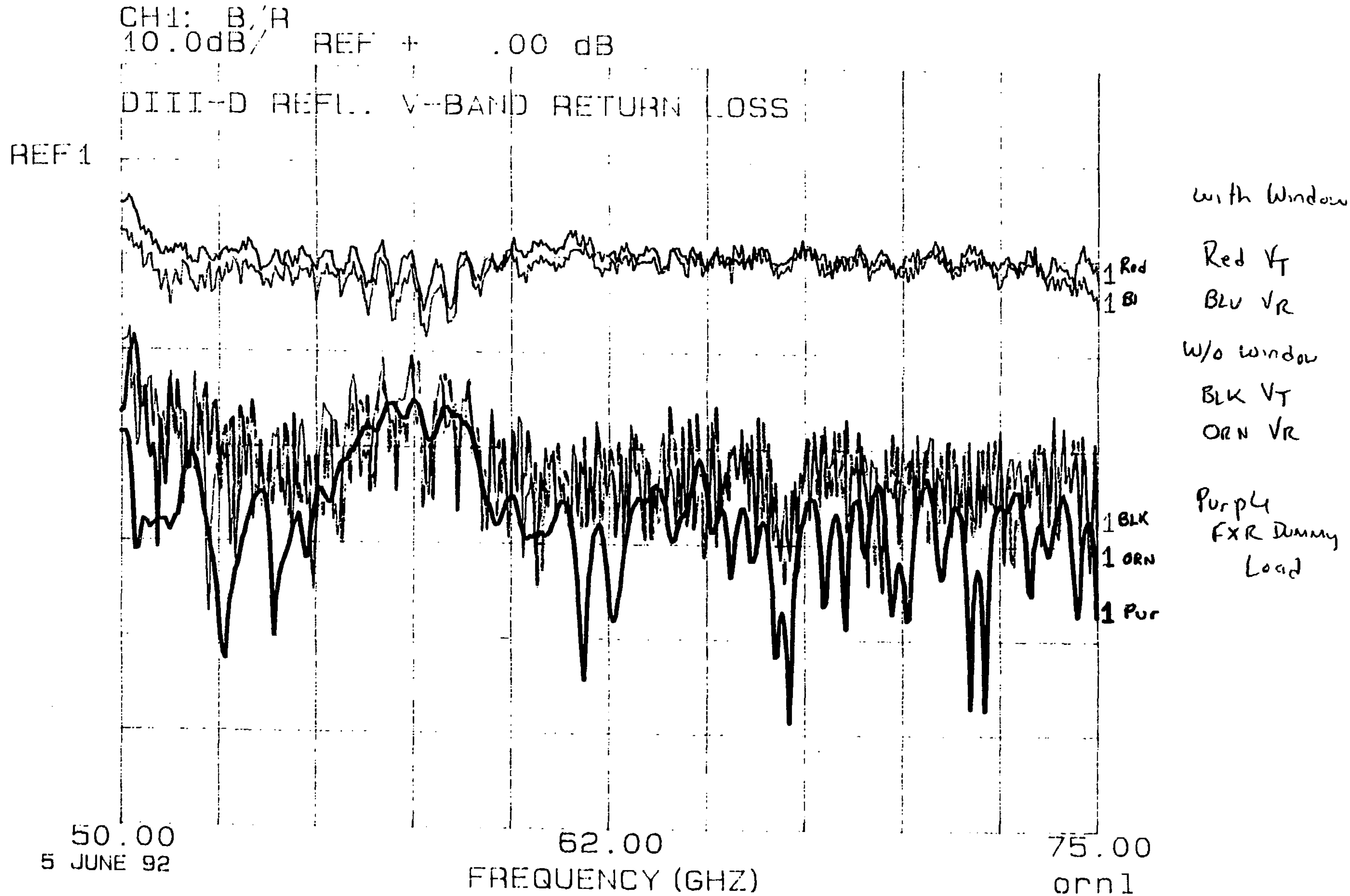


CH1: A/R
5.0dB/ REF - 6.73 dB
DIII-D REFL Q-BAND HORN PATTERN
REF1
BLK
BLU
GRN
Red
1
-90.00
12 JUNE 92
0.00
PATTERN ANGLE (DEG)
90.00
ornl
40 GHz
≈ Hplane
BLK Emax
Red Emin
≈ Eplane
BLU Emax
GRN Emin


