BEFORE THE BOARD OF INQUIRY

IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of applications for resource consent and notices of requirement by Transpower New Zealand Limited for the North Island Grid Upgrade Project

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SUPPLEMENTARY STATEMENT OF EVIDENCE OF MILIND VISHNU KHOT FOR TRANSPOWER NEW ZEALAND LIMITED

(Line rating, conductor selection, EMF, insulation design, lightning performance, RFI/NZECP)

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Introduction

1. **MY** name is Milind Vishnu Khot. I wish to present a supplementary statement of evidence in relation to the calculation for compact towers at easement boundaries.

2. **THIS** supplementary evidence is being presented to provide the Board of Inquiry with the information requested on day 9, 8th April 2008, about the extent of increase in audible noise as a result of compaction of the phase conductors.

3. **IN** response to re-examination by Mr Laing, I had confirmed that the statement in the Notice of Requirement regarding a noise limit of 35 dBA with a tolerance band of 5 dBA at the edge of the designation, to achieve a limit of 40 dBA was correct.

4. **AUDIBLE** noise from high voltage conductors is a highly variable parameter that is quite sensitive to weather changes, as discussed in my evidence in chief, and the 5 dBA tolerance provides a margin of safety during inclement weather. This is confirmed in the evidence in chief of Mr Warren at paragraph 16.

5. **DESIGN** and calculation of audible noise of electrical origin from transmission lines generally considers "wet conductor" conditions, which equate to a rain rate of about 0.75 mm/hr (Reference – EPRI Transmission Line Reference Book – 345 kV and above). This is the equivalent of a light drizzle. Audible noise increases with the rain rate and/or fog/mist. Under conditions of heavy rain the audible noise is the highest, but the noise of the rain itself tends to mask the corona noise from the conductors. However, under moderate rain (such as 2 to 3 mm/hr) audible noise could be higher than the level for 0.75 mm/hr rain rate. The 5 dBA tolerance band covers this and other possibilities such as noise due to raised spots on the conductor surface due to broken strands or bird droppings.

6. **I** have provided calculations in **Appendix "A"**. These calculations are based on the distances discussed with Mr Wilkinson in cross examination on day 9 (8th April 2008) and are calculated solely for the purposes of audible noise only. These distances are not considered as practical for the purpose of live line maintainability, and as such are not supported by Transpower.

7. **IN** addition to the calculations in **Appendix "A"**, I have also provided two sets of graphs covering three scenarios in **Appendix "B"**, as follows:

(a) The calculations and graphs of the audible noise profile for the uncompacted design, as is proposed, i.e. with a phase to phase clearance of 9.8 m and a circuit to tower centreline spacing of 7.55 m for the top phases, 8.05 m for the middle phases and 8.55 m for the bottom phases;

(b) The calculations and graphs of the audible noise profile for a compacted design with a phase to phase clearance of 8.5 m and a uniform circuit to circuit spacing of 11 m for the top, middle and bottom phases (5.5 m on either side of the centreline)*; and,

(c) The calculations and graphs of the audible noise profile for a compacted design with a phase to phase clearance of 7.7 m and a uniform circuit to circuit spacing of 11 m for the top, middle and bottom phases (5.5 m on either side of the centreline)*.

(* Note – A crossarm width of 5.5 m from the centreline is not considered practical. However, for the purposes of the discussion on distances as discussed in cross-examination, this distance is considered for the hypothetical calculation.)

8. **AS** shown in Figures 1 and 2 of **Appendix "B"**, any reduction of the phase to phase distance of 9.8 m results in an increase in audible noise at the edge of the designation, and transgresses into the 5 dBA tolerance band. For a phase to phase spacing of 8.5 m, the audible noise at the edge of the designation of 32.5 m from the centreline would be about 38.5 dBA (43.5 dBA inclusive of the tolerance), ie about 3.5 dBA higher than for the proposed phase to phase spacing. For a phase to phase spacing of 7.7 m, the audible noise would be about 40 dBA (45 dBA inclusive of the tolerance) at the edge of the designation of 32.5 m from the centreline, completely eroding the tolerance buffer of 5 dBA.

9. **CONVERSELY,** as shown in Figures 1 and 2 in **Appendix "B"**, the proposed designation of 32.5 on both sides of the centreline would need to be extended to 69 m from the centreline for a compact design with 8.5 m phase to phase clearance, and to about 89 m from the centreline for a compact design with 7.7 m phase to phase clearance.

10. **AS** can be seen from the Figures 1 and 2 in **Appendix "B"**, the peak noise levels under the line would also well exceed 40 dBA were compact designs to be used.

11. **ALSO** included in **Appendix "A"** are a number of calculation sheets detailing inputs and assumptions for each option. These show the changes in values for audible noise, in addition to the changes in RFI, Electric and Magnetic Field for information to the Board.

Milind Vishnu Khot
20 May 2008

APPENDIX "A"

Calculations

Radio Frequency Interference, Electric Field, Magnetic Field & Audible Noise

Double-Circuit three-phase transmission line

Note that the effect of earthwires is considered negligible at ground level and hence earthwires have not been modelled

Calculations for:
RFI are based on CISPR 18-1, Appendix A, and CISPR 18-3, Appendix A.
Electric Field, Magnetic Field & Audible Noise are based on EPRI Transmission Line Reference Book (345 kV and above)

All Yellow Cells are Inputs

1. Line Data (Note: All dimensions in metres except Conductor/Earthwire diameter which is in centimetres)

Transmission Line name: **Un-Compacted Design 9.8 m Phase Spacing x 15.1m, 16.1m & 17.1m Circuit Spacing**

