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ESA
The Netherlands

CALIBRATION

PRACTICAL EXPERIENCE WITH ERS-1

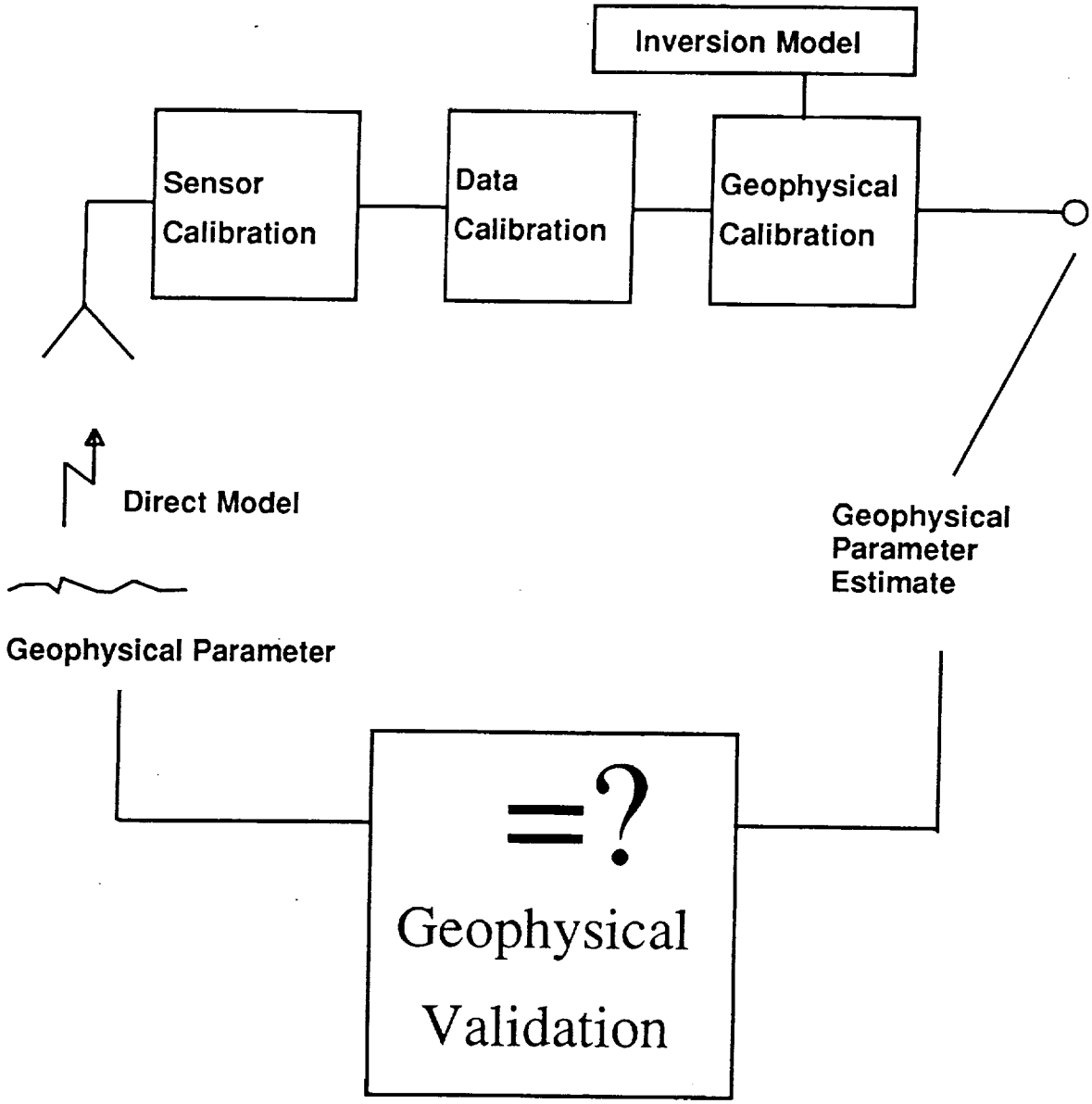
- Introduction
- Radiometric Calibration
- Geometric Calibration
- Phase Calibration
- Polarimetric Calibration

Introduction

Basic SAR measurement parameters are :

- Radar backscattering
- Target position
- Target speed
- Polarisation

SAR calibration facilitates ***quantative*** measurements needed to derive geophysical parameters of the area under observation from basic SAR measurements (e.g. soil moisture, biomass,ocean wave energy,ocean currents, ice type, ice flow,.....)


Inversion Model
Sensor Calibration
Data Calibration
Geophysical Calibration
Direct Model
Geophysical Parameter Estimate
Geophysical Parameter
=?
Geophysical Validation

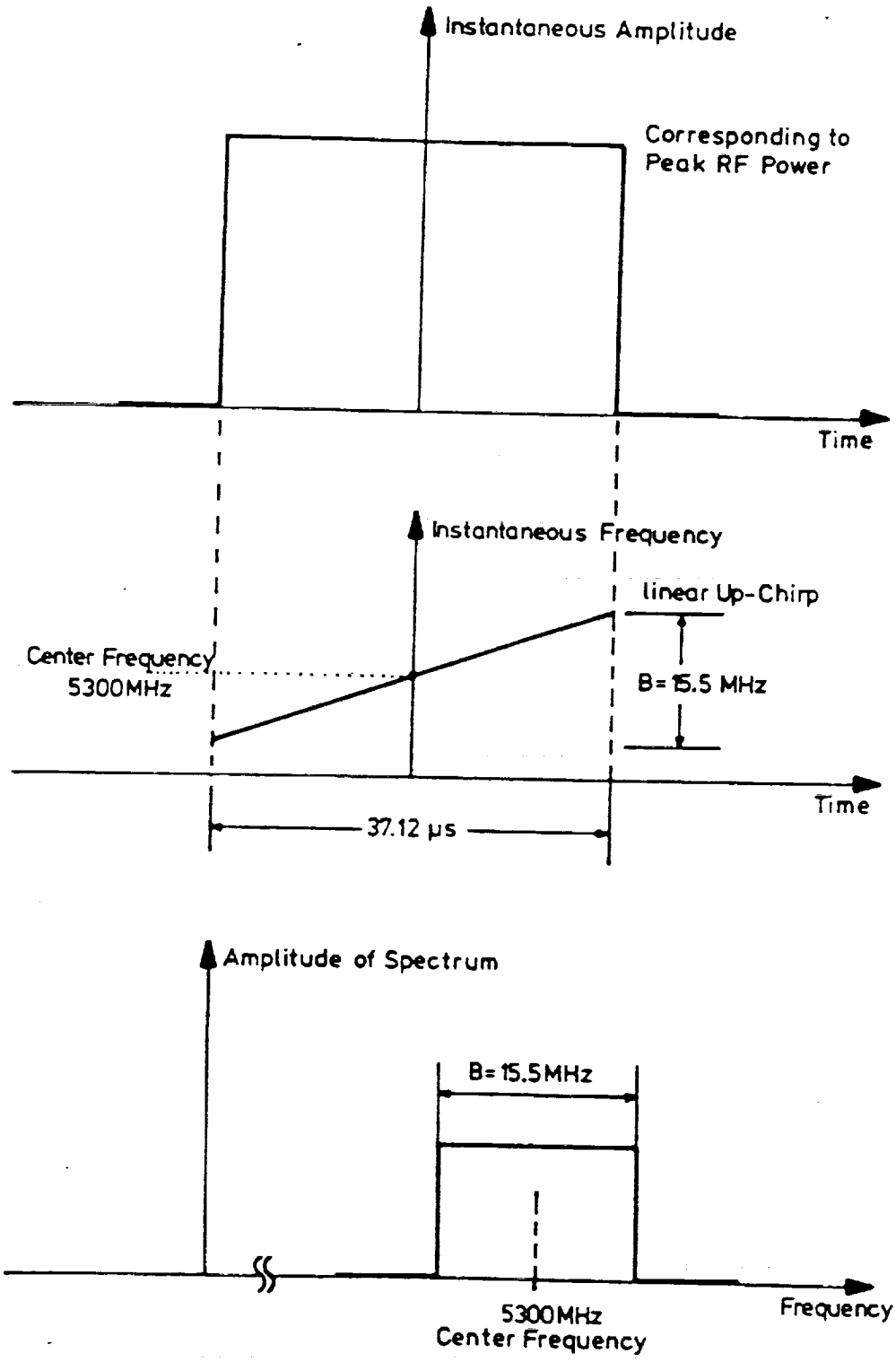
Radiometric Calibration

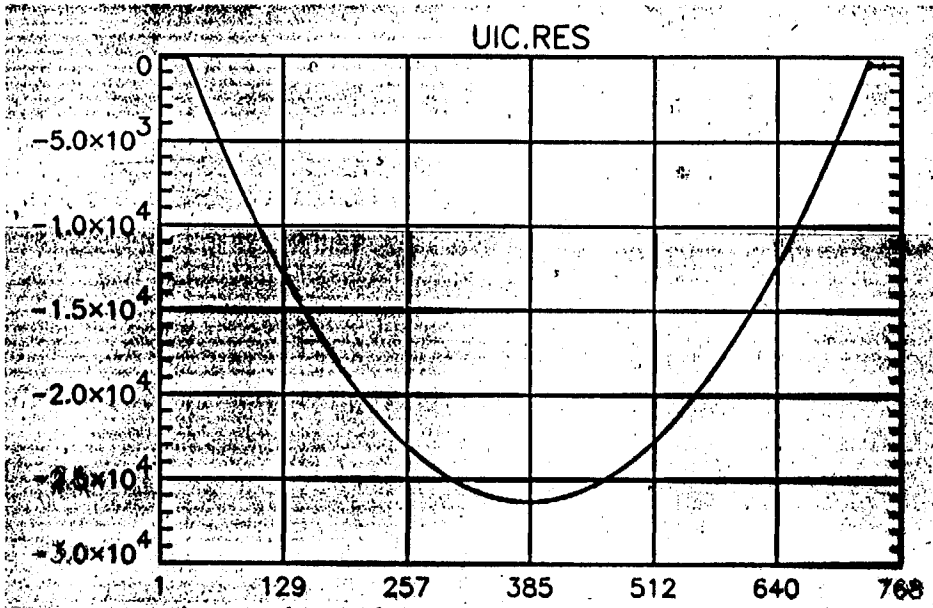
Radiometric calibration is relating the SAR output in terms of digital number to σ^o.

- Design for stability
- Sensor calibration
  - — pre-flight characterisation
  - — internal calibration
  - — external calibration
- Data calibration

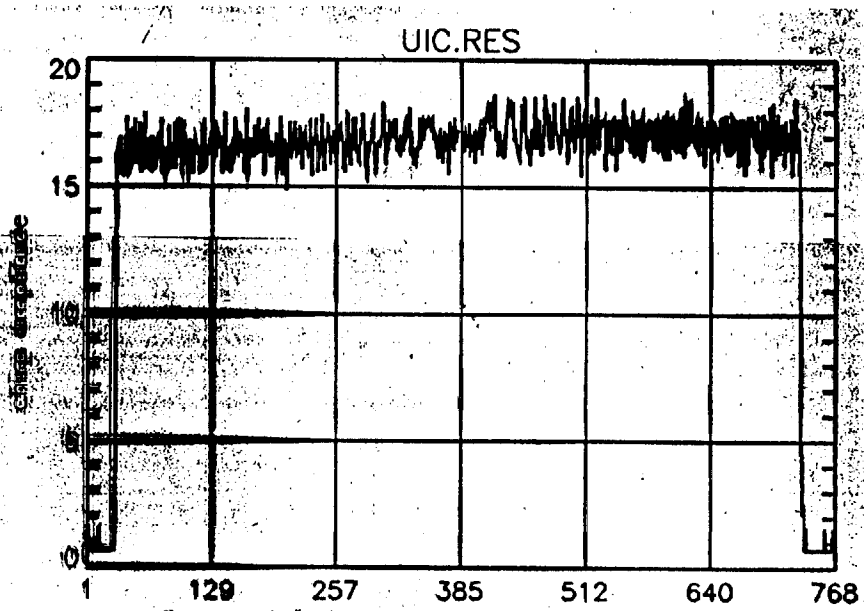
Characterisation parameters for ERS-1

- Transmitter Parameters
  - — Frequency
  - — Pulse power
  - — Pulse duration
  - — Chirp bandwidth
- Antenna Parameters
  - — Relative azimuth pattern
  - — Absolute elevation pattern
- Receiver Parameters
  - — Sensitivity
  - — Bandwidth
  - — Power transfer function
- Calibration Parameters
  - — Internal calibration stability


Instantaneous Amplitude
Corresponding to
Peak RF Power
Time
Instantaneous Frequency
linear Up-Chirp
Center Frequency
5300MHz
B=15.5 MHz
Time
37.12 µs
Amplitude of Spectrum
B=15.5MHz
5300MHz
Center Frequency
Frequency