CH1: A/R
10.0dB/ REF + .00 dB
DIII-D REFL V-BAND T-R COUPLING VS. POS
REF 1
-6dB
≈-15dB
Red
BLK
GRN
0.00
27.50
55.00
SCAN POSITION (CM)
ornl
Position scan
with absorber
GRN 50
BLK 62.5 GHz
Red 75 ghz
(unnormalized)
included
waveguide loss
25 × 25 cm
plots
see freq
sweep for
normalization



CH1: A/R
10.0dB/ REF + .00 dB
DIII-D REFL. V-BAND T-R COUPLING VS FREQ
REF 1
BLK
BRN
RED
BLU
PUR
ORN
GRN
50.00
62.00
75.00
10 JUNE 92
FREQUENCY (GHZ)
with beveled graphite
25x25 cm. □ reflector
(no absorber)
Grn 0 cm
BLU 2.6
Brn 5.5
BLK 11
Red 22
Pur 55 cm
ORN Blocked aperture


CH1: B/R
10.0dB/ REF + .00 dB
DIII-D REFL. V-BAND RETURN LOSS
REF 1
1 Red
1 Bl
1 BLK
1 ORN
1 Pur
50.00
5 JUNE 92
62.00
FREQUENCY (GHZ)
75.00
ornl
with Window
Red V_T
BLU V_R
W/o window
BLK V_T
ORN V_R
Purple
FXR Dummy
Load

PLANNED MEASUREMENTS WITH THE UCLA REFLECTOMETER ELECTRONICS

- Waveguide is being installed to connect the ICRF antenna mounted horns to the UCLA electronics system which is located several ports away

- Installation will be completed soon

- Calibration necessary for phase reference to be performed using in-vessel dummy reflector
  -some post calibration may be necessary since access to horns is limited

- Several experiments have been proposed
  +Study the effect of profile changes on loading
  +Study the effect of the ICRF power level on the profile
  +Is there significant toroidal variation in the profile perturbation?
  +Comparison between reflectometer horn configurations on performance

PROPOSED FUTURE MEASUREMENTS USING THE ORNL TFTR REFLECTOMETER SYSTEM

- A dual-frequency reflectometer system was developed at ORNL for ICRF antenna density profile measurement on the TFTR tokamak at PPPL

- The dual-frequency system uses two swept frequency probe beams for a differential phase measurement