Conductor Data Phase Conductor name: **Sulphur AAAC 1120**

Circuit 1	Diameter of conductor (cm)	d1 := 3.38	r1 := d1/2
	Line Voltage (kV)	Voltage1 := 420	
	Line Current (Amps)	I1 := 2188.8	
	No. of sub-conductors	n1 := 3	
	Sub-conductor bundle dimension (cm)	b1 := 51	Not applicable if n1 = 1
Circuit 2	Diameter of conductor (cm)	d2 := 3.38	r2 := d2/2
	Line Voltage (kV)	Voltage2 := 420	
	Line Current (Amps)	I2 := 2188.8	
	No. of sub-conductors	n2 := 3	
	Sub-conductor bundle dimension (cm)	b2 := 51	Not applicable if n2 = 1

Conductor Co-ordinates (+ or -)

R1 – Phase	R1x := –7.55	R1y := 19.6
Y1 – Phase	Y1x := –8.05	Y1y := 9.8
B1 – Phase	B1x := –8.55	B1y := 0
R2 – Phase	R2x := 8.55	R2y := 0
Y2 – Phase	Y2x := 8.05	Y2y := 9.8
B2 – Phase	B2x := 7.55	B2y := 19.6

x values are horizontal distance from the tower centreline (m)
y values are vertical height above the lowest conductor (m)

Note - The level of the lowest conductor/s is taken as the position of origin (y=0)

Structural Dimensions:

Height of lowest conductor above ground at attachment point on structure (m): h := 28.82

Height of lowest ground clearance point (m): s := 12.8

Average height of lowest conductor above ground (m): $G := h - \left[\frac{2}{3}\cdot(h - s)\right]$ $G = 1.814 \times 10^{1}$

Position of point of measurement (Aerial)

Lateral Distance of *RFI Aerial* from Outer Conductor (m)	dc := 15	*(Do not change this value)*
Height of *Aerial for RFI* Calculations (m)	yaRFI := 2	*(Do not change this value)*
Lateral Aerial Distance from outer conductor for EMF (m)	dcEMF := 0	*(Do not change this value)*
Height of *Aerial for Electric & Magnetic Field* calculations (m)	yaEMF := 1	*(Do not change this value)*
Lateral Aerial Distance from outer conductor for *Audible Noise*	Aud := 25	*(Set to edge of Easement)*
Height of Aerial for *Audible Noise* Calculations (m)	yaAud := 1	*(Do not change this value)*
Plot Maximum Distance from Centreline required (m)	range := 100	*(Do not change this value)*
Frequency of measurement for RFI (MHz) (*Freq > 1MHz only*)	Freq := 2	(This value is not reqd)

Limits for EMF, RFI and AN

Calculated values are checked for OK/No Good against these

EFLimit := 5 MFLimit := 1·gauss MFLimitmG := 1000	**In accordance with ICNIRP - 1998**
RFILimit := if(Voltage1 < 220, 50, 59)	**In accordance with NZS 6869: 2004**
ANLimit := 40	**In accordance with NZS 6802: 1991/1999 or relevant council limit**

(Audible Noise calculations are set to "wet conductor" conditions corresponding to a rain rate of 0.75mm/hr)

