

Performance Specification for Miniature Automotive Coaxial Connectors

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PERFORMANCE SPECIFICATION FOR
MINIATURE AUTOMOTIVE COAXIAL CONNECTORS

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1. SCOPE

This document contains procedures for performance testing of electrical terminals, connectors, and components for coaxial-style cable with an outside cable diameter of 3.6 mm and smaller. These are often called “mini coax connector systems.” This specification applies to coaxial cable connection systems that operate at frequencies from DC to 9 GHz and are intended for road vehicles. The characteristic impedance of the mini coax connection system described here is 50 Ω , however nothing excludes the use of these connectors in systems with a different characteristic impedance. This specification applies only to connection systems using coaxial cable.

2. RELATED DOCUMENTS

2.1 Normative (Required) References

- SAE/USCAR-2, Performance Specification for Automotive Electrical Connector Systems. USCAR-2 is used for all the mechanical and DC electrical testing. USCAR-49 is for the unique testing for coax only.
- SAE/USCAR-17, Performance Specification for Automotive RF Connector Systems. Use is optional as an alternate test method for 4.3.2.
- SAE/USCAR-21, Performance Specification for Cable-to-Terminal Electrical Crimps.
- IEC 62153-4-7, Metallic cables and other passive components test methods - Part 4-7: Electromagnetic compatibility (EMC) - Test method for measuring of transfer impedance and screening attenuation a_s or coupling attenuation a_c of connectors and assemblies - Triaxial tube in tube method.

2.2 Informative (Not-Required) References

- ISO DIS 19642-11, Dimensions and requirements for coaxial RF cables with a specified analog bandwidth up to 6 GHz (20 GHz).
- IEEE 370, IEEE Standard for Electrical Characterization of Printed Circuit Board and Related Interconnects at Frequencies up to 50 GHz.
- IEC 62153-4-6, Metallic cables and other passive components test methods - Part 4-6: Electromagnetic compatibility (EMC) - Surface transfer impedance - Line injection method.
- Touchstone® File Specification, https://www.ibis.org/connector/touchstone_spec11.pdf.

3. CONNECTOR QUALIFICATION

3.1 General Test Requirements

USCAR-49 is used with other USCAR and IEC specifications to form a complete validation test. These test tables are referenced in the applicable testing sections.

- [Table 1](#) lists test requirements for design validation using USCAR-2. These are the basic mechanical and environmental tests that are common with low voltage connectors.
- [Table 2](#) lists the unique tests for mini coax cables per this document.
- [Table 3](#) lists additional samples required for environmental testing to evaluate performance at high frequency.

3.1.1 USCAR-2 and USCAR-21 Testing

Use [Table 1](#) as instructed. It provides design validation involving USCAR-2 and USCAR-21. An X indicates a required test.

Table 1 - Low voltage tests from USCAR-2 and USCAR-21

ID ⁽²⁾	Test Name	Coax Terminal	Mini Coax Connector		Multi-Vendor ⁽³⁾
		All	Sealed	Unsealed	All
A	Term. - Term. Engage/Disengage	X ⁽⁴⁾			
B	Terminal Bend Resistance	X ⁽⁴⁾			
C	Current Cycling	X ⁽⁴⁾			
D	Term. - Conn. Insertion/Retention		X	X	
E	Misc. Component Engage		X	X	
F	Audible Click		X	X	
G	Conn. Conn Mating/Un-mating		X	X	X
H	Polarization Effectiveness		X	X	
I	Drop		X	X	
J	Cavity Damage		X ⁽³⁾	X ⁽³⁾	
K	Header Pin Retention		X	X	
L	Mounting Feature Strength		X	X	
M	Vibration/Mechanical Shock		X	X	
N	Thermal Shock		X	X	
O	Temp./Humidity		X	X	X
P	High Temp. Exposure		X	X	
Q	Fluid Resistance		X		
RSAA	Combined R+S+AA from USCAR-2		X		
TUAB	Combined T+U+AB from USCAR-2		X		
V	Temp./Humidity				X ⁽¹⁾
W	Pressure/Vacuum (Stand Alone)				X ⁽¹⁾
X	Mechanical Assist Integrity		X	X	
Y	Connector Seal Retention - Unmated		X		
Z	Connector Seal Retention - Mated		X		
-	USCAR-21 Core Conductor Crimp	X			

NOTES:

"X" refers to required test sequences for USCAR-49 approval.

