REPORT 1.1

FM ANTENNA RECONSTITUTION

SAMPLE SITE (FM). 3 MARCH 2017.

1/ EXECUTIVE SUMMARY

Sixarms has been commissioned by the Client to verify the performance of the New VHF FM antenna installed at the Sample Site. The verification was made using an unmanned aerial vehicle (UAV) based survey system on the 3rd March 2017.

The FM antenna being surveyed is a newly installed ABC FM broadcast array antenna. It is an omni-directional array, with the VHF FM services being circularly polarised (i.e. Vertical and Horizontal). It consists of 16 panels, 4 levels with 4 faces FM antenna. The antenna has an aperture of 13.6m and is mounted on a mast, with the centre of the array at 88m above ground level.

The verification procedure involved the measurement of the Horizontal Radiation Pattern (HRP) on the main beam and a Vertical Radiation Pattern (VRP) on each of the 4 antenna faces for both the vertical and horizontal components of the circularly polarised antenna. This report concerns the FM antenna performance.

Measurement Findings:

1) The HRP's (both V&H components) are generally omnidirectional in nature. Minor differences in peaks and nulls were observed and are within the tolerances of this report.

2) The VRP's (both V&H components) did not differ significantly from the design. Variations in measured beamtilts versus designed beamtilts had less than 1dB effect on ERP values.

3) Combined V&H measured maximum ERP values (taking uncertainties into consideration) are within Regulator licenced ERP values.

In summary, there appears to be no significant differences between the design and what has been measured. No further investigation is needed.

CONTENTS

DOCUMENT REVISION

Version	Date	Revision Details
1.0	3 March 2017	Initial Release

CONTACTS

SIXARMS
Jason Schreiber RF Engineer +61 437 502 068 Jason@Sixarms.com

ABBREVIATIONS

AUT Antenna Under Test

DTV/DVB-T Digital Television

ERP Effective Radiated Power

FM Frequency Modulation

GPS Global Positioning System

IMU Inertial Management Unit

ITU International Telecommunication Union

HRP Horizontal Radiation Patter

RF Radio Frequency

UAV Unmanned Aerial Vehicle

VRP Vertical Radiation Pattern

VHF Very High Frequency

2/ INTRODUCTION

Sixarms has developed a method of commissioning broadcast antennas by measuring the radiation pattern from an airborne platform equipped with appropriate field strength, receive antenna, and positional measuring equipment.

This method is an efficient and accurate way to rapidly evaluate the antenna performance in both horizontal and vertical planes, as a high number of sample points can be acquired within a short time frame.

The measurement survey involves the following actions carried out during the flight:

- Field strength data acquisition with a calibrated receive antenna and field strength meter,
- Positional data acquisition of the UAVs location in 6-dimensional space with a GPS and IMU and barometer

The measured field strengths are acquired in a free space situation. The UAV measurement system will have two main objectives to complete once it is airborne. Firstly, to measure the VRP and secondly, to measure the HRP of the antenna (these measurements include the ERP). VRP runs are carried out from a static distance away from the mast in the far field, with an incremental vertical rise from below the antenna to above the antenna to capture the vertical pattern. HRP runs are carried out from a static height in relation to the antenna but at a slow fixed-distance orbit in the far-field to capture the horizontal pattern. The outcome is a complete characterisation and verification of the performance of the antenna being measured. This system is based on the *ITU Recommendation ITU-R SM.2056-1 "Airborne verification of antenna patterns of broadcasting stations".*

The report that follows presents the measurements obtained on site on the 3rd March 2017 and compares them to the supplied design pattern and details any discrepancies or areas of interest.

3/ RESULTS AND PLOTS

The measurement survey was carried out on the 3rd March 2017. In total, 10 complete data sets were collected for each FM service operating on the new VHF FM antenna. This consisted of four vertical measurement runs and one horizontal measurement run, for both the vertical and horizontal components.

The actual flight paths and distances can be found in the Appendices but all flights were chosen to be approximately 120m from the transmission site to allow for measurements to be taken in the far-field. Most measurements experienced fluctuations in their values predominantly due to reflections off other structures as well as ground reflections within the vicinity of the measurement location. These fluctuations had minimal effect on the accuracy of the plots. All vertical flights were made between approximately 18 degrees below the horizon and 16 degrees above the horizon. Measurements of Face A (20°) were taken at 27° due to the vicinity of the public carpark.

The following sections outline the VRP and HRP measured plots and results and the plots have been organised according to depression angle (HRP) and azimuth (VRP). Included in the plots are:

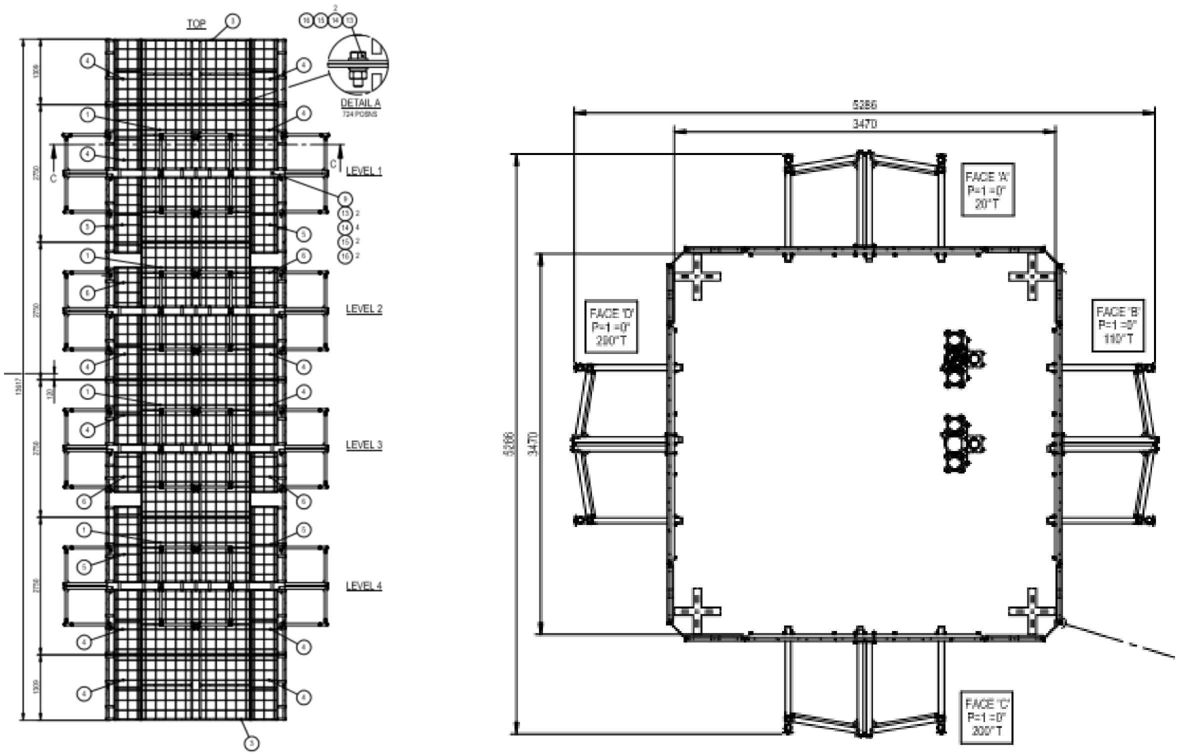
- Normalised plots (E/Emax) and comparison with designed
- ERP (dBW) comparisons (helpful when calculating coverage predictions)

Transmission, reception and uncertainties for the measured antenna can be found in the Appendices.

3/1 VHF FM ANTENNA AND DESIGN PLOTS

The VHF antenna being surveyed is an ABC Manufactured FM array model number 123456-4x4D. It is a omni-directional array operating from 88-108MHz. The antenna consists of 16 panels, 4 levels with 4 faces. The antenna has an aperture of 13.6m and is mounted on a mast, with the centre of the array at 88m above ground level.

All design patterns were taken out of the ABC handbook (number 12.76432.002) and were used as comparison against the measured data.



Diagrams of the design of the new FM antenna

3/2 VERTICAL COMPONENT OF HRP

Depression Angle	Plot Type		Service MHz	Results	Plot Number & Page
1°	V - Pol	Normalised (to Self)	92.90 93.90 100.90 101.70 105.70 106.50 107.30	Minor differences in direction of nulls and peaks, also minor differences in the size of the main lobes.	Plot 1 - 4 Page 11
		ERP	92.90 93.90 100.90 101.70 105.70 106.50 107.30	45.2 dBW 44.3 dBW 40.6 dBW 39.6 dBW 45.1 dBW 35.2 dBW 41.8 dBW	

3/3 VERTICAL COMPONENT OF VRP

Azimuth	Plot Type		Service	Results (BeamTilt/ERP)	Plot Number & Page
27° FACE A	V-Pol	Normalised (to self)	92.90 93.90 100.90 101.70 105.70 106.50 107.30	2.0° 1.3° 0.5° 0.5° -0.3° 1.1° 1.3°	Plot 5 - 8 Page 12
		ERP	92.90 93.90 100.90 101.70 105.70 106.50 107.30	42.0 dBW 41.9 dBW 38.3 dBW 37.2 dBW 42.3 dBW 32.8 dBW 39.6 dBW	
110° FACE B	V-Pol	Normalised (to self)	92.90 93.90 100.90 101.70 105.70 106.50 107.30	1.2° 1.1° 1.0° 0.6° 0.6° 1.1° 1.3°	Plot 9 - 12 Page 13
		ERP	92.90 93.90 100.90 101.70 105.70 106.50 107.30	43.0 dBW 42.0 dBW 37.6 dBW 36.5 dBW 41.7 dBW 31.8 dBW 38.4 dBW	
200° FACE C	V-Pol	Normalised (to self)	92.90 93.90 100.90 101.70 105.70 106.50 107.30	1.4° 0.8° 0.7° 0.5° 2.1° 1.2° 2.0°	Plot 13 - 16 Page 14
		ERP	92.90 93.90 100.90	42.5 dBW 42.3 dBW 38.9 dBW	

SIXARMS

			101.70 105.70 106.50 107.30	38.3 dBW 43.6 dBW 33.8 dBW 40.3 dBW	
290° FACE D	V-Pol	Normalised (to self)	92.90 93.90 100.90 101.70 105.70 106.50 107.30	2.0° 1.7° 1.0° 1.9° 1.9° 2.3° 2.1°	Plot 17 - 20 Page 15
		ERP	92.90 93.90 100.90 101.70 105.70 106.50 107.30	42.5 dBW 42.4 dBW 39.0 dBW 37.7 dBW 43.6 dBW 33.7 dBW 40.1 dBW	

Best fit polynomials have been used to smooth the data on VRPs.