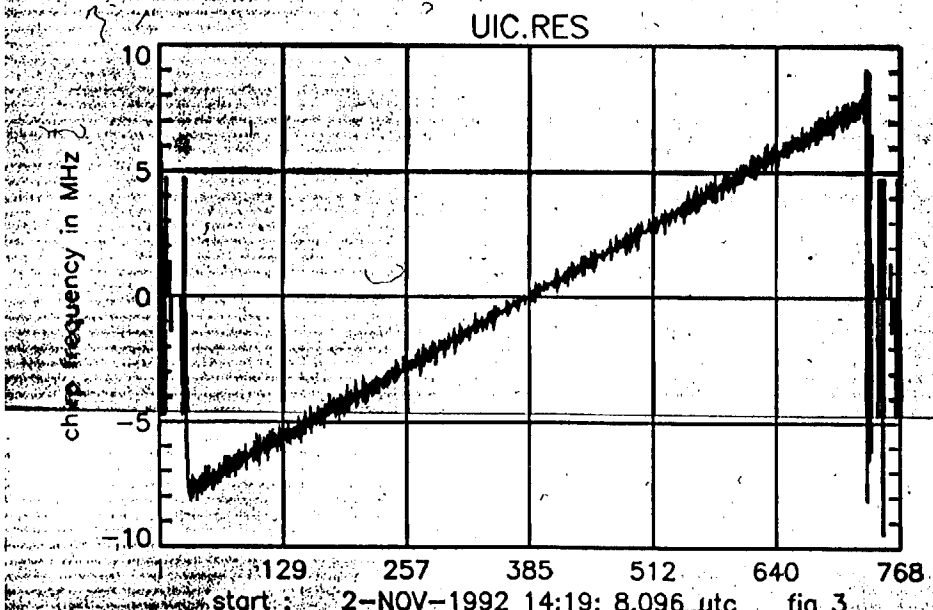


jpg plotting : 12-Nov-1992 10:30:48.00_local fig 1

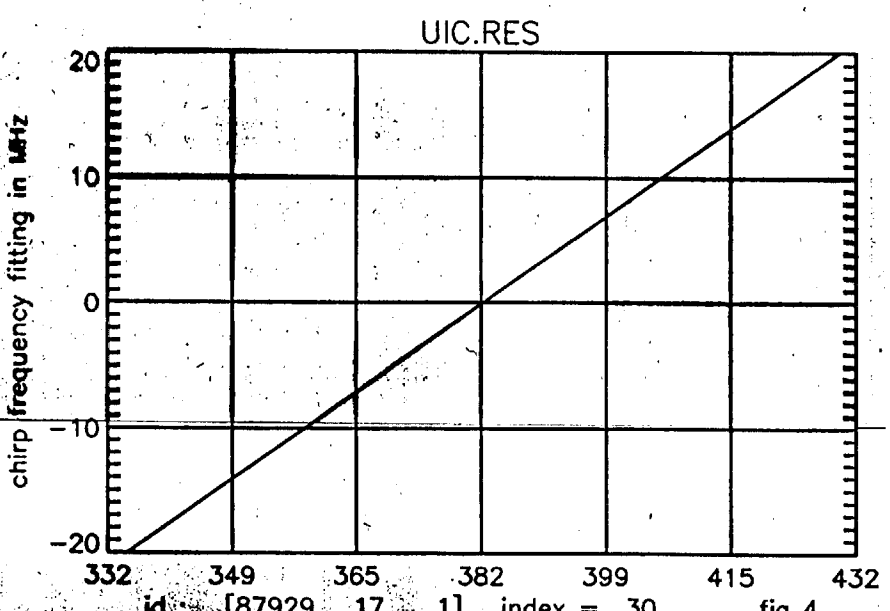


file : uic$:uic__921102kscf9928.e1;1 fig 2

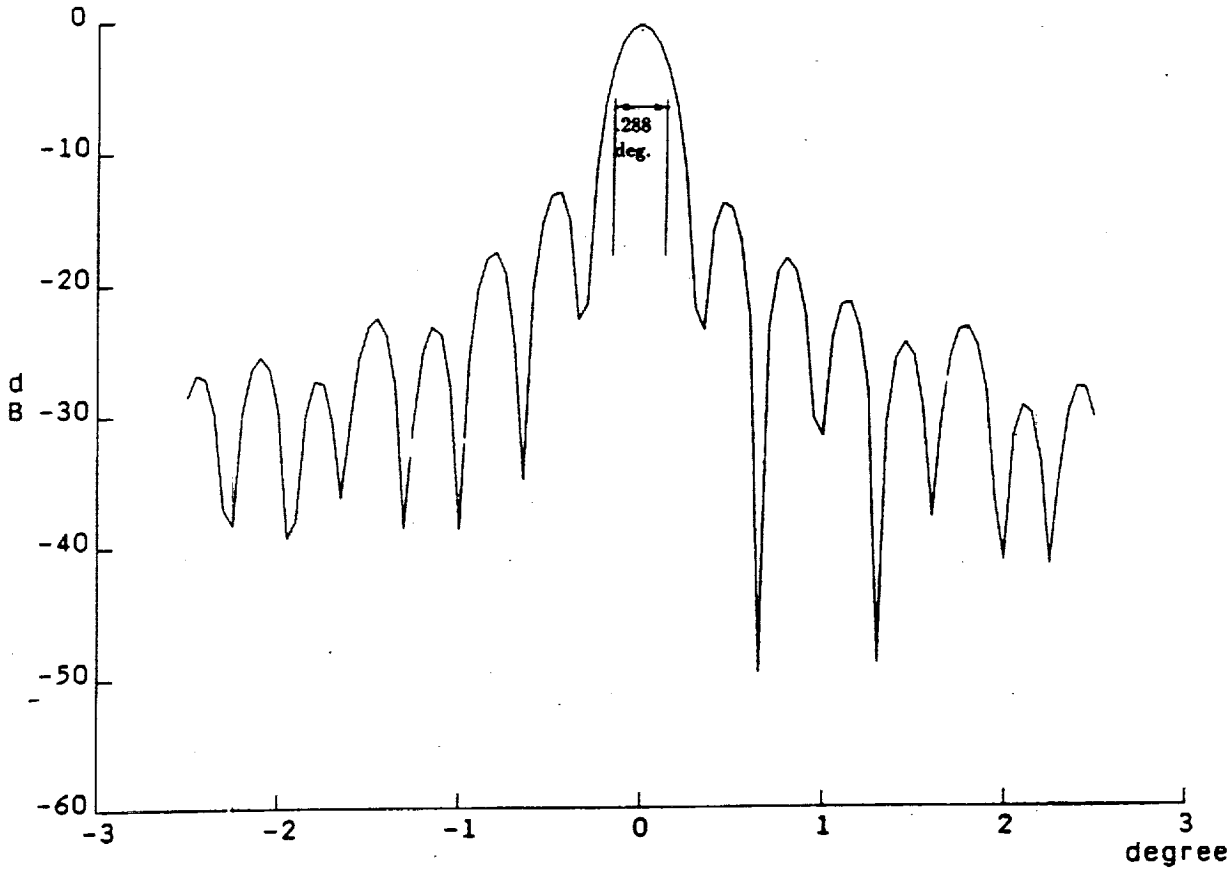
305

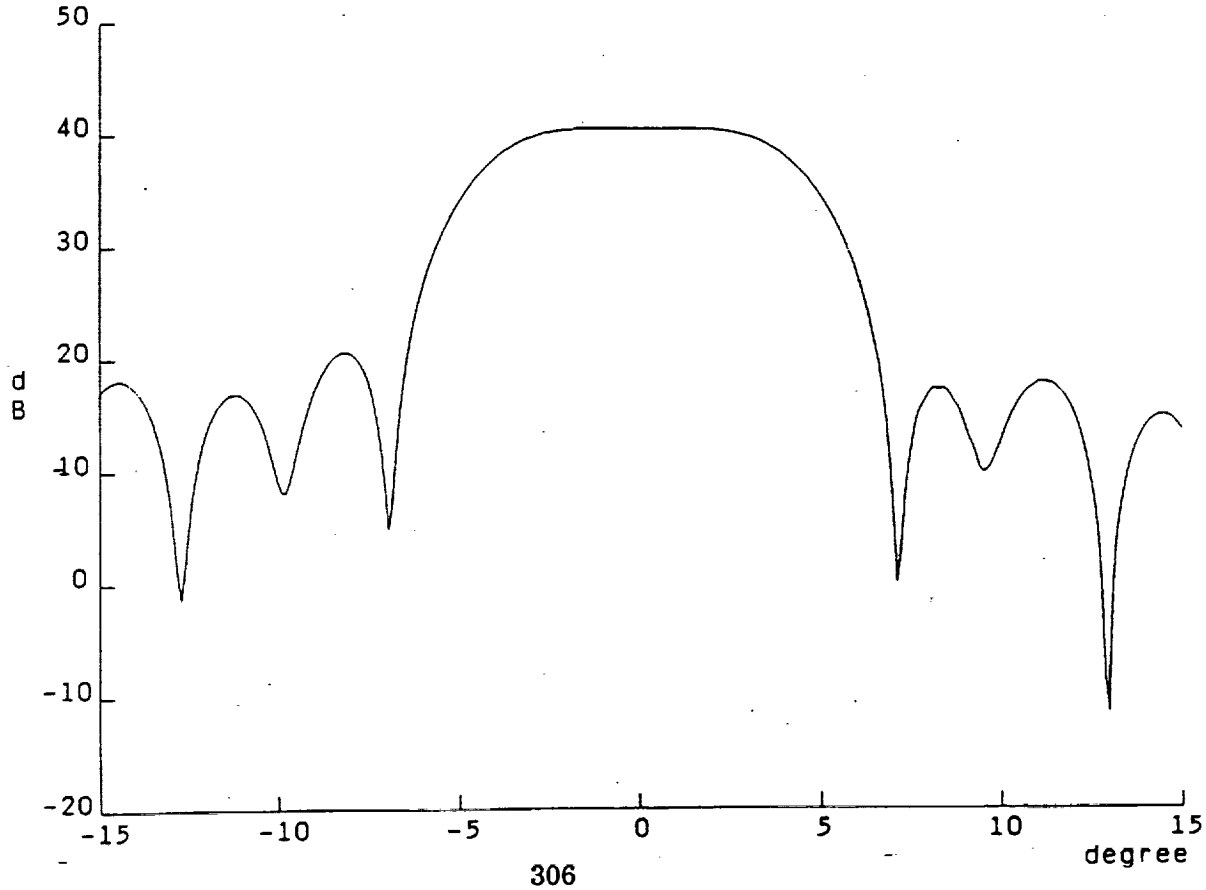


start : 2-NOV-1992 14:19: 8.096_utc fig 3

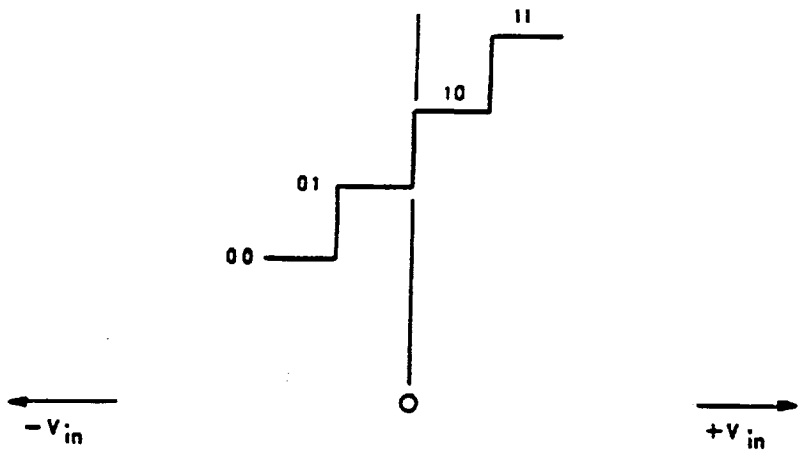


id : [87929 17 1] index = 30 fig 4

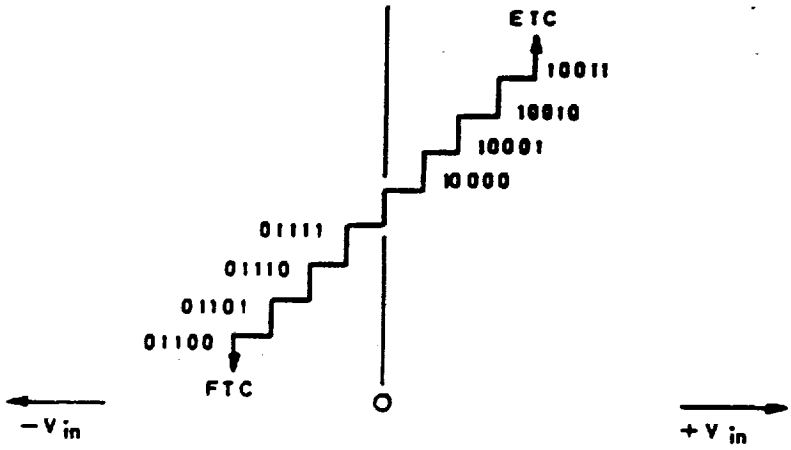

0
-10
-20
d
B -30
-40
-50
-60
-3
-2
-1
0
1
2
3
degree
.288
deg.