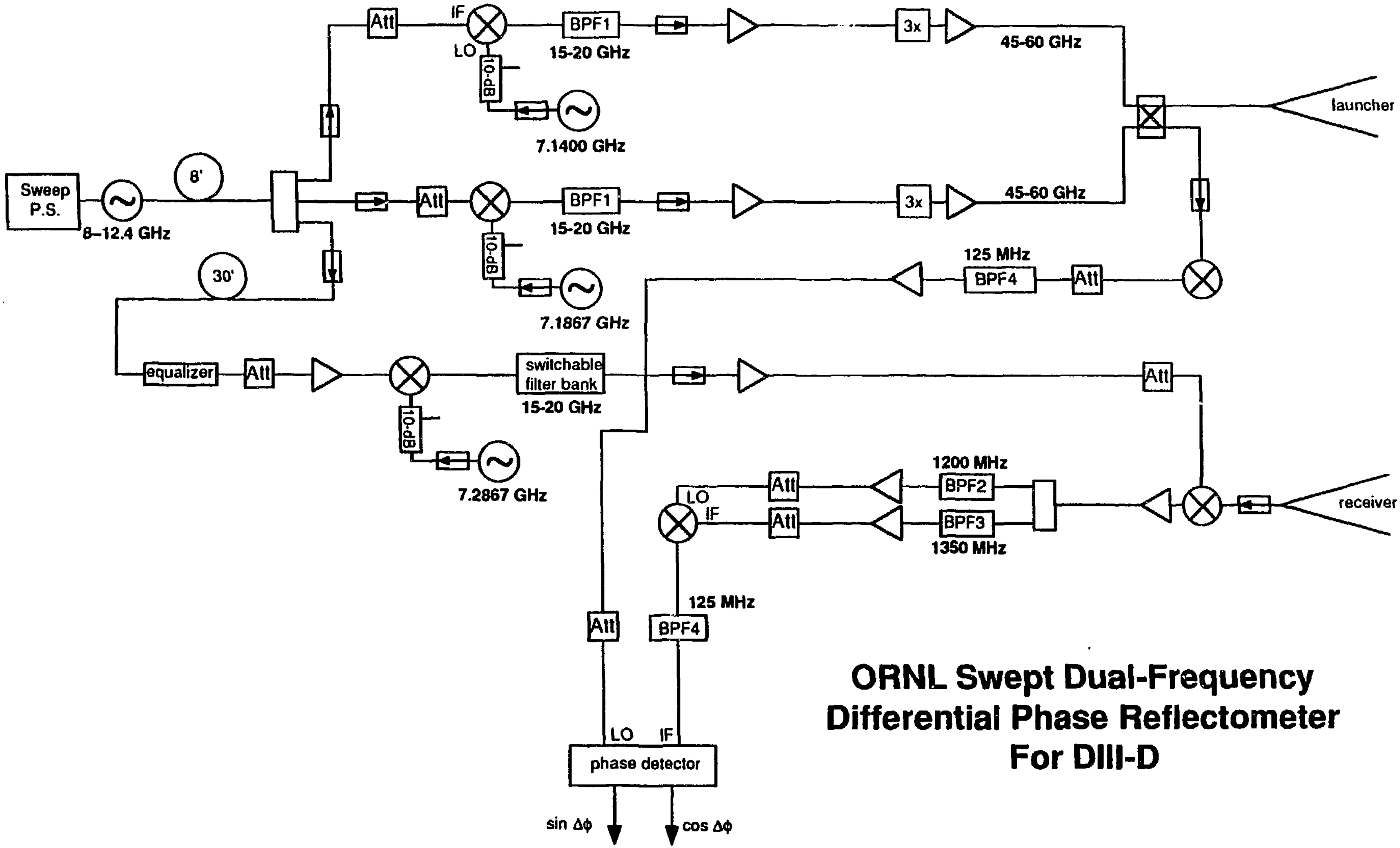
  Several advantages result:
  +Reduction of the fringe count to <5
  + Cancellation of the effect of a large portion of the density fluctuations
  +Larger dynamic range possible since the system is a heterodyne type
  +All solid-state electronics
  +Significantly faster sweep speeds are possible
  +Long waveguide runs produce no fringes and significantly reduce calibration problems

  Some disadvantages exist which have been largely worked out:
  -A large number of components increases the costs
  -Some interference occurs at certain frequencies where mixer intermodulation products overlap with the IF frequency

- Initial measurements using this system have been performed on TFTR and the results are encouraging. Some improvements are being implemented for the D-T operation phase of TFTR

- This system will no longer be needed on TFTR in ~1.5 years at which time it can be easily modified to sweep from 45-60 GHz which is suitable for DIII-D edge plasma profiling

- Moving the electronics to DIII-D and incorporating them into the UCLA system has been proposed and could occur in 1994.



ORNL Swept Dual-Frequency Differential Phase Reflectometer For DIII-D

TYPICAL MEASURED PROFILE DATA