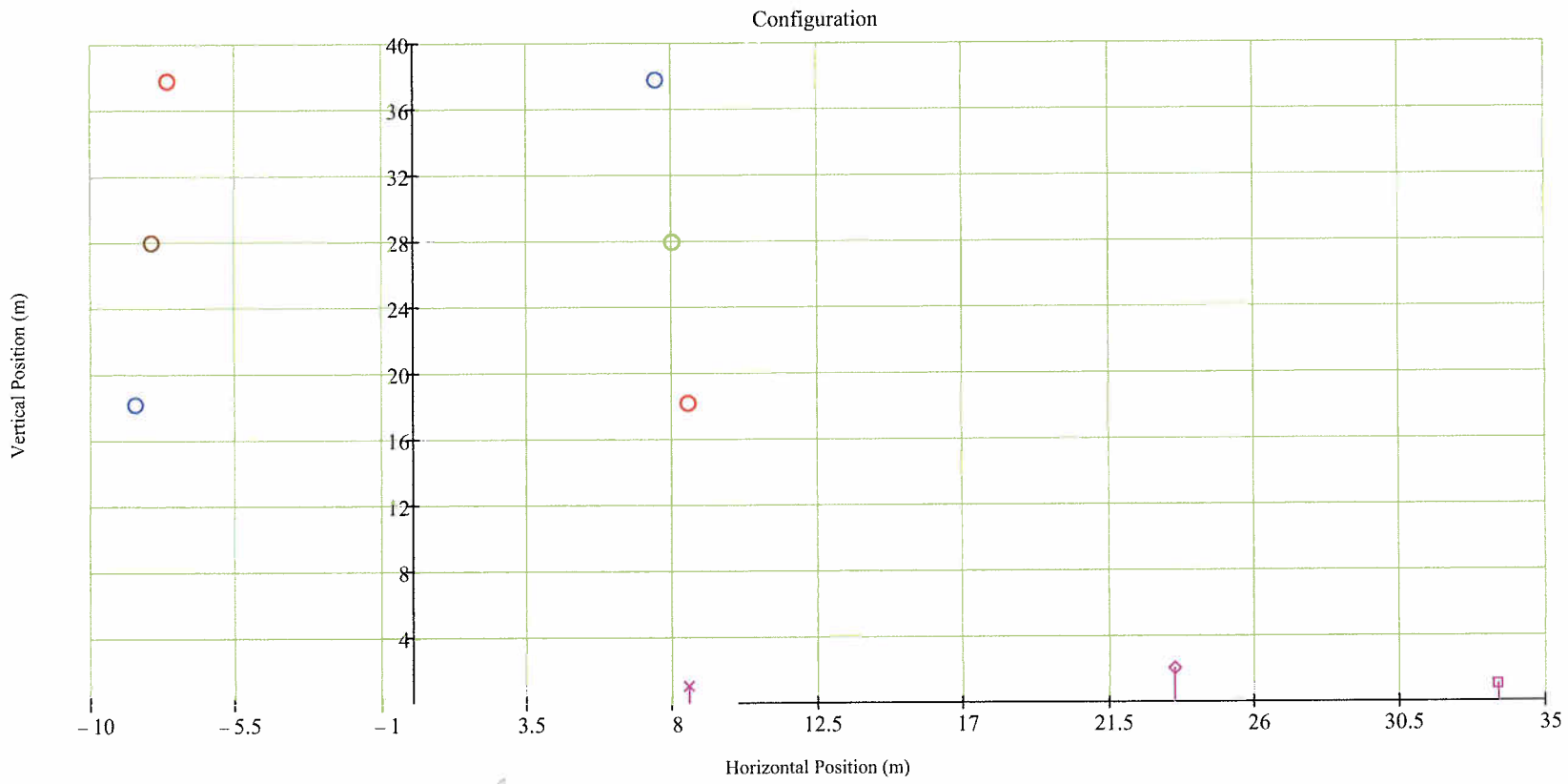
14. Calculation Summary

RFI @ 0.5MHz	Voltage = 420	RFI500 = 42.48	CheckRFI = "OK"	RFILimit = 59
Electric Field @	Voltage = 420	max(EF) = 4.938	CheckEF = "OK"	EFLimit := 5
Magnetic Field @	Current = 2.189×10^{3}	$\frac{\max(Bmax)}{10} = 25.041$	CheckMF = "OK"	MFLimit = 1×10^{0} ·gauss
Audible Noise @	Voltage = 420	PdBtA = 35.214	CheckANOutdoor = "OK"	ANLimit = 40

Corona Calculations

Max Surface Voltage Gradient gmaxGM = 13.048

Conductor/Earthwire/Measurement Antenna Configuration



RFI Frequency Interference profile at 500 kHz (db above 1μV/m)

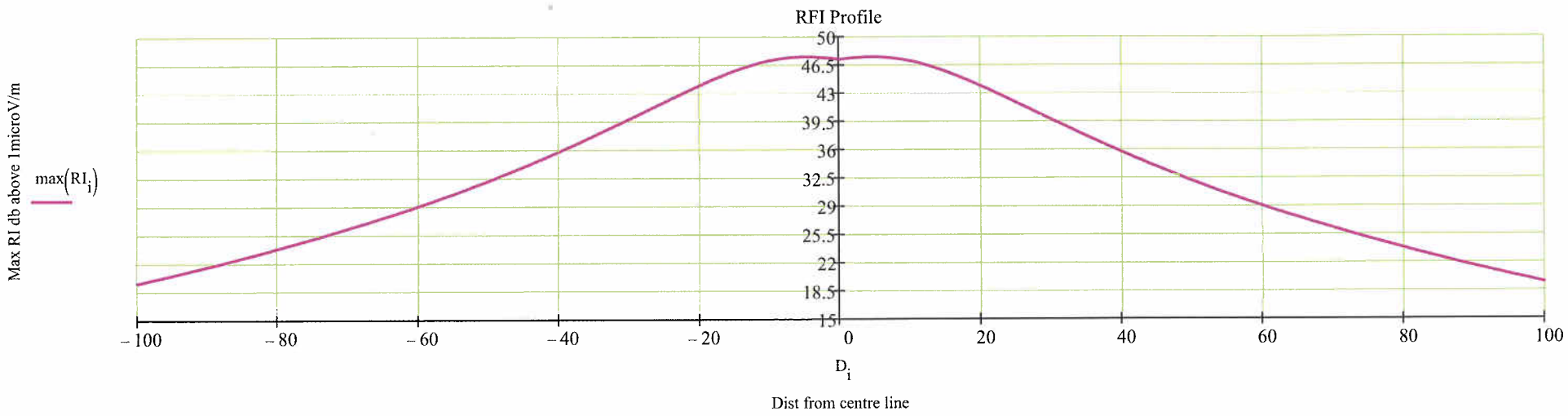
CheckRFI = "OK"

RFI = 36.98 @ 1MHz - Dry

RFI500 = 42.48 @ 0.5MHz - Dry

Note:
The values shown on the graph are calculated at 500kHz and can be corrected as per factors specified in CISPR 18-1, Fig B12, or NZS 6869: 2004.

NZS 6869: 2004 requires compliance at 0.5MHz



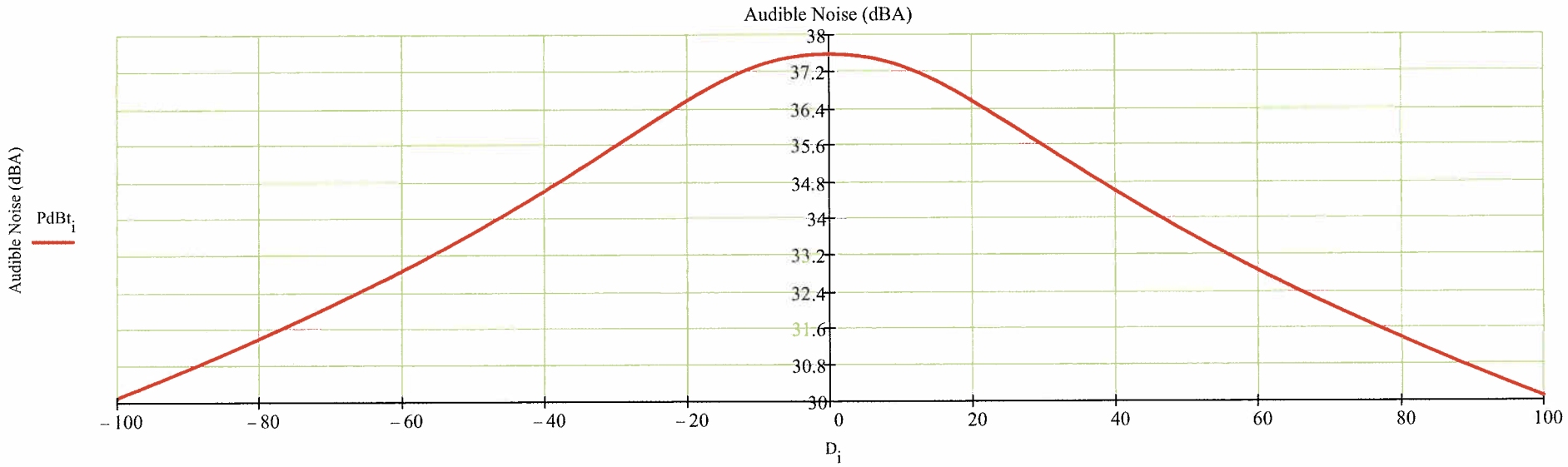
Audible Noise dB(A)

max(PdBt) = 37.57

CheckANOutdoor = "OK"