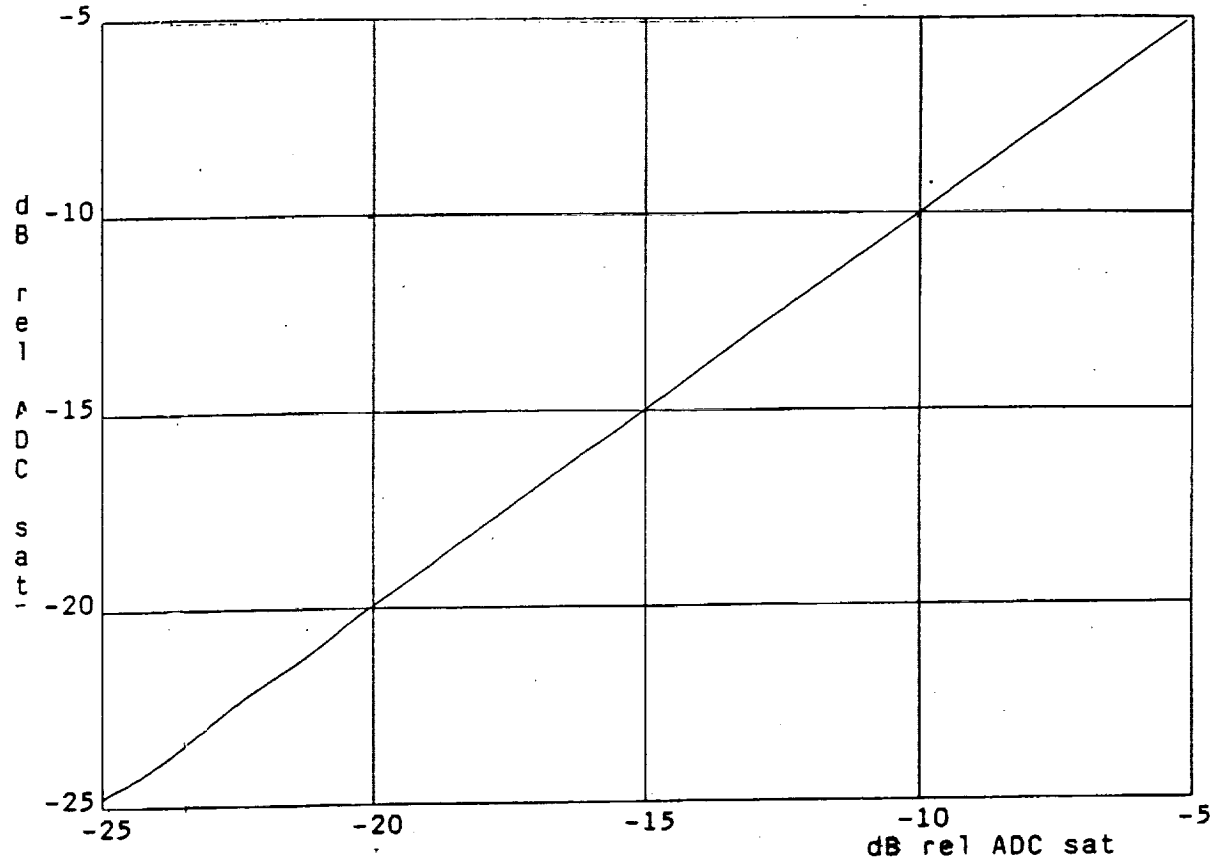

50
40
30
20
d
B
10
0
-10
-20
-15
-10
-5
0
5
10
15
degree

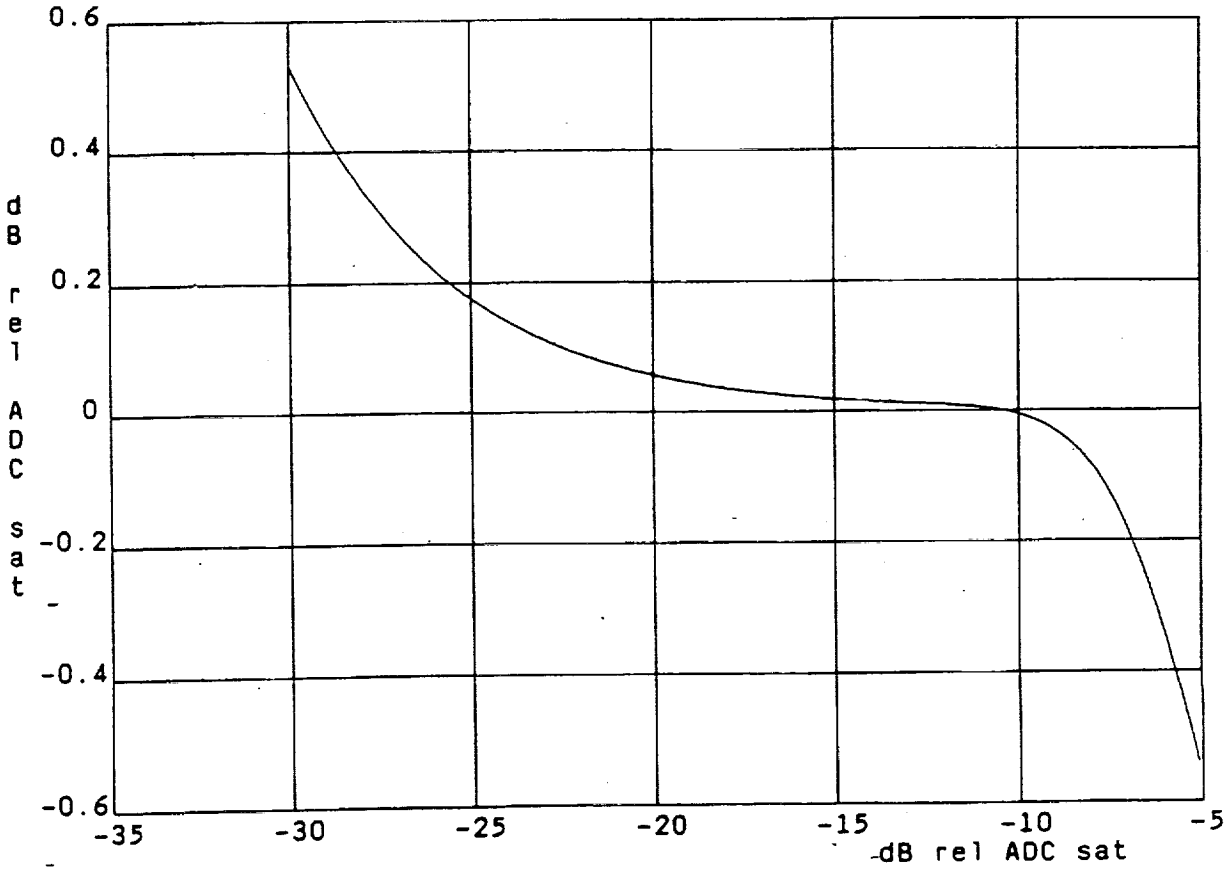
EXAMPLE OF 2-BIT CODE



EXAMPLE OF 5-BIT CODE




-5
-10
-15
-20
-25
dB rel ADC sat
-25
-20
-15
-10
-5
dB rel ADC sat


0.6
0.4
0.2
0
-0.2
-0.4
-0.6
dB rel ADC sat
-35
-30
-25
-20
-15
-10
-5
dB rel ADC sat

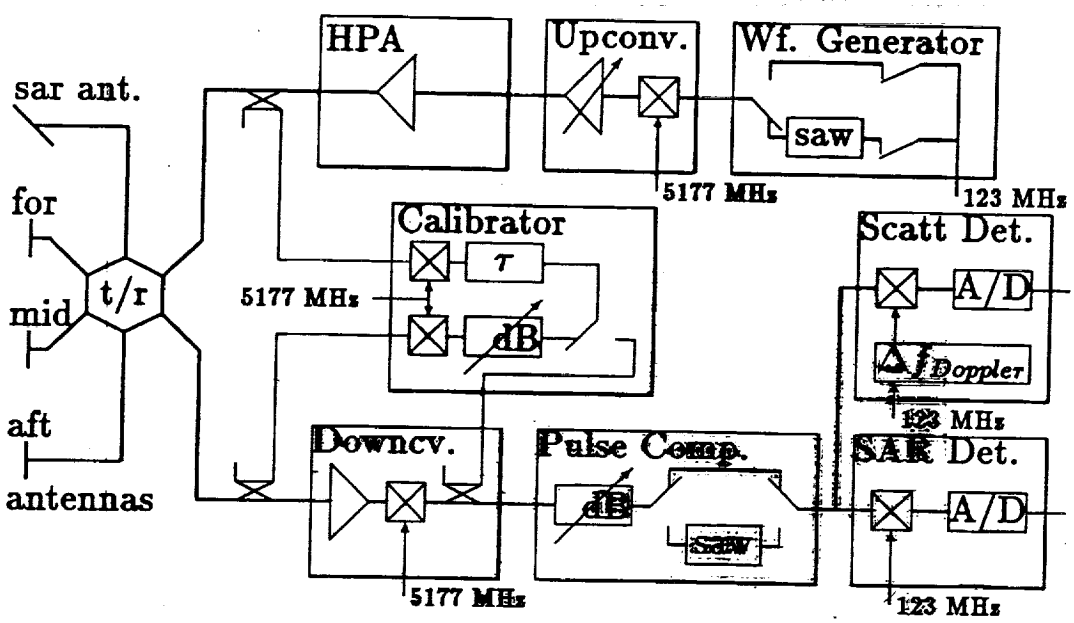
Internal Calibration

The objective of internal calibration is monitoring system parameter changes with time, such as

- Output power
- Receiver gain
- Linear distortion (amplitude & phase)
- Non-linear distortion (amplitude & phase)
- Noise level
- Level of spurious signals

Internal calibration methods include

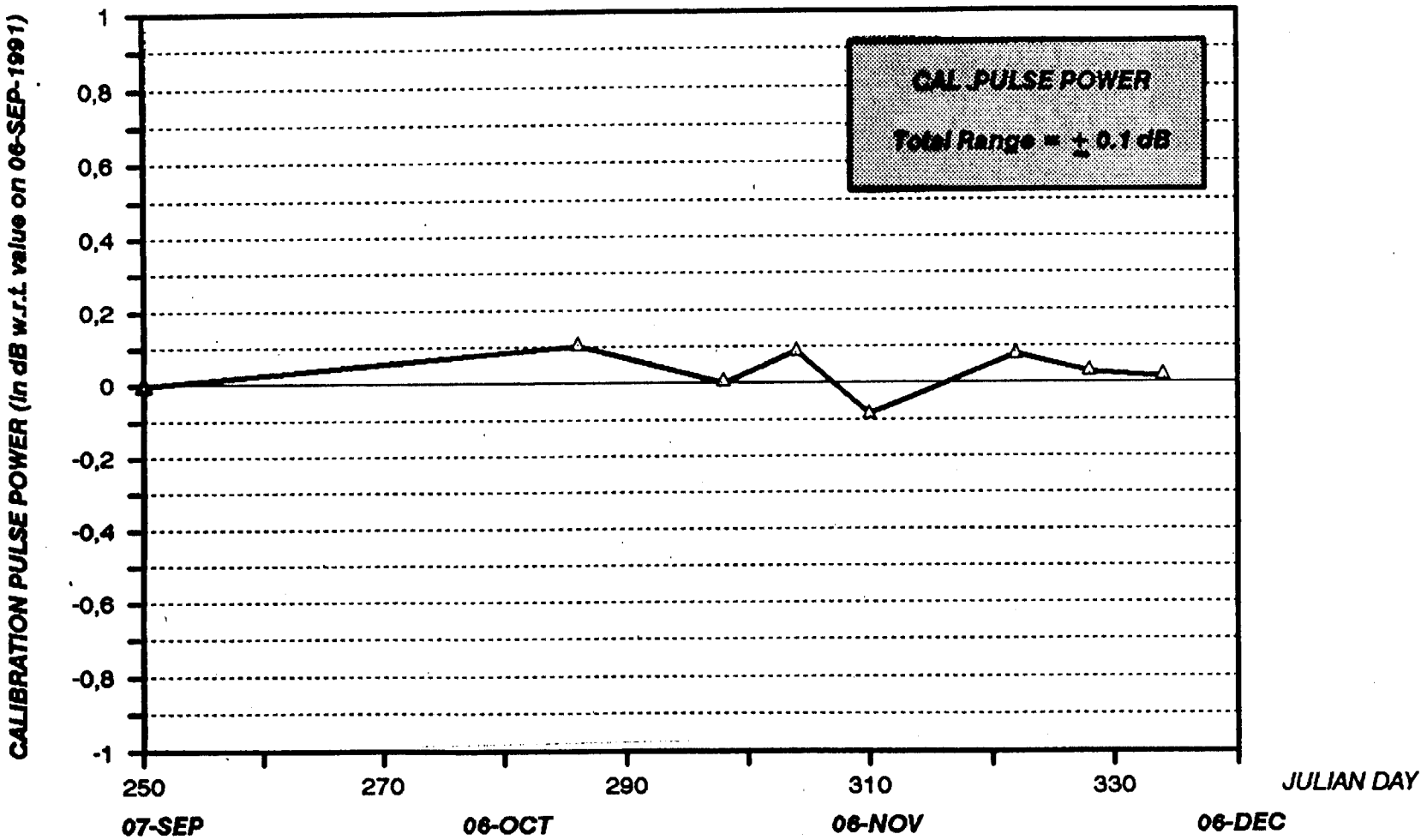
- Calibration using transmit pulse sample (ERS-1 method)
- Reference signals : noise, cw
- Transmit power measurements


sar ant.
for
mid
aft
antennas
t/r
HPA
Upconv.
Wf. Generator
saw
5177 MHz
123 MHz
Calibrator
τ
5177 MHz
dB
Scatt Det.
A/D
Δf Doppler
123 MHz
Downcv.
Pulse Comp.
dB
saw
SAR Det.
A/D
5177 MHz
123 MHz

ERS-1

CALIBRATION PULSE POWER SEQUENCE

COMMISSIONNING PHASE (from 7-SEP-1991 to 6-DEC-1991)



External Calibration

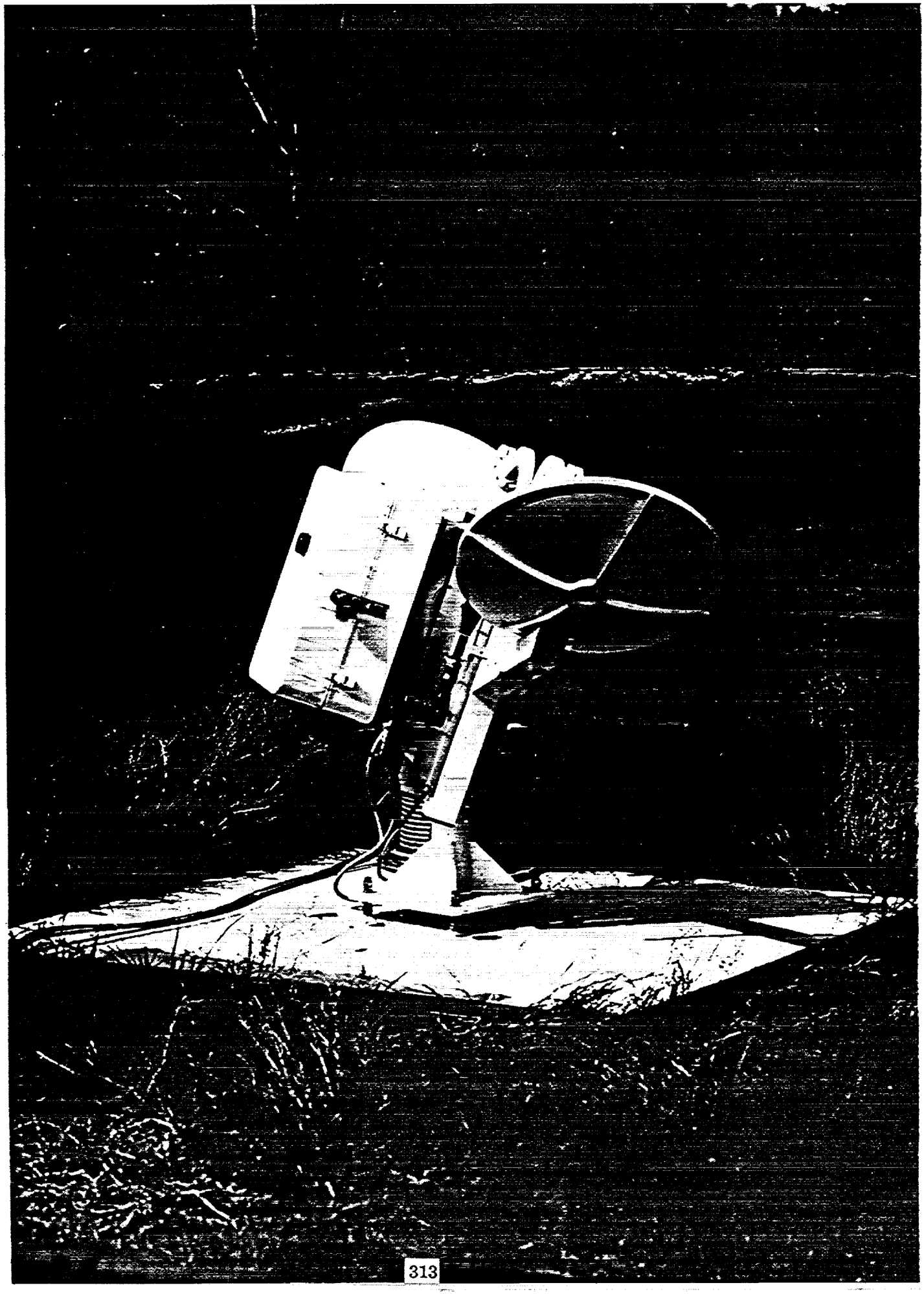
The objective of external calibration is to measure and monitor system components outside the internal calibration loop.

