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PATH LOSS REPORT FOR HUMANSRUS 3, COPPERTON

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ACRONYMS AND ABBREVIATIONS

AC	Alternating Current
AM	Amplitude Modulation
CAL	Calibration
CCW	Counter Clockwise
CM	Common Mode
E-Fields	Electric Fields
EM	Electro Magnetic
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
Eq	Equation
EUT	Equipment Under Test
Fr	Resonant frequency
H- Fields	Magnetic Fields
IEEE	Institute of Electrical and Electronic Engineers
MIL-STD	Military Standard
PSU	Power Supply Unit
R&S	Rohde and Schwarz
RF	Radio Frequency
SE	Shielding Effectiveness
SELDS	Shielded Enclosure Leak Detection System
SKA	Square Kilometre Array

TABLE OF CONTENTS

1. INTRODUCTION

The SKA is a stakeholder mentioned in the Environmental Authorisation of the Humansrus Solar 3 Photovoltaic project. In order to determine whether the planned facility could have any influence on the SKA, Humansrus Solar 3 (Pty) Ltd requested a risk evaluation of the planned development to SKA activities.

The frequency band of concern for SKA mid-band is 200MHz to 20GHz. This assessment does not consider any potential telecommunication services or networks that are to be established as part of the operational plan. This initial high level risk assessment would then enable one to estimate the maximum permissible radiated emissions from the equipment installed within the Humansrus Photovoltaic Facility.

1.1 REFERENCED AND APPLICABLE DOCUMENTS

[1] Regulations on Radio Astronomy Protection Levels in Astronomy Advantage Areas Declared for the Purposes of Radio Astronomy No.R 90. Government Gazette 10 February 2012 (35007).
[2] K0000-2001V1-02 R: SKA Standard for calculating RFI Threshold Levels – RT Lord 8 December 2010.
[3] CISPR 11: Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement.
[4] NTIA Report 82-100: A guide to the use of the ITS Irregular Terrain Model in the Area Prediction Mode

2. METHODOLOGY

This phase of assessment consists of a paper exercise to determine technology risks (power conversion, wireless control systems etc) of the renewable energy system. A second phase of assessment may become necessary, consisting of in-field measurements, to confirm results or provide further input. The proposed site of the renewable energy installation is also plotted with reference to the MeerKAT, SKA Phase 1 and SKA Phase 2 telescope locations. SARAS receiver protection levels against expected received amplitudes from the renewable power technology are determined and plotted. The CISPR11 Class A emission standards [3] are also provided as reference.

The expected loss as determined by the Irregular Terrain Model [3] (Longley Rice model applicable for frequencies between 20MHz and 20GHz) between the proposed site and nearest SKA stations is presented in Graph 1 to Graph 3. The reduction in power density of an electromagnetic wave as it propagates is a function of free-space loss (natural expansion of the wave front in free space i.e distance between source and receiver), diffraction loss (part of the wave front is obstructed by an obstacle, in this case terrain such as a hill), vegetation and foliage (environment) and the propagation medium (dry/ moist air in this case) to name a few.

Should test reports be available containing measurement data, it can be evaluated in terms of test methods used, accreditation status of facility that performed the tests, credibility of test results and the usability of the report.

Although reference is made to CISPR 11 in this document, it should be noted that the quasi-peak detector used for CISPR tests will result in low amplitudes being recorded for signals with a low pulse repetition rate. Due to the number of potential sources on the plant (72 inverters and 720 tracker systems) and the characteristics of a radio telescope, peak detection (max hold function) should be used when evaluating impulse signals with low repetition rates.

3. TECHNOLOGY DESCRIPTION (HUMANSRUS SOLAR ENERGY FACILITY 3)

Photovoltaic (PV) panels convert the energy delivered by the sun to direct current (DC) electric energy. The array of PV modules is connected to an inverter by means of a network of cables. The DC power is inverted to alternating current (AC) power by a grid-tied inverter. The AC power can then be added to the national electricity network (grid). The voltage at which power is generated is stepped up to the required voltage and frequency of the national grid by using a transformer. The electricity is distributed from the on-site transformers (substation) via distribution lines to the nearest ESKOM substation. From the ESKOM substation the electricity is fed into the national (ESKOM) grid. The infrastructure of the facility includes the ground-mounted structures, solar PV modules, cables, inverter rooms, access roads, auxiliary roads, an on-site substation, and a distribution line. The primary input of the system is sunlight, which is converted to electricity. In the case of sun tracker technology the facility may also utilize auxiliary electricity from the Eskom grid to power tracker motors in order to optimize the amount of sunlight on the solar PV infrastructure. In addition to auxiliary power being used for powering tracker motors, small amounts of auxiliary power would be used for on-site usage on items such as, but not limited to, security and site office energy requirements. A tracking system is ground-mounted and follows the sun's path with the use of typically single or dual-axis technology in order to maximize the amount of direct sunlight on the Solar PV modules. By following the sun, the tracked array rises quickly to full power and stays there on a clear sunny day, while the fixed array only maintains maximum power for a few hours in the middle of the day. Main industrial equipment in the PV plant are the following:

- Photovoltaic generator
- PV tracker system
- Inverters
- Power Station (transformer + MV cubicles)
- Electrical inter-connection system
- Electrical protections
- Evacuation infrastructure

In addition, some typical equipment will be installed according to the final client preferences:
SCADA system, Security system, firefighting system, etc.