⁽¹⁾ Sealed only.

⁽²⁾ ID and test name refer to USCAR-2.

⁽³⁾ The term multi-vendor applies to connectors previously validated that are being tested for interoperability with a different connector maker's (also previously validated) part.

⁽⁴⁾ Check to see if testing is waived by test requester due to not being relevant to specific design of coax connector.

3.1.2 USCAR-49 Testing

Use [Table 2](#) as instructed to apply USCAR-49 test sequences. Validations require passing test groups AF, either AG or AH, AI, and AJ. The sequence for testing is shown by number, where the test marked as number “1” is performed first and the sequence continues in the order listed.

Table 2 - Test sequences

		Test Groups for Unaged Mini Coax Connectors				
	Test Name	S Parameters	Shielding Performance Injection Line	Shielding Performance Tube-in-Tube	Dielectric Withstand Voltage	Header Side Load
Section Reference	Test Sequence ID	AF	AG ⁽⁶⁾	AH ⁽⁶⁾	AI	AJ
	Connector Sample Size, minimum	3 ⁽¹⁾	3	3	3	3
	Applicable Cable Size	Applicable Cable ⁽²⁾	Applicable Cable ⁽²⁾	Applicable Cable ⁽²⁾	Applicable Cable ⁽²⁾	N/A
5.1 ⁽⁴⁾	General	1	1	1	1	1
5.1.8 ⁽⁴⁾	Visual Inspection	2	2	2	2	
5.1.7 ⁽⁴⁾	Connector Cycling	3	3	3	3	
4.2	S Parameters (IL, RL)	4				
4.3	S Parameters (Impedance)	5				
4.4	S Parameters (Crosstalk)	6				
4.5	Injection Line		4			
4.6	Tube-in-Tube			4		
4.7	Dielectric Withstand Voltage				4 ⁽⁵⁾	
4.8	Mechanical Side Load					2 ⁽³⁾
5.1.8 ⁽⁴⁾	Visual Inspection-Final	7	5	5	5	3

NOTES:

⁽¹⁾ Make complete sample using equipment intended for serial (series) production. Do not hand-build any portion.

⁽²⁾ Each different cable, including type of shielding, requires separate validation.

⁽³⁾ Note that procedure for side load requires concurrent circuit continuity monitoring per USCAR-2 section 5.1.9.

⁽⁴⁾ Test references USCAR-2.

⁽⁵⁾ Test may be omitted if USCAR-2 section 5.5.1 (insulation resistance test) is run and passed.

⁽⁶⁾ Perform either test path AG or AH - but not both - to assess shielding performance. Choose which one based on customer preference, if given. Test path AG is the most economical and should be chosen if there is no conflicting customer requirement or lab preference.

3.1.3 RF Testing After Environmental Exposure

Use [Table 3](#) as instructed for testing specially prepared coax terminals after environmental exposure. The samples are specially made in a way that lets them be measured on a network analyzer. Testing per this table is in addition to USCAR-2 environmental testing (test groups N, M, O, and P as called for in USCAR-2 per [Table 1](#)). Typically, 28 samples are required beyond what is called for in for USCAR-2 test paths M, N, O, and P.