SIXARMS

3/4 HORIZONTAL COMPONENT OF HRP

Depression Angle	Plot Type		Service MHz	Results	Plot Number & Page
1°	H - Pol	Normalised (to Self)	92.90 93.90 100.90 101.70 105.70 106.50 107.30	Minor differences in direction of nulls and peaks, also minor differences in the size of the main lobes.	Plot 21 - 24 Page 16
		ERP	92.90 93.90 100.90 101.70 105.70 106.50 107.30	45.5 dBW 44.5 dBW 38.9 dBW 37.3 dBW 42.3 dBW 32.3 dBW 39.0 dBW	

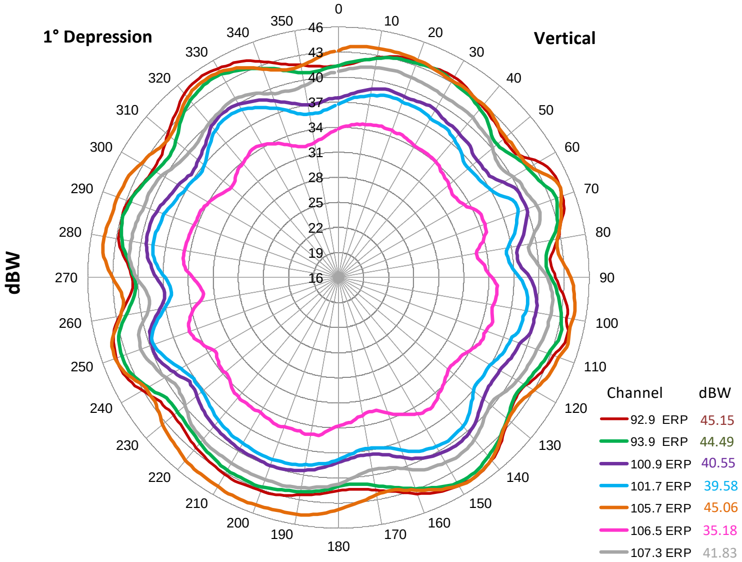
3/5 HORIZONTAL COMPONENT OF VRP

Azimuth	Plot Type		Service	Results (BeamTilt/ERP)	Plot Number & Page
27° FACE A	H-Pol	Normalised (to self)	92.90 93.90 100.90 101.70 105.70 106.50 107.30	0.7° 0.5° 1.0° 0.4° 0.2° 0.7° 1.3°	Plot 25 - 28 Page 17
		ERP	92.90 93.90 100.90 101.70 105.70 106.50 107.30	44.0 dBW 43.1 dBW 37.0 dBW 35.8 dBW 40.6 dBW 30.9 dBW 37.1 dBW	
110° FACE B	H-Pol	Normalised (to self)	92.90 93.90 100.90 101.70 105.70 106.50 107.30	0.4° 0.3° 0.9° 0.6° 0.1° 0.6° 0.7°	Plot 29 - 32 Page 18
		ERP	92.90 93.90 100.90 101.70 105.70 106.50 107.30	44.4 dBW 43.1 dBW 37.3 dBW 35.9 dBW 40.8 dBW 30.9 dBW 37.2 dBW	
200° FACE C	H-Pol	Normalised (to self)	92.90 93.90 100.90 101.70 105.70 106.50 107.30	0.5° 1.0° 1.2° 1.5° 1.5° 1.4° 1.4°	Plot 33 - 36 Page 19
		ERP	92.90 93.90 100.90	44.3 dBW 43.6 dBW 37.3 dBW	

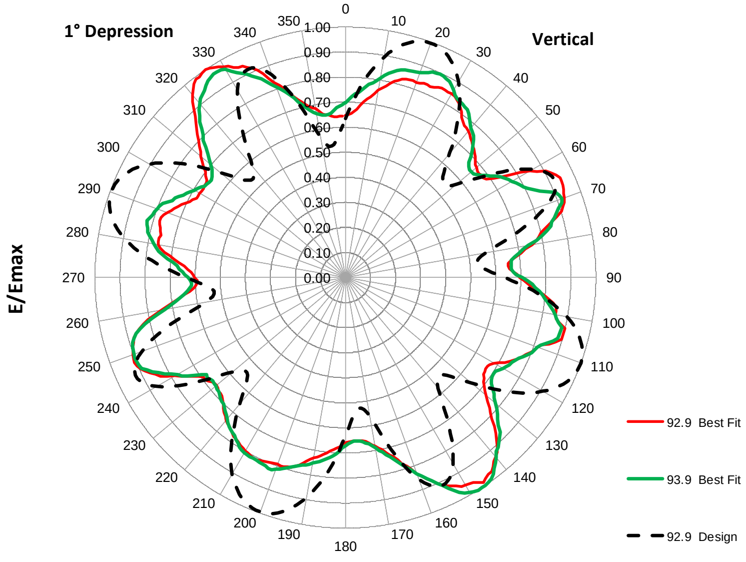
			101.70 105.70 106.50 107.30	36.2 dBW 40.4 dBW 30.3 dBW 36.5 dBW	
290° FACE D	H-Pol	Normalised (to self)	92.90 93.90 100.90 101.70 105.70 106.50 107.30	0.5° 0.6° 0.4° 0.6° 0.5° 0.7° 0.6°	Plot 37 - 40 Page 20
		ERP	92.90 93.90 100.90 101.70 105.70 106.50 107.30	35.1 dBW 34.6 dBW 34.2 dBW 34.1 dBW 40.6 dBW 32.9 dBW 38.2 dBW	

Best fit polynomials have been used to smooth the data on VRPs.

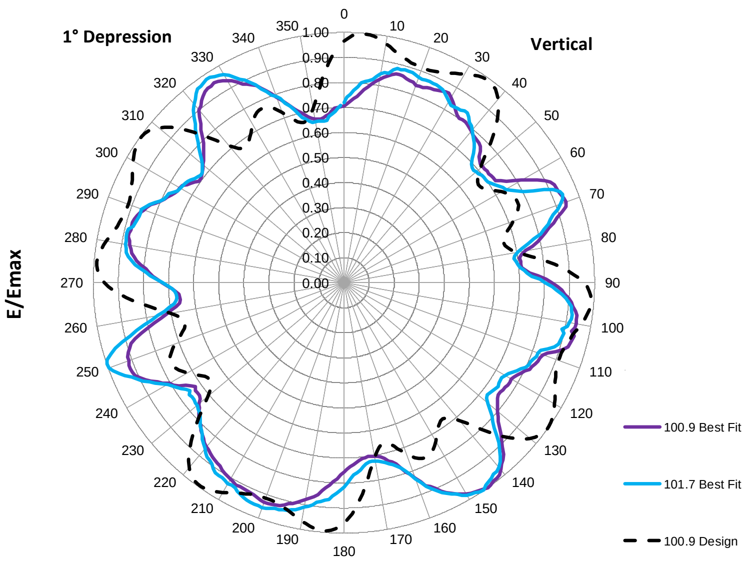
Vertical Component of HRPs at 1° Below the Horizon



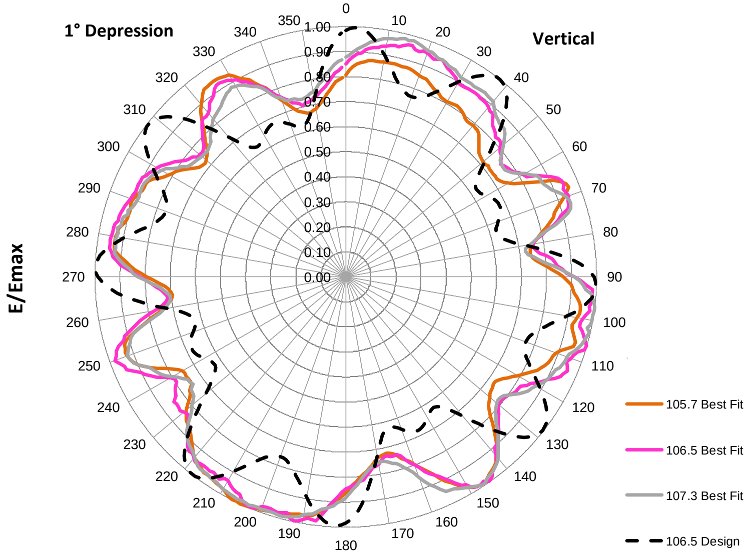
Plot 1: All Channels ERP (dBW)