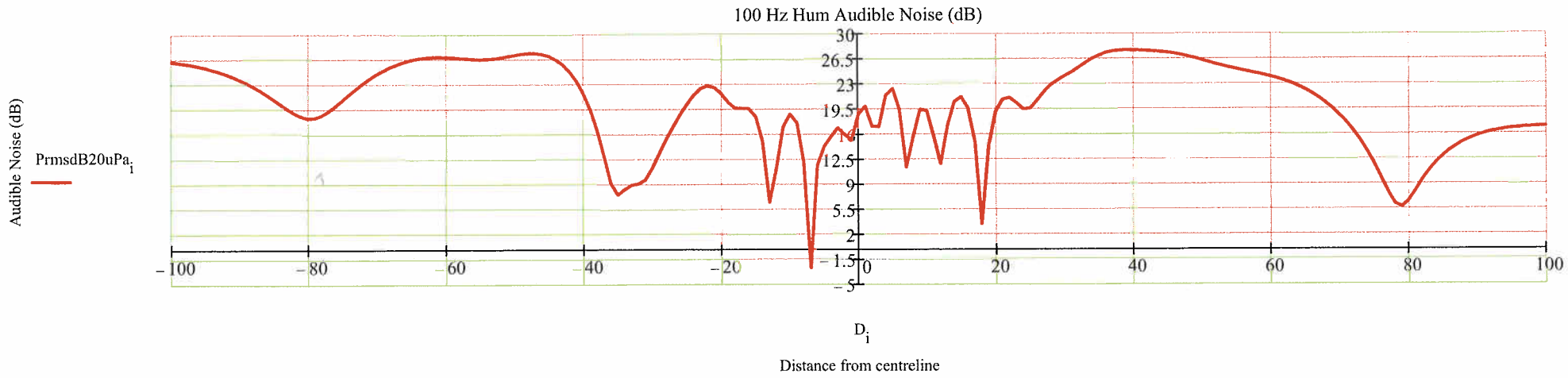
PdBtA = 35.214 **Noise at Aerial location**

Audible Noise as per Standard NZS 6802: 1991 or 1999
Note: Audible Noise calculated for 0.75 mm/hr rain so will be at this level around 5% of the time (dependent upon local climate conditions).



Audible Noise - 100Hz Hum (dB)

max(PrmsdB20uPa) = 27.675

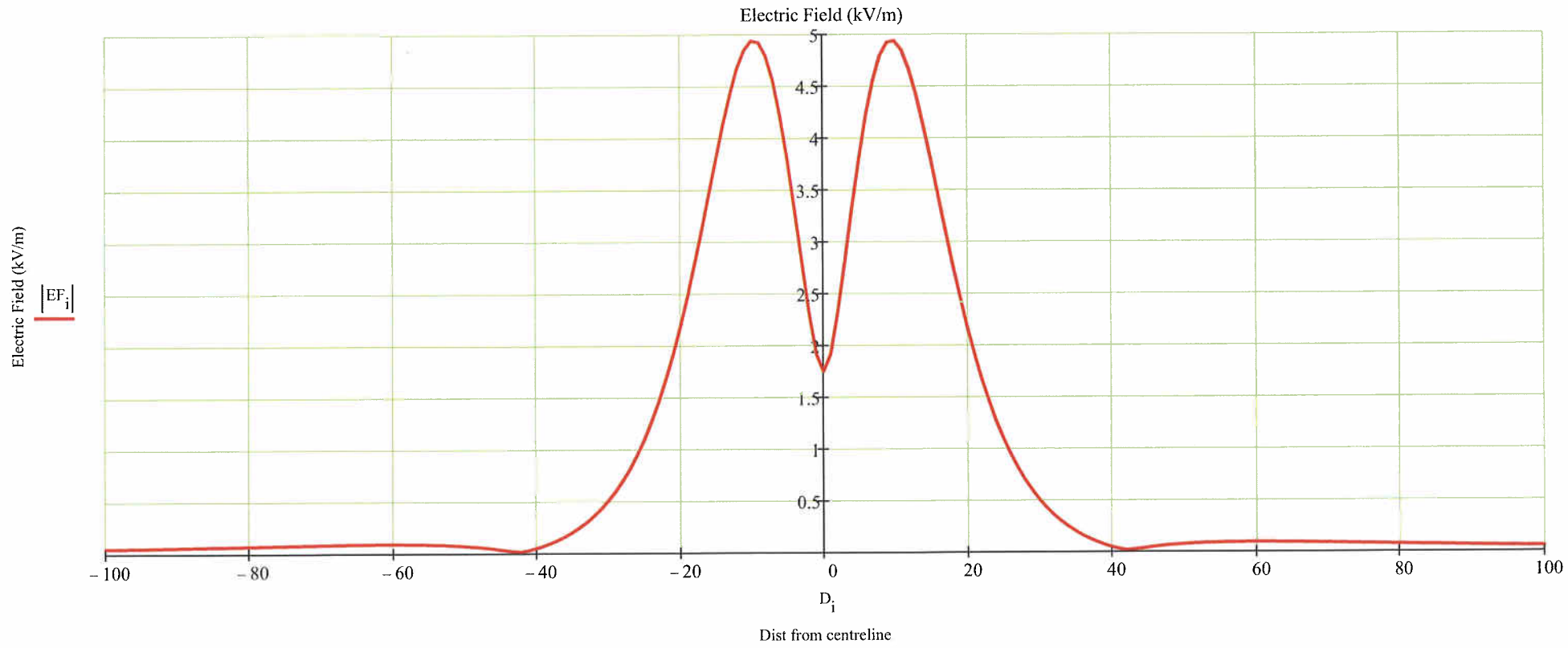


Electric Field Strength (kV/m)

max(EF) = 4.938

CheckEF = "OK"

Max Allowable limit for Electric Field Strength
is 5 kV/m as per the National Radiation Laboratory.