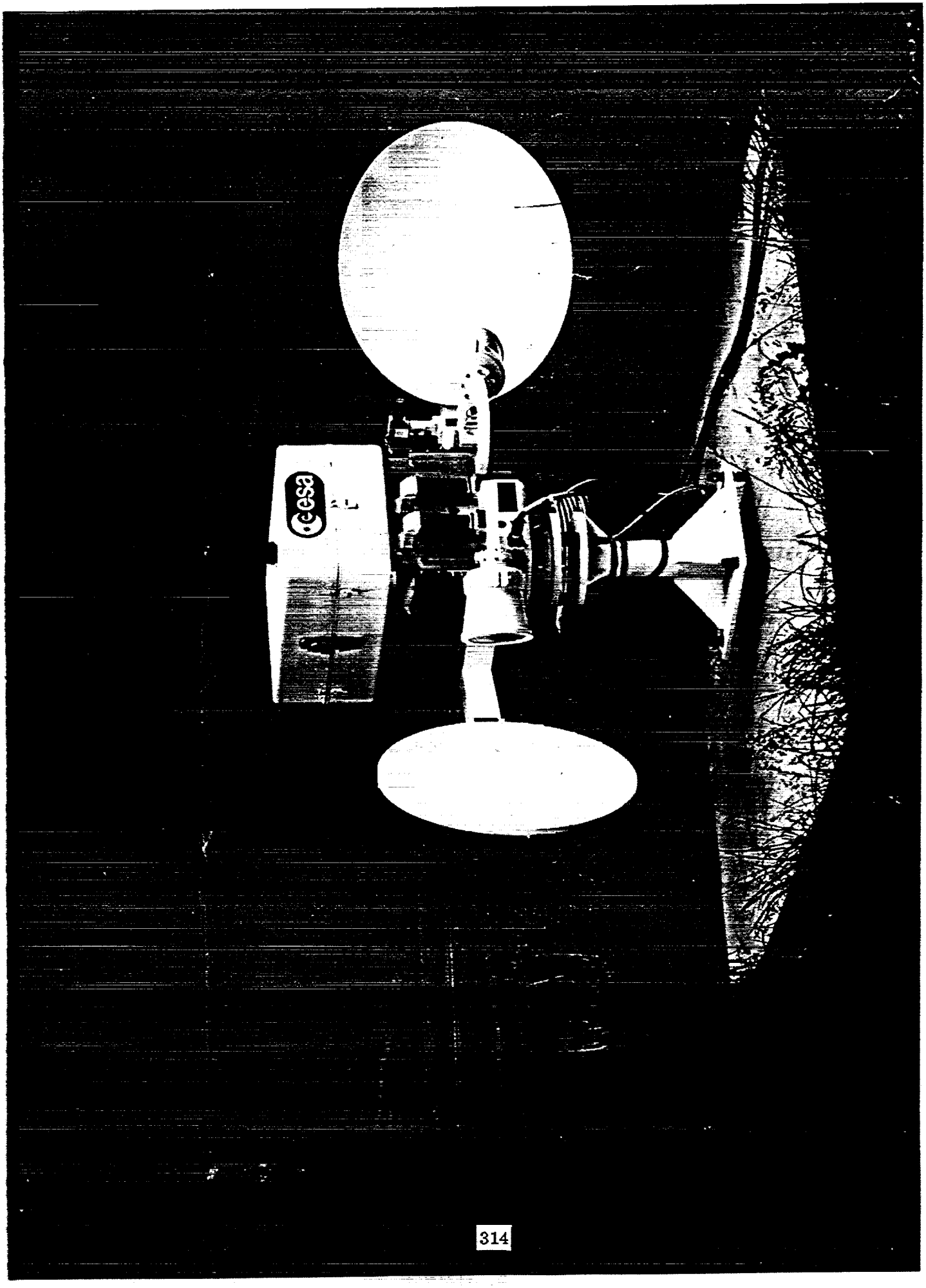
External calibration uses made-made or natural targets.

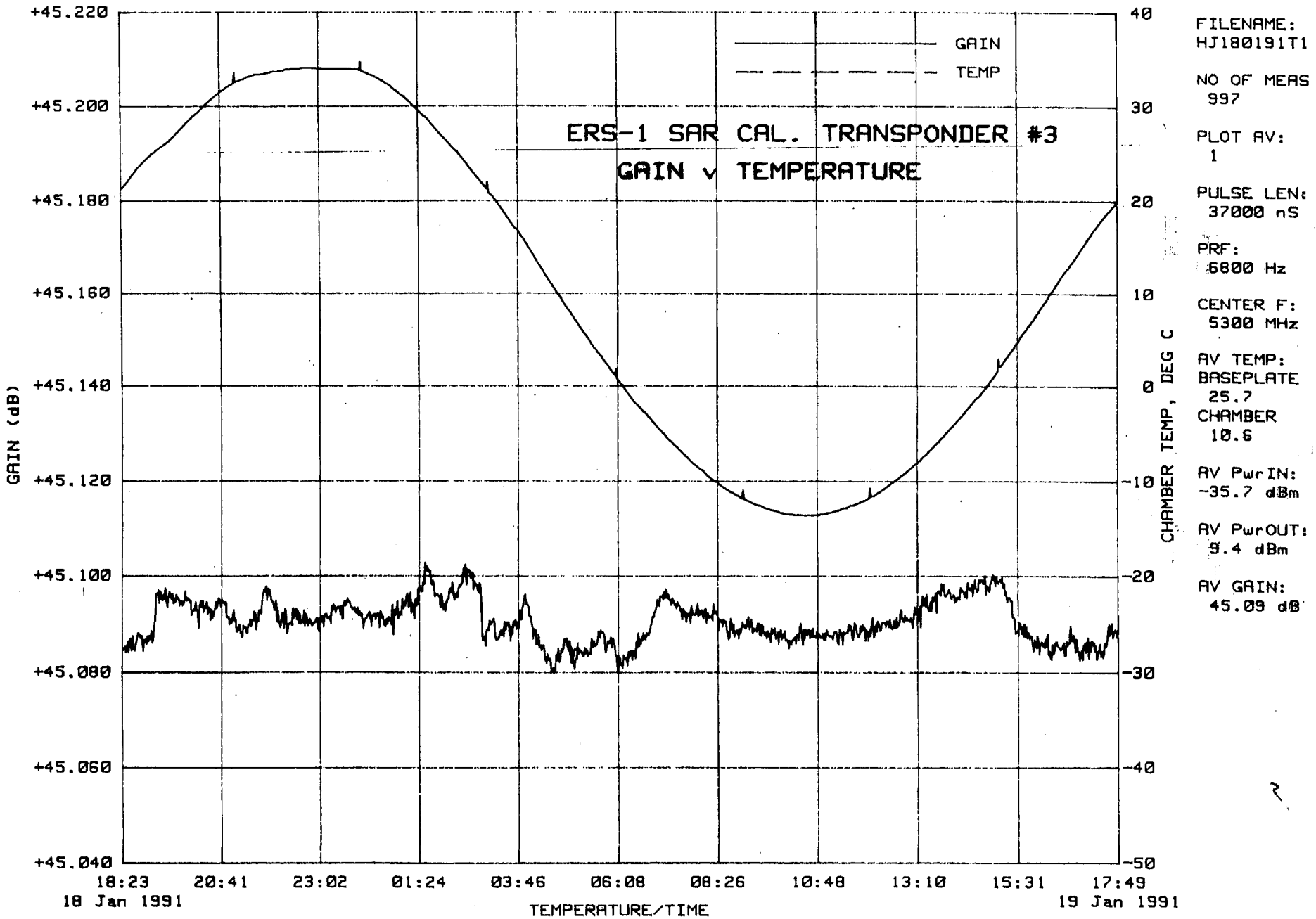
External calibration can be used to determine the radar image calibration factor either in combination or without reference to internal calibration.

AMI Transponder Specifications

Parameter	Wind Mode	Image/Wave
Radar Cross Section	$87.5 dBm^2$	$65.0 dBm^2$
Adjustment Range	$+0, -5dB$	$+0, -5dB$
Calibration Accuracy	$\pm.5dB$	$\pm.5dB$
Cross-calibration Accuracy	$\pm.2dB$	$\pm.2dB$
Stability(Over 3 Years)	$\pm.1dB$	$\pm.1dB$