Plot 2: Lower Channels - Normalised



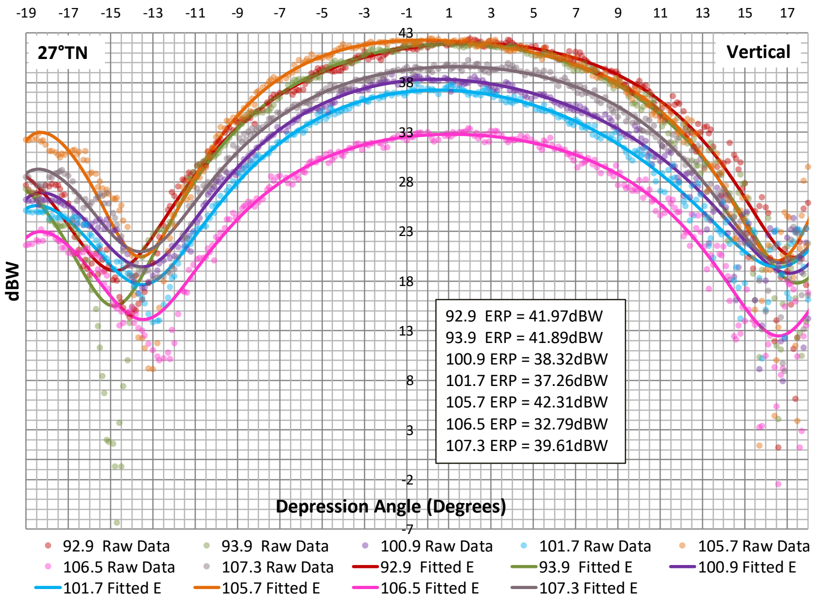
Plot 3 Middle Channels - Normalised



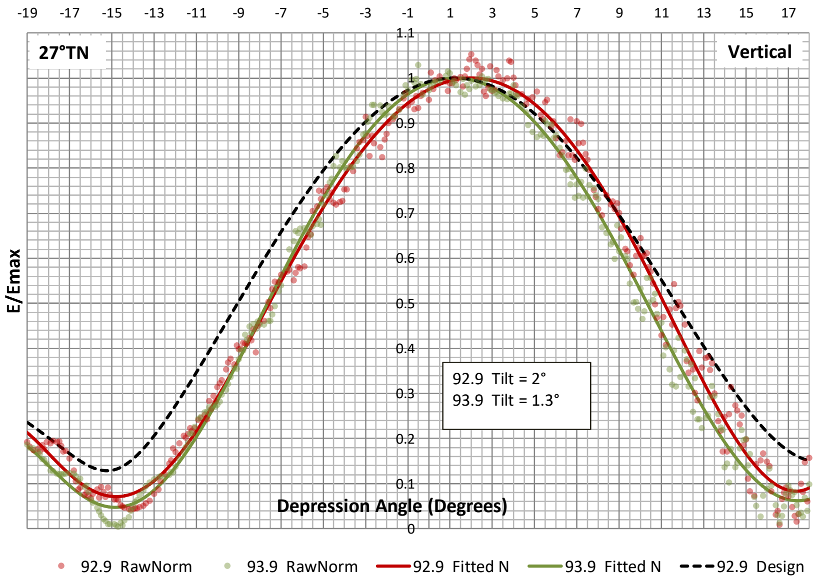
Plot 4 Upper Channels - Normalised

SIXARMS

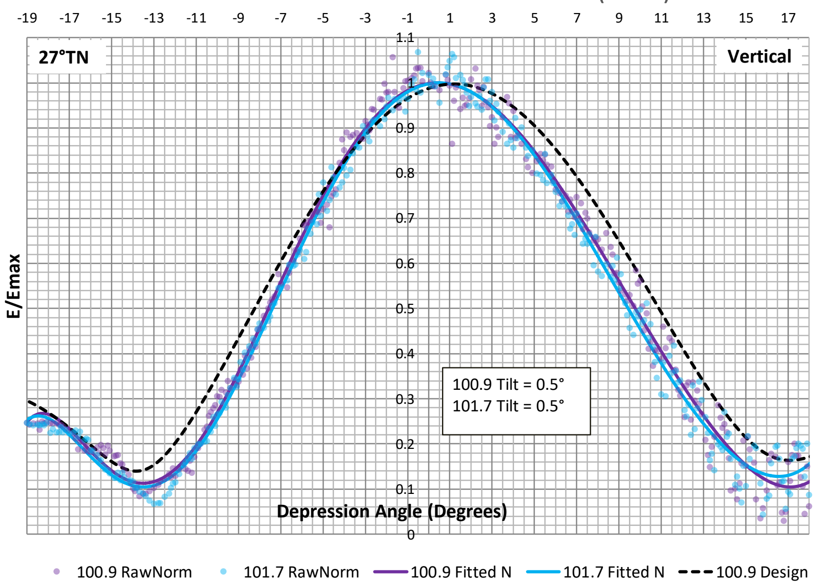
Vertical Component of VRPs – Face A - 20˚TN



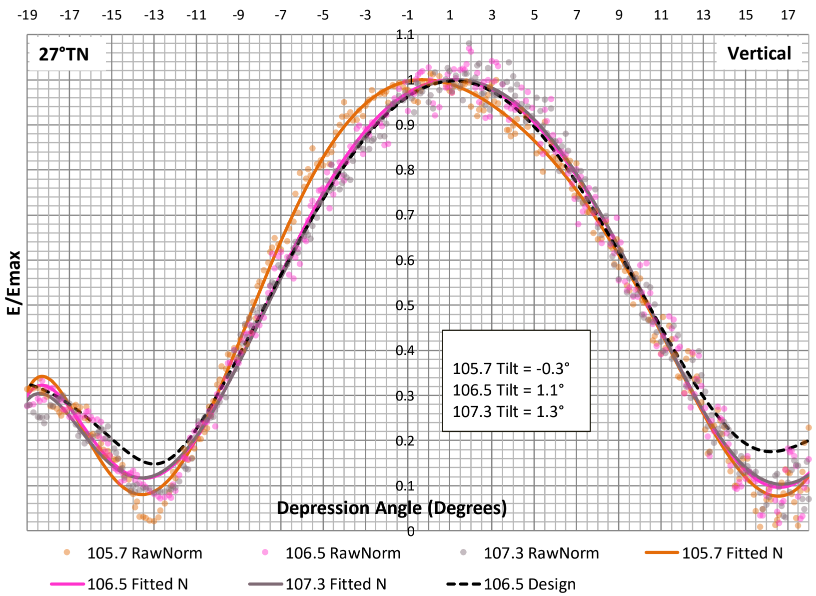
Plot 5: All Channels ERP (dBW)



Plot 6: Lower Channels - Normalised

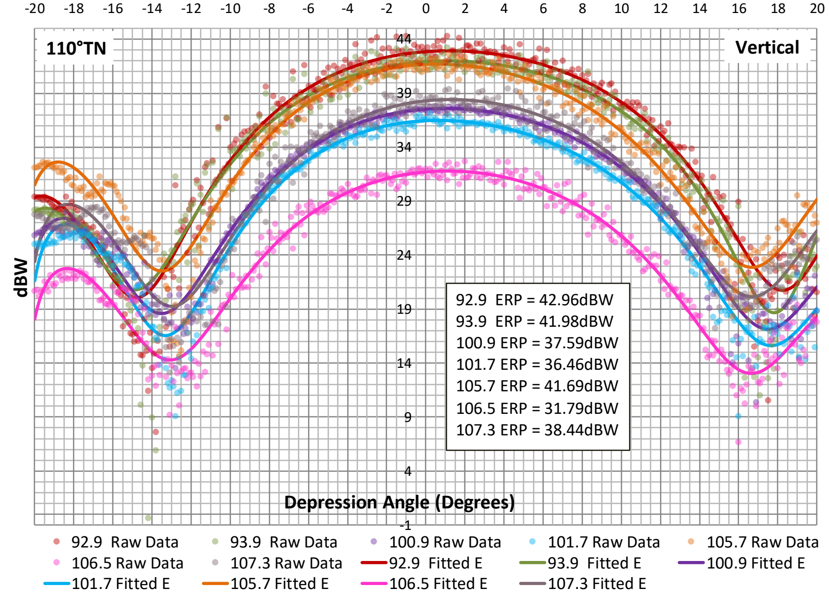


Plot 7 Middle Channels - Normalised

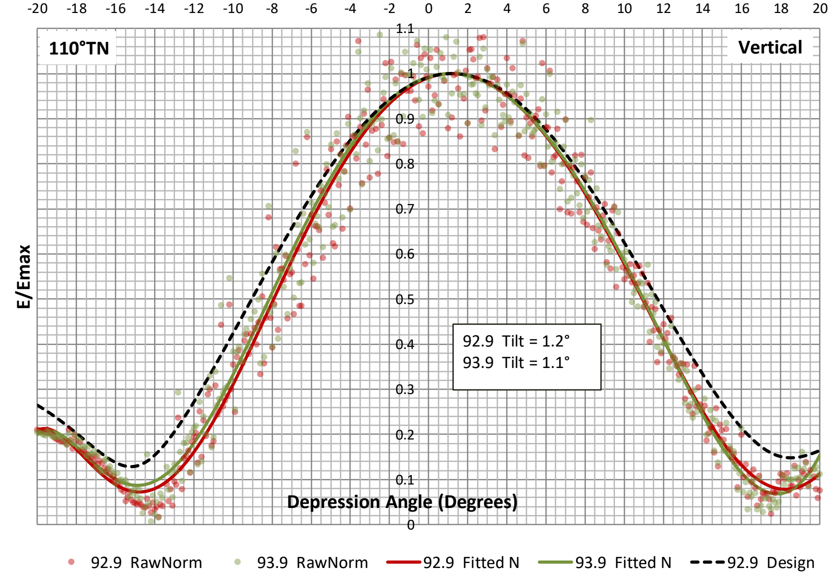


Plot 8 Upper Channels - Normalised

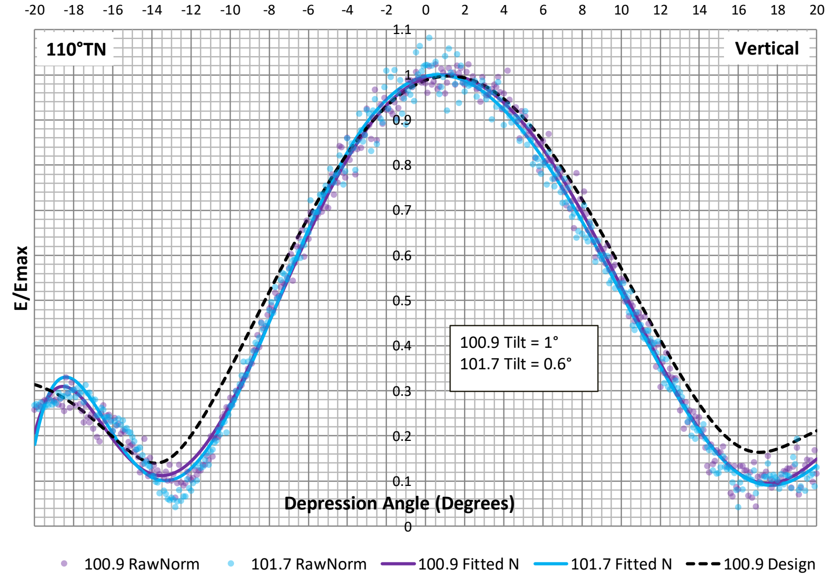
Vertical Component of VRPs – Face B - 110˚TN



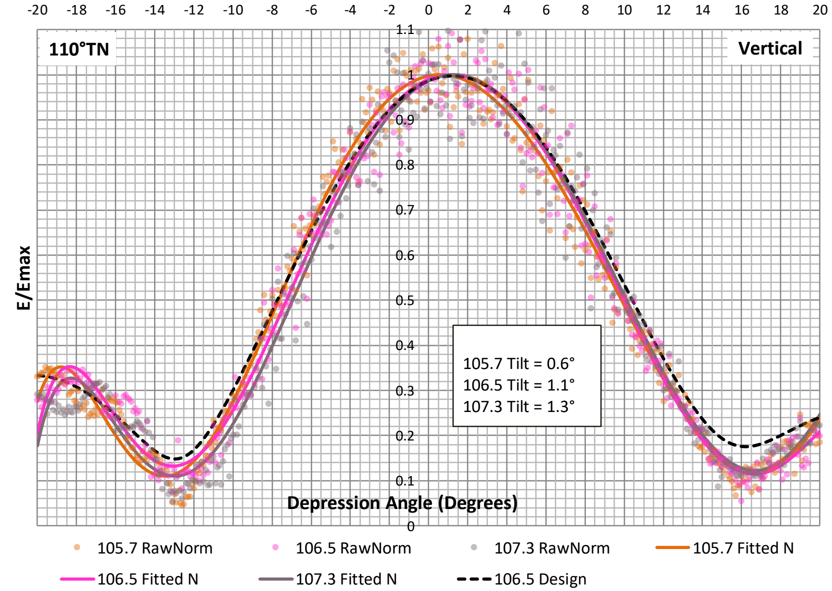
Plot 9: All Channels ERP (dBW)



