System Electromagnetic Compatibility and Radio Frequency Interference Mitigation Requirements

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Change Record

Version	Date	Author	Affected Section(s)	Reason
01	2017-10-02	R. Selina	All	Started first draft; used 020.25.00.00.00-0001-SPE-A as a template
02	2017-10-12	R. Selina	2.1, 3, 4.1	Incorporated feedback from W. Grammer and R. Treacy
03	2018-05-09	R. Selina	3.1	Updated for consistency with case outlined in SCI0116
04	2018-09-27	R. Selina	1.3, 2.1, 3.1, 4.	Updated based on review by D. Mertely
A	2019-07-09	A. Lear	All	Prepared document for approvals & release

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1 Introduction

1.1 Purpose

This document presents system-level Electromagnetic Compatibility (EMC) and Radio Frequency Interference (RFI) mitigation requirements. This specification is a subsection of the preliminary Next Generation Very Large Array (ngVLA) System Requirements [AD01], which in turn flow down from the preliminary Science Requirements and Stakeholder Requirements.

1.2 Scope

This document covers all buildings, infrastructure, and equipment located at the ngVLA core and other outlying stations. All related ngVLA system elements shall be specified to comply with this specification.

1.3 Project Background

The ngVLA is a project of the National Radio Astronomy Observatory (NRAO) to design and build an astronomical observatory that will operate at centimeter wavelengths (25 to 0.26 centimeters, corresponding to a frequency range extending from 1.2 GHz to 116 GHz). The observatory will be a synthesis radio telescope constituted of approximately 244 reflector antennas each of 18 meters diameter and 19 reflector antennas each of 6 meters diameter, operating in a phased or interferometric mode.

The facility will be operated as a proposal-driven instrument with the science program determined by Principal Investigator (PI)-led proposals. Data will generally be delivered to PIs and the broader scientific community as Science Ready Data Products; automated pipelines will calibrate raw data and create higher level data products (typically image cubes). Data and quality assured data products will be made available through an Observatory science archive. Data exploration tools will allow users to analyze the data directly from the archive, reducing the need for data transmission and reprocessing at the user's institution.

The array signal processing center will be located at the Very Large Array site on the Plains of San Agustin, New Mexico. The array will include stations in other locations throughout New Mexico, west Texas, eastern Arizona, and northern Mexico. Long baseline stations are located in Hawaii, Washington, California, Iowa, Massachusetts, New Hampshire, Puerto Rico, the US Virgin Islands, and Canada.

Array operations will be conducted from both the VLA Site and the Array Operations and Repair Centers in Socorro, NM. A Science Operations Center and Data Center will likely be located in a large metropolitan area and will be the base for science operations and support staff, software operations, and related administration. Research and development activities will be split among these centers as appropriate.

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents are applicable to this Technical Specification to the extent specified. In the event of conflict between the documents referenced herein and the content of this Technical Specification, the content of the Technical Specification shall be considered as a superseding requirement.

Reference No.	Document Title	Rev / Doc. No.
AD01	ngVLA Preliminary System Requirements	020.10.15.10.00-0003-REQ

2.2 Reference Documents

The following references provide supporting context:

Reference No.	Document Title	Rev / Doc. No.
RD01	RFI Emission Limits for Equipment at the EVLA Site	EVLA Memo #106. Perley, Brundage, Mertely.
RD02	Attenuation of Radio Frequency Interference by Interferometric Fringe Rotation	EVLA Memo #49. Perley.
RD03	Protection Criteria Used for Radio Astronomical Measurements	Recommendation ITU-R RA.769-2
RD04	Notes on RFI Emission Levels	VLA/VLBA Interference Memo #34

3 EMC/RFI Requirements

3.1 Spurious Signals/Radio Frequency Interference Generation

Parameter	Req. #	Value	Traceability
Spurious Signal Level	EMC0310	Not to exceed the equivalent isotropic radiated power limits in Table 1.	SYS2104, SCI0116

The electronics within the antenna must be shielded to avoid radio frequency interference (RFI) being received by the Front End electronics, degrading system sensitivity. The table below is based on the analysis presented in [RD01], updated for longer integrations consistent with SCI0116.

Freq. (GHz)	1	2	4	6	8	10	20	30
F_h (w/m²)	1.5E-19	1.1E-18	8.9E-18	2.9E-17	6.3E-17	1.2E-16	1.2E-15	4.3E-15
$EIRP_h$ (W)	1.9E-16	1.4E-15	1.1E-14	3.7E-14	7.9E-14	1.5E-13	1.6E-12	5.4E-12
$EIRP_h$ (dBm)	**–127**	**–119**	**–110**	**–104**	**–101**	**–98**	**–88**	**–83**

Table 1 - Allowable radiation power for electronic components.

