NATIONAL PHYSICAL LABORATORY

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Certificate of Calibration

Thomas Keating Ltd W-Band Antenna
Model: TK_TAS_LGA_W-Band 23249
Serial Number: 2

FOR:	Thomas Keating Ltd Station Mills Daux Road Billingshurst West Sussex RH14 9SH
ORDER NUMBER:	T47520.
DESCRIPTION:	Thomas Keating Ltd W-band antenna model TK_TAS_LGA_W-Band 23249, s/n 2 with RAM tile.
FREQUENCIES:	108.0 GHz to 110.0 GHz in 0.025 GHz steps for gain and reflection coefficients, 0.05 GHz steps for polarization and 0.5 GHz steps for pattern.
DATE(S) OF CALIBRATION:	21 July to 3 August 2016.

Reference: 2016020146WL

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Date of Issue: 6 October 2016

Signed: D G Gentle

(Authorised Signatory)

Checked by: ZT

Name: D G Gentle

on behalf of NPLML

MEASUREMENTS

In the following, the IEEE definition of gain is used: the gain of an antenna in a given direction is defined as “the ratio of the radiation intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were isotropically radiated”.

The antenna has a dedicated RAM tile attached to it with a “+Y” label on the back to define the +y-axis direction.

The antenna coordinate system is defined as follows. The z-axis of the antenna is the normal to its aperture and passes through the centre of it, the positive direction being out of the antenna. The x-axis is defined as the horizontal line passing through the z-axis and normal to it when the antenna is oriented in space such that the z-axis is horizontal and the broad wall of the waveguide aperture is horizontal with the “+Y” label on the RAM tile uppermost. The y-axis is mutually normal to the x and z-axes and forms a right handed set, with the x-y plane coincident with the aperture of the probe. With the “+Y” label uppermost the positive y-axis points upwards and the positive x-axis points to the right looking into the antenna aperture.

Gain

The gain of the antenna was determined by the three antenna technique [1] on an extrapolation range. Alignment of the source and test antenna was achieved by auto-reflection using a micro-alignment telescope. The gain of the antenna was measured along an axis normal to the aperture of the antenna. The insertion loss was measured for antenna separations ranging from 0.33 m to 1.00 m. The separations were measured by a laser interferometer system.

Reflection coefficients

A vector network analyser was used to measure the complex reflection coefficients of the antennas and components used in the measurement circuit. Mismatch corrections were calculated using these reflection coefficient measurements.

Axial ratio, tilt and sense of polarisation

The axial ratio, tilt and sense of polarisation were measured using a three antenna technique [2]. To reduce uncertainties due to reflected and depolarised signals, three sets of data were measured at different distances and averaged. The tilt angle is defined as the angle between the positive x-axis and the major axis of the oscillation ellipse measured in the direction of the positive y-axis. The sense of the polarisation is in accordance with the IEEE definition; ie the polarisation is right handed if the electric vector transmitted by the antenna rotates clockwise for an observer looking in the direction of propagation for a given position in space.

Pattern measurements

Far-field co-polar and cross-polar pattern measurements were made using a roll-over-azimuth positioner for $\theta = \pm 90°$ in 0.5° steps and for cut angles $\Phi = 0°, 45°, 90°$ and 135°. A.C. Ludwig’s 3rd definition [3] of cross polar was used for these measurements. Before making the measurements the antenna was first oriented so that it’s +y-axis was vertical. It was then rotated 0.47° counter-clockwise to compensate for its previously measured tilt angle and the Φ axis encoder was then set to 0°. In this way, the E-field was vertical on average for $\Phi = 0°$.

Similarly the source antenna was also adjusted to compensate for its previously measured tilt angle so that at $\Psi = 0°$ its E-field was vertical on average. The minimum axial ratio of the source antenna was 71.6 dB for the frequencies at which pattern measurements were performed. The finite axial ratio and the variation of the tilt angle with frequency were corrected for in the final results.

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For the co-polar measurements the antenna under test (AUT) was rotated in Φ to the relevant cut angle and the source antenna was then rotated so that $\Psi = -\Phi$. For the cross-polar measurements the source antenna was rotated to $\Psi = -\Phi + 90°$, in accordance with Ludwig's 3rd definition of cross-polar.

The cross-polar discrimination (XPD) is defined as the ratio of the cross-polar to the co-polar pattern levels and was calculated from the measured co-polar and cross-polar patterns. The on-axis XPD is equal to the measured axial ratio.

Pattern plots have been provided in this certificate at 110 GHz only. The full set of pattern data has been provided separately in Excel spreadsheets.

All measurements were made in a temperature controlled electromagnetic anechoic chamber in a screened laboratory at a temperature of 23 ± 2°C.

MEASUREMENT UNCERTAINTIES

For each of the parameters measured, with the exception of the tilt angle, the reported expanded uncertainties are based on a standard uncertainty multiplied by a coverage factor $k = 2$, providing a coverage probability of approximately 95%. For the tilt angle the expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k = 2.23$, which for a t-distribution with $V_{eff} = 12$ degrees of freedom corresponds to a coverage probability of approximately 95%. The uncertainty in the measured axial ratio is asymmetric and depends on the measured value. Examples are given in the table below. These uncertainties apply only to the measured values and give no indication of the long term stability of the antenna.

Parameter	**Uncertainty**
Gain	± 0.11 dB
Tilt angle	± 0.11°
Reflection coefficient – real or imaginary part	± 0.010 units
Co-polar pattern uncertainty within $\theta = \pm 10°$	± 0.04 dB
X-polar pattern uncertainty @ -40 dB	± 1.1 dB

The relative uncertainty in the gain values for adjacent frequency points is less than the absolute uncertainty given in the table above. For this reason the gain values have been given to more decimal places than the associated uncertainty. The additional decimal places in the result help to show the underlying frequency response.