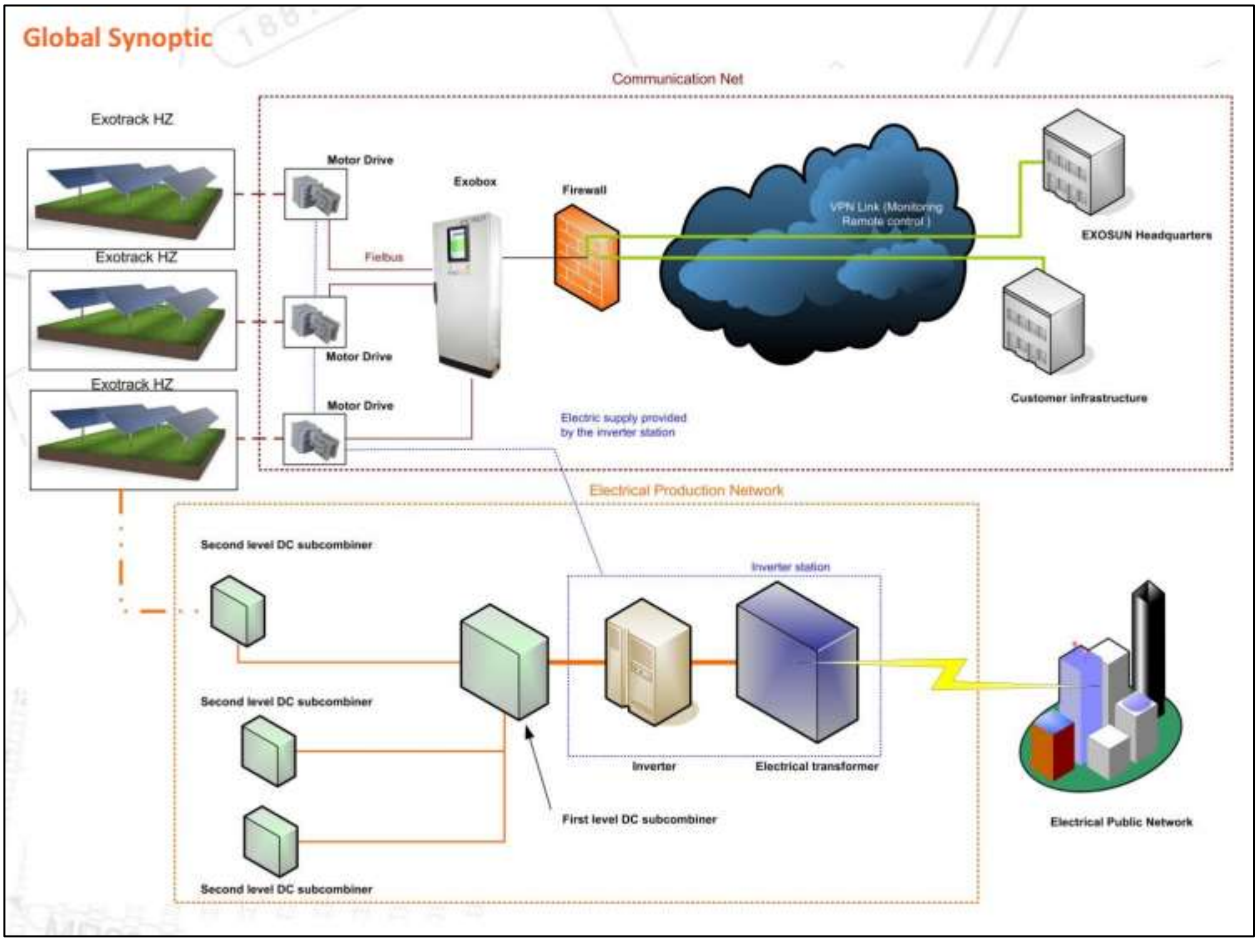


Figure 1: System block diagram

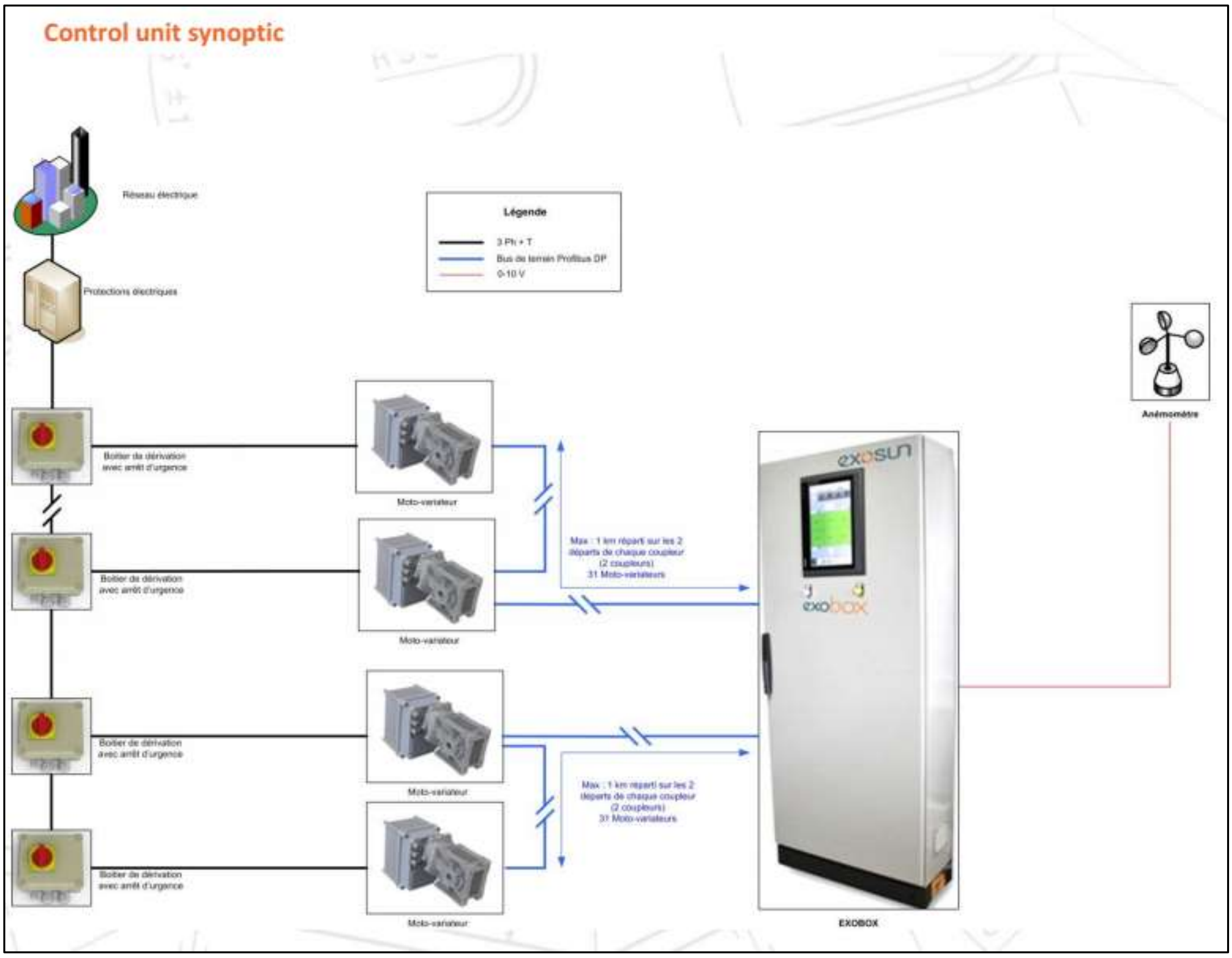


Figure 2: Control system diagram

4. RISK IDENTIFICATION

4.1 TECHNOLOGY RISKS

The following building blocks are viewed as potential interference sources:

- PV tracker system
- Inverters (AC as well as DC path)
- PV Generator control and management
- Control and operations centre (computer equipment)

4.1.1 PV Tracker System

Relevant tracking system components are listed below:

- Drive unit for solar tracking
- Internal communication system (PLC)

All components used should be compliant to CISPR 11 Class A less the mitigation required per unit (Table 2) based on cumulative effect requirements for 720 units (4.1.5 refers) and the fact that the expected (calculated) path loss is less than the required path loss as shown in column 8 of Table 2.

4.1.2 Inverter

Different inverter technologies are in use worldwide. Metal enclosures should be used for components installed at each panel. All components used should be compliant to CISPR 11 Class A less the mitigation required per unit (Table 4) based on cumulative effect requirements for 72 units (4.1.5 refers) and the fact that the expected (calculated) path loss is less than the required path loss as shown in column 8 of Table 4.

4.1.3 PV Generator control and management

The communications infrastructure that enables the transfer of information between the various elements connected to the network, such as the local office of the SCADA and PLCs. will be a MODBUS RS485 protocol, and a triple-ring with multimode optical fibre cable that will interconnect all the nodes (PLCs and SCADA local post).

4.1.4 Control and operations centre

Equipment installed in the control and operations centre shall comply with CISPR 22 Class B. The control and operations building shielding effectiveness should be at least 17dB, unless a 17dB safety margin is added to the CISPR 22 Class B limit.

4.1.5 Cumulative emissions

A large number of non-correlated noise sources (inverters, PV panel controls etc.) could increase the noise floor at a receiving site distant from the noise sources. This will however be included in the measurement data of a single PV plant. Adding more plants will result in a theoretical increase of 10 log N dB where N equals the number of plants. For an additional 3 plants (4 in total) a margin of 6dB can be added to the expected emission field strength from a single plant.