The table is based on unity gain, assuming the RFI enters through a sidelobe of the antenna. F_h is the harmful power flux density level, and $EIRP_h$ is the harmful effective isotropic radiated power. The ratio of the emitting device EIRP to the harmful EIRP ($EIRP_h$) is the shielding required. For example, a device with an EIRP of 1nW @2GHz would require of order 59dB of shielding.

The table above assumes the radiator is 10 m from the antenna feed. For other distances, the $EIRP_h$ can be calculated as follows:

$$EIRP_h = \frac{4\pi r^2 S F_h}{G}$$

where *r* is the distance in meters, *S* is the device shielding ratio, *G* is equal to 1, and F_h is from Table 1.

Radiated Power shall be computed over a bandwidth that corresponds to a spectral resolution of 100 m/s. This can be calculated as 333 Hz * ν_G, where ν_G is the RF frequency in GHz.

3.2 Electromagnetic Compatibility Requirements

All ngVLA equipment shall exhibit complete electromagnetic compatibility (EMC) among components (intra-system electromagnetic compatibility). Prevention of electromagnetic interference (EMI) between the antenna and other sub-systems (inter-system electromagnetic compatibility) is also critical.

The following requirements shall be fulfilled *as a minimum* to achieve both intra- and inter-system EMC, but the designer may propose alternatives if quantitative evidence is provided that they are at least as effective as those specified. Shielding requirements may be computed as described in Section 3.1.

Parameter	Req. #	Value	Traceability
Drive System Shielding	EMC0320	All motor leads, both power and control, shall be filtered.	SYS2104
Relay Contact Arcing	EMC0321	All relay contacts and actuators shall be properly bypassed with snubber circuits, shielded, and/or filtered.	SYS2104
Amplifiers & Oscillators	EMC0322	All amplifiers and oscillators shall be mounted in shielded enclosures that will provide effective shielding of radio frequency energy.	SYS2104
Silicone Controlled Rectifiers	EMC0323	Silicon-controlled rectifier switching devices shall not be used unless phase controlled and zero current crossing switching techniques are used.	SYS2104
Gaseous Discharge Devices	EMC0324	No gaseous discharge devices, except noise sources for test and calibration, shall be employed.	SYS2104
Static Discharge Mitigation	EMC0325	Means shall be employed to reduce static electricity and the consequent radio frequency noise generated in any rotating machinery.	SYS2104
Display Shielding	EMC0326	All displays (LCD, plasma, LED, CRT) shall have a RFI shield in front of the display to avoid radiated RFI. This requirement may be waived if the screen is powered off during typical operation and is used for maintenance purposes only. It must be possible to monitor and turn off such emitting devices remotely (via M&C System).	SYS2104
Digital Equipment Shielding	EMC0327	All digital equipment, whether a simple logic circuit, embedded CPU, or rack mounted PC shall be shielded and have its AC power line and communication line(s) filtered at the chassis.	SYS2104
EMC Test Frequencies	EMC0328	The frequency range to be covered by these design measures for radiated radio-frequency interference (RFI) suppression shall extend from 50 MHz up to 12 GHz. Demonstration of EMC above 12 GHz is not required because mitigation at 12 GHz and below is expected to be adequate at higher frequencies. An exception is made for the fundamental and harmonic frequencies of LO signals, which shall be tested up to 40 GHz.	SYS2104

The goal of these requirements is to limit the use of devices that are likely to cause harmful emission levels, shield the remaining necessary emitters, and establish practical testing standards. This list is not comprehensive, and the designer should exercise due diligence in limiting the harmful emissions generated by his/her design. Design for EMC/RFI mitigation is expected to be a significant effort in most electronic components of the ngVLA.

4 Appendix

4.1 Abbreviations & Acronyms

Acronym	Description
AD	Applicable Document
CDR	Critical Design Review
CoDR	Conceptual Design Review
CFD	Computational Fluid Dynamics
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
FDR	Final Design Review
HVAC	Heating, Ventilation & Air Conditioning
ICD	Interface Control Document
IPT	Integrated Product Team
LRU	Line Replaceable Unit
ngVLA	Next Generation VLA
RD	Reference Document
RFI	Radio Frequency Interference
RMS	Root Mean Square
RSS	Root of Sum of Squares
SAC	Science Advisory Council
SRSS	Square Root Sum of the Square
SWG	Science Working Group
TAC	Technical Advisory Council
TBD	To Be Determined
VLA	Jansky Very Large Array