Axial Ratio Uncertainties for Ratios Shown

Measured Axial Ratio [dB]	Positive Uncertainty [dB]	Negative Uncertainty [dB]
51.0	2.5	-2.0
52.0	2.9	-2.2
53.0	3.3	-2.4
54.0	3.8	-2.6
55.0	4.4	-2.9
56.0	5.2	-3.2
57.0	6.1	-3.5
58.0	7.2	-3.9
59.0	8.7	-4.3
60.0	10.7	-4.7
61.0	13.8	-5.1
62.0	19.4	-5.5
63.0	∞	-6.0

Summary of measured results compared to technical specification

The table below summarises the results of the measurements against the requirements set out in the Thales Alenia Space specifications document [4]. Note that the illuminator directivity was calculated from the gain result by using a calculated ohmic loss of 0.21 dB. The antenna complies with the stated specifications at the measured points for the stated confidence level, due allowance having been made for the uncertainty of the measurements.

Parameter	REQ #	Measured	With measurement uncertainty	Specification	Remark	Compliance
Illuminator Directivity	3	13.03 dBi to 13.13 dBi	12.92 dBi to 13.24 dBi worst case	(13.0 ± 0.5) dBi	Assumes 0.21 dB calculated Ohmic loss. ± 0.11 dB measurement uncertainty.	Y
Illuminator Gain	4	12.82 dB	12.71 dB worst case	>12 dB	± 0.11 dB uncertainty	Y
Maximum VSWR	5	1.15 (23.1 dB return loss)	1.18 worst case (21.5 dB return loss)	<1.3 (18 dB return loss)	Measurement uncertainty of ± 0.01 in real and imaginary parts.	Y
On boresight XPD	6	53.0 dB @ 110 GHz 51.8 dB at remaining frequencies	50.6 dB @ 110 GHz 49.6 dB at remaining frequencies	>46 dB @ 110 GHz >45 dB remaining frequencies	-2.2 dB uncertainty	Y
Xpol over FOV	7	-46.2 dB	-45.1 dB	Xpol <-45 dB over theta ± 9.8°	1.1 dB uncertainty	Y

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RESULTS

Freq [GHz]	Gain [dB]	Reflection Coefficients		VSWR	Return Loss [dB]
		Real Part	Imaginary Part		
108.000	12.841	-0.035	-0.061	1.15	23.0
108.025	12.832	-0.037	-0.060	1.15	23.1
108.050	12.839	-0.039	-0.058	1.15	23.1
108.075	12.827	-0.041	-0.057	1.15	23.2
108.100	12.836	-0.042	-0.055	1.15	23.2
108.125	12.826	-0.044	-0.053	1.15	23.2
108.150	12.827	-0.045	-0.051	1.15	23.3
108.175	12.833	-0.047	-0.049	1.15	23.3
108.200	12.827	-0.048	-0.048	1.15	23.4
108.225	12.836	-0.050	-0.046	1.14	23.4
108.250	12.835	-0.051	-0.044	1.14	23.4
108.275	12.835	-0.052	-0.042	1.14	23.5
108.300	12.839	-0.054	-0.040	1.14	23.5
108.325	12.822	-0.055	-0.038	1.14	23.6
108.350	12.827	-0.056	-0.035	1.14	23.6
108.375	12.825	-0.057	-0.033	1.14	23.7
108.400	12.847	-0.058	-0.031	1.14	23.7
108.425	12.853	-0.058	-0.029	1.14	23.7
108.450	12.858	-0.059	-0.027	1.14	23.8
108.475	12.867	-0.060	-0.024	1.14	23.8
108.500	12.856	-0.060	-0.022	1.14	23.9
108.525	12.858	-0.061	-0.020	1.14	23.9
108.550	12.844	-0.061	-0.017	1.14	24.0
108.575	12.847	-0.061	-0.015	1.14	24.0
108.600	12.844	-0.062	-0.013	1.13	24.0
108.625	12.843	-0.062	-0.011	1.13	24.1
108.650	12.840	-0.062	-0.008	1.13	24.1
108.675	12.846	-0.062	-0.006	1.13	24.1
108.700	12.833	-0.062	-0.003	1.13	24.2
108.725	12.827	-0.062	-0.001	1.13	24.2
108.750	12.845	-0.061	0.001	1.13	24.3
108.775	12.832	-0.061	0.003	1.13	24.3
108.800	12.842	-0.061	0.006	1.13	24.3
108.825	12.848	-0.060	0.008	1.13	24.4
108.850	12.846	-0.059	0.010	1.13	24.4
108.875	12.871	-0.059	0.012	1.13	24.4
108.900	12.854	-0.058	0.015	1.13	24.5
108.925	12.883	-0.057	0.017	1.13	24.5
108.950	12.882	-0.056	0.019	1.13	24.5
108.975	12.864	-0.056	0.021	1.13	24.5