Plot 10: Lower Channels - Normalised

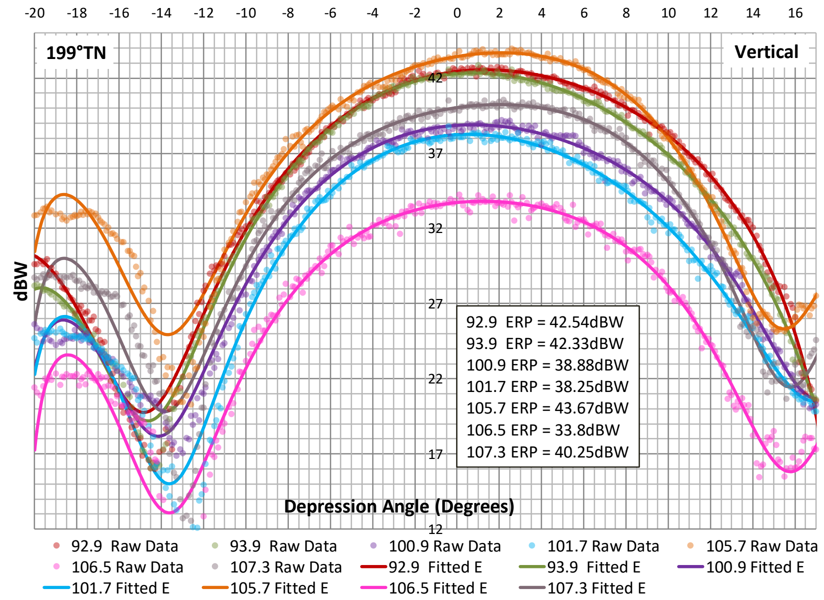


Plot 11 Middle Channels - Normalised



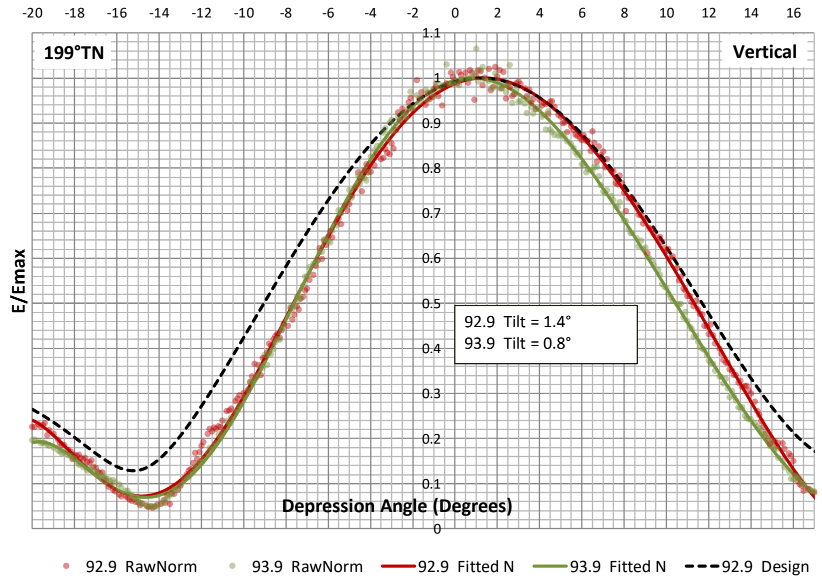
Plot 12 Upper Channels - Normalised

Vertical Component of VRPs – Face C - 200˚TN



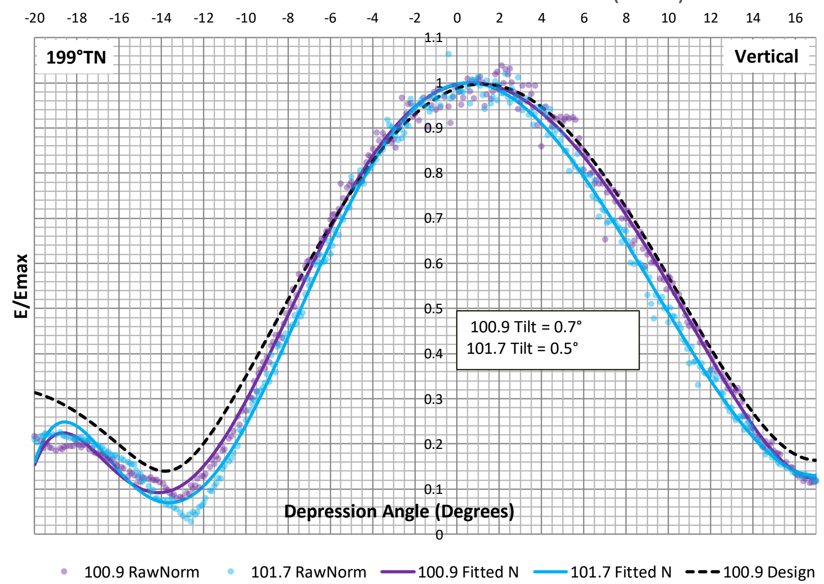
Plot 13: All Channels ERP (dBW)

3



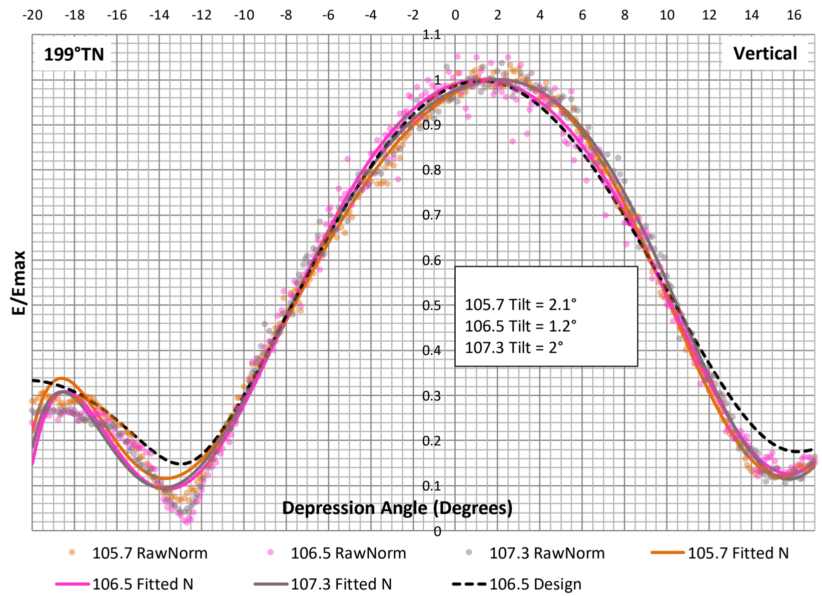
Plot 14: Lower Channels - Normalised

3



Plot 15 Middle Channels - Normalised

3

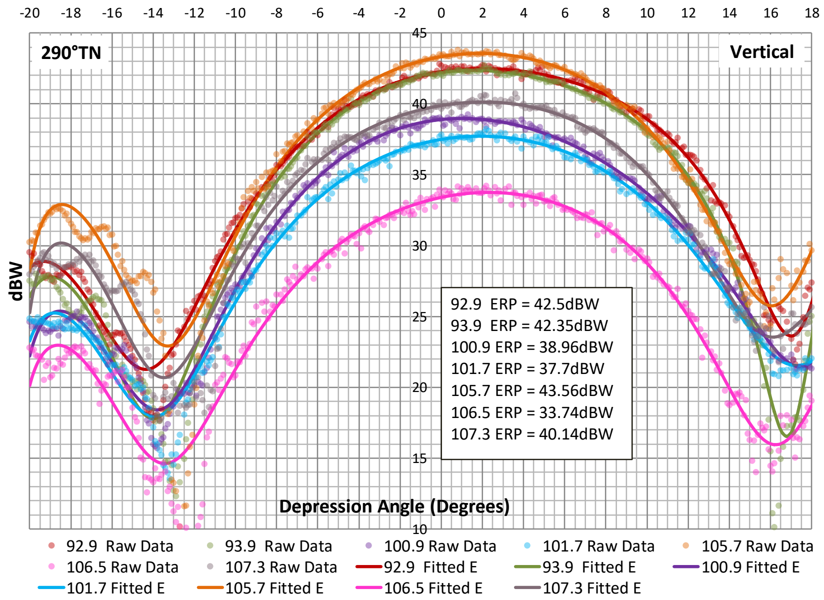


Plot 16 Upper Channels - Normalised

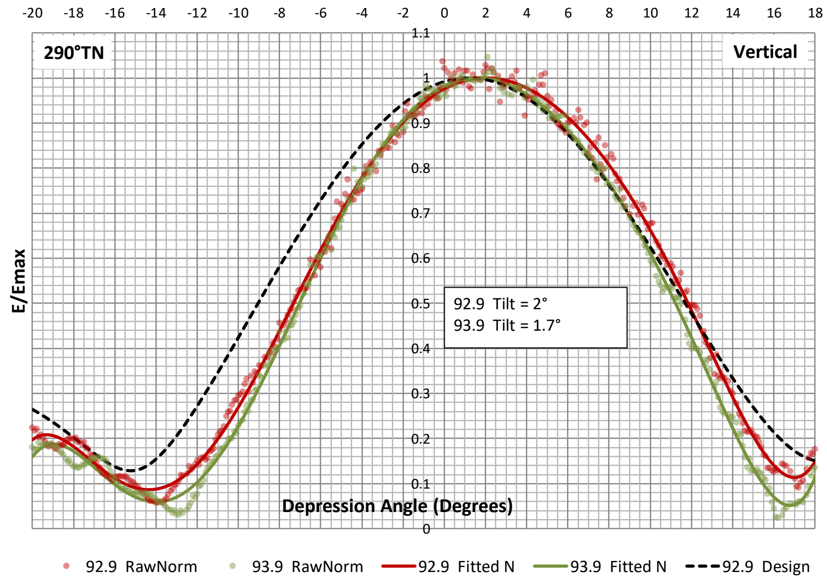
3

SIXARMS

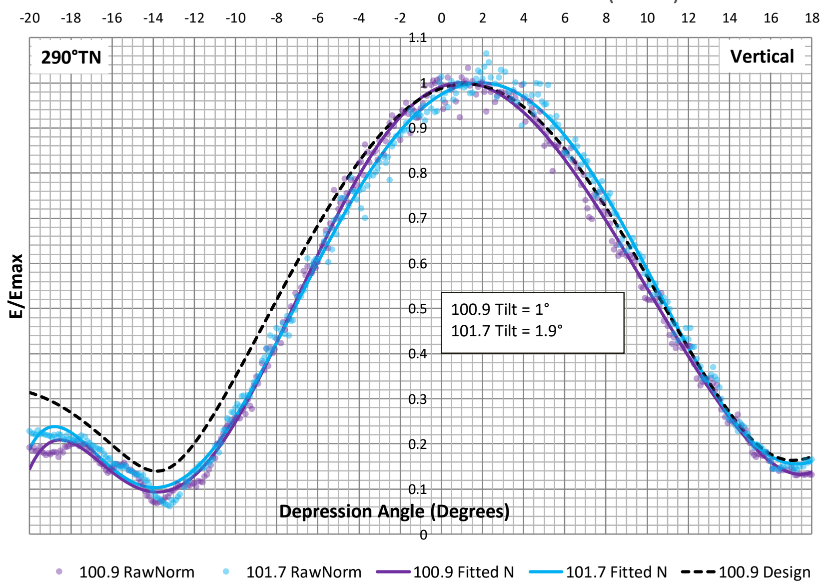
Vertical Component of VRPs – Face D - 290˚TN