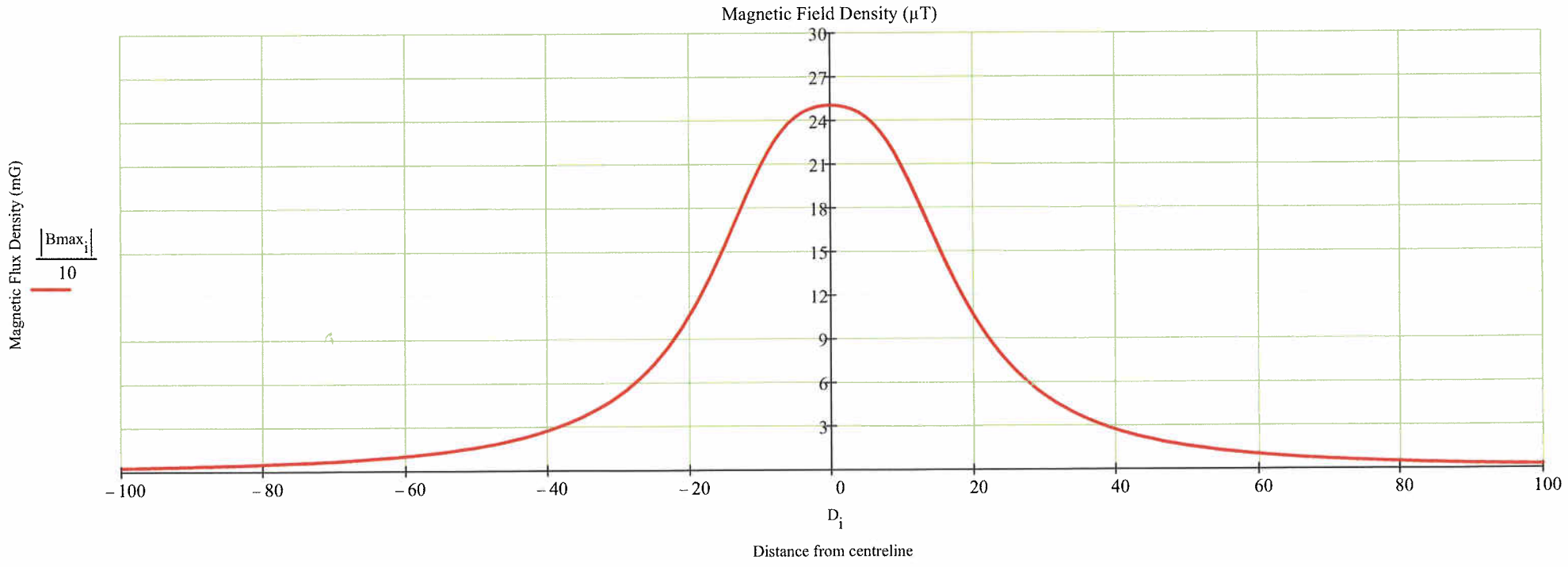


Magnetic Field Flux Density (μT)

$\frac{\max(Bmax)}{10} = 25.041$

CheckMF = "OK"

Max Allowable limit for Magnetic Field Flux Density
is 100 μT as per the National Radiation Laboratory.



Radio Frequency Interference, Electric Field, Magnetic Field & Audible Noise

Double-Circuit three-phase transmission line

Note that the effect of earthwires is considered negligible at ground level and hence earthwires have not been modelled

Calculations for:
RFI are based on CISPR 18-1, Appendix A, and CISPR 18-3, Appendix A.
Electric Field, Magnetic Field & Audible Noise are based on EPRI Transmission Line Reference Book (345 kV and above)

All Yellow Cells are Inputs

Compact Design - 7.7 m Phase Spacing x 11 m Circuit Spacing

1. Line Data

(Note: All dimensions in metres except Conductor/Earthwire diameter which is in centimetres)

Transmission Line name: BHL-WHN A

Conductor Data Phase Conductor name: **Sulphur AAAC 1120 - Triplex**

Circuit 1	Diameter of conductor (cm)	d1 := 3.38	r1 := d1/2
	Line Voltage (kV)	Voltage1 := 420	
	Line Current (Amps)	I1 := 2880	
	No. of sub-conductors	n1 := 3	
	Sub-conductor bundle dimension (cm)	b1 := 51	Not applicable if n1 = 1
Circuit 2	Diameter of conductor (cm)	d2 := 3.38	r2 := d2/2
	Line Voltage (kV)	Voltage2 := 420	
	Line Current (Amps)	I2 := 2880	
	No. of sub-conductors	n2 := 3	
	Sub-conductor bundle dimension (cm)	b2 := 51	Not applicable if n2 = 1

Conductor Co-ordinates (+ or -)

R1 – Phase	R1x := –5.5	R1y := 15.4
Y1 – Phase	Y1x := –5.5	Y1y := 7.7
B1 – Phase	B1x := –5.5	B1y := 0
R2 – Phase	R2x := 5.5	R2y := 0
Y2 – Phase	Y2x := 5.5	Y2y := 7.7
B2 – Phase	B2x := 5.5	B2y := 15.4

x values are horizontal distance from the tower centreline (m)
y values are vertical height above the lowest conductor (m)