4.2 Supporting Calculations: Derivation of RFI Generation Requirements

The EIRP limits listed in Section 3.1 are based on the analysis presented in [RD01]. The allowable emission limits are computed for an interferometer with attenuation of a stationary RFI source provided by phase winding. The specifications in Section 3.1 rely on this attenuation, and are not suitable for total power radiometry. The analysis in [RD01] uses an expression for the attenuation factor from [RD02]:

$$R = 12\sqrt{\tau \nu_G B_K \cos\delta}$$

where τ is the integration time in seconds, ν_G is the RF frequency in GHz, B_K is the maximum baseline in km, and δ is the source declination. The coefficient 12 is unique to the VLA, and must be recomputed for ngVLA. This coefficient was derived from equation 16 in [RD02]:

$$C = \frac{\sqrt{1000}}{1.34\sqrt{f}} = 12$$

The square root of 1000 accounts for the fact that RD02 Equation 16 is in MHz rather than GHz. *f* is the ratio of B_{MAX}/B_{MEAN} which, for VLA, is approximately 4.

The computation for ngVLA is complicated by the likely use of sub-arrays. The attenuation is minimized when the array is compact and the source is high in the sky. Standalone use of the compact core likely presents a conservative case, and the following input parameters (Table 2) were used to determine the attenuation factor:

Parameter	Value	Units	Notes
N_a	86		Core sub-array case. 40% of collecting area.
$B_{Max,K}$	2.0	km	Core sub-array case.
δ	85	degrees	Gets worse at high declination.
$B_{Min,K}$	0.032	km	Approx. 1.75 x D_{ANT}
f	63		Ratio of max to mean baseline, in core.

Table 2 - Input parameters to fringe rotation attenuation computation.

The ratio of max to mean baseline requires further knowledge of the array configuration. In this analysis, the ratio of the max and min baseline is used to provide an additional margin. This should be revisited once the configuration design is stable.

The remainder of the analysis follows the process outlined in [RD01]. An integration period of 46,800 seconds (13 hours) was used for consistency with SCI0116, and the emitter was placed at a distance of 10m from the receiver. Resolution bandwidth is also consistent with SCI0116.

ν_G (GHz)	**1**	**2**	**4**	**6**	**8**	**10**	**20**
T_{SYS} (K)	25	25	27	27	25	25	33
$\Delta\nu$ (Hz)	333.33	666.67	1,333.33	2,000.00	2,666.67	3,333.33	6,666.67
σ_P (W) *single dish*	2.91E-23	4.12E-23	6.29E-23	7.70E-23	8.24E-23	9.21E-23	1.72E-22
$P_{HARM\text{-}SD}$ (W) *single dish*	2.91E-24	4.12E-24	6.29E-24	7.70E-24	8.24E-24	9.21E-24	1.72E-23
R [Attenuation Factor, Memo #49]	3.64E+02	4.75E+02	6.33E+02	7.54E+02	8.57E+02	9.47E+02	1.30E+03

$P_{HARM-INT}$ (W) ***interferometer***	1.06E-21	1.96E-21	3.98E-21	5.81E-21	7.05E-21	8.72E-21	2.23E-20
A_e (m^2)	0.007162	0.001790	0.000448	0.000199	0.000112	0.000072	0.000018
F_{HARM} (watt/m^2) ***interferometer***	1.5E-19	1.1E-18	8.9E-18	2.9E-17	6.3E-17	1.2E-16	1.2E-15
EIRP limit (watts) ***interferometer***	1.9E-16	1.4E-15	1.1E-14	3.7E-14	7.9E-14	1.5E-13	1.6E-12
EIRP (dBm) ***interferometer***	–127	–119	–110	–104	–101	–98	–88

Table 3 - Computed values that support the emission limit specification.

The parameters in Table 3 are described below, along with any constants used in their computation.

Parameter	Description
ν_G (GHz)	The point frequency applicable to this analysis.
T_{SYS} (K)	The system temperature
$\Delta\nu$ (Hz)	The bandwidth over which the RFI is integrated.
σP (W)	The noise power generated by the system, at the specified T_{SYS} and bandwidth, over a period of 46,800 seconds.
$P_{HARM-SD}$ (W)	The harmful emission threshold applicable to single-dish total power radiometry.
R	The interferometric attenuation factor, as described in EVLA Memo #49 [AD02].
$P_{HARM-INT}$ (W)	The harmful emission threshold applicable to interferometric measurements.
A_e (m^2)	An isotropic antenna's effective cross-section area.
F_{HARM} (W/m^2)	The harmful threshold in power flux density units.
EIRP (watts)	The limit in effective isotropic radiated power, expressed in watts, 10m from the receiver.
EIRP (dBm)	The limit in effective isotropic radiated power, expressed in dBm, 10m from the receiver.