Table 3 - Additional samples for environmental sequence

		Additional DUT Samples for Environmental Sequences			
Test Name⁽¹⁾		Vibration/ Shock	Thermal Shock	Temp./Humidity Cycling	High Temp. Exposure
Test Sequence ID		M-RF	N-RF	O-RF	P-RF
Sample Size, minimum		7 ⁽³⁾	7 ⁽³⁾	7 ⁽³⁾	7 ⁽³⁾
Cable Size to Test		Largest Permitted	Largest Permitted	Largest Permitted	Largest Permitted
USCAR-2 5.1	General	1	1	1	1
USCAR-2 5.1.8	Visual Inspection	2,7	2,7	2,7	2,7
USCAR-2 5.1.7	Connector Cycling	3	3	3	3
USCAR-2 5.4.6	Vibration/Shock	5 ⁽²⁾			
USCAR-2 5.6.1	Thermal Shock		5		
USCAR-2 5.6.2	Temp./Humidity Cycling			5	
USCAR-2 5.6.3	High Temp. Exposure				5
Divide Group: 4.2 (on 5 pcs.) 4.5 (on 2 pcs.)	Perform either: - RL - Shielding Performance	4,6 ⁽³⁾	4,6 ⁽³⁾	4,6 ⁽³⁾	4,6 ⁽³⁾

NOTES:

⁽¹⁾ Test structure mirrors the USCAR-2 test paths M, N, O, and P. Apply environmental conditioning to samples along with the USCAR-2 groups being aged for best use of environmental chambers.

⁽²⁾ Vibration step does not have fixtures shaken; only DUT goes on the vibration plate.

⁽³⁾ Test samples to be divided with five samples prepped and tested for return loss and two samples prepped and tested for shielding performance. Apply applicable measurement (return loss or S performance) to the prepared sample.

3.2 Equipment List

In addition to the equipment listed in USCAR-2 and the other normative references, a 10 GHz network analyzer is required that is S-Parameter capable and time domain capable. Applicable de-embedding software is also required.

4. TEST PROCEDURES

4.1 Required Tests

1. Prepare and test as directed per [Table 1](#). [Table 1](#) tests specify the applicable USCAR-2 (low voltage connector) tests. Note that some USCAR-2 tests were updated in Revision 8 to accommodate coax testing so be sure to use the latest version.
2. Prepare and test as directed in [Table 2](#). [Table 2](#) specifies test requirements native to USCAR-49 (except the environmental tests).
3. Prepare and test as directed in [Table 3](#). [Table 3](#) specifies environmental test requirements native to USCAR-49. Note that [Table 3](#) was separated from [Table 2](#) to make it clear which samples go in the environmental chamber.

4.2 Return Loss and Insertion Loss

4.2.1 Purpose

Return loss measures the mismatch loss between the connector and the cable at the frequencies of interest. This test is designed to be used for both single vendor and multi-vendor mated pair test samples, using de-embedding.

4.2.2 Sample Preparation

In-Line Connector Sample Preparation:

1. Prepare one FIX-FIX as shown in [Figure 3A](#). The cable length for the FIX-FIX structure is $470 \text{ mm} \pm 10 \text{ mm}$. See NOTE 4.2.3.E for cable length details. Make sample using equipment intended for serial production. Do not hand-build.
2. Prepare the number of FIX-DUT-FIX samples as required in the test sequence chart shown in [Figure 3B](#). The two cable segments for the FIX-DUT-FIX structure are 250 mm each. See NOTE 4.2.3.E for cable length details. Note that [Figure 3C](#) is a magnification of [Figure 3A](#).

Board Mount Connector Sample Preparation:

1. Prepare one FIX-FIX1 and one FIX-FIX2 as shown in [Figure 4](#).
2. Calculate the PCB trace length of FIX-FIX1 (see [Figure 4A](#)). It is two times the trace length of the board mount connector PCB shown in [Figure 4C](#) (see NOTE 4.2.3.G for trace length details).
3. The cable length for the FIX-FIX2 is $470 \text{ mm} \pm 10 \text{ mm}$ (see [Figure 4B](#)), which is the same as FIX-FIX sample (see [Figure 2A](#)) from the in-line connector test.
4. The FIX-DUT-FIX structure for the board mount connector is shown in [Figure 4C](#).
5. The PCB trace length should be half of the trace length used in FIX-FIX1 as shown in [Figure 4A](#).
6. The cable length for the FIX-DUT-FIX structure is $250 \text{ mm} \pm 5 \text{ mm}$, identical to the female in-line test sample depicted in [Figure 3B](#). See NOTE 4.2.3.E for cable length details.