Freq [GHz]	Gain [dB]	Reflection Coefficients		VSWR	Return Loss [dB]
		Real Part	Imaginary Part		
109.000	12.855	-0.054	0.023	1.13	24.6
109.025	12.862	-0.053	0.025	1.13	24.6
109.050	12.837	-0.052	0.027	1.12	24.6
109.075	12.854	-0.051	0.029	1.13	24.6
109.100	12.841	-0.050	0.031	1.12	24.6
109.125	12.856	-0.049	0.033	1.12	24.7
109.150	12.862	-0.047	0.034	1.12	24.7
109.175	12.866	-0.046	0.036	1.12	24.7
109.200	12.887	-0.044	0.038	1.12	24.7
109.225	12.878	-0.043	0.039	1.12	24.7
109.250	12.875	-0.041	0.041	1.12	24.8
109.275	12.883	-0.039	0.042	1.12	24.8
109.300	12.881	-0.038	0.044	1.12	24.8
109.325	12.876	-0.036	0.045	1.12	24.8
109.350	12.865	-0.034	0.046	1.12	24.8
109.375	12.878	-0.032	0.048	1.12	24.8
109.400	12.886	-0.030	0.049	1.12	24.8
109.425	12.895	-0.028	0.050	1.12	24.8
109.450	12.896	-0.026	0.051	1.12	24.8
109.475	12.917	-0.024	0.052	1.12	24.9
109.500	12.900	-0.022	0.053	1.12	24.8
109.525	12.890	-0.020	0.054	1.12	24.9
109.550	12.893	-0.018	0.054	1.12	24.8
109.575	12.908	-0.016	0.055	1.12	24.8
109.600	12.902	-0.014	0.056	1.12	24.8
109.625	12.898	-0.012	0.056	1.12	24.8
109.650	12.921	-0.010	0.057	1.12	24.8
109.675	12.892	-0.007	0.057	1.12	24.8
109.700	12.877	-0.005	0.057	1.12	24.8
109.725	12.886	-0.003	0.058	1.12	24.8
109.750	12.883	-0.001	0.057	1.12	24.8
109.775	12.911	0.001	0.058	1.12	24.8
109.800	12.902	0.003	0.058	1.12	24.8
109.825	12.891	0.006	0.058	1.12	24.7
109.850	12.894	0.008	0.058	1.12	24.7
109.875	12.877	0.010	0.057	1.12	24.7
109.900	12.883	0.012	0.057	1.12	24.7
109.925	12.885	0.014	0.057	1.12	24.7
109.950	12.886	0.016	0.056	1.12	24.7
109.975	12.877	0.018	0.056	1.12	24.6
110.000	12.881	0.020	0.055	1.12	24.6

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Polarisation Parameters

Freq [GHz]	Axial Ratio [dB]	Tilt [deg]	Sense
108.00	51.8	89.53	Left
108.05	54.2	89.59	Left
108.10	53.1	89.54	Left
108.15	54.1	89.55	Left
108.20	53.7	89.60	Left
108.25	53.7	89.58	Left
108.30	54.9	89.54	Left
108.35	59.6	89.59	Left
108.40	55.0	89.57	Left
108.45	56.0	89.53	Left
108.50	57.9	89.51	Left
108.55	56.9	89.53	Left
108.60	59.1	89.54	Left
108.65	56.1	89.54	Left
108.70	59.7	89.55	Left
108.75	56.0	89.51	Left
108.80	58.7	89.54	Left
108.85	62.1	89.53	Left
108.90	56.4	89.53	Left
108.95	61.7	89.49	Left
109.00	57.7	89.52	Left
109.05	63.7	89.50	Left
109.10	57.3	89.51	Left
109.15	58.5	89.50	Left
109.20	57.8	89.48	Left
109.25	57.8	89.50	Left
109.30	58.1	89.50	Left
109.35	57.6	89.50	Left
109.40	56.8	89.54	Left
109.45	55.3	89.49	Left
109.50	56.7	89.48	Left
109.55	55.1	89.48	Left
109.60	57.0	89.48	Left
109.65	54.9	89.49	Left
109.70	56.6	89.50	Left
109.75	55.0	89.46	Left
109.80	54.7	89.53	Left
109.85	54.1	89.46	Left
109.90	53.3	89.48	Left
109.95	55.0	89.50	Left
110.00	53.0	89.50	Left