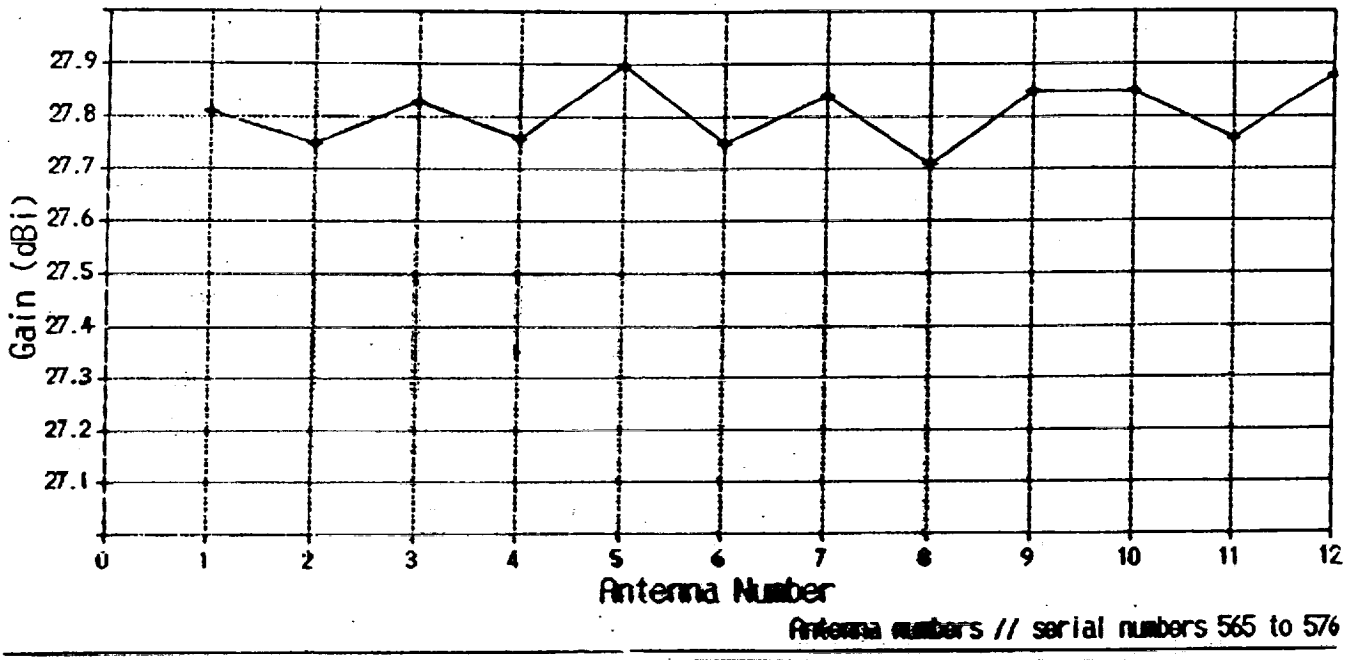

esa



XRI Laboratory ESTEC ESA

ERS-1 Transponder Antennas

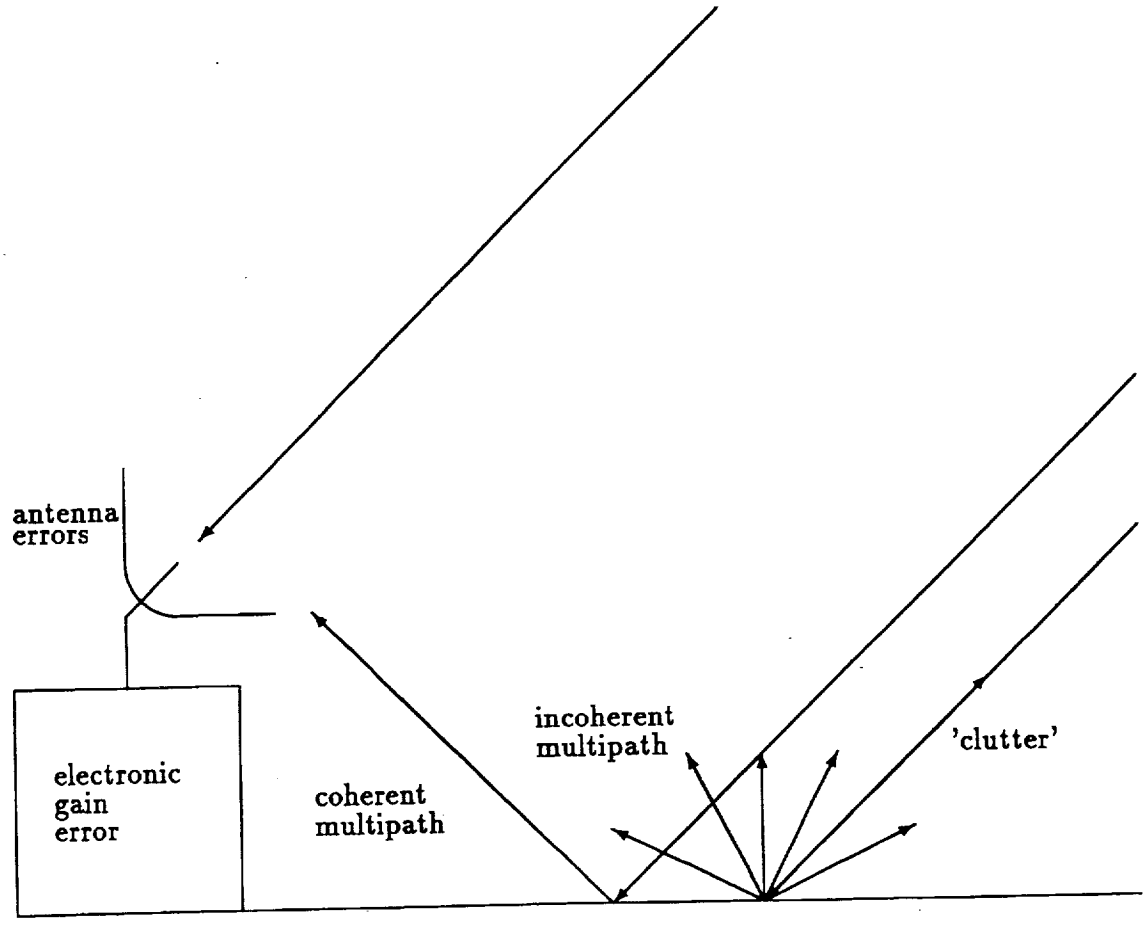
Gain Values for 12 Antennas

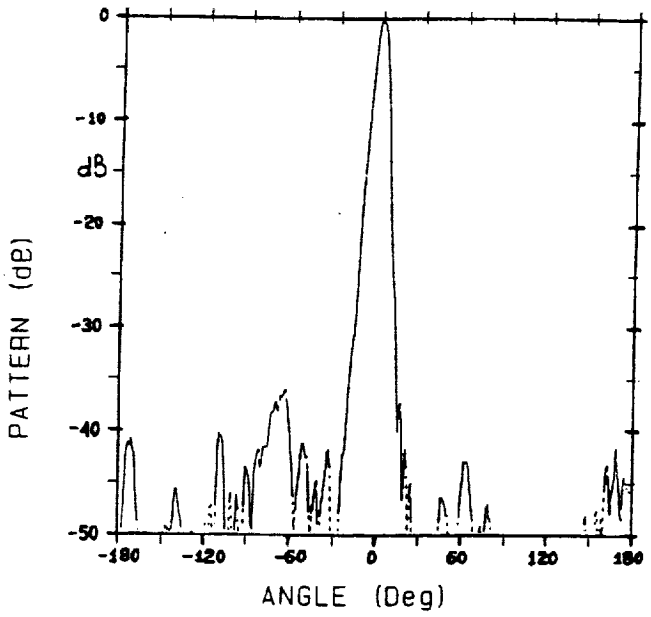


Average Gain = 27.81 dB

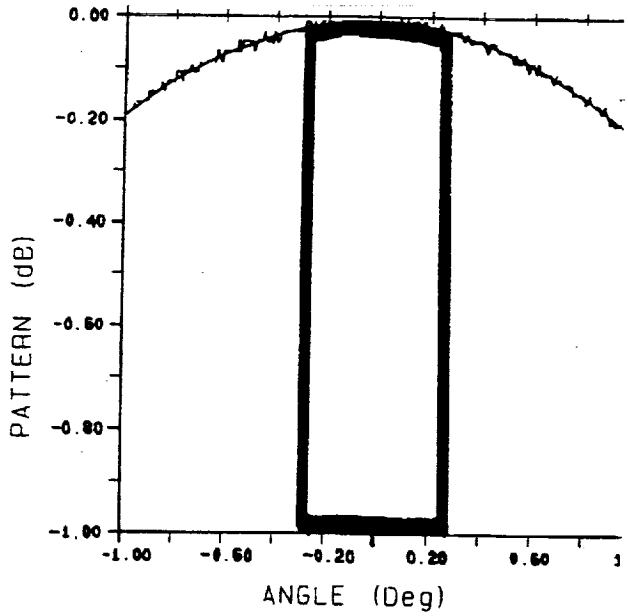
Standard Deviation = 0.06 dB

Transponder Error Model

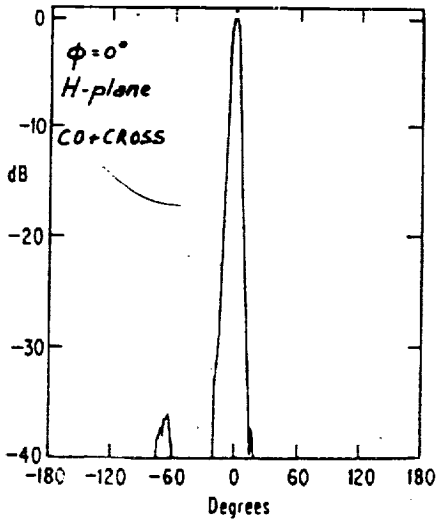


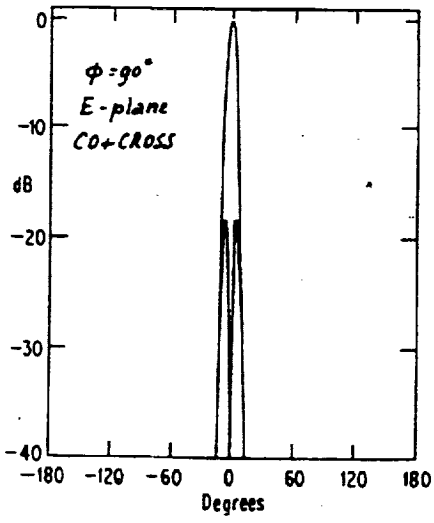


Sidelobe structure in H-plane pattern (plane of offset).

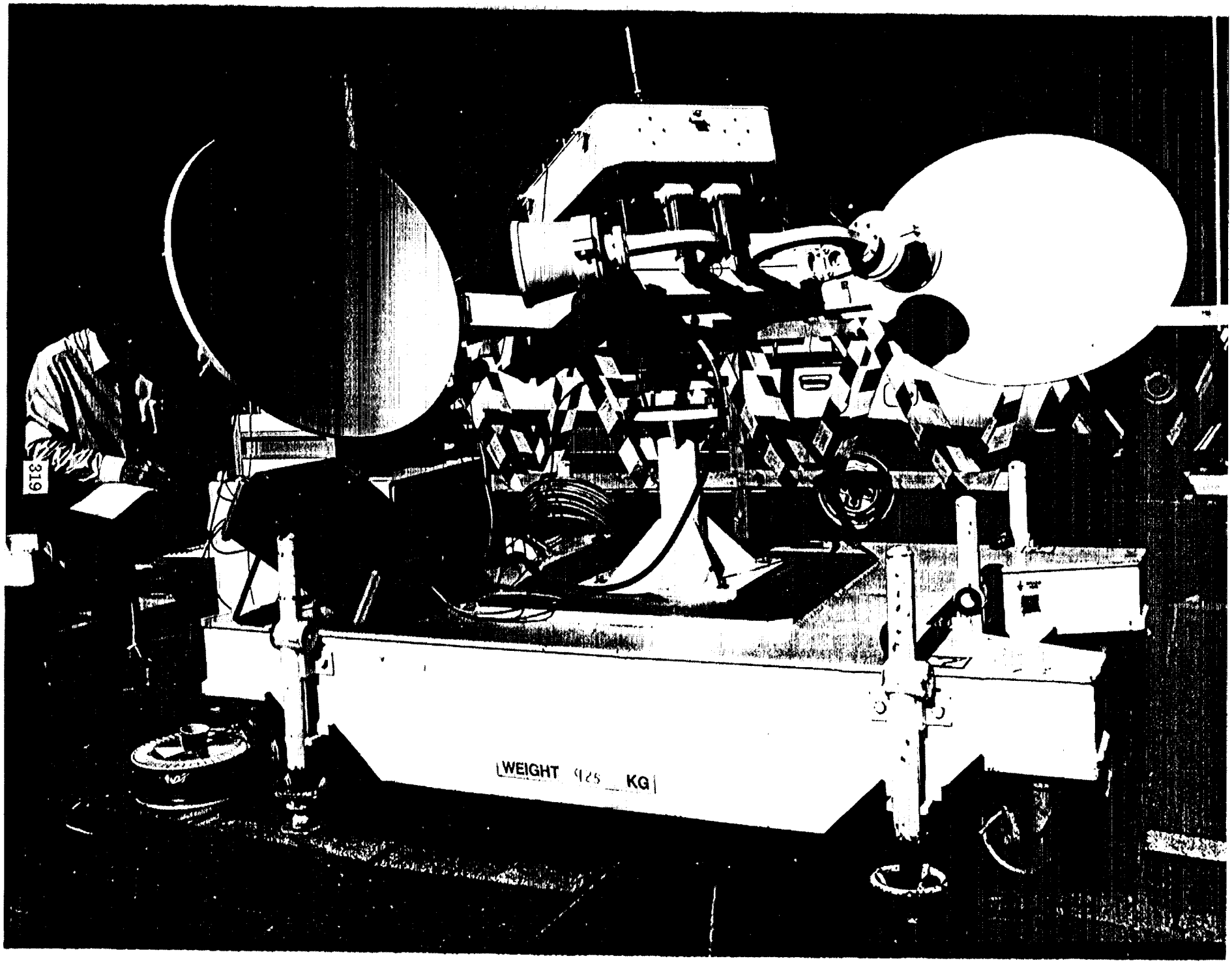


Pointing evaluation E-plane, based on LMS curve fit





E and H plane patterns, co and cross-polarisation.


319
WEIGHT 125 KG

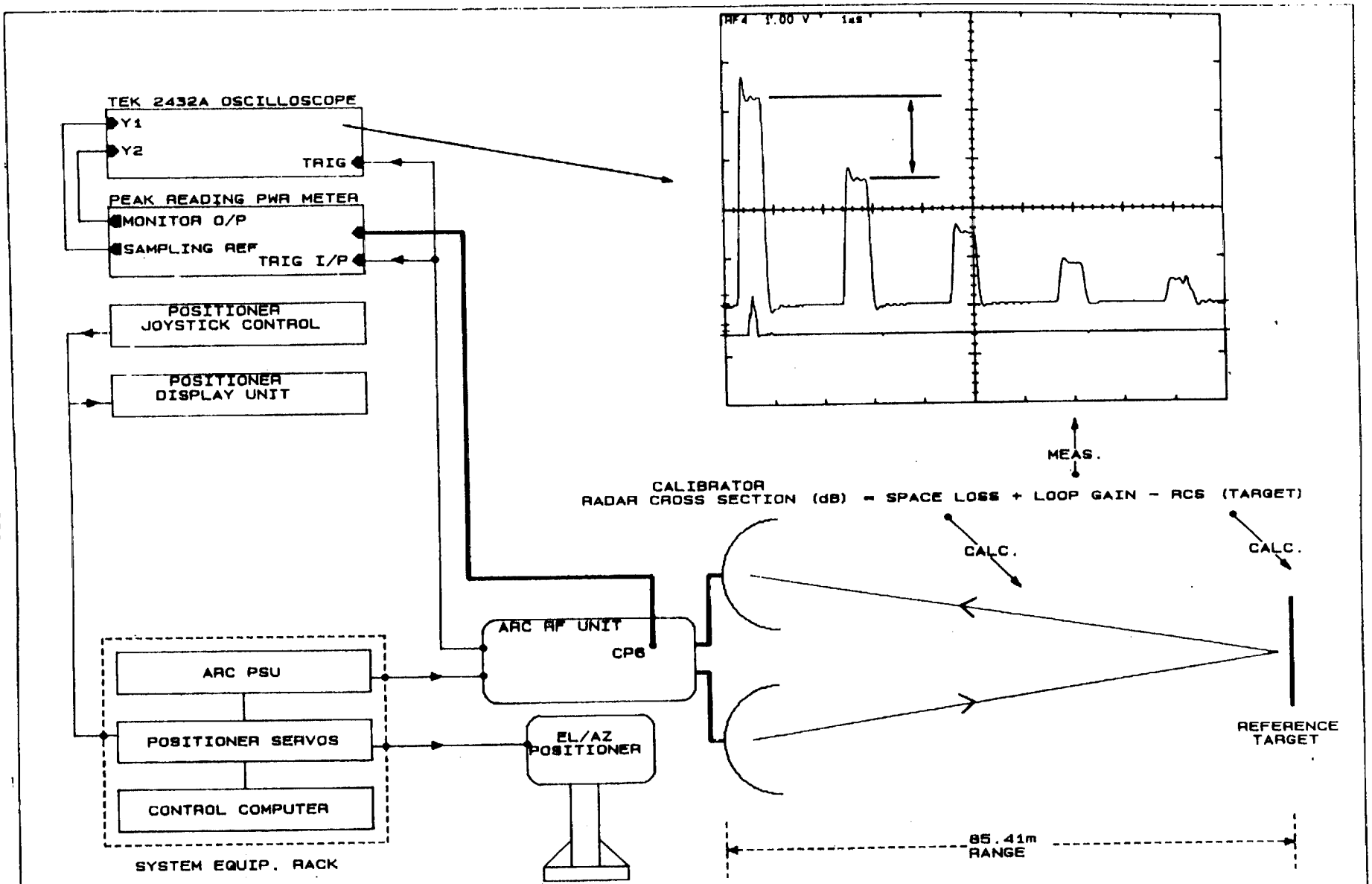
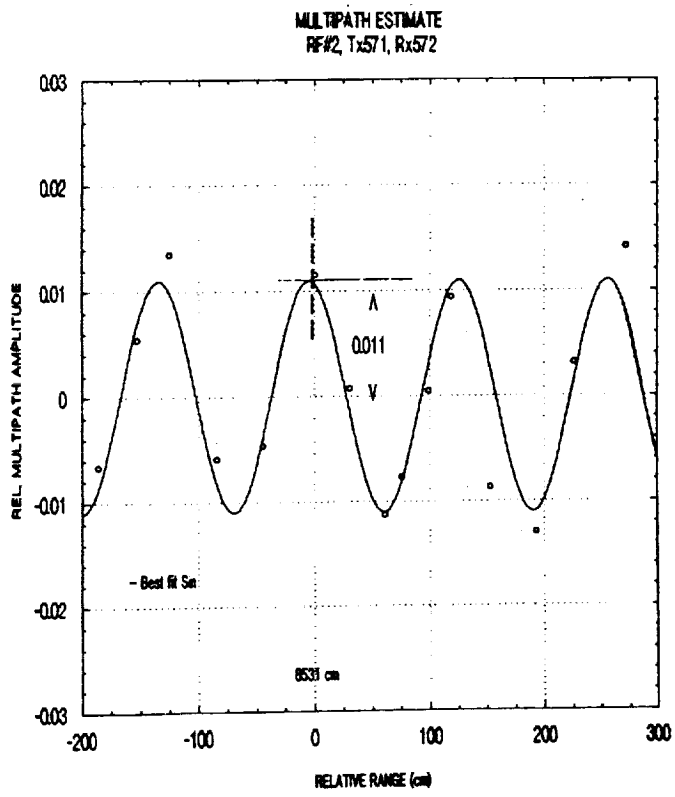
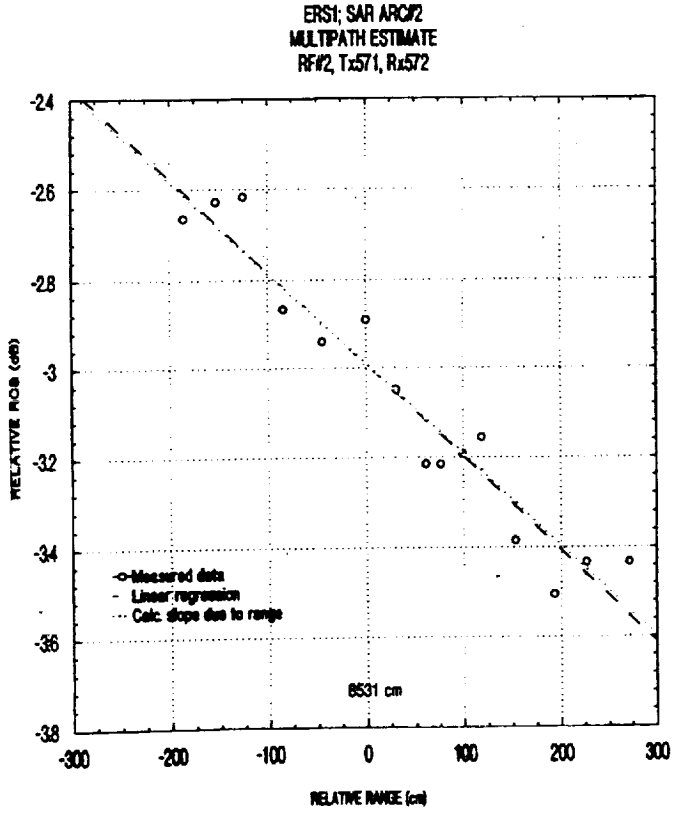