4.2 SITE LOCATION

4.2.1 Area Map

Picture 1: Area Map showing Humansrus and SKA core area

4.2.2 Local Map

Picture 2: Local map showing closest SKA Stations

4.2.3 Elevation Maps

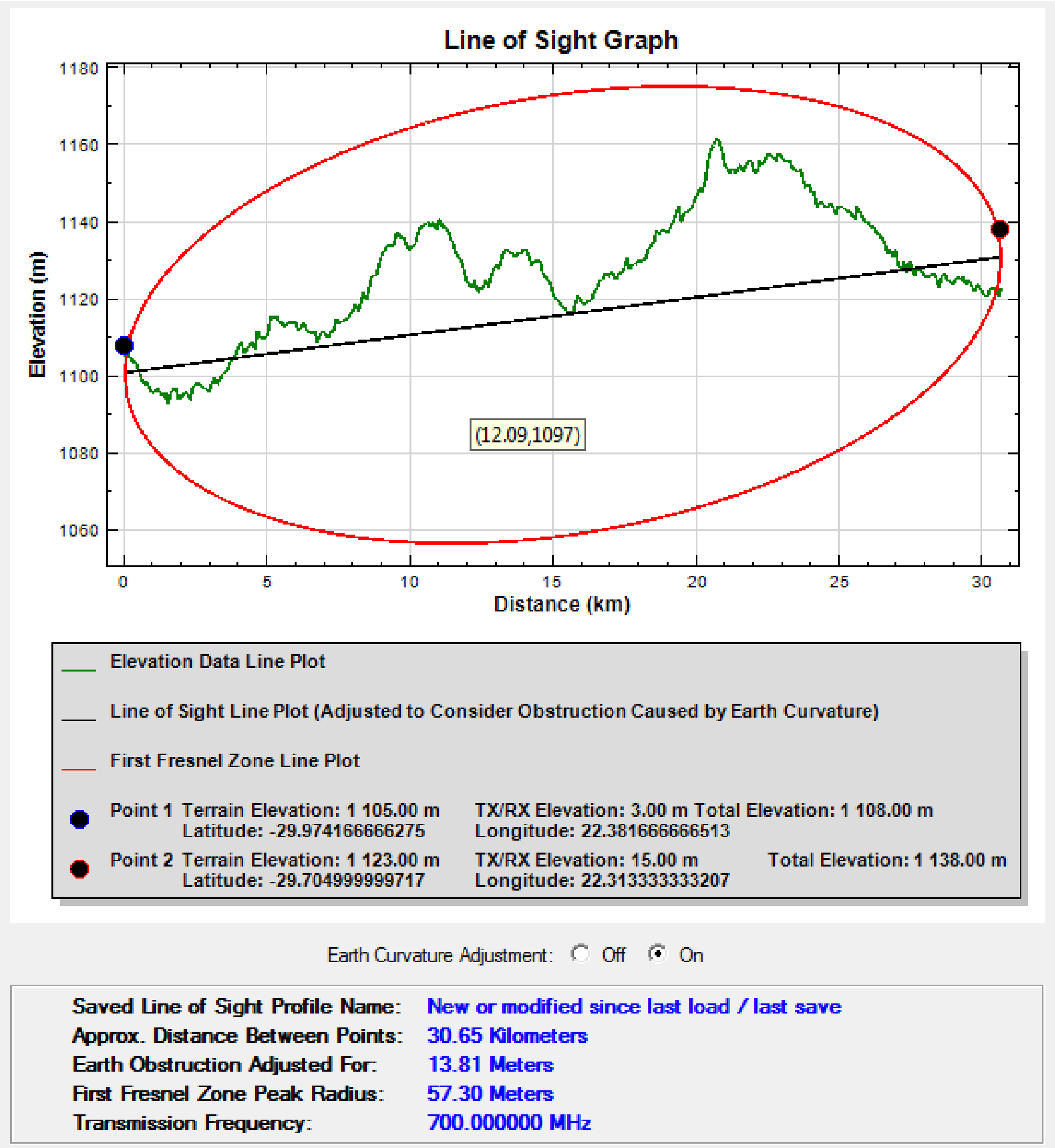


Figure 3: HR3 North to SKA ID 1895

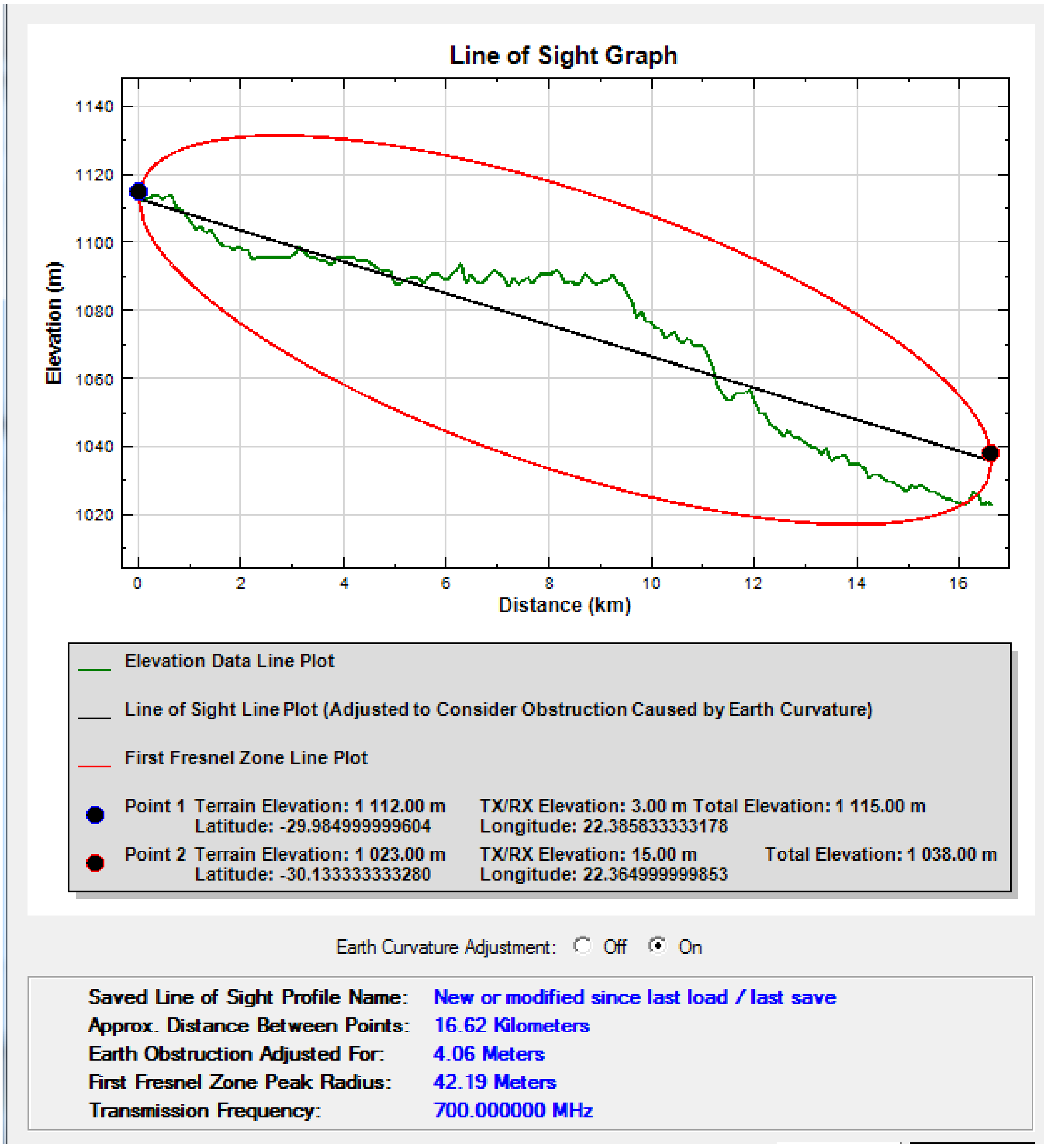
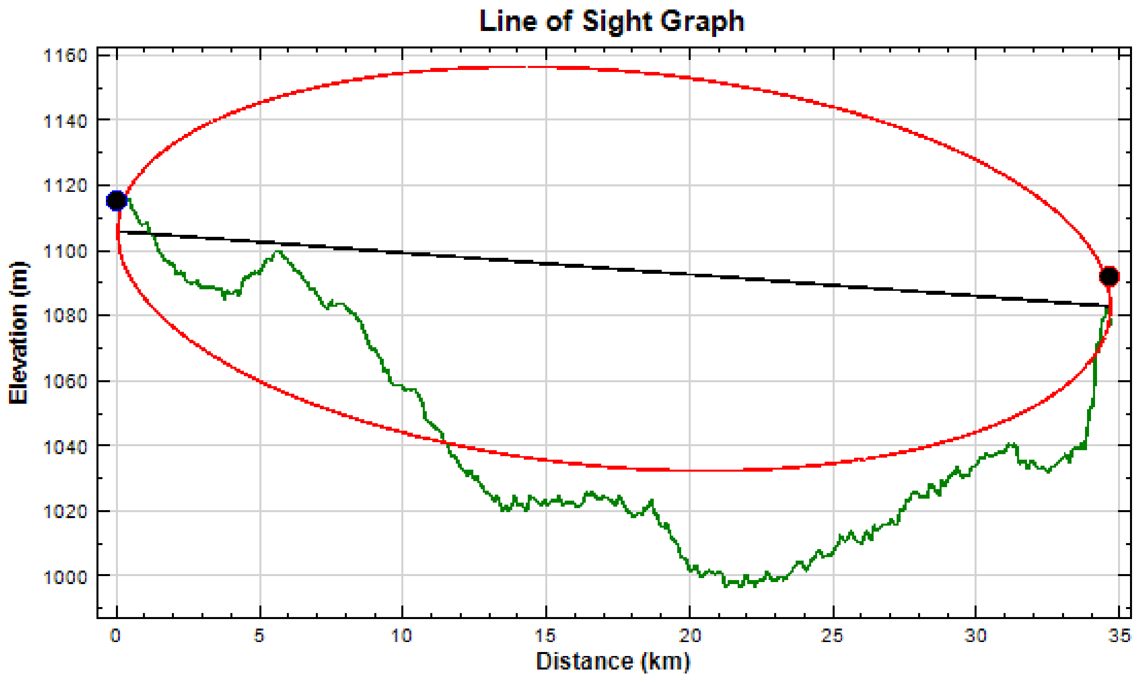