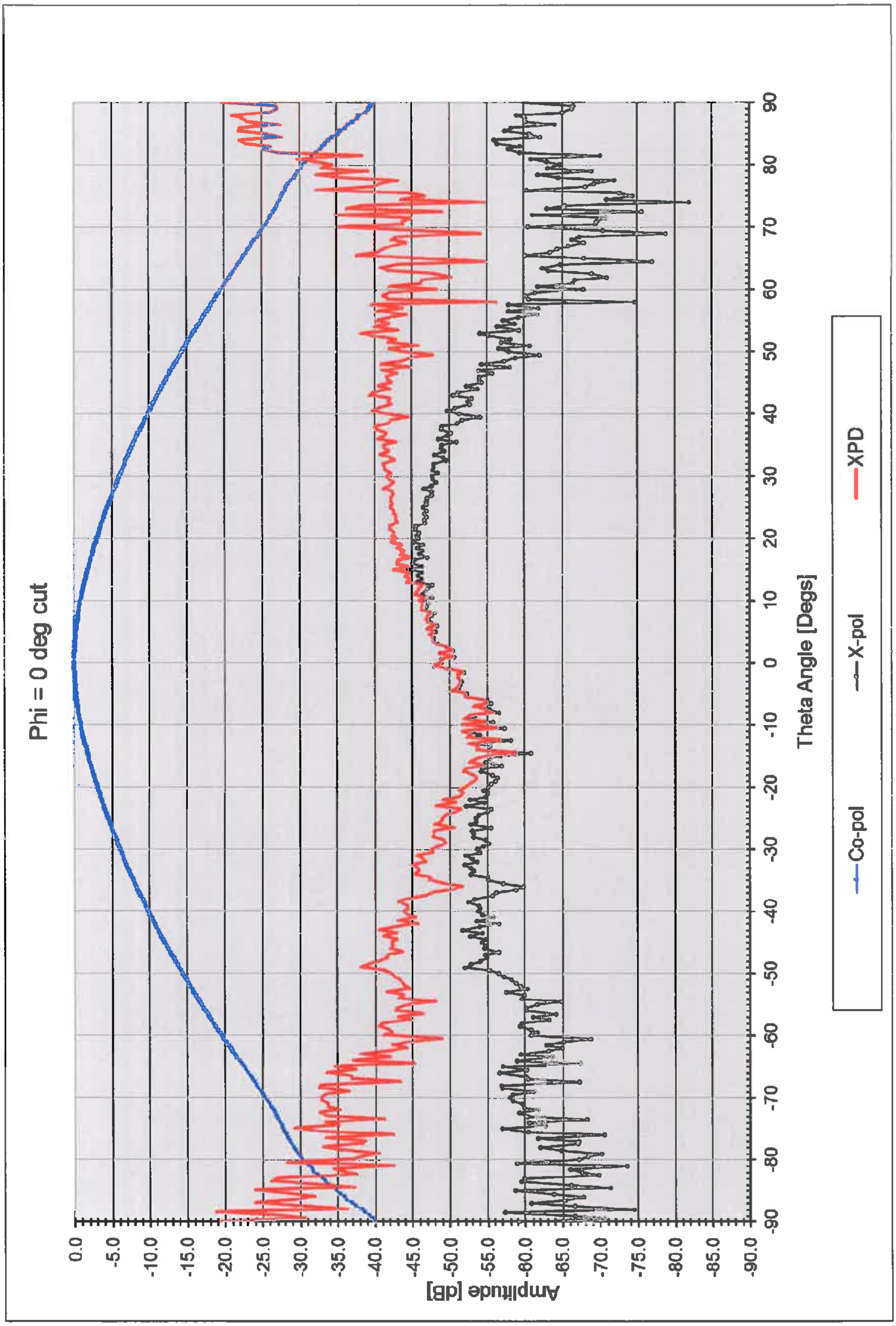

Figure 1 Φ = 0° cut at 110 GHz

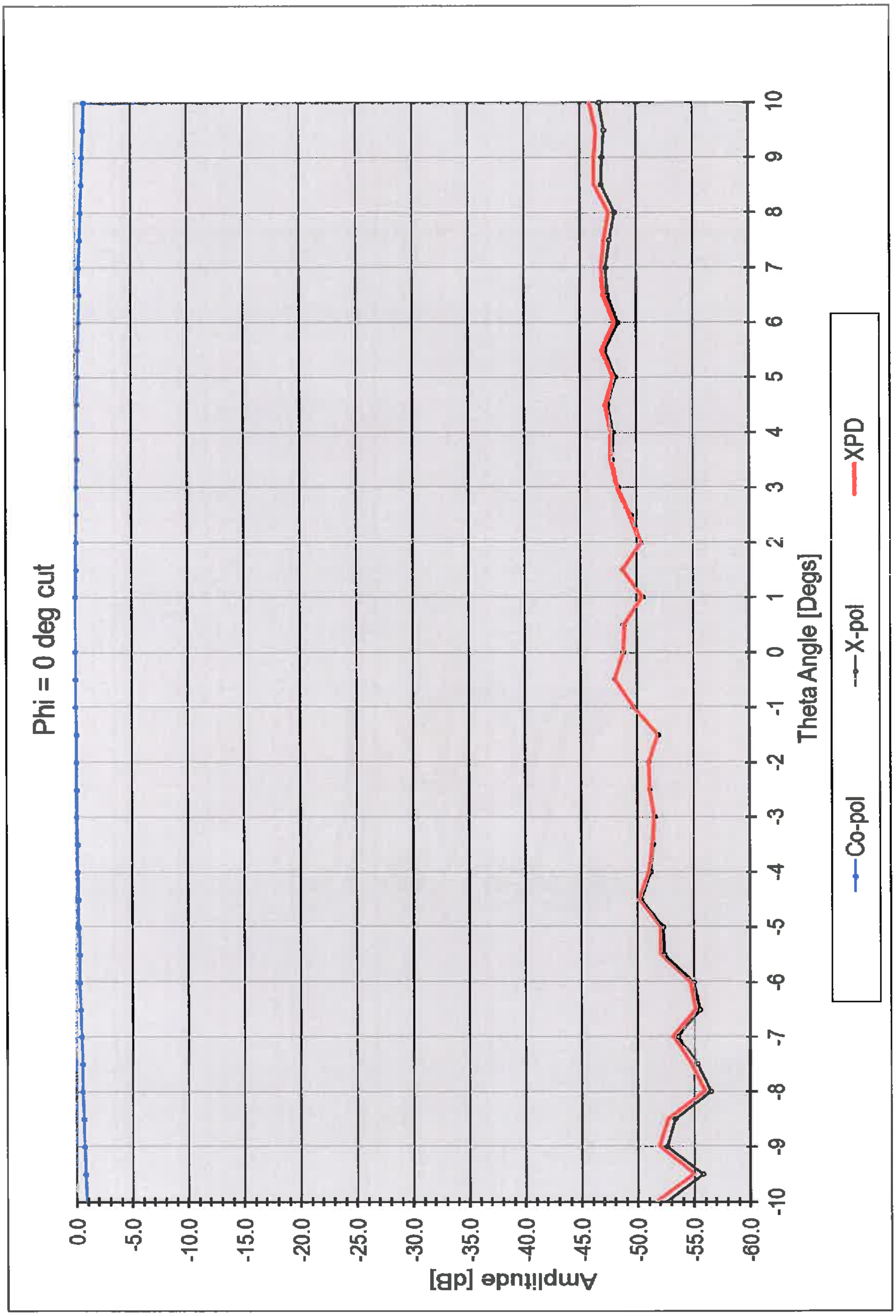