Note - The level of the lowest conductor/s is taken as the position of origin (y=0)

Structural Dimensions:

Height of lowest conductor above ground at attachment point on structure (m)	h := 27.5
Height of lowest ground clearance point (m)	s := 11.5
Average height of lowest conductor above ground (m)	$G := h - \left[\frac{2}{3}\cdot(h - s)\right]$ $G = 1.683 \times 10^{1}$

Position of point of measurement (Aerial)

Lateral Distance of *RFI Aerial* from Outer Conductor (m)	dc := 15	*(Do not change this value)*
Height of *Aerial for RFI* Calculations (m)	yaRFI := 2	*(Do not change this value)*
Lateral Aerial Distance from outer conductor for EMF (m)	dcEMF := 0	*(Do not change this value)*
Height of *Aerial for Electric & Magnetic Field* calculations (m)	yaEMF := 1	*(Do not change this value)*
Lateral Aerial Distance from outer conductor for *Audible Noise*	Aud := 27	*(Set to edge of Designation*
Height of Aerial for *Audible Noise* Calculations (m)	yaAud := 1	*(Do not change this value)*
Plot Maximum Distance from Centreline required (m)	range := 100	*(Do not change this value)*
Frequency of measurement for RFI (MHz) (*Freq > 1MHz only*)	Freq := 2	(This value is not reqd)

Limits for EMF, RFI and AN

Calculated values are checked for OK/No Good against these

EFLimit := 5 MFLimit := 1·gauss MFLimitmG := 1000	**In accordance with ICNIRP - 1998**
RFILimit := if(Voltage1 < 220, 50, 59)	**In accordance with NZS 6869: 2004**
ANLimit := 40	**In accordance with NZS 6802: 1991/1999 or relevant council limit**

(Audible Noise calculations are set to "wet conductor" conditions corresponding to a rain rate of 0.75mm/hr)

Mon Feb 11 11:08:34 2008

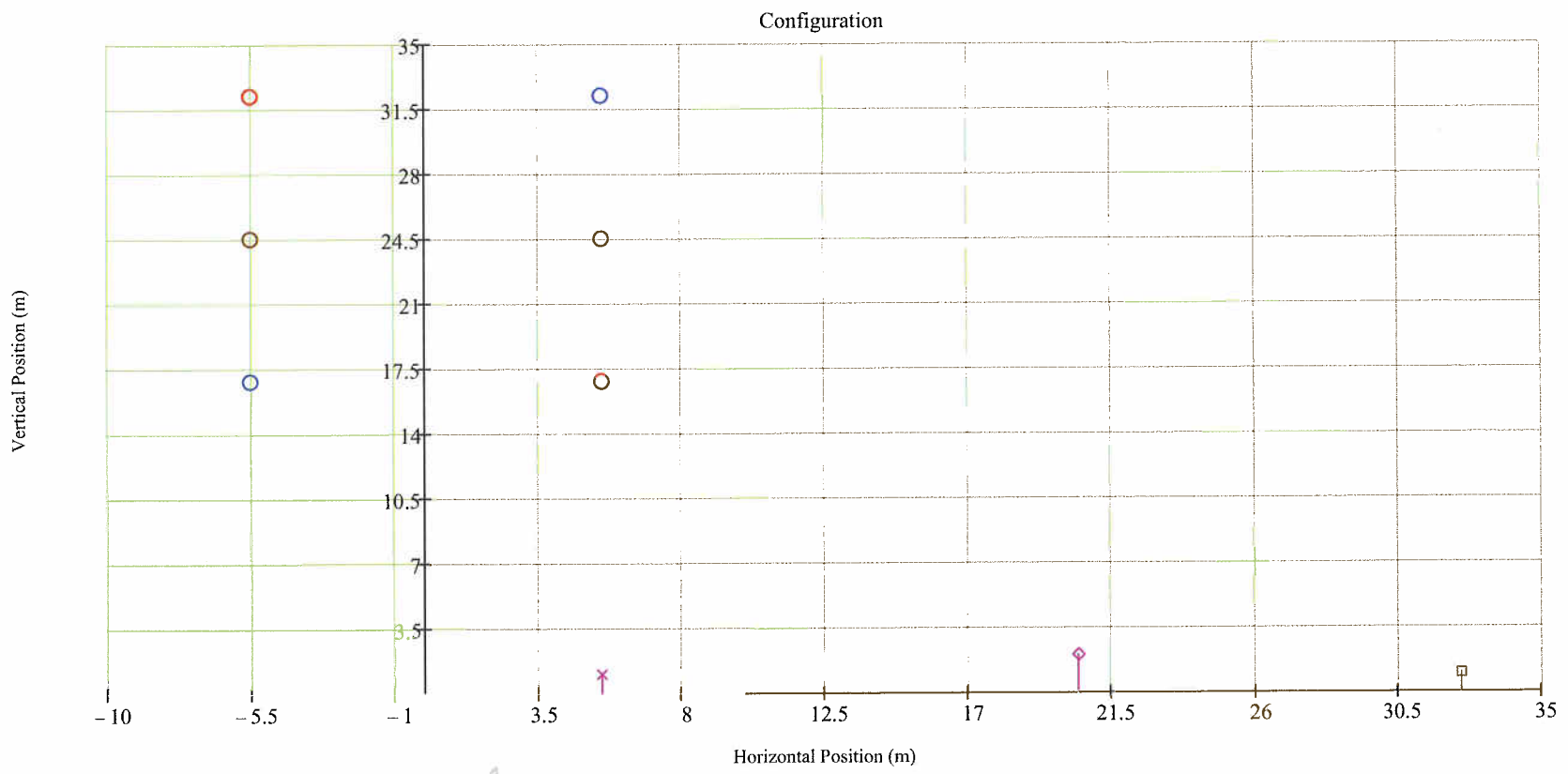
14. Calculation Summary

RFI @ 0.5MHz	Voltage = 420	RFI500 = 49.118	CheckRFI = "OK"	RFILimit = 59
Electric Field @	Voltage = 420	max(EF) = 4.934	CheckEF = "OK"	EFLimit := 5
Magnetic Field @	Current = 2.88×10^{3}	$\frac{\max(Bmax)}{10} = 31.228$	CheckMF = "OK"	MFLimit = 1×10^{0} ·gauss
Audible Noise @	Voltage = 420	PdBtA = 39.998	CheckANOutdoor = "OK"	ANLimit = 40