Figure 4: HR3 South to SKA ID 1890



Elevation Data Line Plot

Line of Sight Line Plot (Adjusted to Consider Obstruction Caused by Earth Curvature)

First Fresnel Zone Line Plot

Point 1 Terrain Elevation: 1 112.00 m TX/RX Elevation: 3.00 m Total Elevation: 1 115.00 m
Latitude: -29.984999999604 Longitude: 22.385833333178

Point 2 Terrain Elevation: 1 077.00 m TX/RX Elevation: 15.00 m Total Elevation: 1 092.00 m
Latitude: -30.262499999895 Longitude: 22.221666666578

Earth Curvature Adjustment: Off On

Saved Line of Sight Profile Name:	HR3_S to S2_17
Approx. Distance Between Points:	34.66 Kilometers
Earth Obstruction Adjusted For:	17.66 Meters
First Fresnel Zone Peak Radius:	60.94 Meters
Transmission Frequency:	700.000000 MHz

Figure 5: HR3 South South to SKA S2_17

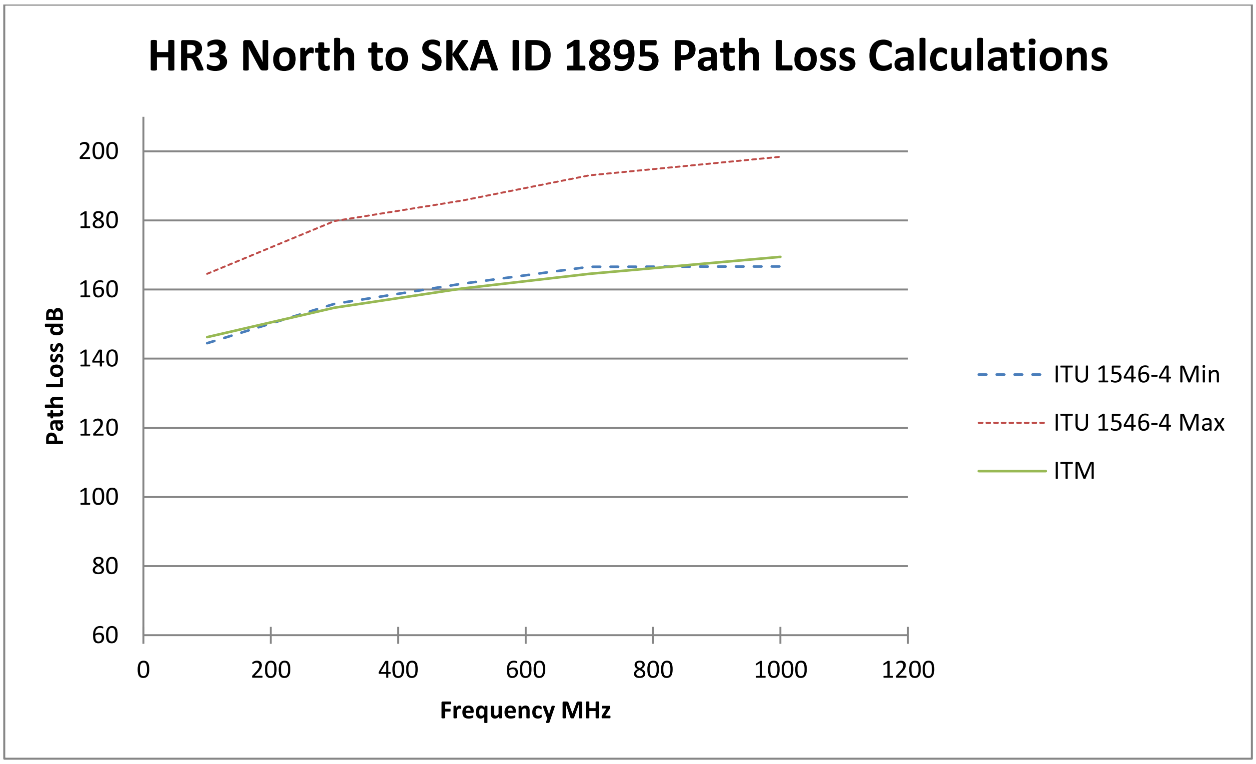
4.3 INPUT DATA

Parameter	Description	Quantity	Comment
Source/ Victim separation distance	SKA ID 1890 to Inverter South SKA ID 1895 to Inverter North SKA S2-17 to Inverter South	16.6km 30.6km 34.6km	
Frequency	Frequencies assessed	100MHz, 300MHz, 500MHz, 1000MHz	Free space loss increases with frequency. Frequencies above 1GHz were not included in the calculations
TX Power	EN CISPR 11 Class A @ 10m	40 dBµV/m for >230MHz 47 dBµV/m for <230MHz	Based on the allowable emission limit for Class A equipment with a CE mark
SARAS	Protection level	dBm/Hz = -17.2708 log 10 (f) - 192.0714 for f<2GHz	Government Gazette 10 February 2012
Location	Inverter HR3 North	Latt: -29.974775 Long: 22.381742	Waypoint received from Solek (Pty) Ltd
Location	Inverter HR3 South	Latt: -29.985752 Long: 22.385974	Waypoint received from Solek (Pty) Ltd
Location	SKA ID 1890	Latt: -30.13335 Long: 22.365428	Waypoint received from SKA SA (Pty) Ltd
Location	SKA ID 1895	Latt: -29.705208 Long: 22.313447	Waypoint received from SKA SA (Pty) Ltd
Location	SKA 004	Latt: -30.262608 Long: 22.221794	Waypoint received from SKA SA (Pty) Ltd
TX height	Inverter / Tracker	3m	Height of the inverter/ control electronics enclosure
RX height	All SKA receivers	15m	Height used for SKA receive horn