Figure 2 Φ = 0° cut at 110 GHz in θ = ± 10° range

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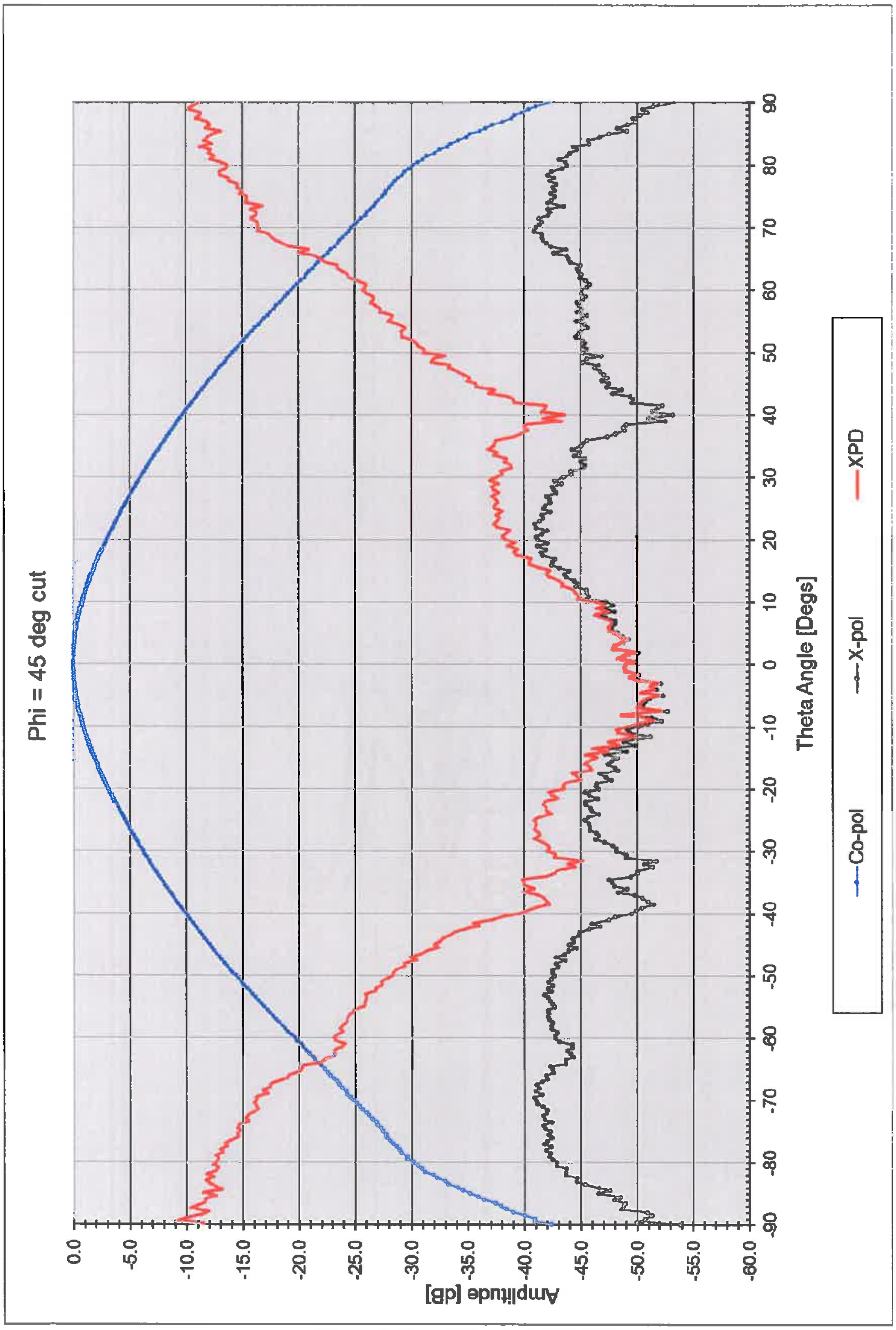