Corona Calculations

Max Surface Voltage Gradient gmaxGM = 13.936

Conductor/Earthwire/Measurement Antenna Configuration



RFI Frequency Interference profile at 500 kHz (db above 1μV/m)

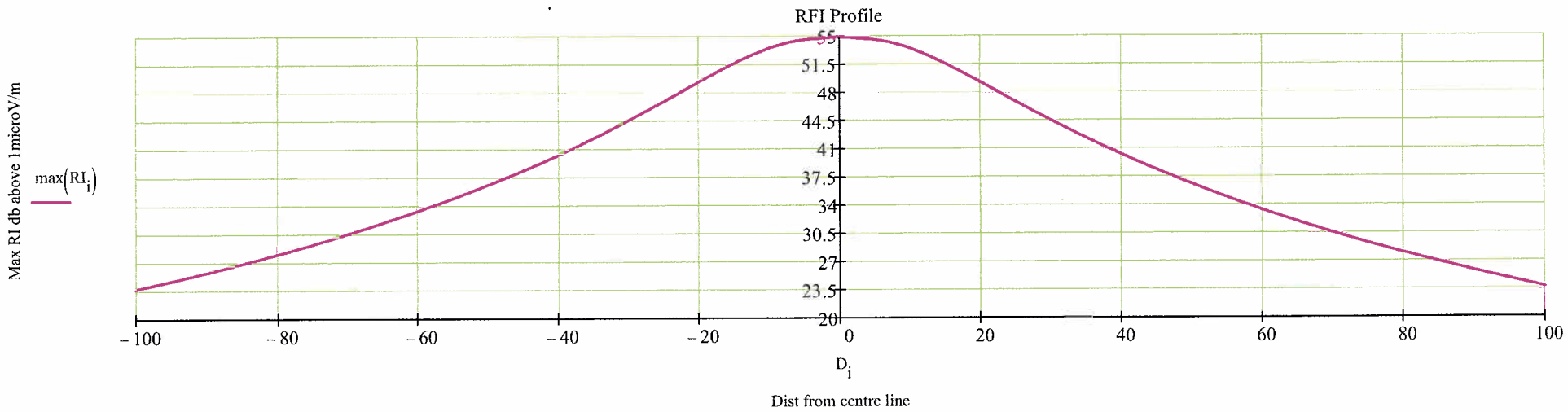
CheckRFI = "OK"

RFI = 43.618 @ 1MHz - Dry

RFI500 = 49.118 @ 0.5MHz - Dry

Note:
The values shown on the graph are calculated at 500kHz and can be corrected as per factors specified in CISPR 18-1, Fig B12, or NZS 6869: 2004.

NZS 6869: 2004 requires compliance at 0.5MHz



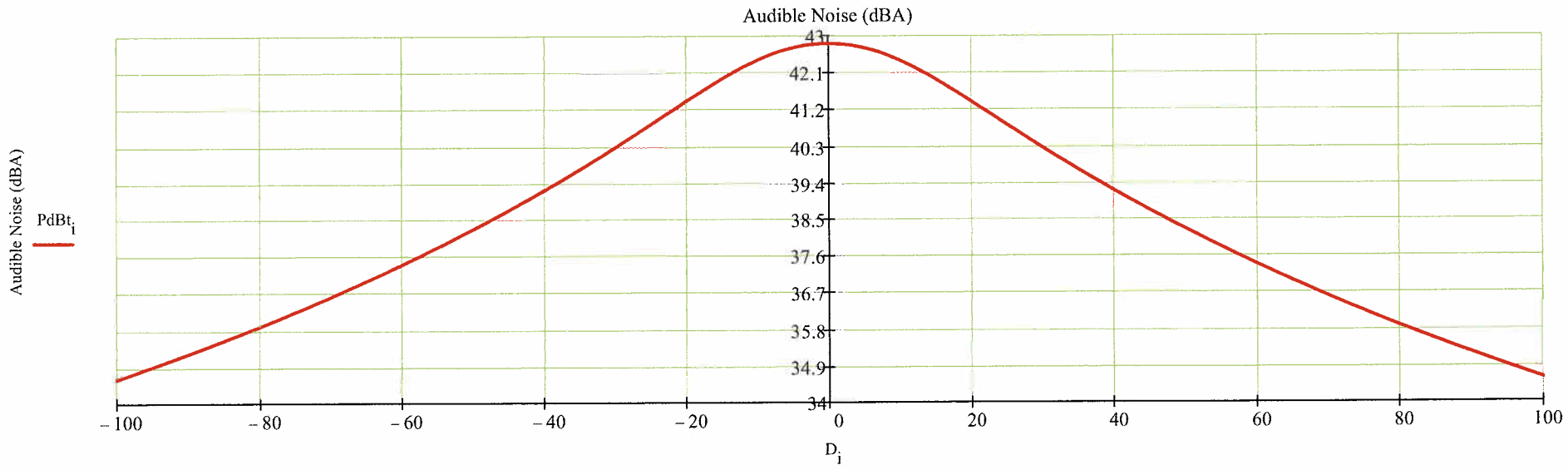
Audible Noise dB(A)

max(PdBt) = 42.82

CheckANOutdoor = "OK"