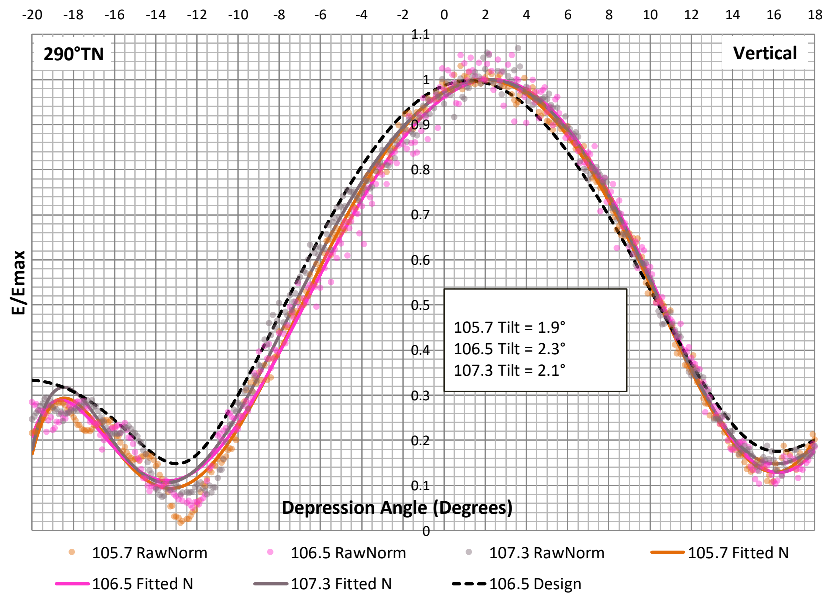
Plot 17: All Channels ERP (dBW)



Plot 18: Lower Channels - Normalised

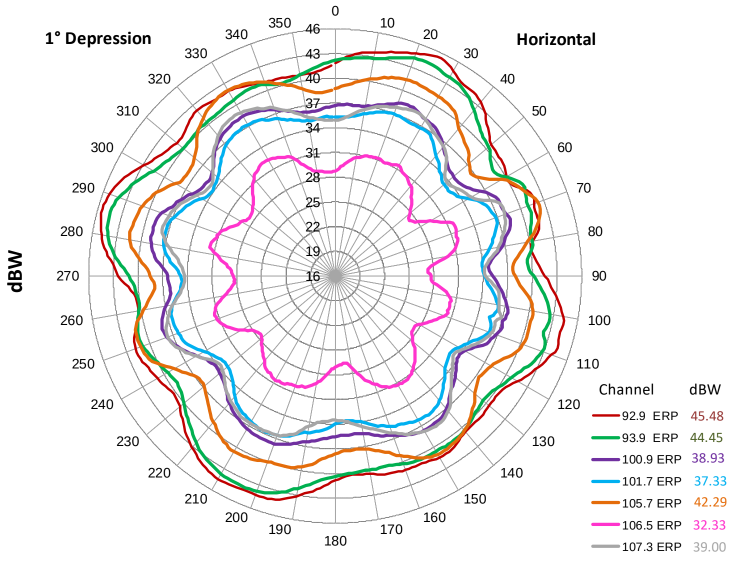


Plot 19 Middle Channels - Normalised

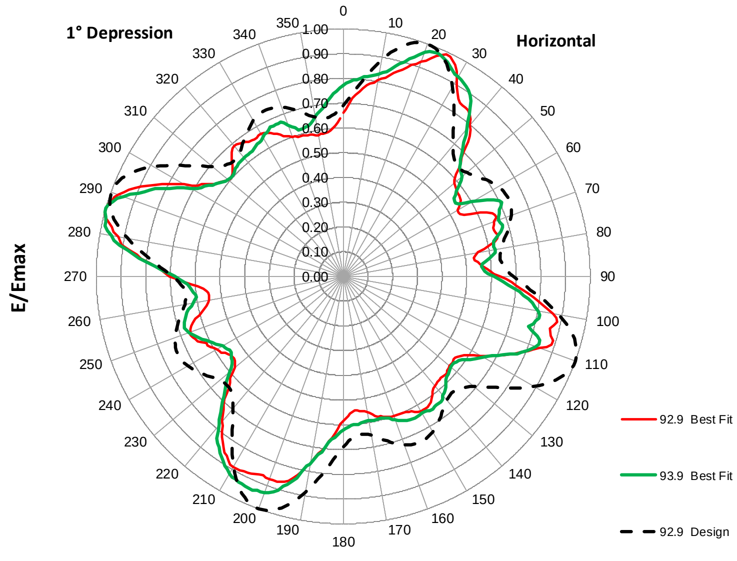


Plot 20 Upper Channels - Normalised

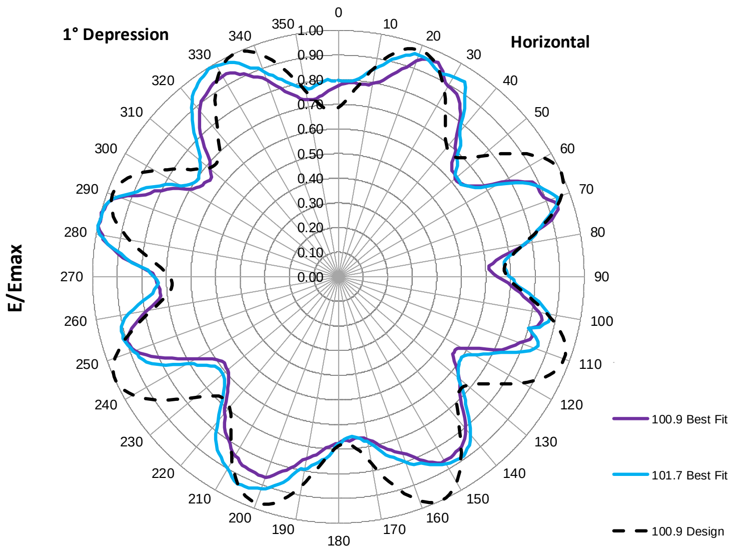
Horizontal Component of HRPs at 1° Below the Horizon



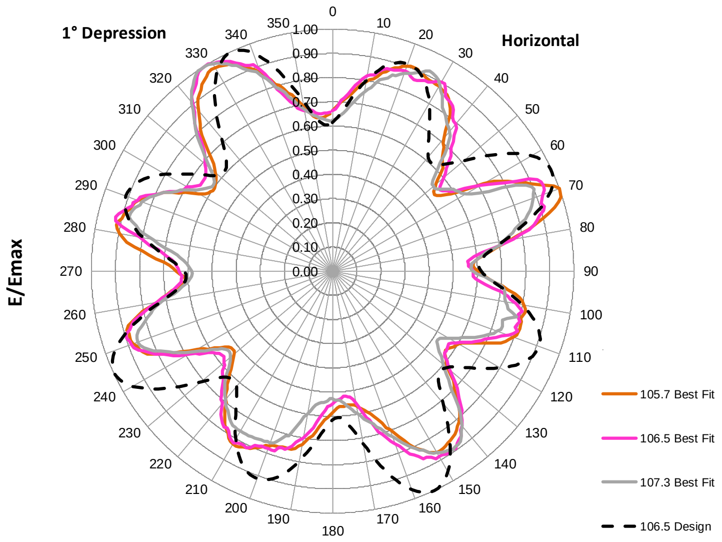
Plot 21: All Channels ERP (dBW)



Plot 22: Lower Channels - Normalised

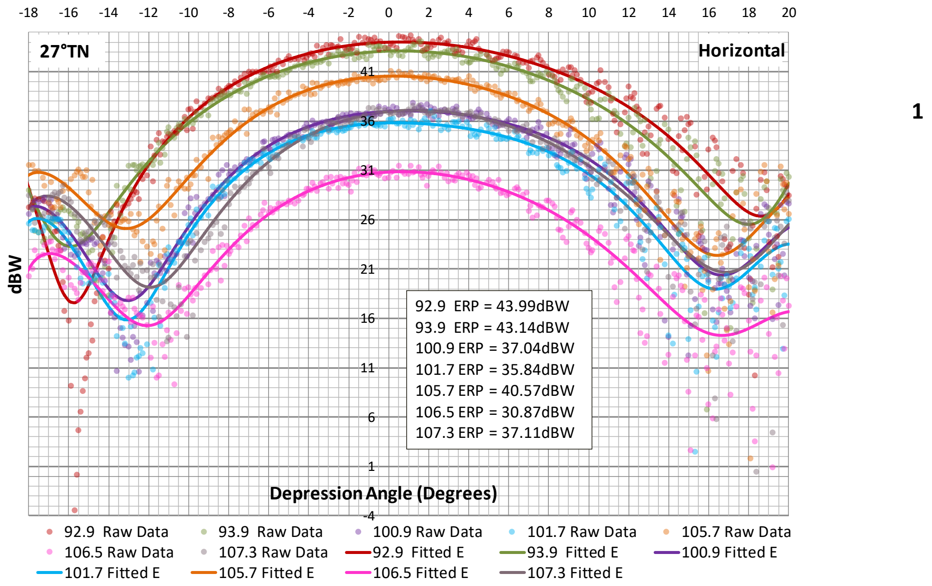


Plot 23 Middle Channels - Normalised

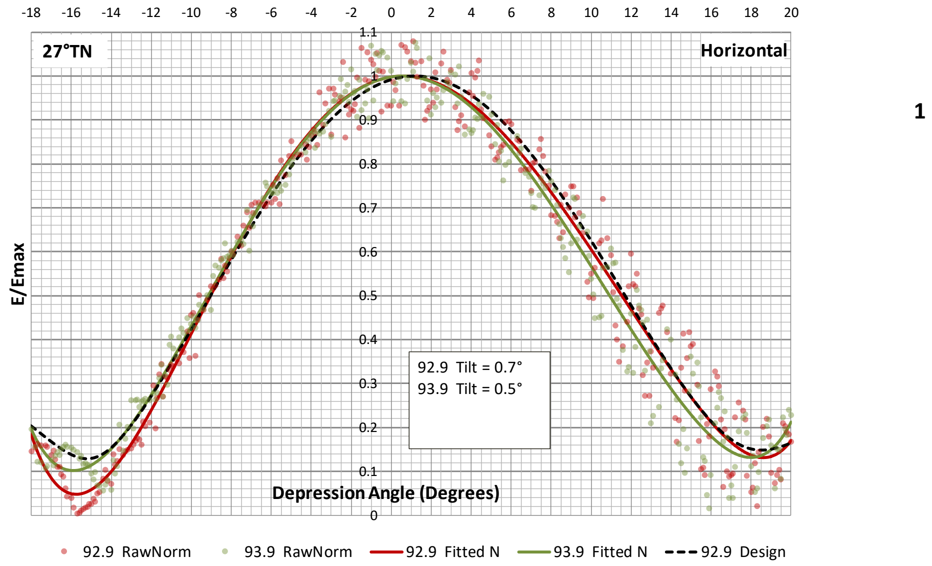


Plot 24 Upper Channels - Normalised

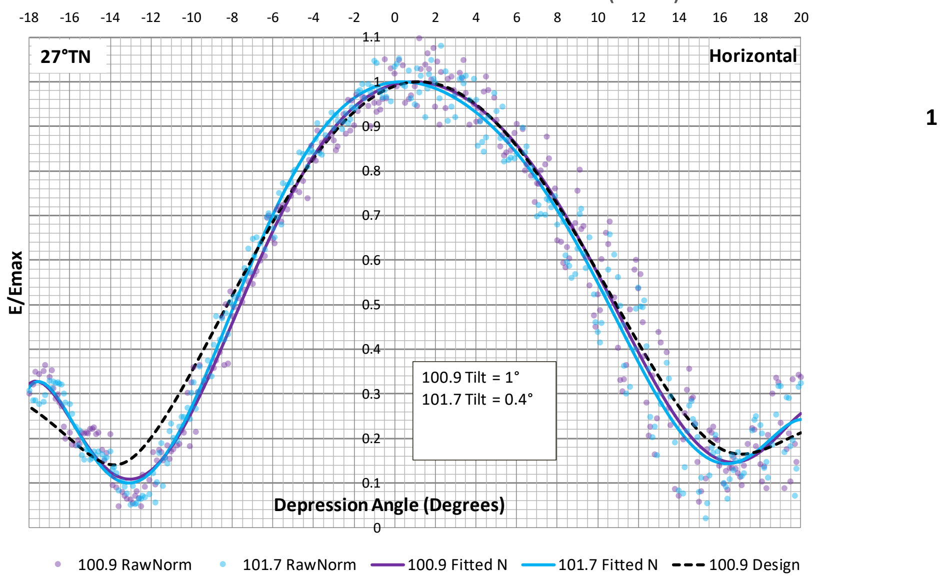
Horizontal Component of VRPs – Face A - 20˚TN