FIGURE 2. RADAR CROSS SECTION CALIBRATION


MULTIPATH ESTIMATE
RF#2, Tx571, Rx572
REL MULTIPATH AMPLITUDE
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
λ
0.011
V
Best fit Sin
6531 cm
-200
-100
0
100
200
300
RELATIVE RANGE (cm)


ERS1; SAR ARC#2
MULTIPATH ESTIMATE
RF#2, Tx571, Rx572
RELATIVE RCS (dB)
-24
-26
-28
-3
-32
-34
-36
-38
Measured data
Linear regression
Calc. slope due to range
6531 cm
-300
-200
-100
0
100
200
300
RELATIVE RANGE (cm)

Transponder Calibration Accuracy

		SAR	SCATT	
		full range	full range	
A	Antenna Gain Error	0.028	0.032	dB
	Pointing Error	0.53	0.56	deg
B	Electronic Gain Error	0.05	0.056	dB
C	Antenna Coupling Error	0.002	-	dB
	Transponder Stability A+B+C	.08	0.088	dB
		$1\ \sigma$	$1\ \sigma$	
D	Transponder Stability $1\ \sigma$ = (A+B+C)/3	0.027	0.029	dB
E	Clutter & Noise against $\sigma^0 = 0$ background	0.0495	0.0217	dB
F	Coherent Multipath	0.0207	0.0388	dB
G	Incoherent Multipath	0.0410	0.0767	dB
	Single Transponder Observation Error $\sqrt{D^2 + E^2 + F^2 + G^2}$	0.07	0.093	dB
H	Atmospheric Loss Uncertainty	0.07	0.07	dB
	Combined Error = $\sqrt{D^2 + E^2 + F^2 + G^2 + H^2}$	0.1	0.117	dB
I	Transponder Calibration Accuracy	0.2	0.2	dB

Representative SAR Calibration Budgets

SAR Radiometric Accuracy

			1σ	
A	Absolute Calibration Error	a	0.14	dB
B	Cross Swath Calibration Error	b	0.08	dB
C	Radiometric Stability Drift	b	0.25	dB
	Nominal Calibration Accuracy		0.3	dB
D	Radiometric Stability Drift Nominal - Observation	c	0.25	dB
E	Across Swath Characterisation Error	c	0.1	dB
F	Across Dynamic Range Characterisation	c	0.1	dB
G	Atmospheric Loss Uncertainty	c	0.07	dB
	Total Radiometric Error = $\sqrt{A^2+B^2+C^2}+\sqrt{D^2+E^2+F^2+G^2}$		0.6	dB

(a) Dominated by transponder calibration

(b) Single sample error, reduced by in-flight monitoring

(c) Random error per observation

Absolute Calibration Error

		Number of Samples	Single Sample Error(1σ)	
H	Transponder Calibration Accuracy	3	0.2	dB
I	Antenna Gain Characterisation	3	0.1	dB
J	Single Transponder Observation Error	3	0.07	dB
K	Atmospheric Loss Uncertainty	3	0.07	dB
	Combined Error = $\sqrt{H^2/3+I^2/3+J^2/3+K^2/3}$		0.14	dB

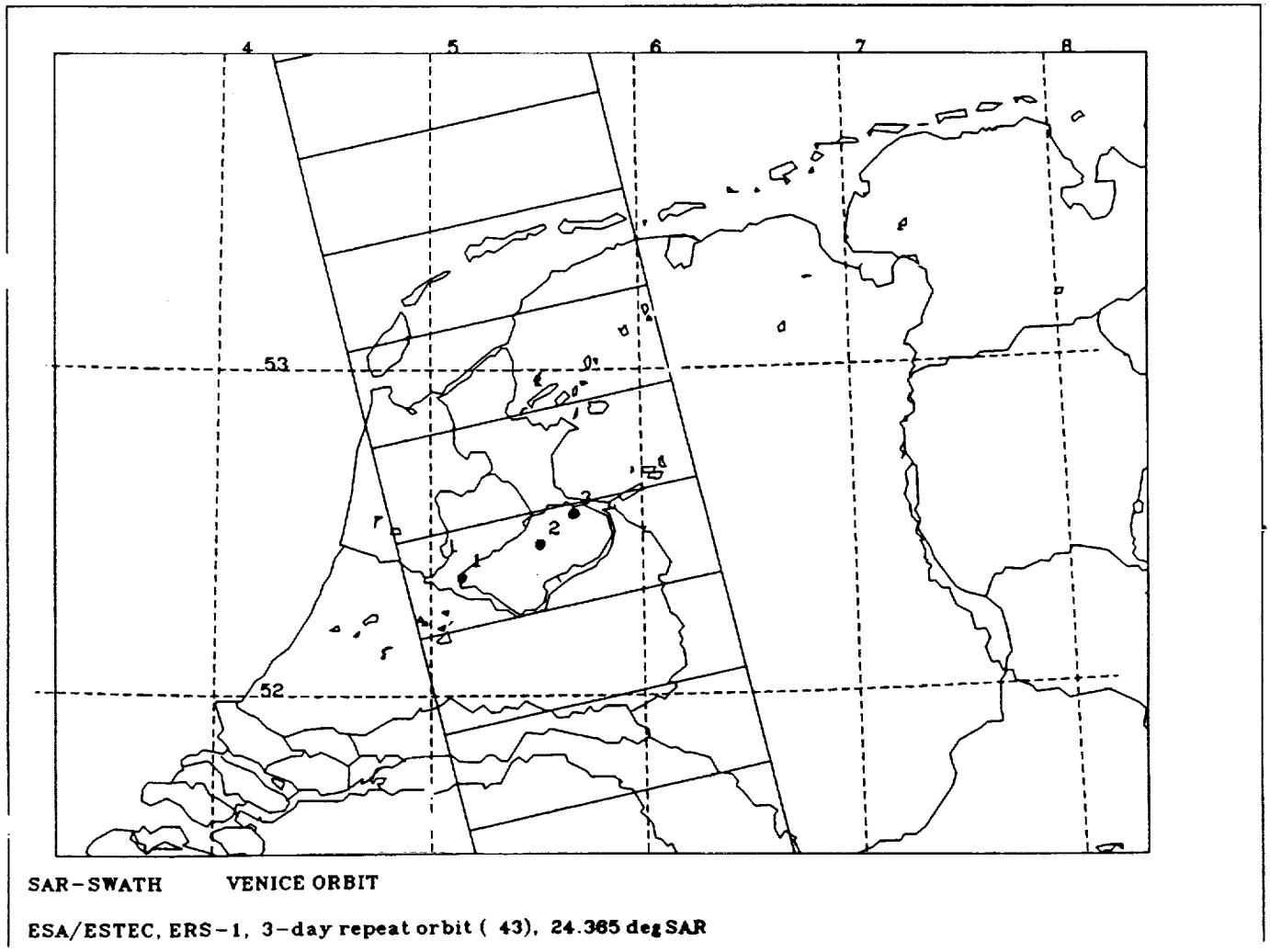
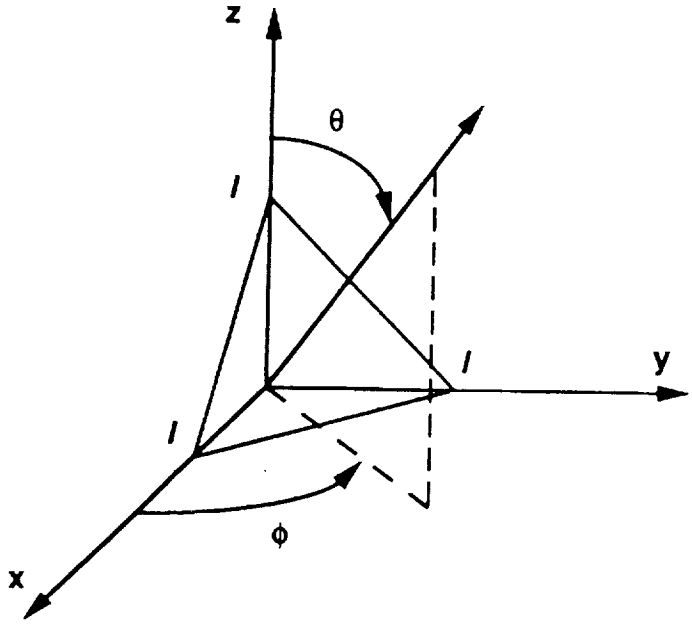
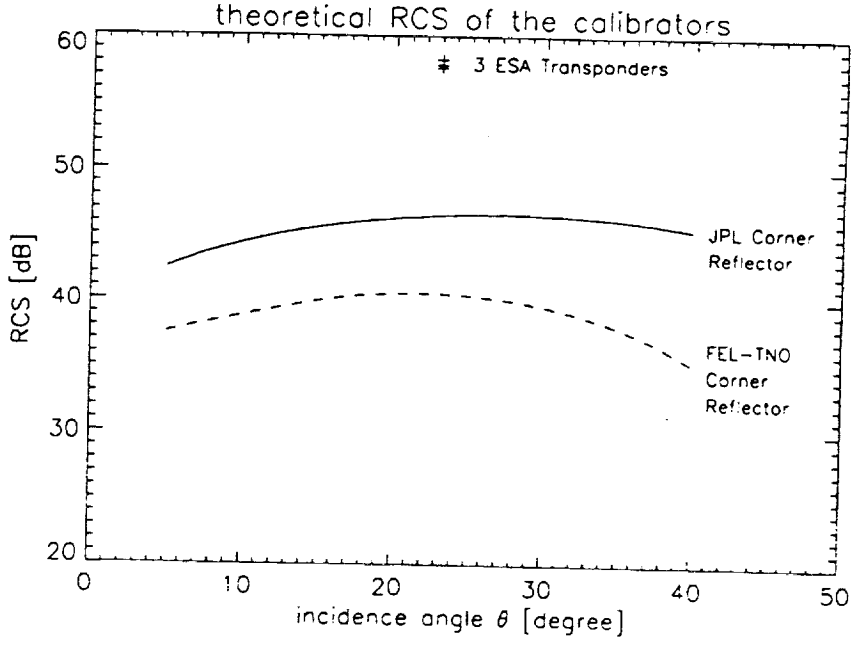