Test port adapters may be used for both the in-line and board mount connector tests, but they must meet the requirements shown in [Table 6](#). Examples of test port adapters include SMA connectors, adapters, and PCBs. Note that the same test port adapters must be reused for testing all the FIX-FIX and FIX-DUT-FIX structures.

4.2.3 Procedure

Prior to performing this procedure, determine whether the accuracy of the de-embedding tool must be confirmed per Appendix B by customer consultation.

1. Set the VNA to the parameters listed in [Table 4](#). Use de-embedding algorithm of impedance-corrected 2X-thru either internal to VNA or external using software not embedded to VNA.

Table 4 - VNA requirements

Attribute	Relation	Value
Frequency start	=	5 MHz
Frequency stop	=	10 GHz
Frequency step	=	5 MHz
Measurement bandwidth	≤	1 kHz
Port output power	≥	-10 dBm

2. Establish the FIX-FIX structures. The requirement for FIX-FIX (derived from IEEE 370 specification) is shown in [Table 5](#).

Table 5 - FIX-FIX structure requirements

Test Parameter	Requirement	Applicable Range
S_{11}, S_{22}	≤ -6 dB	$F_{start} \leq f \leq f_{limit}$
S_{21}	≥ -15 dB	$F_{start} \leq f \leq f_{limit}$
$S_{21}, \text{dB} - S_{11}, \text{dB}$	≥ 0 dB	$F_{start} \leq f \leq f_{limit}$
$\text{unwrap}(\arg(S_{21}))$	≤ -1080 degrees	@ f_{stop}

NOTE 1: (f_{limit} = maximum frequency for connector performance specification [e.g., 9 GHz])
($\text{unwrap}(\arg(S_{21}))$) requirement limits minimum PCB fixture length L_{trace} for PCB header de-embedding)

NOTE 2: The " $\text{unwrap}(\arg(S_{21}))$ " requirement limits minimum PCB fixture length L_{trace} for PCB header de-embedding.

3. Perform a SOLT or SOLR calibration of the VNA.

NOTE: SOLT and SOLR are the labelling of the Keysight VNA. In an R&S brand VNA, you can choose a TOSM calibration which is the same as SOLT.

4. Measure and save the S-parameter data set(s) as Touchstone® file(s). See NOTE 4.2.3.C for Touchstone® file details.
 - For in-line connectors, one cable FIX-FIX structure (see [Figure 2A](#)) per group of samples.
 - For board mount connectors, one PCB FIX-FIX1 structure (see [Figure 3A](#)) per group of samples.
5. Provide the FIX-FIX Touchstone® file(s) to the de-embedding software tool and perform a self-de-embedding of the FIX-FIX structure(s). Use measured file as FIX-FIX and FIX-DUT-FIX input for the tool. Compare the result with the consistency check requirements in [Table 6](#).

Table 6 - Self de-embedding consistency check requirements for 2X THRU (FIX-FIX)

Test Parameter	Requirement
S_{21}	$-0.1 \text{ dB} \leq 20 \log(S_{21}) \leq 0.1 \text{ dB}$ $-1 \text{ degree} \leq \arg(S_{21}) \leq 1 \text{ degree}$

6. Measure the samples and save the S-parameters as Touchstone® files.
7. Provide the Touchstone® files of the sample measurements and the FIX-FIX file(s) to the de-embedding software tool and perform the de-embedding. For board mount connectors, the de-embedding typically is a two-step process, removing one fixture side per step while skipping the other side.