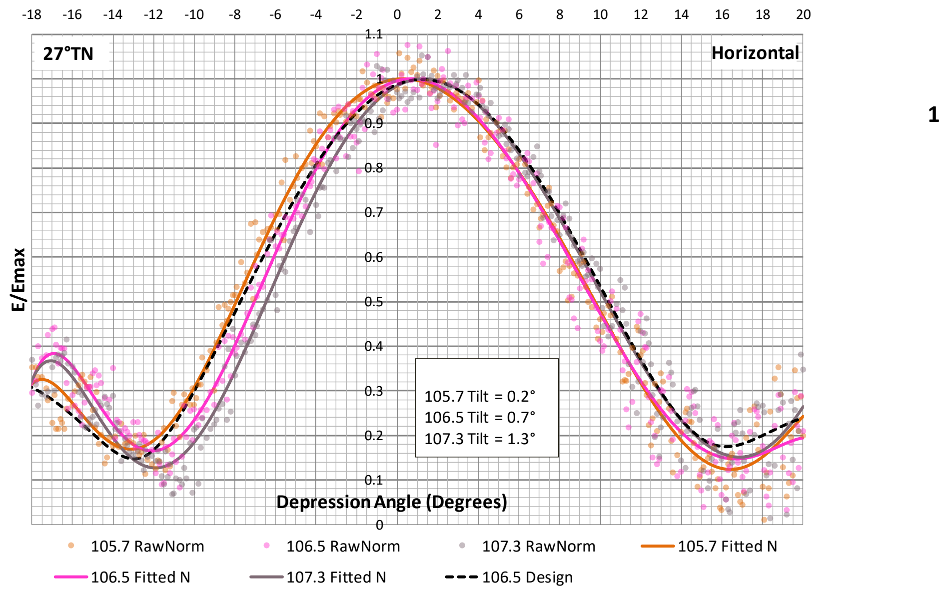
Plot 25: All Channels ERP (dBW)



Plot 26: Lower Channels - Normalised

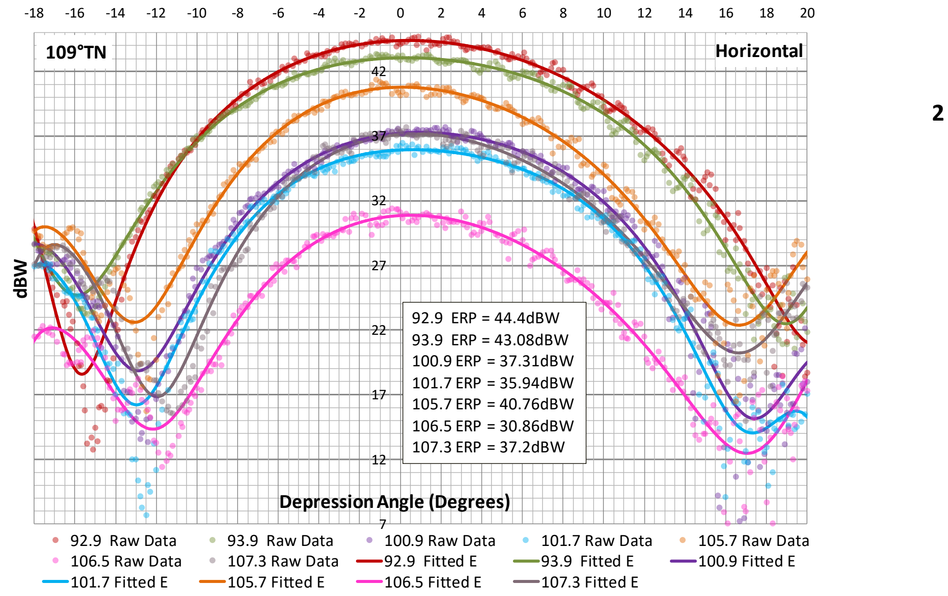


Plot 27 Middle Channels - Normalised

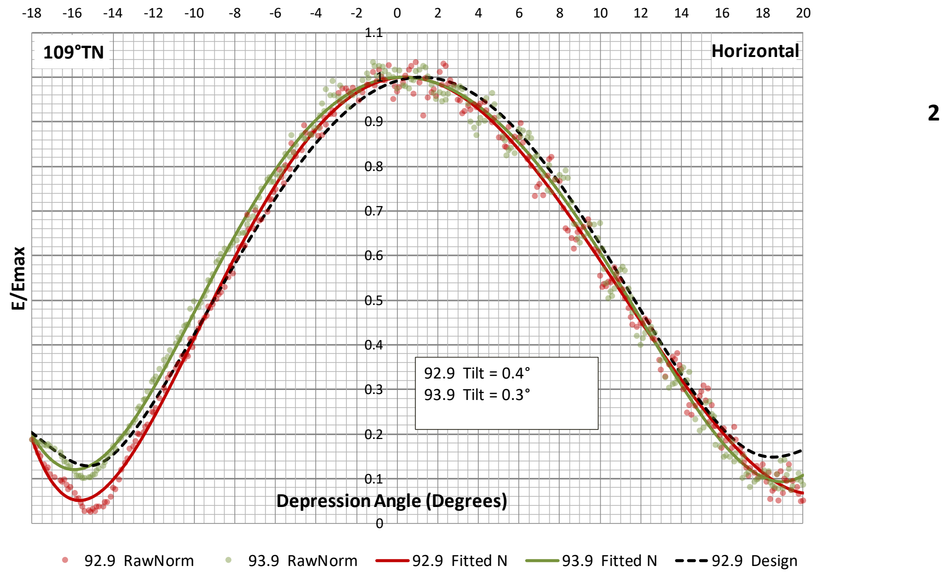


Plot 28 Upper Channels - Normalised

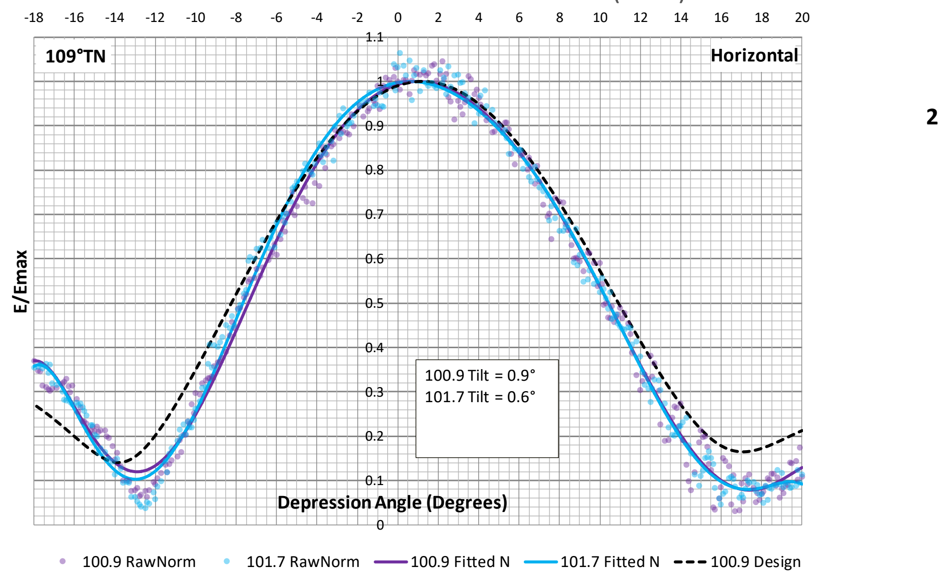
Horizontal Component of VRPs – Face B - 110˚TN



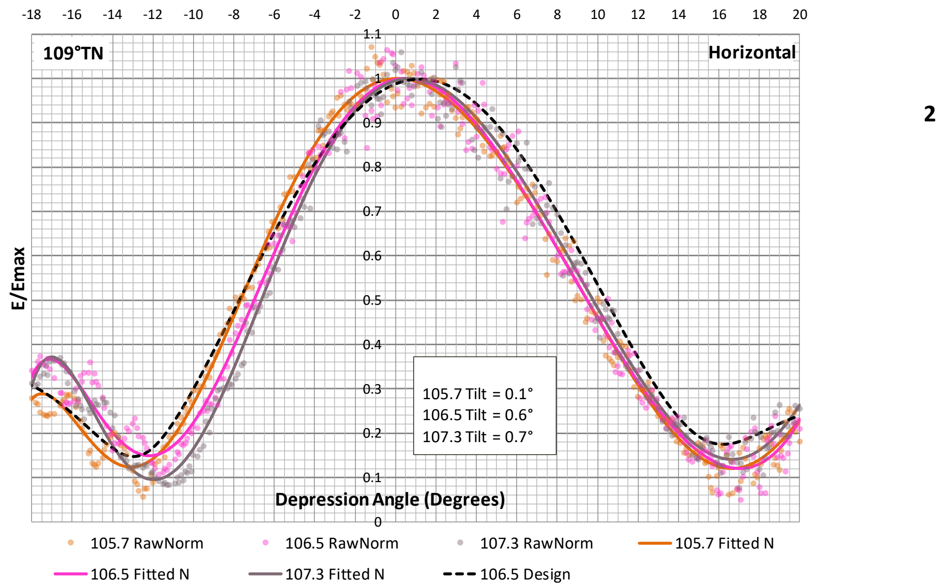
Plot 29: All Channels ERP (dBW)