Figure 7: Transponder Sites Flevoland, Commissioning Phase Coverage

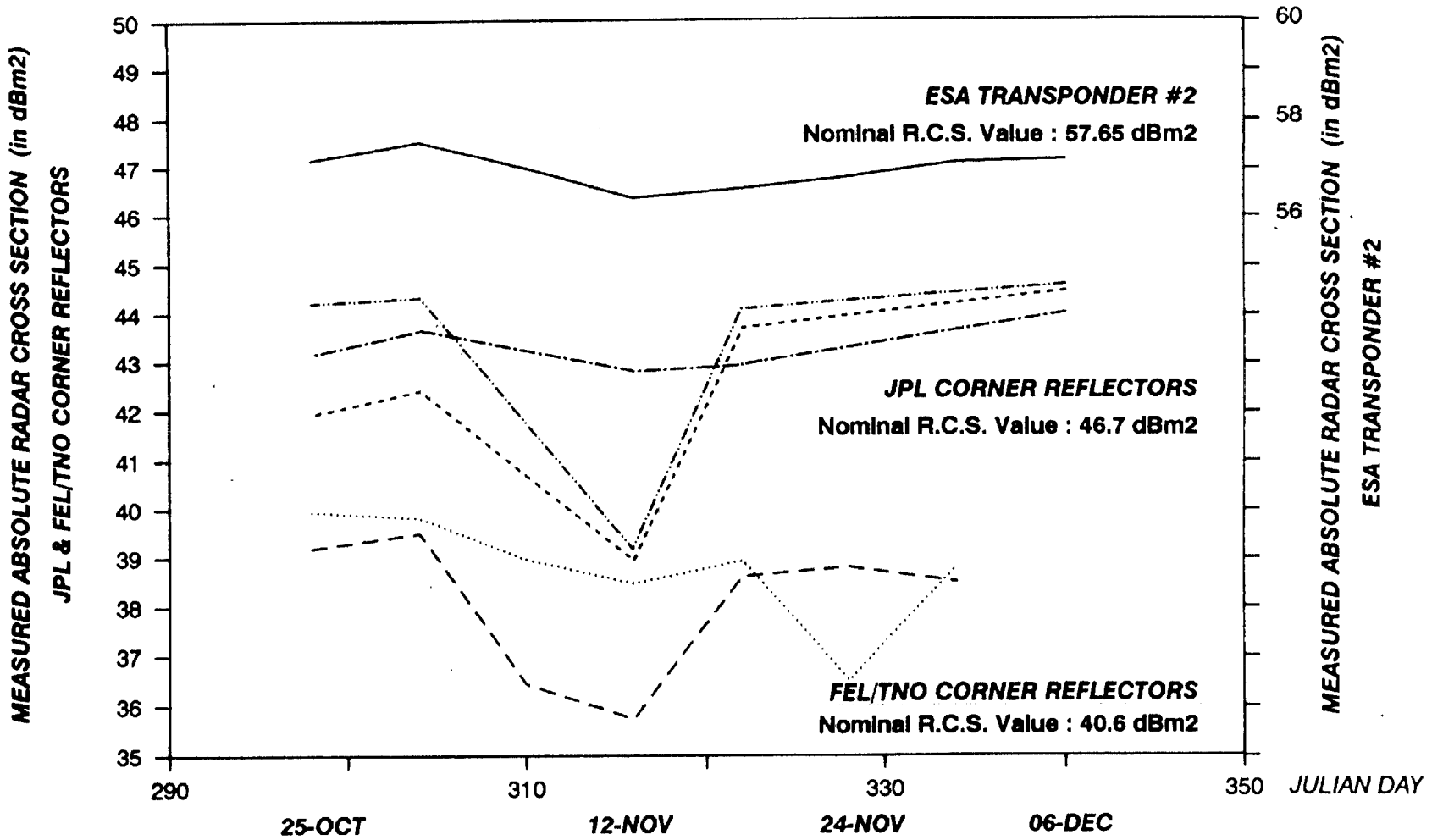

z
θ
l
l
l
y
x
ϕ


theoretical RCS of the calibrators
3 ESA Transponders
JPL Corner Reflector
FEL-TNO Corner Reflector
RCS [dB]
60
50
40
30
20
0
10
20
30
40
50
incidence angle θ [degree]

ERS-1

TRANSPONDER & CORNER REFLECTORS ABSOLUTE R.C.S.

COMMISSIONNING PHASE (from 25-OCT-1991 to 6-DEC-1991)



SAME CALIBRATION CONSTANT USED *Reference : 13-OCT-1991 Transponder #2*

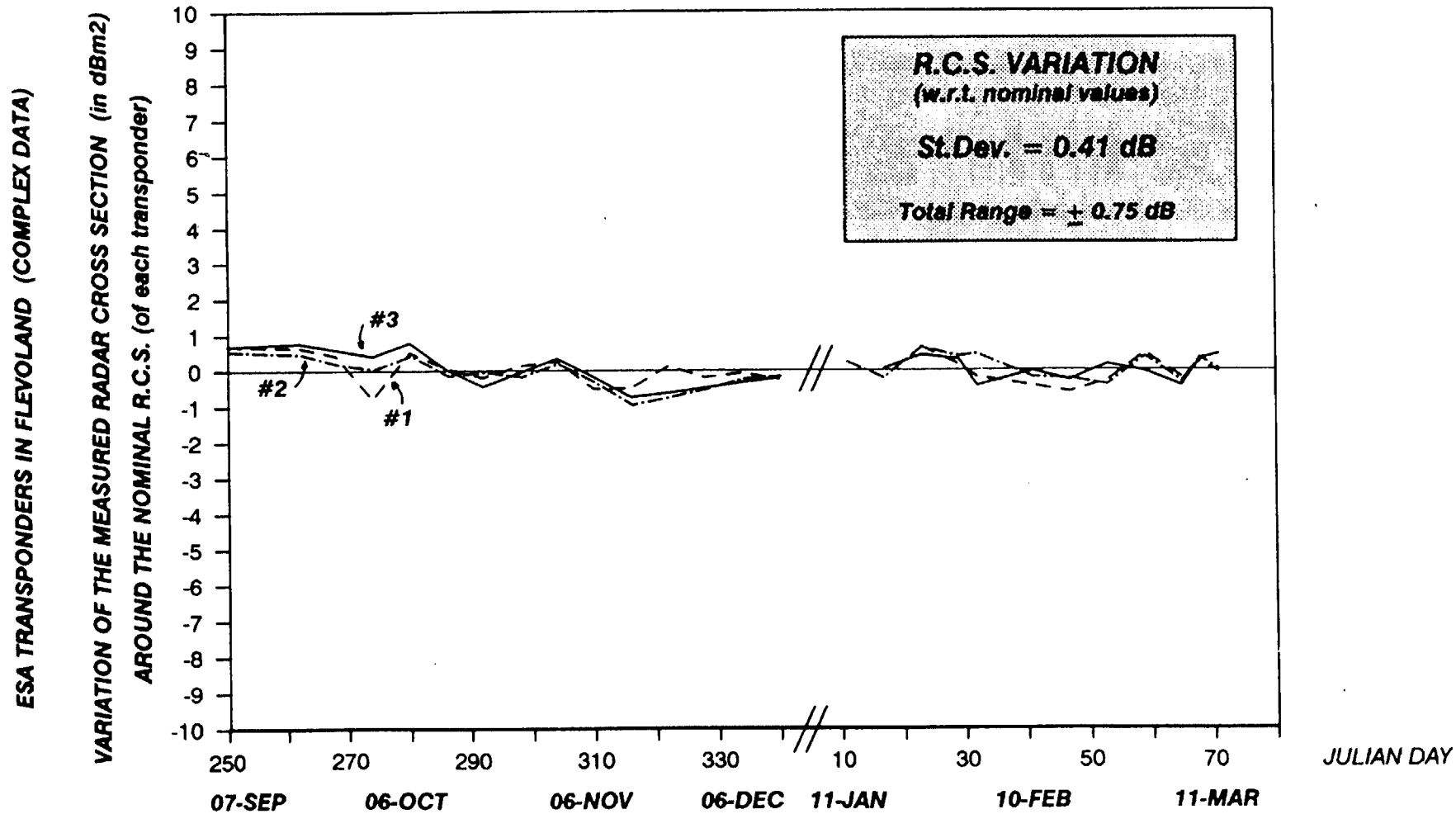
esa

ESRIN / ERS-1 PRODUCT CONTROL SERVICE

ERS-1

SAR CALIBRATION HISTORY

COMMISSIONNING PHASE & ICE PHASE (from 7-SEP-1991 to 11-MAR-1992)

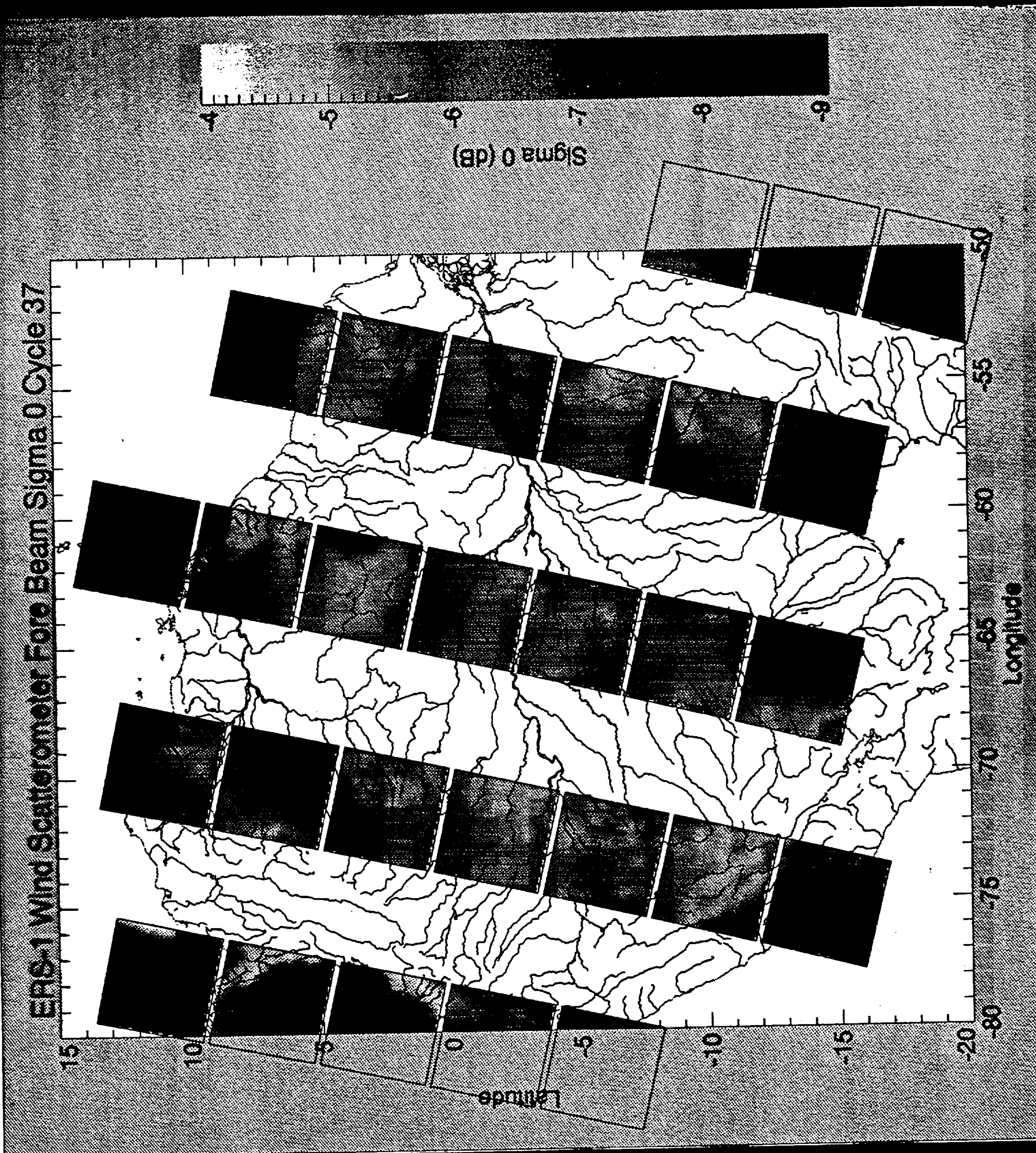


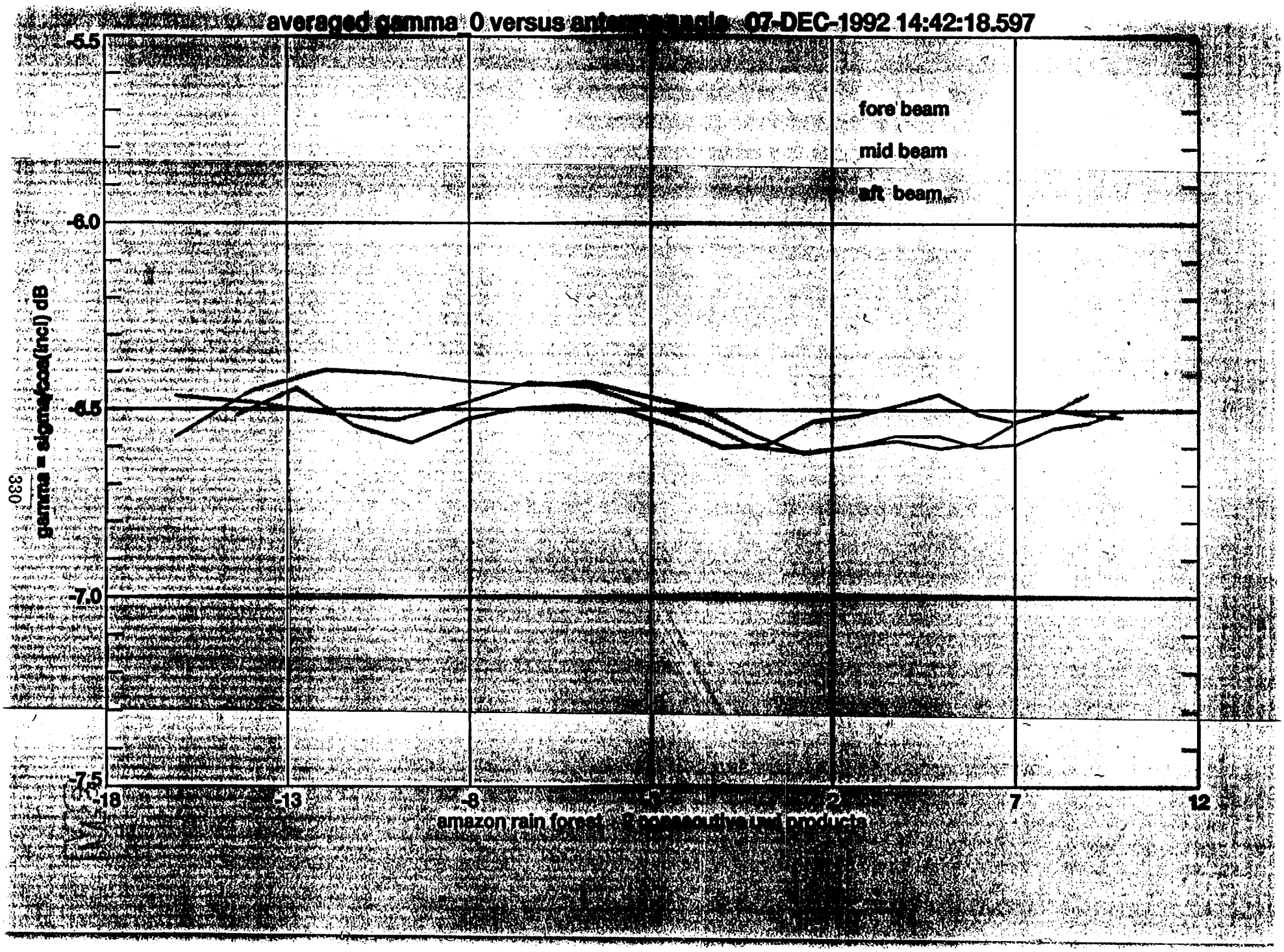
Calibration of other areas

The application of the calibration factor to other areas requires knowledge of geometry (range & antenna angle) and stability over time.