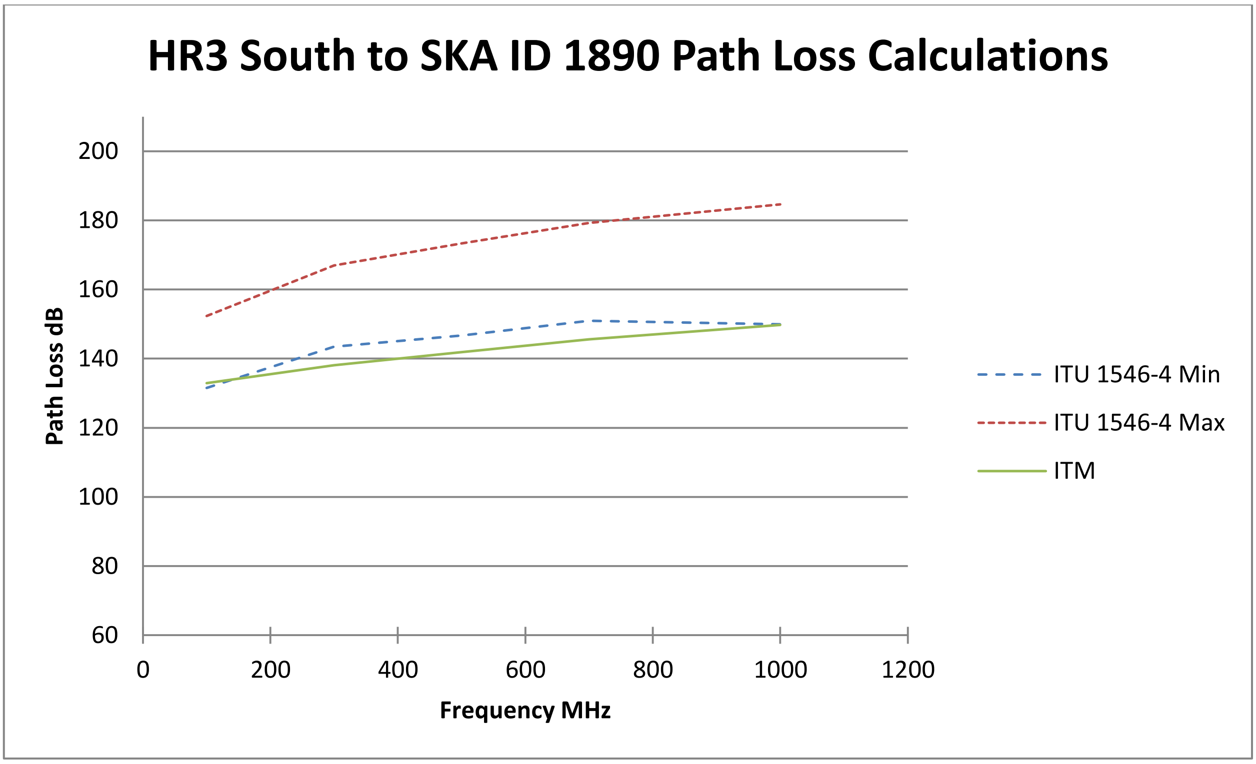
Table 1: Parameters used for calculations

4.4 PATH LOSS CALCULATIONS (ITU-R P.1546-4 AND ITM)

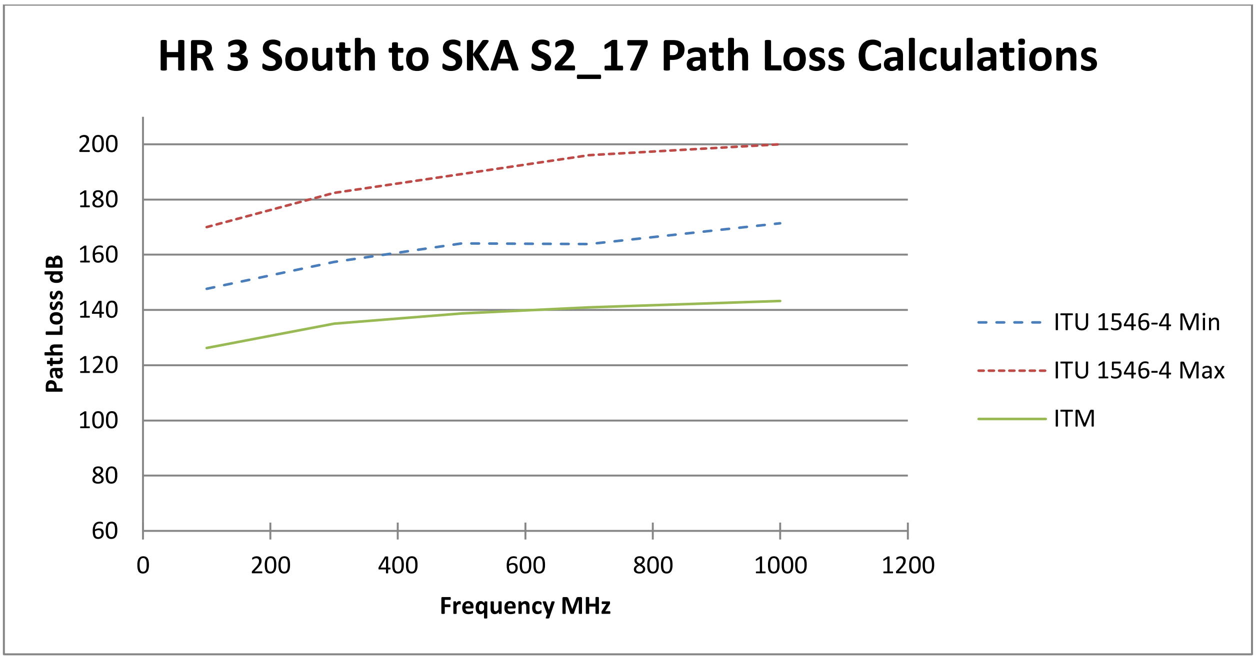
The path loss was calculated using the parameters as specified in Table 1.