Figure 3 Φ = 45° cut at 110 GHz

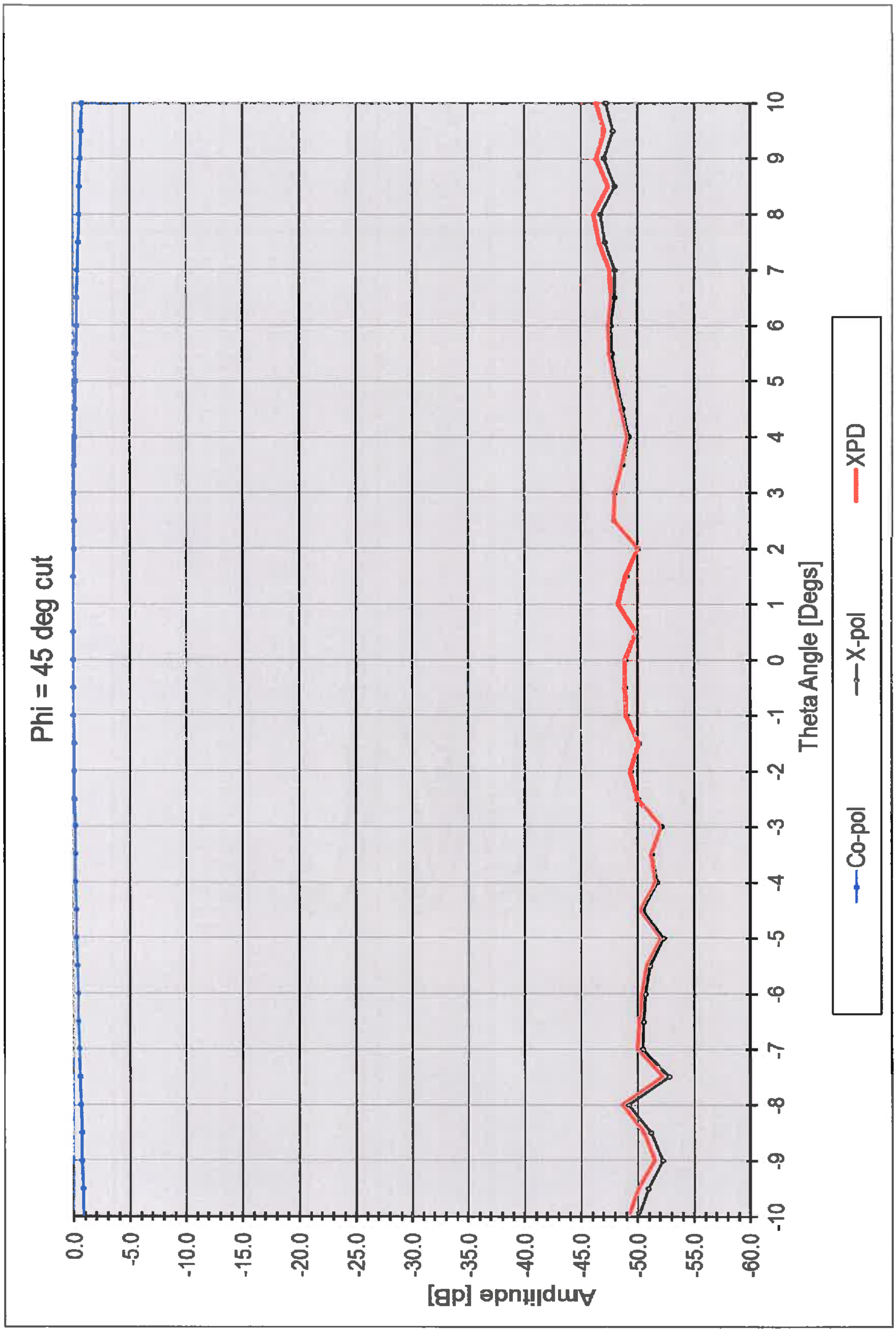

Figure 4 Φ = 45° cut at 110 GHz in θ = ± 10° range

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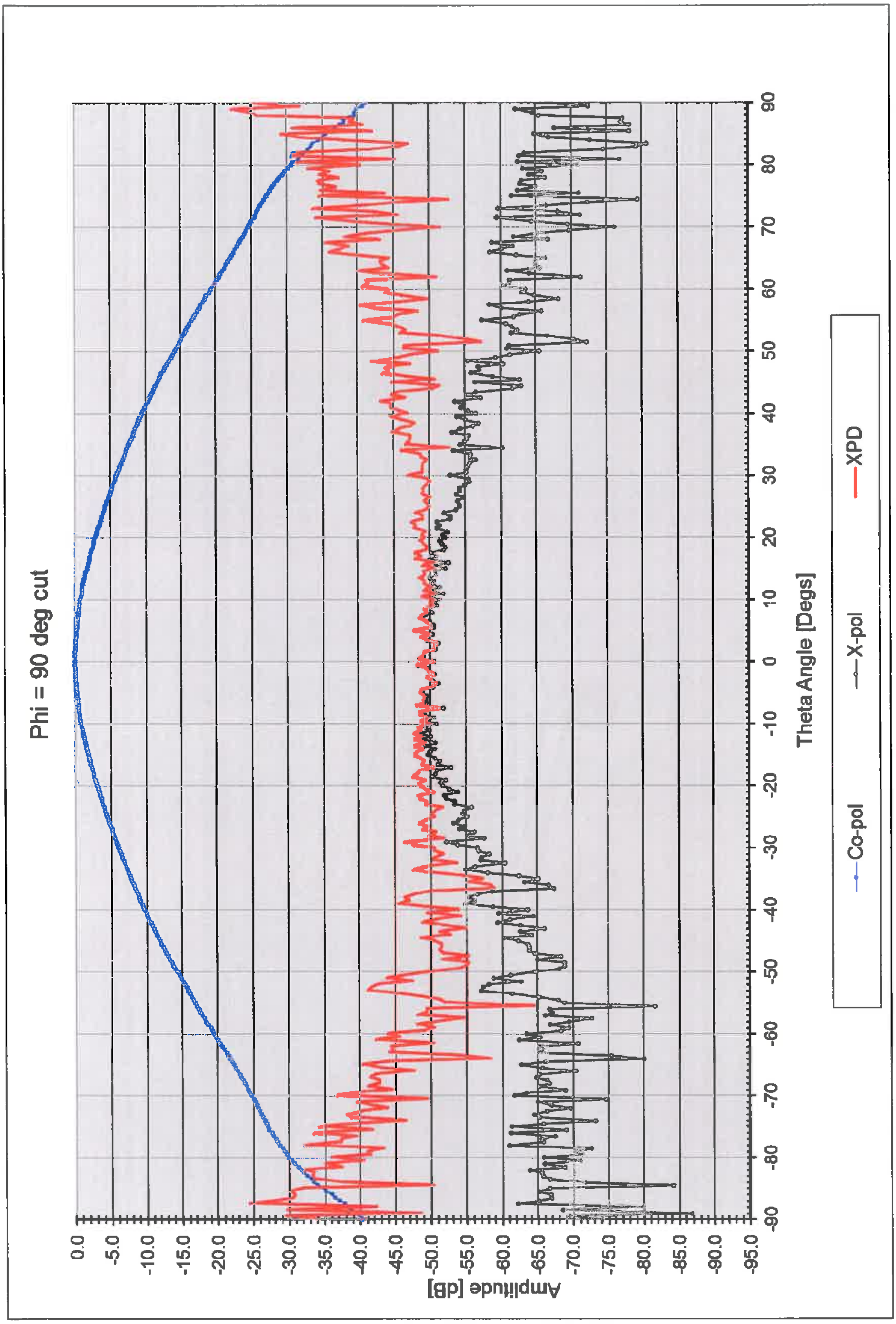