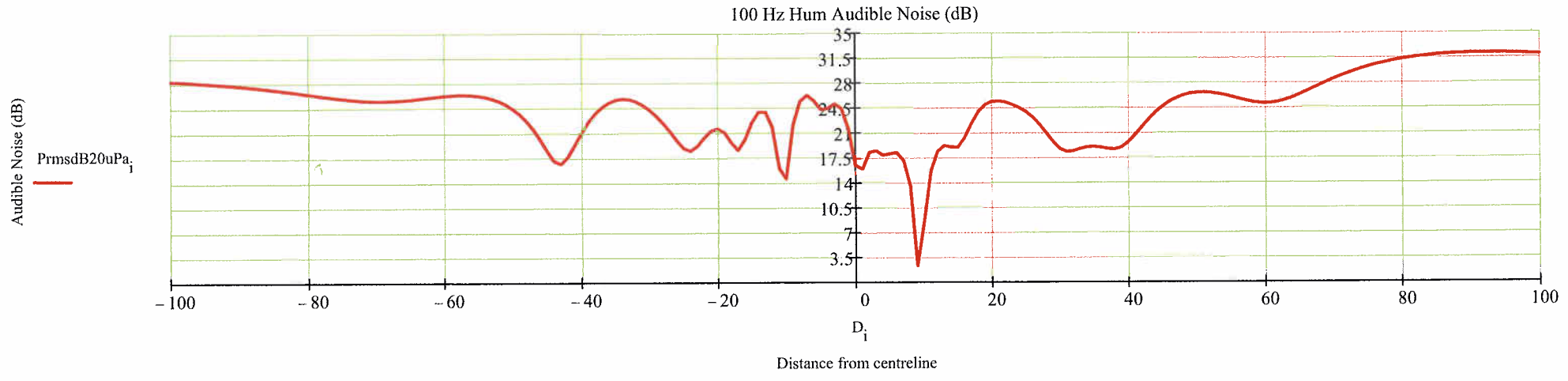
Noise at Aerial location

Audible Noise as per Standard NZS 6802: 1991 or 1999
Note: Audible Noise calculated for 0.75 mm/hr rain so will be at this level around 5% of the time (dependent upon local climate conditions).



Audible Noise - 100Hz Hum (dB)

max(PrmsdB20uPa) = 32.144

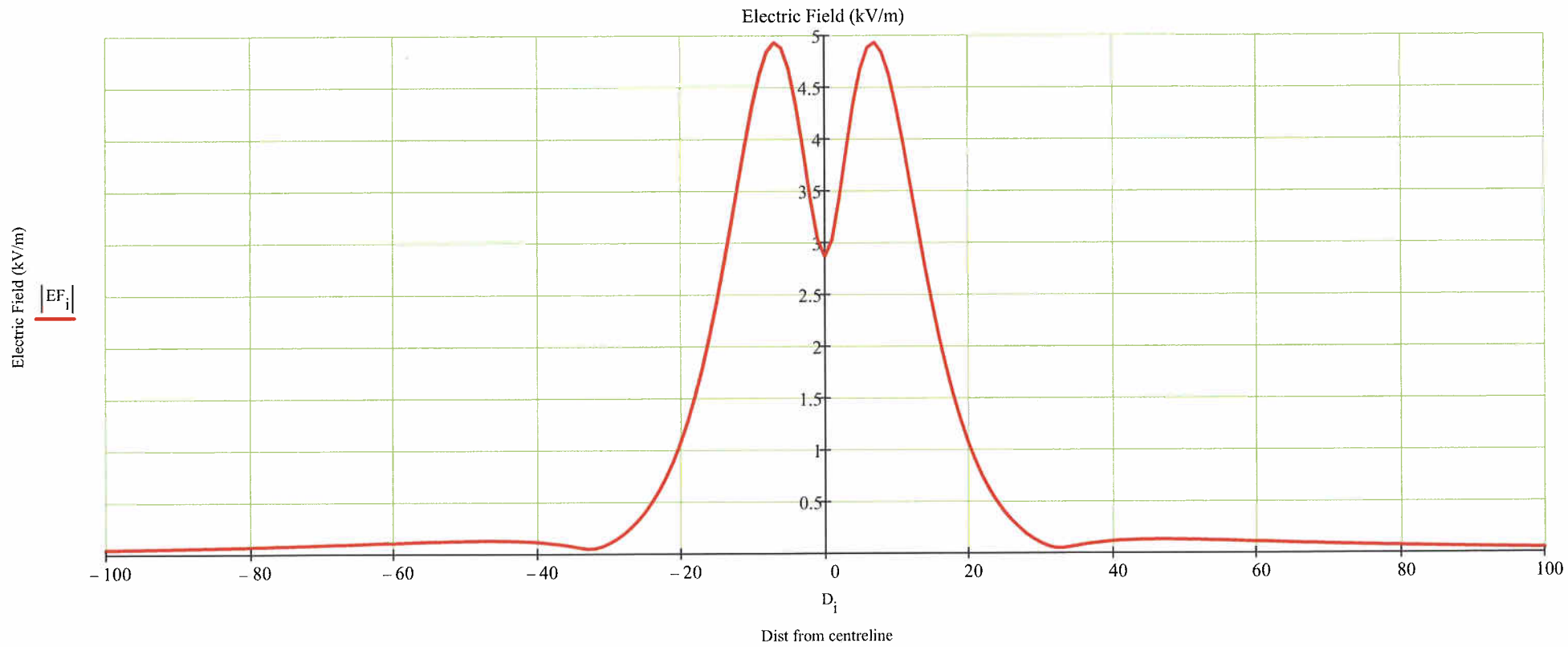


Electric Field Strength (kV/m)

max(EF) = 4.934

CheckEF = "OK"

Max Allowable limit for Electric Field Strength
is 5 kV/m as per the National Radiation Laboratory.



Magnetic Field Flux Density (µT)

$\frac{\max(Bmax)}{10} = 31.228$

CheckMF = "OK"

Max Allowable limit for Magnetic Field Flux Density
is 100 µT as per the National Radiation Laboratory.