Graph 1: HR3 North to SKA 1895 Path Loss Calculation Results



Graph 2: HR3 South to SKA ID 1890 Calculation Results



Graph 3: HR3 South to SKA S2 17 Calculation Results

Graph 1 to Graph 3 show the expected loss as determined by the Irregular Terrain Model (Longley Rice model applicable for frequencies between 20MHz and 20GHz) and the minimum and maximum values of the ITU-R P.1546-4 Land Path propagation model statistical simulation based on the Monte-Carlo method.
The reduction in power density of an electromagnetic wave as it propagates is a function of free-space loss (natural expansion of the wave front in free space i.e distance between source and receiver), diffraction loss (part of the wave front is obstructed by an obstacle, in this case terrain such as a hill), vegetation and foliage (environment) and the propagation medium (dry/ moist air in this case) to name a few.

Although the distance from HR3 South to SKA ID 1890 is 16.5km vs the distance from HR3 South to SKA 2_17 of 34.6km, the path loss of HR3 South to SKA 2_17 is less due to the terrain effects. Calculations that follow will be done using the path loss values of HR3 South to SKA 2_17.

5. MITIGATION REQUIRED

5.1 TRACKER SYSTEM

Based on compliance of the tracker system to CISPR 11 Class A additional attenuation per unit will be required as shown in Table 2.

Humansrus 3 South to SKA S2-17							
Frequency	**CISPR 11 Class A [dBW]**	**Saras [dBW/Hz]**	**Required path loss if CISPR 11 Class A compliant**	**Path Loss (Measured or calculated)**	**Number of units in facility**	**Mitigation required for facility**	**Mitigation required per unit**
70	-74.80	-253.94	128.35	123.3	720	5.05	33.62
230	-74.80	-262.86	137.27	132.7	720	4.57	33.14
230	-67.80	-262.86	144.27	132.7	720	11.57	40.14
1000	-67.80	-273.88	155.29	142.9	720	12.39	40.97
1000	-55.26	-273.88	158.63	142.9	720	15.73	44.30
3000	-55.26	-279.09	163.84	149.9	720	13.94	42.51
3000	-51.26	-279.09	167.84	149.9	720	17.94	46.51
6000	-51.26	-279.11	167.86	155.6	720	12.26	40.83

Table 2: Tracker system analysis based on CISPR 11 Class A compliance

The mitigation required for the facility (column 7) is the result of the calculated path loss between the SKA S2_17 (column 5) and the facility being lower than the required path loss (column 4). The mitigation required per unit is due to the 720 units for the facility. Should this be achieved, the mitigation required for the facility will also be met. In the absence of detailed test reports for the tracker system to be used, it is assumed that the emissions of the tracker are the maximum allowed by CISPR 11 Class A. This is not necessarily the case, especially at the higher frequencies.

Test results from a Sunpower Tracker System and Inverter shows worst case emission levels measured at 10m distance as tabulated below:

Frequency (MHz)	Amplitude (dBµV/m)	EIRP (dBm)	CISPR 11 Class A -17dB (dBµV/m)
77	30	-54.8	23
230	30	-54.8	23
1142	58	-26.8	30
1600	40	-44.8	30

Table 3: Sunpower Tracker Systems tracking system emission levels

A short discussion of the mitigation measures can be found in Paragraph 8

5.2 INVERTERS

Based on compliance of the inverters to CISPR 11 Class A additional attenuation per unit will be required as shown in Table 2.

Humansrus 3 South to SKA S2-17							
Frequency	**CISPR 11 Class A [dBW]**	**Saras [dBW/Hz]**	**Required path loss if CISPR 11 Class A compliant**	**Path Loss (Measured or calculated)**	**Number of units in facility**	**Mitigation required for facility**	**Mitigation required per unit**
70	-74.80	-253.94	128.35	123.3	72	5.05	23.62
230	-74.80	-262.86	137.27	132.7	72	4.57	23.14
230	-67.80	-262.86	144.27	132.7	72	11.57	30.14
1000	-67.80	-273.88	155.29	142.9	72	12.39	30.97
1000	-55.26	-273.88	158.63	142.9	72	15.73	34.30
3000	-55.26	-279.09	163.84	149.9	72	13.94	32.51

3000	-51.26	-279.09	167.84	149.9	72	17.94	36.51
6000	-51.26	-279.11	167.86	155.6	72	12.26	30.83

Table 4: Inverter system analysis based on CISPR 11 Class A compliance

The mitigation required for the facility (column 7) is the result of the calculated path loss between the SKA S2_17 (column 5) and the facility being lower than the required path loss (column 4). The mitigation required per unit is due to the 72 units for the facility. Should this be achieved, the mitigation required for the facility will also be met. In the absence of detailed test reports for the inverter to be used, it is assumed that the emissions of the inverter are the maximum allowed by CISPR11 Class A. This is not necessarily the case, especially at the higher frequencies.

6. MITIGATION

Shielding and filtering solutions are available to ensure installed plant equipment emissions remain within SKA risk tolerances. From laboratory test experience it is known that insufficiently shielded cabling (looms) account for most of the non-compliance to specification levels. It would therefore be recommended to shield and correctly terminate the shields of all cables installed on the PV project site. The shielding can be achieved with braids, but it is often easier to make use of a shielded conduit system as individual wires can be replaced without compromising the shielded integrity.

7. CONCLUSION

Based on the current SKA location information, a first order impact analysis shows a possible interference scenario between the Humansrus Solar PV Energy Facility 3 and the SKA installations as shown. In order to negate the risk to an acceptable level, all equipment to be installed on site must comply with levels of 40dB below the CISPR 11 Class A limit as the primary mitigation measure to accommodate cumulative effect of the high number of potential sources. Where equipment exceeds this threshold, additional shielding and filtering should be implemented to reduce the electromagnetic emissions from the PV facility. Shielding and filtering solutions are available to ensure the required 40dB below CISPR 11 Class A for equipment is reached. Should all equipment comply with the required 40dB below CISPR 11 Class A emissions, the total installed plant equipment emissions is expected to remain approximately 15dB below the CISPR 11 Class A limit. The compliance of the total facility to 15dB below the CISPR 11 Class A emissions is expected to result in emissions within SKA risk tolerances.