Plot 30: Lower Channels - Normalised



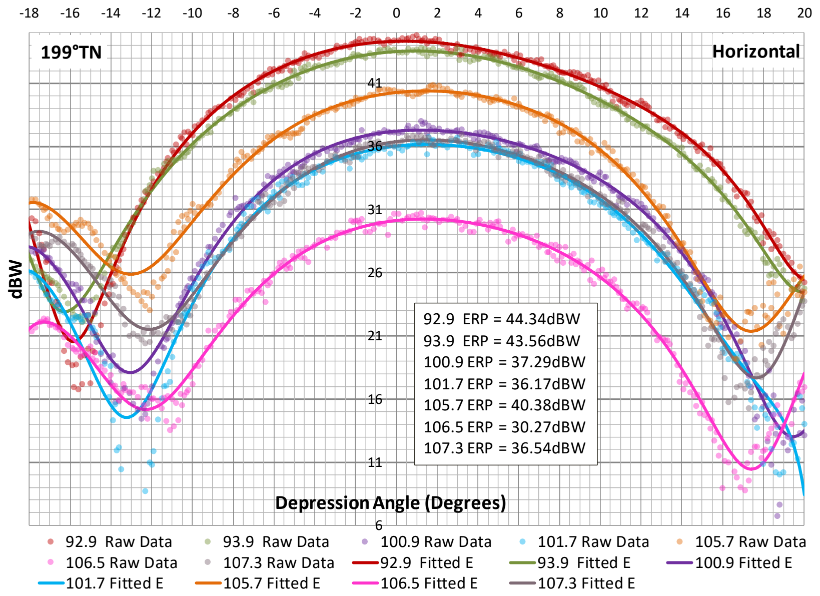
Plot 31 Middle Channels - Normalised



Plot 32 Upper Channels - Normalised

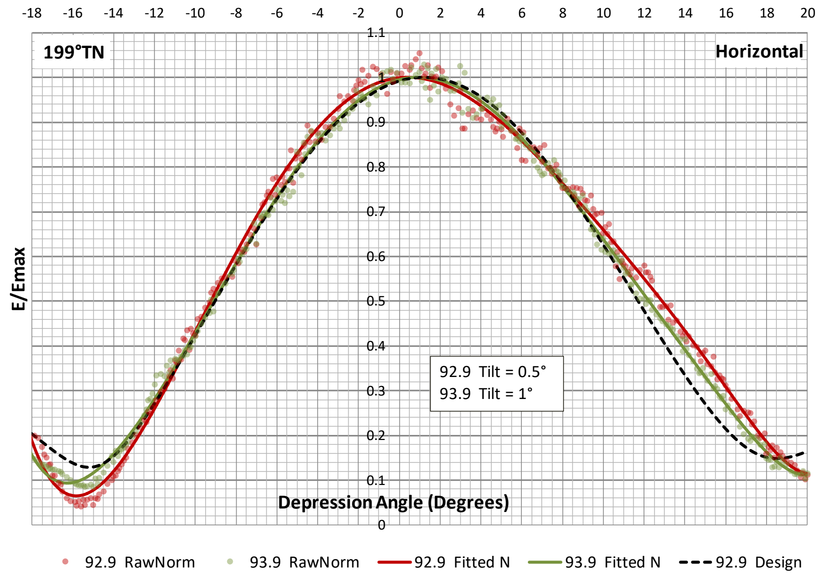
SIXARMS

Horizontal Component of VRPs – Face C - 200˚TN



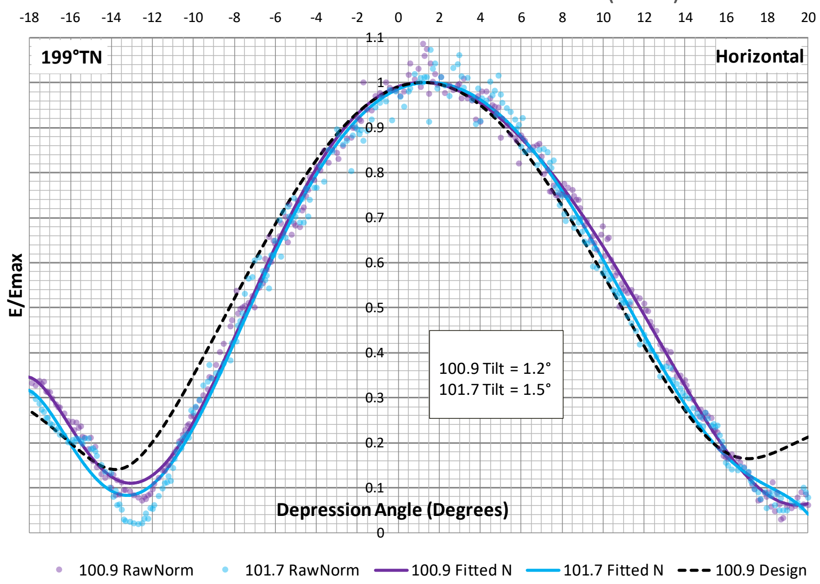
Plot 33: All Channels ERP (dBW)

3



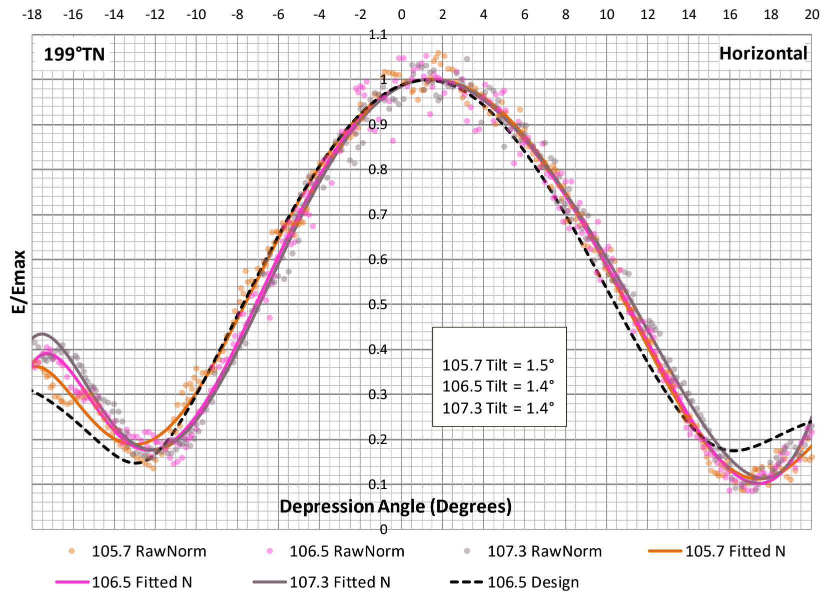
Plot 34: Lower Channels - Normalised

3



Plot 35 Middle Channels - Normalised

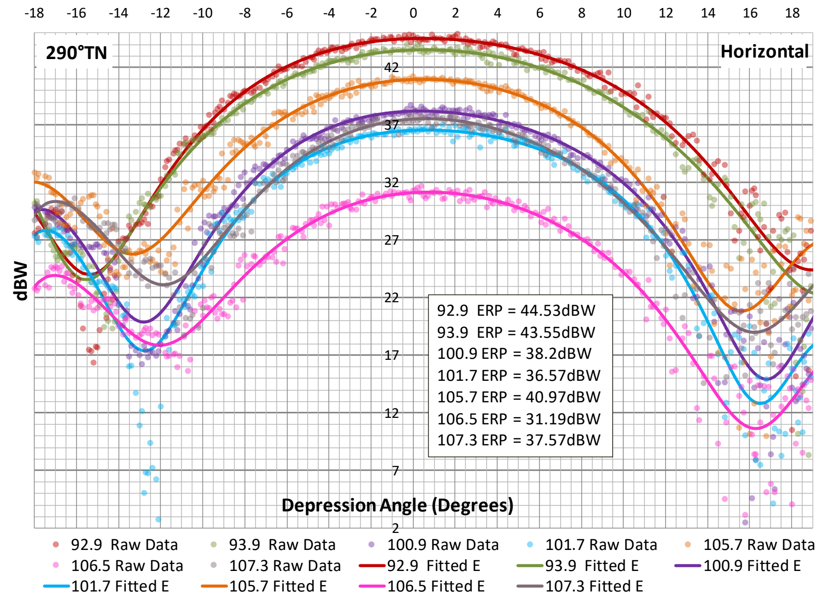
3



Plot 36 Upper Channels - Normalised

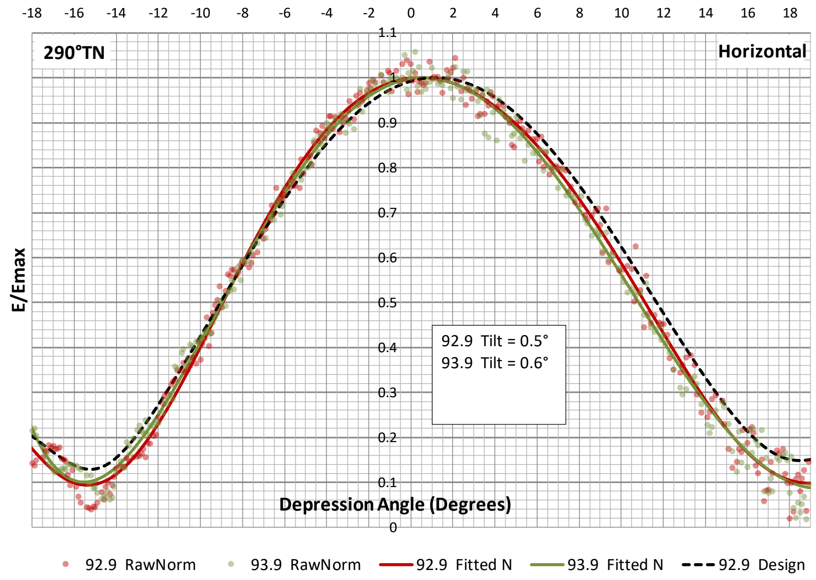
3

Horizontal Component of VRPs – Face D - 290˚TN



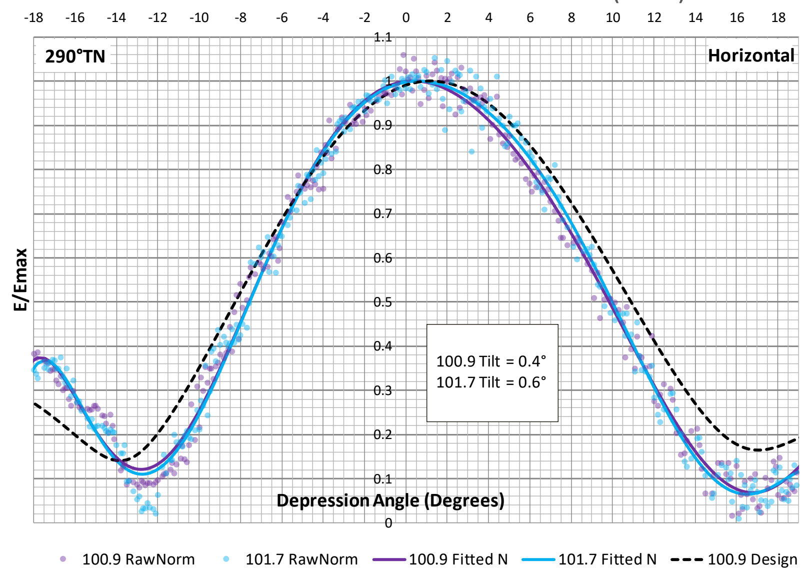
4

Plot 37: All Channels ERP (dBW)