NOTES 4.2.3.A thru 4.2.3.G for conducting the S-parameter assessment:

- NOTE 4.2.3.A. Always protect the test port adapters during environmental exposure with a mating connector or plug.
- NOTE 4.2.3.B. Make the sample length per [Figures 2, 3, and 4](#). Ensure that all the samples are within ± 5 mm of these nominal values.
- NOTE 4.2.3.C. Multiple Touchstone® file formats exist. It's advisable to save the measurement data in a format that corresponds to the de-embedding software tool used (otherwise, the measurement data must be converted). In USCAR-49, the generic name "Touchstone® file" is used to describe all formats. At the time of publication, most instruments/CAD tools use the Touchstone® 1.1 format (file extension sNp where N is the number of VNA ports used for measurement) listed in the reference section.
- NOTE 4.2.3.D. Document the software tool used for de-embedding, including its version, and the settings.
- NOTE 4.2.3.E. Measure the cable length within the cable geometry that is unaffected by the termination, e.g., by possible cable squeezing in the crimp zones or other mechanical support such as sealings and cable ties. This is typically the cable distance between the cable-crimp ferrules. See [Figure 1](#) for measurement details.

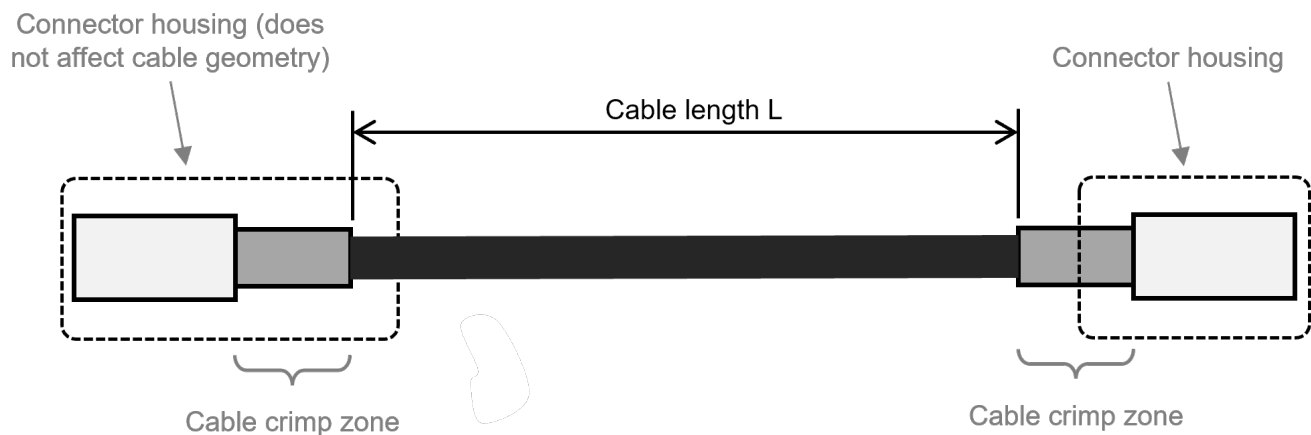


Figure 1 - Measurement location for length on a sample connector

- NOTE 4.2.3.F. Maximize symmetry and similarity of the test fixtures used for the measurements by following these guides as much as possible. Compliance minimizes errors from the de-embedding process.
 - Take PCBs and board mount connectors for the two fixtures from the same batches.
 - Use reproducible soldering processes.
 - Take cables used in FIX-FIX and FIX-DUT-FIX structures from one batch.

- Minimize cable bending.
- When applying environmental conditions (heat, cold, and humidity but not vibration) to the fixtures used in the FIX-DUT-FIX measurement, apply the same conditions to the fixtures used in the FIX-FIX measurement.
- NOTE 4.2.3.G. For de-embedding of board mounted connectors, include the complete PCB footprint of the connector in the DUT. Make reference plane that separates FIX and DUT a minimum of 10 mm to any discontinuity (via, matching element, etc.). The PCB trace length - L_{trace} - is defined up to the reference plane shown in [Figure 2](#).