8. APPENDIX A: SUNPOWER TRACKER SYSTEM INFORMATION

1. Tracker information – other suppliers

This document aims to provide an overview of tracker systems on the market and its corresponding EMI/RFI emissions.

The Humansrus projects planned to utilise Exosun trackers which complies to CISPR 11 Class A emissions, but additional information could not be obtained in terms of the emission data. The motivation behind this document is therefore to obtain such information from other suppliers with the aimed outcome to prove that there are tracker technologies which have emissions below the Class A emissions.

1.1. Sunpower Tracker Systems

We obtained feedback from Sunpower in terms of their tracker systems and the corresponding EMI and RFI emissions.

Three main noise-producing equipment elements are identified within the plant which can have a significant influence on the level of RFI emitted. Two of these elements are the Inverters and the power tracker controllers (TMAC) with a third possible source being the cabling and its configuration. The rest of the elements are not considered likely RFI emitters such as "tracker motors, PV panels, combiner boxes and high voltage transformers".

1. **Inverters:** Large possibility of being a considerable source of interference (direct radiation or through common mode current).
2. **Solar Power Tracker Controller (TMAC):** Separate measures were taken and are provided below. Operation and monitoring of the system include a wireless mesh network which operates in 2.4 GHz band with Zigbee technology. There is other electrical components part of the controller system which could further act as sources of interference.
3. **Cabling:** The cabling design of the full site is key towards the emission. These are however an outcome of the "detail facility design" and should be designed to ensure that no large conductive loops are formed between "blocks of panels". Emissions from cabling can be reduced by laying the cabling directly in soil and not utilising any sleeving. Earthing (bare copper wire directly within soil) should further ensure that no long and closed conductive loops are created. Key to run all DC cabling in earthed cable trays and placing all LV and MV cables in soil filled trenches.

1.1.1. Inverters

Mitigation measures in the form of additional shielding can be applied to the inverter enclosures if required. Most of these mitigation measures can be retrofitted and will have minimal cost implications.

1.1.2. TMAC controllers

The WiFi mesh network module operates at 2.4GHz. Additionally to the WiFi module additional electronics within the TMAC controller could emit such as sampling clock, reference oscillator, switch-mode power supply, contractor relays and communication channels. The controllers can be installed at a relatively low height which will reduce the potential impact.

Mitigation includes changing WiFi communication between relevant controllers to a fixed line connection. Additionally the shielding of these cables should be considered to further reduce the RFI levels.

Emission values

Sunpower received measurements made by BACL at a distance of 10m from the PV facility in California. The worst case derived peak level emissions from these measurements for controlers are 1142MHz and 1600MHz. For the inverters these are 77 and 230MHz expected. The following table depicts these measured levels:

Frequency (MHz)	Measured Level (dBµV/m)	EIRP (dBm)
77	30	-54.8
230	30	-54.8
1142	58	-26.8
1600	40	-44.8

1.2. Schletter Tracker Systems

The following feedback was provided by Schletter in terms of our EMI enquiry on their tracker systems.

Information set 1

"What we can offer are the certifications of the electro-magnetic-compatibility of the tracking system itself. This is based on some norms that have to be proven to get a CE-conformation." (Hans Urban, Schletter)

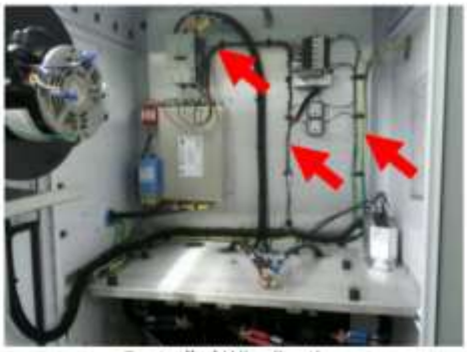
Information set 2

The following feedback was received from Schletter regarding their tracker system and its corresponding EMI influence and classes.

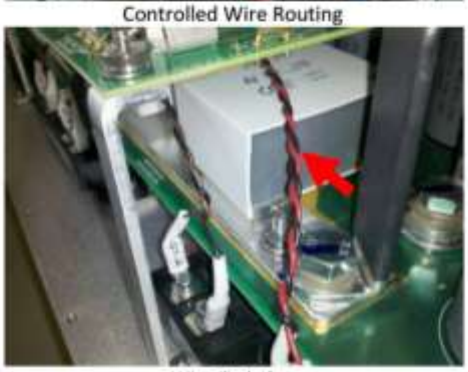
- According to the supplier one actuator is below 70 dBA. The tracker as a whole, Schletter has not done measurements thus far, but our samples did not generate any noise apart from the actuator.
- In terms of EMI codes of compliance the tracker conforms to the following norms
  - EN 61000-6-4 / 2007,
  - EN 61000-6-4 +A1 / 2011
  - EN 61000-6-2 / 2005.
- Once the updated EG-Konformitätserklärung has been issued I will send it through.
- According to my colleagues compared to the PV-panels and the PV-inverters the EMI-radiation of our actuator and our drive control unit should be secondary.

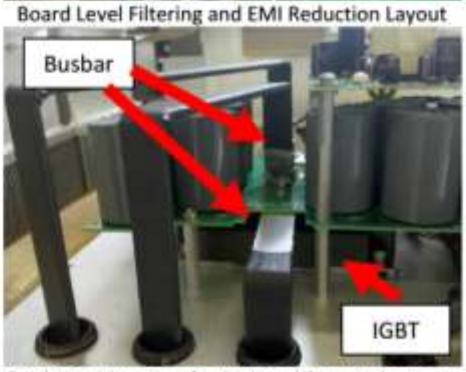
9. APPENDIX B: GENERIC MITIGATION METHODS (SOURCE SOLECTRIA RENEWABLES)


Solid Grounding


Controlled Wire Routing


Board Level Filtering and EMI Reduction Layout


Wire Twisting



Stack Configuration for Reduced Stray Inductance


Power Electronics Enclosure for EMI Shielding


Analog Signal Conditioning using Ferrite Beads


DC side High Power Wiring for EMI shielding