Figure 5 Φ = 90° cut at 110 GHz

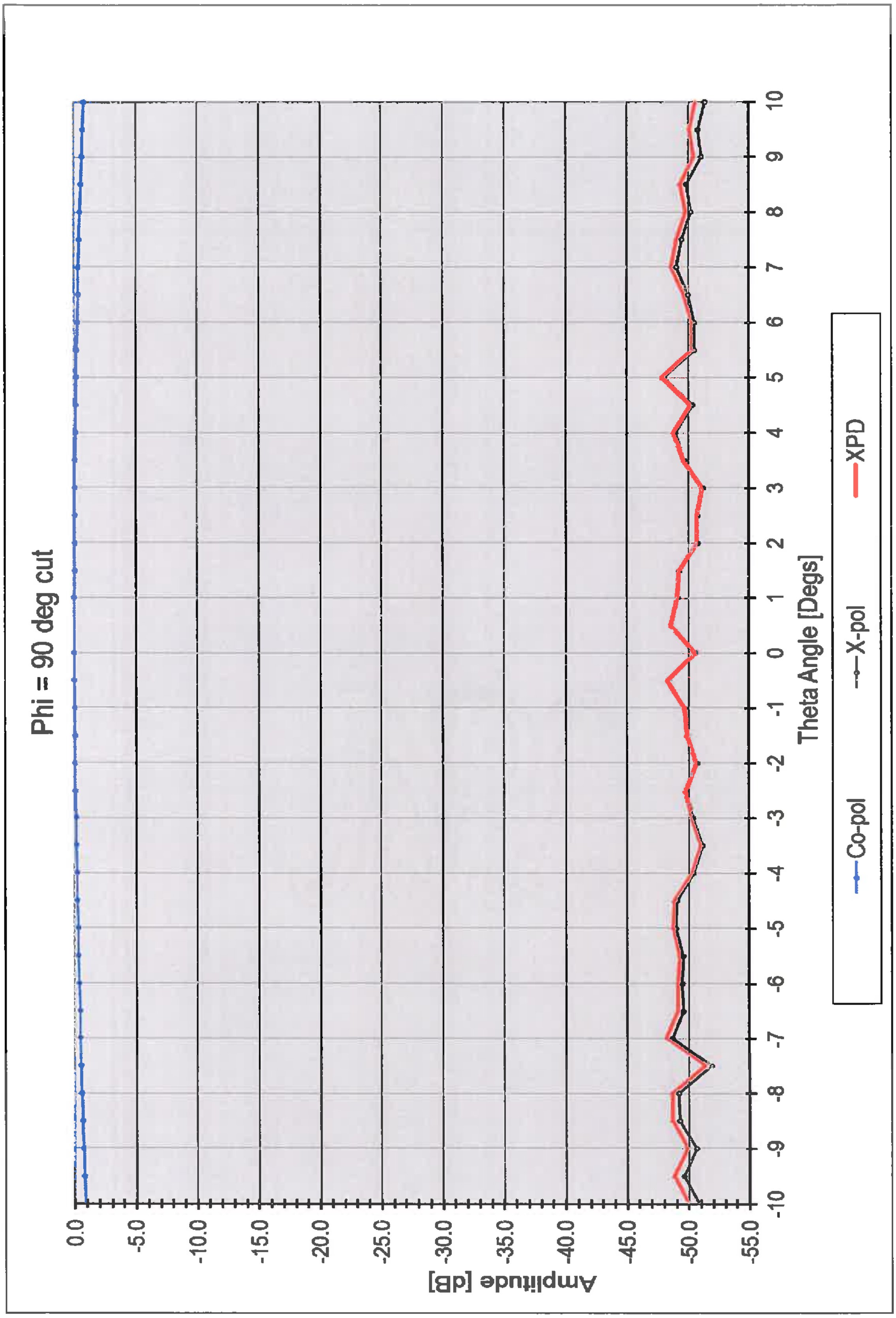

Figure 6 Φ = 90° cut at 110 GHz in θ = ± 10° range

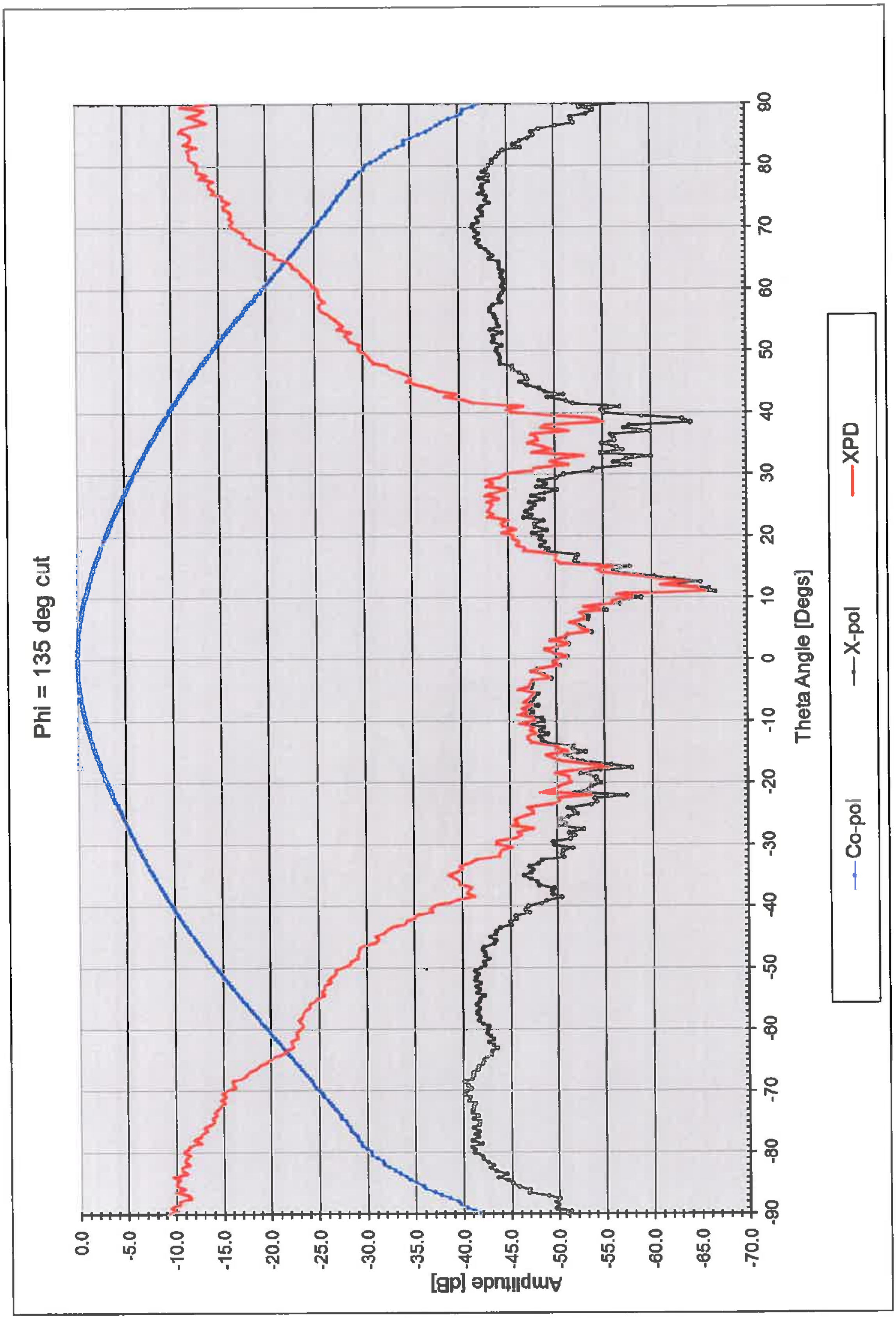

Figure 7 $\Phi = 135°$ cut at 110 GHz

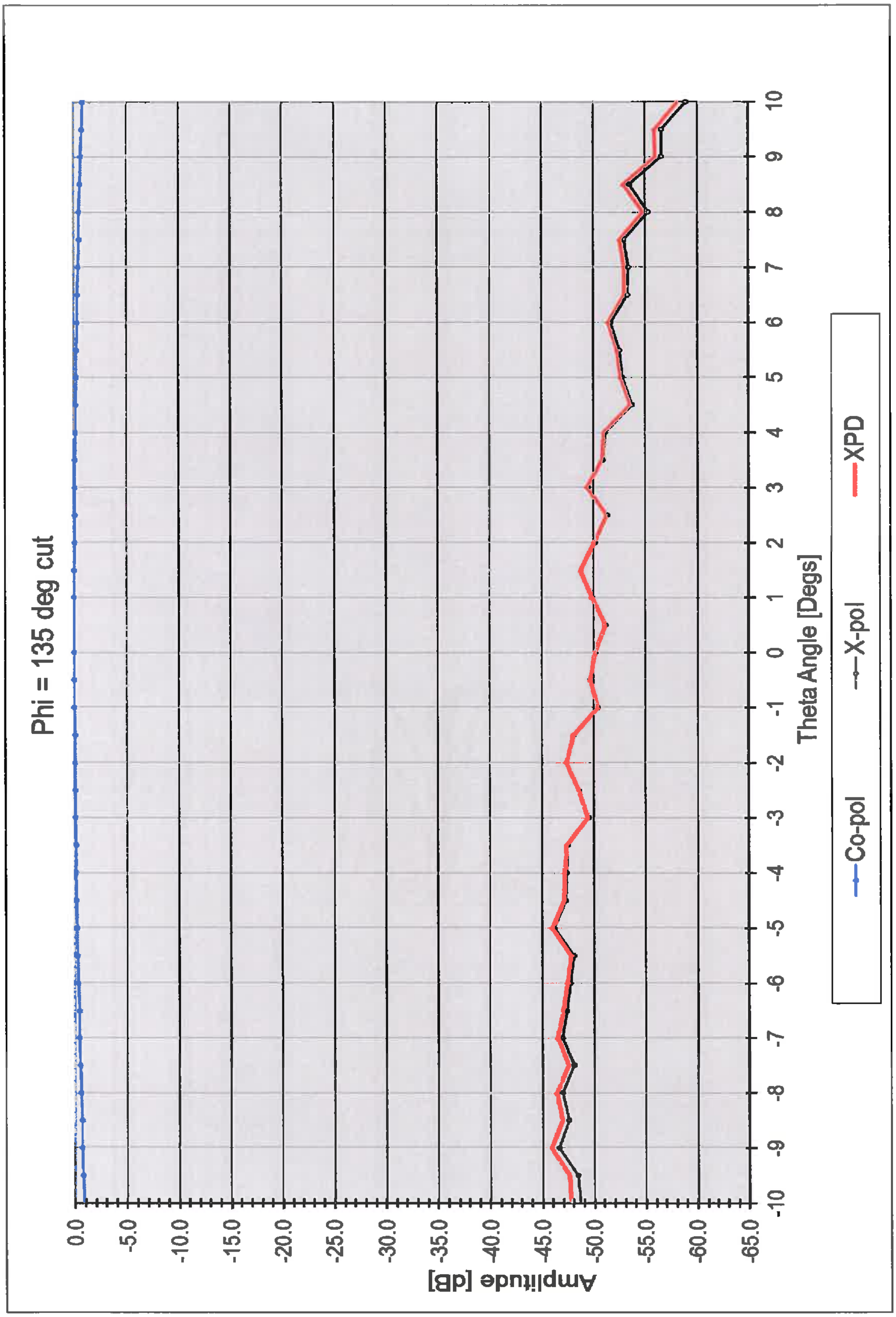

Figure 8 $\Phi = 135^\circ$ cut at 110 GHz in $\theta = \pm 10^\circ$ range

REFERENCES

[1] "Accurate Measurement of Antenna Gain and Polarization at Reduced Distances by an Extrapolation Technique", A.C. Newell at al., IEEE Trans AP, Vol. 21, No. 4, pp 418 – 431, July 1973.

[2] "Improved Polarization Measurements Using a Modified Three-Antenna Technique", A.C. Newell, IEEE Trans AP, Vol. 36, No. 6, pp 852 – 854, June 1988.

[3] "The Definition of Cross Polarization", A. C. Ludwig, IEEE Trans AP, Vol. 21, Issue 1, pp116-119, January 1973.

[4] "Statement of Work and Technical Specification for the procurement of CATR illuminator and probe W-Band and V-Band – linear polarization", reference xxxxxx, issue 01, dated 15 December 2015.