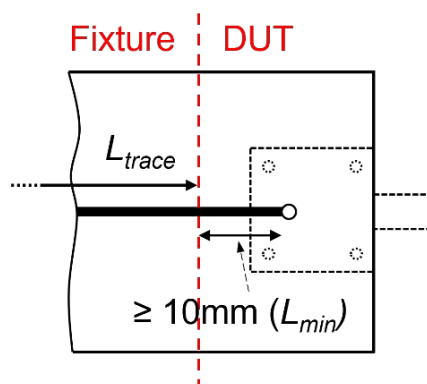


Figure 2 - Structure for de-embedding board-mount connectors

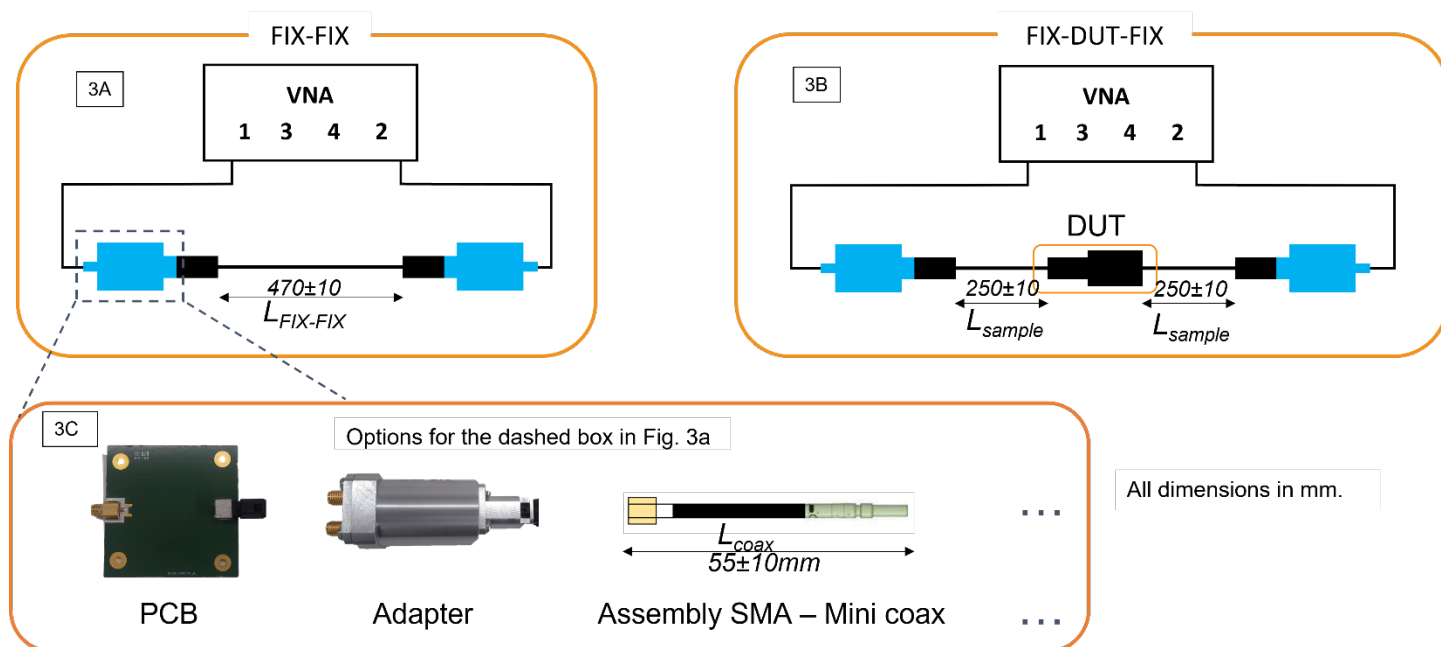


Figure 3 - Structure for de-embedding in-line connectors

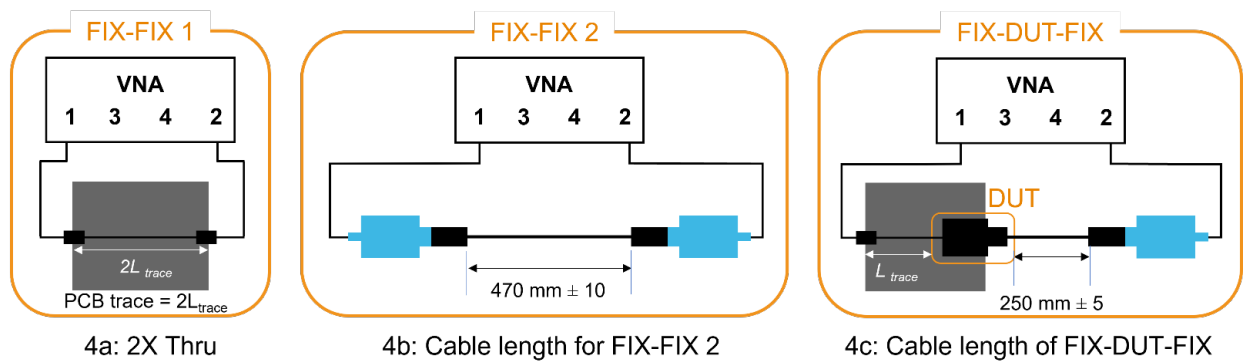


Figure 4 - RF de-embedding configuration for PCB headers

4.2.4 Requirements

Return loss of the mated connector pair after de-embedding shall satisfy [Table 