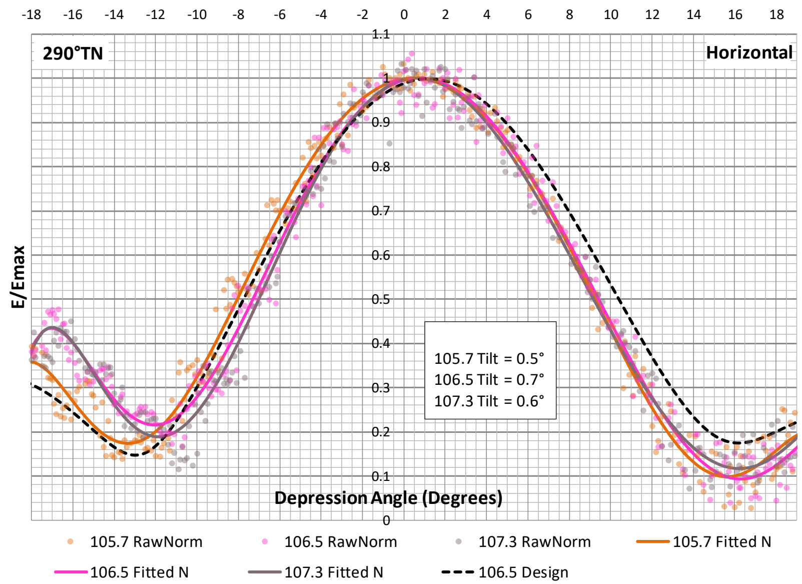
4

Plot 38: Lower Channels - Normalised



4

Plot 39 Middle Channels - Normalised



4

Plot 40 Upper Channels - Normalised

4/ CONCLUSIONS

The following conclusions can be drawn from the VHF FM antenna measurement survey for all channels measured:

- Both the Horizontal and Vertical components measurements had good correlation to the designed patterns.
- All measured beamtilts fall within ±1.5˚ of the designed beamtilt of 1.2˚. Due to the broad nature of the main beam of the VRP, this has less than 1dB effect on the ERP. Beamtilt differences greater than 1˚ are highlighted in the Results Table in Section 3.
- The measured HRPs (for both components) show minor differences compared to the designed patterns. Areas of interest include:
  - Vertical – very good correlation between design and measured.
  - Horizontal Antenna – All measured patterns displayed narrower peaks than the designed pattern but are still within the uncertainty of this report. Offsets of approximately 5˚ between peaks and nulls are observed
- The omni design is achieved with variations of less than 2.5 dB between design and measured at all azimuths. Peaks and nulls are aligned.
- Combined measured ERP Maximum values (H&V) are:
  - 92.9MHz = 48.3dBW, 93.9MHz = 47.5dBW, 105.7MHz = 46.9dBW -> Licensed = 47.5dBW
  - 100.9MHz = 42.8dBW, 101.7MHz = 41.6dBW, 106.5MHz = 37dBW, 107.30MHz = 43.6dBW -> Licenced = 45.5dBW

This antenna is concluded as operating very close to the design.

APPENDIX 1: TRANSMISSION PARAMETERS

The following details and parameters were used in calculations in this report:

SITE DETAILS

Site (City)	Site Grid Reference Lat, Lon, (WGS84)	Service Freq. (MHZ)	Mast Base AHD[1] (metres)	Antenna Electrical Centre RL (metres)	Antenna Details Panel Faces
Sample Site	-xx.xxxxxx° yyy.yyyyyy°	92.90 93.90 100.90 101.70 105.70 106.50 107.30	1369	88	Face A =20°TN Face B =110°TN Face C =200°TN Face D =290°TN

[1] Australian Height Datum

ERP CALCULATION DETAILS

Service	Antenna Gain (dBd)	Antenna Factor (dB)	Cable Loss (dB)	Attenuation Loss (dB)	Other Loss (dB)	Final Cal Factor (dB)
92.90	-4.35	7.43	0.20	29.70	6.00	47.68
93.90	-3.65	7.52	0.20	29.70	6.00	47.07
100.90	-4.65	8.15	0.20	29.70	6.00	48.70
101.70	-4.85	8.21	0.20	29.70	6.00	48.96
105.70	-6.15	8.55	0.20	29.70	6.00	50.60
106.50	-6.25	8.62	0.20	29.70	6.00	50.77
107.30	-6.35	8.68	0.20	29.70	6.00	50.93

APPENDIX 2: EQUIPMENT AND FLIGHT PARAMETERS

The following equipment was used during the antenna reconstitution process as well as the actual flight details and measurement tolerances.

EQUIPMENT USED

	Serial	Calibration/Verification Date
Unmanned Aerial Vehicle	#Franky	N/A
Receiver System	#32950324	06/01/2017
Antenna System	#FMM01	26/12/2016
1m LCU195 Cable	#LCU195-1m	10/6/2016
Attenuation	#1237 &#0839	10/6/2016

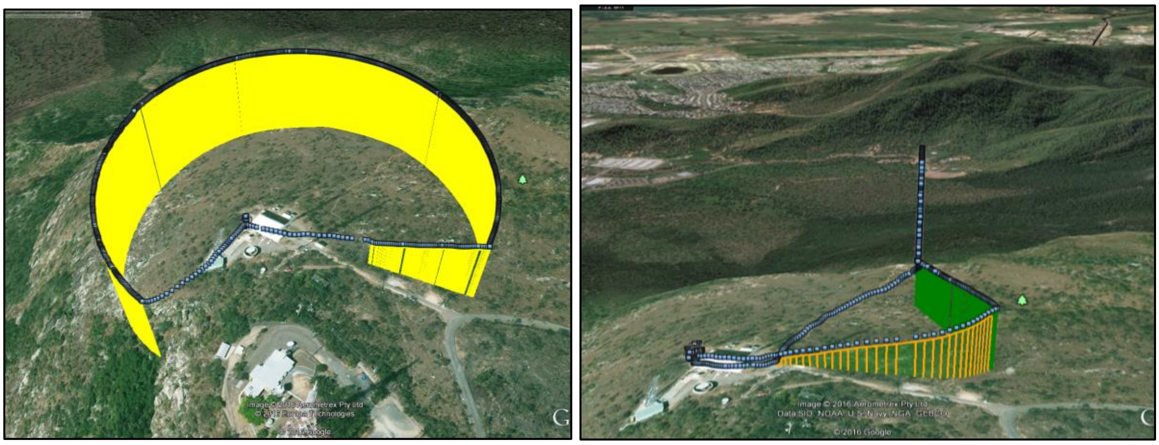
FM Measurement System

SIXARMS

ACTUAL FLIGHT PROFILES

The following flight profiles were used:

Type	Azimuth	Distance from Site	Depression Angle
VRP	27°	120m	18 to -18
	110°	120m	18 to -18
	200°	120m	18 to -18
	290	120m	18 to -18
HRP	Full	120m	1°



Actual Flight Paths (mapped in Google Earth) -HRP and 200 VRP

VALID SAMPLE TOLERANCES

No measurements outside the tolerances listed below were used in the pattern calculations.

Parameter	Tolerance
UAV Azimuth	±10°
UAV Pitch	±5°
UAV Roll	±5°
Depression Angle	±0.5°
Distance	±2.0m
Height	±1.0m

SIXARMS

APPENDIX 3: UNCERTAINTY CALCULATIONS

The system model is indicated below. In this model, all sensitivity coefficients of the influence quantities are equal to 1. The common unit is the dB variation of the received field strength.

$$\Delta f = g_1 + g_2 + \ldots + g_N \qquad (1)$$

where: Δf is the total dB variation of the fields due to uncertainty in and correction of the influence quantities, g_i.

g_1, g_2, … g_N are the corrections and uncertainties in the influence quantities expressed as dB variations.

ABSOLUTE

For Absolute measurements, positional accuracy is estimated to vary with a triangular distribution with an uncertainty of 1.0dB. Scattering effects from nearby objects has been assumed to be varying in a symmetric rectangular distribution with a span of 1.0dB. The Spectrum Analyser has a standard uncertainty with a normal symmetry of 1.5dB. The feeder loss has a standard rectangular distribution with an uncertainty of 0.2dB (from Calibrated Scalar Analyser). The antenna azimuth alignment has is a triangular distribution with an uncertainty of 0.5dB. The variation in antenna gain over the channels of interest is estimated to vary in a symmetric rectangular distribution with a span of 0.5dB.

Source of uncertainty	Unit	Uncertainty				
		Probability distribution	Semi span a or σ	Divisor d	$u_i = a/d$	u_i^2
Positional Accuracy	dB	Triangular	1.0	√6	0.408	0.167
Scattering Effects	dB	Rectangular	1.0	√3	0.577	0.333
Spectrum Analyser	dB	Normal	1.5	2	0.750	0.563
Feeder Loss	dB	Rectangular	0.2	√3	0.115	0.013
Azimuth Alignment	dB	Triangular	0.5	√6	0.204	0.042
Antenna Gain	dB	Rectangular	0.5	√3	0.289	0.083
SUMS						1.2
Combined standard uncertainty, uc = $\sqrt{\Sigma(ui^2)}$						1.1
Coverage factor, k						2 (95% CI)
Expanded Uncertainty, U = k × uc						**±2.2 dB**

SIXARMS

RELATIVE

For Relative measurements, positional accuracy is estimated to vary with a triangular distribution with an uncertainty of 0.5dB. Scattering effects from nearby objects has been assumed to be varying in a symmetric rectangular distribution with a span of 1.0dB. The Spectrum Analyser variation has a standard uncertainty with a normal symmetry of 0.2dB. The feeder loss variation has a standard rectangular distribution with an uncertainty of 0.05dB. The antenna azimuth alignment has is a triangular distribution with an uncertainty of 0.5dB. The variation in antenna gain over a complete FM Band is estimated to vary in a symmetric rectangular distribution with a span of 0.2dB

Source of uncertainty	Unit	Uncertainty				
		Probability distribution	Semi span a or σ	Divisor d	$u_i = a/d$	u_i^2
Positional Accuracy	dB	Triangular	1.0	√6	0.408	0.167
Scattering Effects	dB	Rectangular	1.0	√3	0.577	0.333
Spectrum Analyser Var	dB	Normal	0.2	2	0.100	0.010
Feeder Loss Variation	dB	Rectangular	0.05	√3	0.029	0.001
Azimuth Alignment	dB	Triangular	0.5	√6	0.204	0.042
Antenna Gain Variation	dB	Rectangular	0.2	√3	0.115	0.013
SUMS						0.57
Combined standard uncertainty, uc = $\sqrt{\Sigma(ui^2)}$						0.8
Coverage factor, k						2 (95% CI)
Expanded Uncertainty, U = k × uc						**±1.6 dB**