High resolution information about the antenna diagram can be obtained from imagery of extended uniform targets such as the tropical forest or ice shelves.

No absolute information is required for these 'targets of opportunity'. Stability over time and a smooth dependence of σ^0 on incidence angle is necessary.

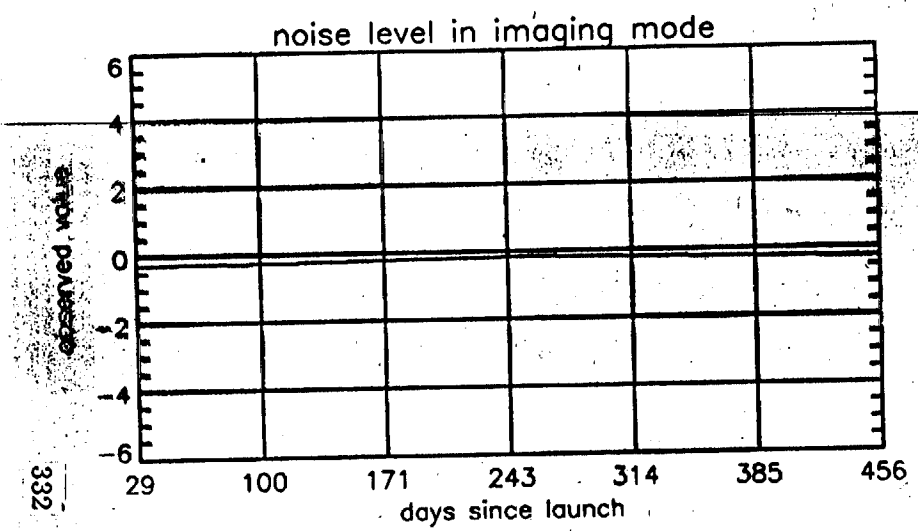

ERS-1 Wind Scatterometer Fore Beam Sigma 0 Cycle 37
Sigma 0 (dB)
-4
-5
-6
-7
-8
-9
Latitude
15
10
5
0
-5
-10
-15
-20
Longitude
-80
-75
-70
-65
-60
-55
-50

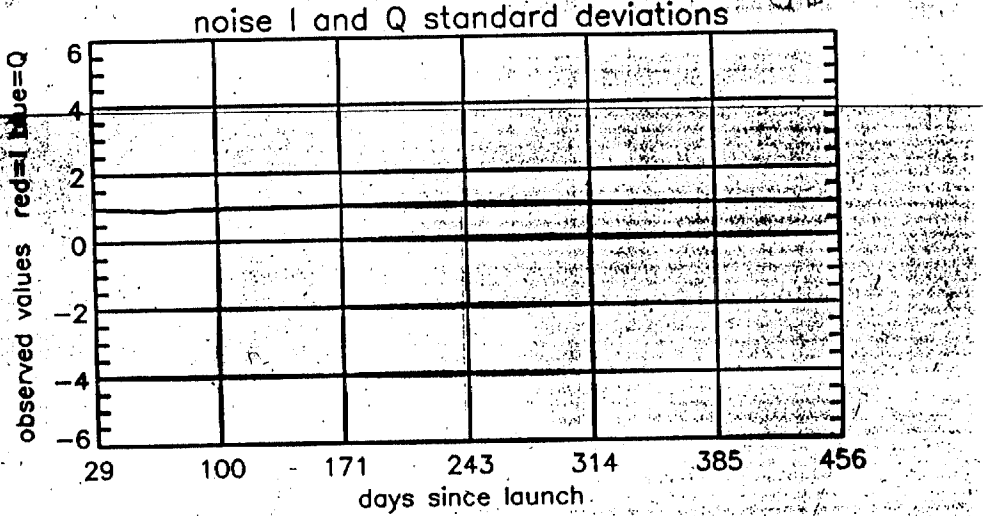

averaged gamma 0 versus antenna angle 07-DEC-1992 14:42:18.597
fore beam
mid beam
aft beam
-5.5
-6.0
-6.5
-7.0
-7.5
gamma = sigma/cos(incl) dB
330
-18
-13
-8
-3
2
7
12
amazon rain forest - 3 consecutive rev products

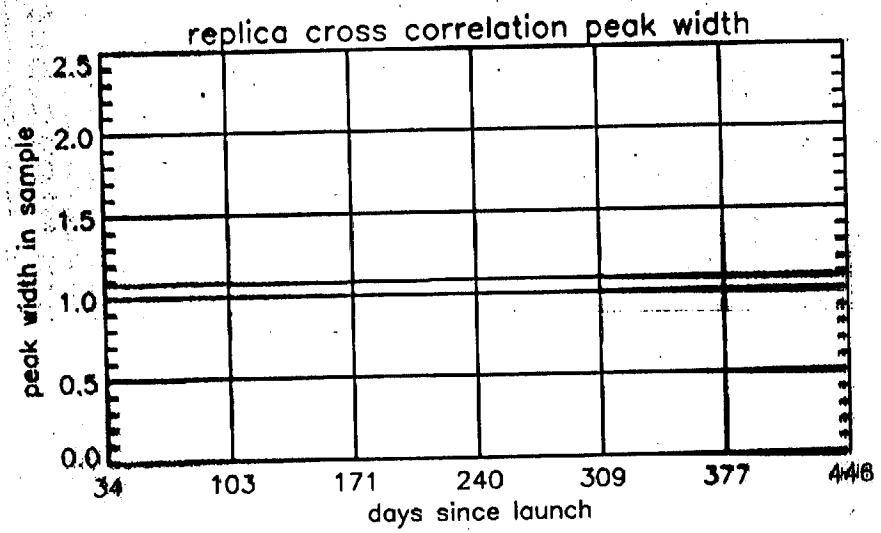
Data calibration

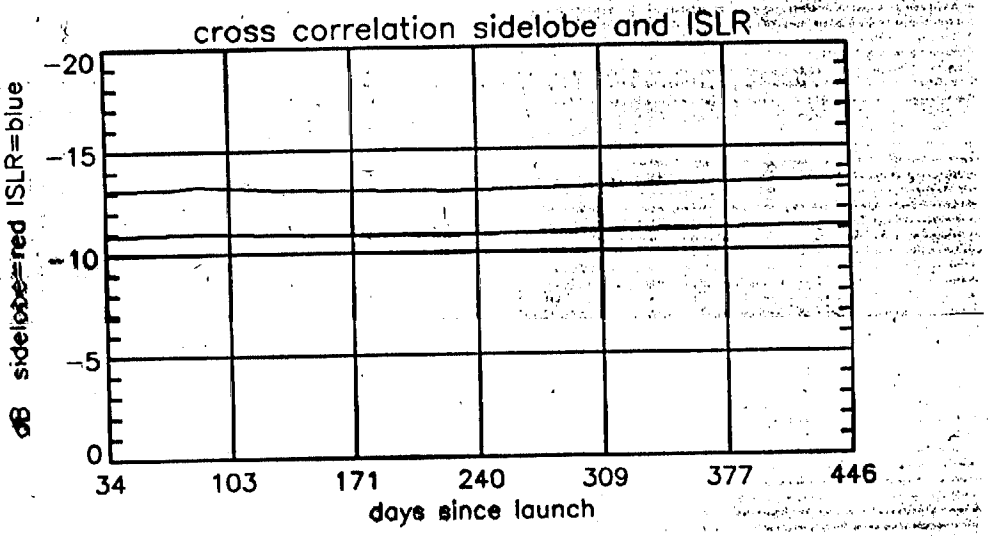
Data calibration include the following steps

- Correct raw data for a number of system parameters
  - — Linear distortion (amplitude & phase)
  - — Non-linear distortion
  - — Detector imperfections (DC-biases, amplitude & phase imbalance)
  - — time variations as measured by internal calibration
  - — noise bias
- Application of calibration factor to the entire image, taking into account geometry and antenna angle.


noise level in imaging mode
observed, noise
6
4
2
0
-2
-4
-6
29
100
171
243
314
385
456
days since launch


noise I and Q standard deviations
observed values red=I blue=Q
6
4
2
0
-2
-4
-6
29
100
171
243
314
385
456
days since launch


replica cross correlation peak width
peak width in sample
2.5
2.0
1.5
1.0
0.5
0.0
34
103
171
240
309
377
446
days since launch

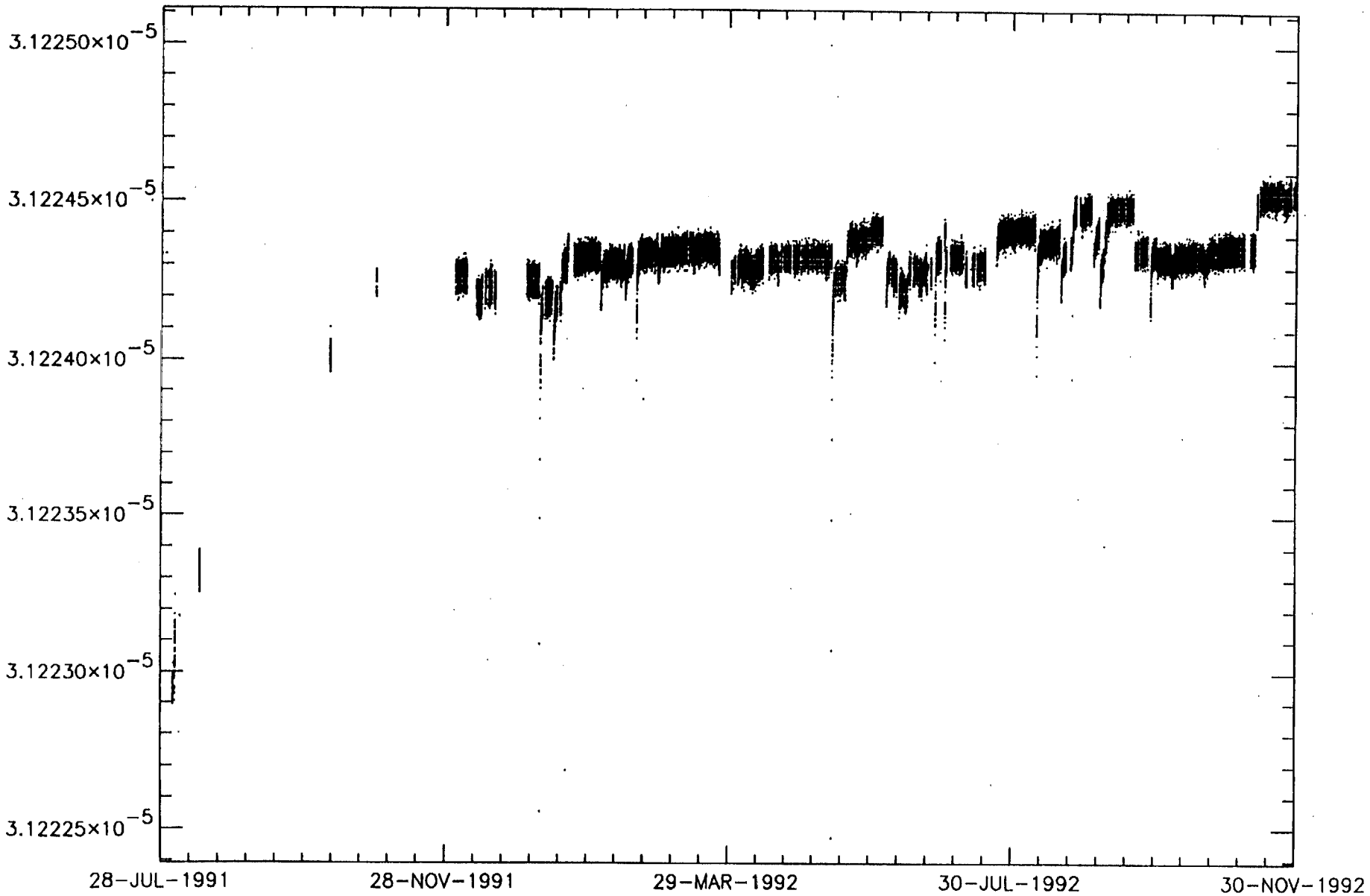

cross correlation sidelobe and ISLR
dB sidelobe red ISLR=blue
-20
-15
-10
-5
0
34
103
171
240
309
377
446
days since launch

Geometric calibration

Geometric calibration can be achieved following the same principles as for radiometric calibration.

- Design for stability
- Characterise SAR system in terms of delay, phase error and frequency offset
- Calibrate using point target with accurately known position

Geometric image calibration is carried out in the data calibration stage by correction for known system biases and applying geometry information (platform position & attitude and terrain models).


3.12250×10^-5
3.12245×10^-5
3.12240×10^-5
3.12235×10^-5
3.12230×10^-5
3.12225×10^-5
28-JUL-1991
28-NOV-1991
29-MAR-1992
30-JUL-1992
30-NOV-1992

Phase calibration

During the formation of an intensity image the phase information in the radar data is lost. For applications in interferometry and polarimetry complex images are formed which provide two data points per pixel, amplitude & phase or real & imaginary parts of the complex signal.

Careful and elaborate phase characterisation of both the SAR sensor and the SAR processor are required. Time stability is critical for the above applications.

Polarimetric calibration

Polarimetric calibration can be treated essentially as a multi-channel extension of the methods discussed above. Polarimetric SAR differ from single channel SAR in the following ways.

- There are two orthogonal transmit channels to consider and four receive channels.
- Radiometric calibration can be separated into absolute calibration and relative between channel calibration
- Geometric calibration can be separated into absolute calibration and relative between channel calibration
- Phase calibration between channels is essential
- Crosstalk has to be taken into account