7](#). There is no requirement for IL. Appendix E lists considerations for setting customer-specific IL limits.

Table 7 - Return loss requirement

Frequency, GHz	Return Loss
$0.01 < f \leq 2$	$\leq -17.5 \text{ dB}$
$2 < f \leq 6$	$\leq -14 \text{ dB}$
$6 < f \leq 7$	$\leq -12 \text{ dB}$
$7 < f \leq 9$	$\leq -10 \text{ dB}$

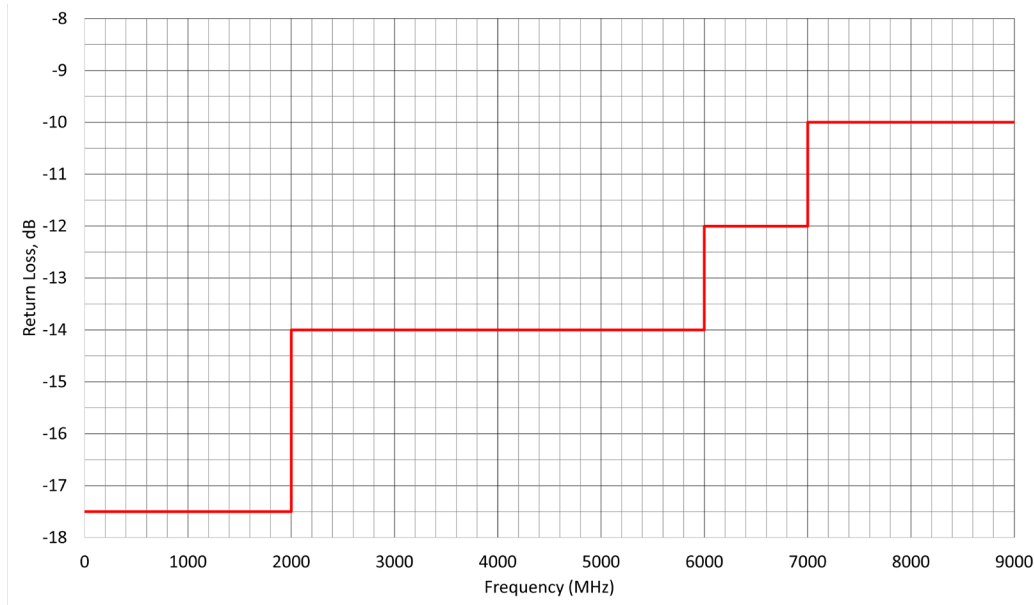


Figure 5 - Return loss requirement as graphic