PCB design Support for Coaxial connector

Oct 2015

Hirose Electric Co., Ltd.
Outline

• Introduction
• Mechanical performance
• Products
• Specifications
• Electrical performance
• PCB design considerations
• Appendix
Introduction

◆ **Purpose**
Excellent performance connector for test port with screw mount up to 50GHz. Realizes good electrical performance with stub-less structure and easy assembly with screw mount. This design guide provides the information of product performance and PCB design in order to obtain full performance of the connectors.

◆ **Scope**
Show the simulation and measurement results using 2.4mm, 2.92mm vertical mount RF connector.

◆ **Application and Interpretation**
This connector allows high density test port layout due to its vertical mount feature, which also provides flexible pattern design.
Excellent high frequency performance is achieved with stub-less design and stable assembly.

**Mechanical performance**

**Reliability**

![Diagram of mechanical reliability](image)

- Compliant pin design

![Diagram of compliant pin design](image)

- Soldering:
  - Soldered center conductor could cause signal reflection by stub.
- Screw mount:
  - Center conductor with butt connection reduces signal reflection.

**Parameters**

- Dimensions: 9.55, 1.7, 10, 7.16, 5.8
- Part number: 2x0-80UNF-2B
Mechanical performance

◆ Accepts various PCB thickness
While through hole dip mount type does not accept various PCB thickness, screw compression mount type allows various PCB thickness with one specific connector type.

Flexible PCB thickness!!

NOTE: Accepts Min. 1.6 mm thickness PCB.

◆ Washers to attach by screws

Washer

0-80UNF-2A

Locking structure !!

Screw mount streamlines assembly process.
Note
1. Please use gold plating on GND pad and signal pad.
Products

Performance of a 2.4mm and 2.92mm connector thru measurements to be shown.

2.4mm
Range: 0 to 50GHz
(H2.4-R-SR2)

2.92mm
Range: 0 to 40GHz
(HK-R-SR2-1)
# Specifications

## Material & Finish

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>MATERIAL</th>
<th>FINISH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>Steel stainless</td>
<td>Passivation</td>
</tr>
<tr>
<td>Center Conductor</td>
<td>Beryllium copper</td>
<td>Gold plated</td>
</tr>
<tr>
<td>Insulator</td>
<td>PTFE resin</td>
<td>-</td>
</tr>
</tbody>
</table>

## Electrical Performance

<table>
<thead>
<tr>
<th></th>
<th>H2.4-R-SR2</th>
<th>HK-R-SR2-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact Resistance</td>
<td>4 mΩ max. (Center and Outer) at 100 mA DC</td>
<td>4 mΩ max. (Center and Outer) at 100 mA DC</td>
</tr>
<tr>
<td>Withstanding Voltage</td>
<td>500 V AC for 1 minute</td>
<td>500 V AC for 1 minute</td>
</tr>
<tr>
<td>Insulation Resistance</td>
<td>5000 MΩ min. at 500 V DC</td>
<td>1000 MΩ min. at 500 V DC</td>
</tr>
<tr>
<td>Durability</td>
<td>500 cycles</td>
<td>500 cycles</td>
</tr>
<tr>
<td>Characteristic Impedance</td>
<td>50 Ω</td>
<td>50 Ω</td>
</tr>
<tr>
<td>V.S.W.R.</td>
<td>1.35 Max. [DC to 26.5 GHz]</td>
<td>1.35 Max. [DC to 26.5 GHz]</td>
</tr>
<tr>
<td></td>
<td>1.40 Max. [26.5 GHz to 40 GHz]</td>
<td>1.40 Max. [26.5 GHz to 40 GHz]</td>
</tr>
<tr>
<td></td>
<td>1.45 Max. [40 GHz to 50 GHz]</td>
<td>1.45 Max. [40 GHz to 50 GHz]</td>
</tr>
</tbody>
</table>
Electrical performance

- Electrical performance of back-to-back connection
- PCB stackup/foot print/routing layer
- Electrical performance on PCB

PNA set up
4 port Agilent 5227A PNA
Ecal : Agilent N4694-60003
Frequency range : 25MHz – 50GHz / 2000 points
IF band : 300Hz
Electrical performance of back-to-back (HK)

- **Measurement method of back-to-back**

![Diagram of measurement setup]

- **Graphs showing performance comparison**

![Graphs with Frequency (GHz) and S parameters (dB)]

![Graphs with Frequency (GHz) and SWSR]
Electrical performance of back-to-back (H2.4)

◆ Measurement method by back-to-back

![Block Diagram]

![Graphs]

- PORT 1
- Vector Network Analyzer
- PORT 2

APC2.4 (m) - H2.4 - R - SR2+ H2.4 - R - SR2 - APC2.4 (m)

D.U.T.
PCB stackup/foot print/routing layer

Evaluation PCB

SMT land for coaxial connector

PCB stackup

Top
- 43micron (Copper foil + Plating)
- 100micron (Megtron 6 R5775K #3313)
- 70micron (Megtron 6 R5670 #1080)
- 18micron (Copper foil)
- 200micron (Megtron 6 R5775K #3313)
- 18micron (Copper foil)
- 70micron (Megtron 6 R5670 #1080)
- 18micron (Copper foil)
- 43micron (Copper foil + Plating)

2nd
- 18micron (Copper foil)
- 200micron (Megtron 6 R5775K #3313)

3rd
- 18micron (Copper foil)
- 70micron (Megtron 6 R5670 #1080)

4th
- 18micron (Copper foil)
- 200micron (Megtron 6 R5775K #3313)

Bottom

Routing layer

25mm [984mils]
Performance (HK)
Performance (H2.4)
PCB design considerations

- Optimized GND via locations for 50GHz
- Tapered trace and diving board design
- Via stub impact
- Consideration of copper wicking
- Stitching via space recommendation for CPWG
- Stitching via separation recommendation for CPWG
- Substrate thickness between 2 GND planes
- Antipad optimization (thick PCB)
- Antipad optimization (thin PCB)
- The effect of glass weave style
- Surface roughness of copper foil
- Measurement vs. simulation correlation
Tapered trace and diving board design

◆ Tapering signal pad to trace and pushing out GND, referred to as “diving board” design, achieves better impedance matching in the anti pad area and improves insertion loss and return loss beyond 35GHz.

**Drill diameter**
- Signal: 0.25mm [10mils]
- Ground: inner ring 0.25mm [10mils] / outer ring 0.3mm [12mils]

Megtron 6 (Dk : 3.6, Df : 0.004)

2.4 mm coaxial connector

5.1mm[200 mil] strip line

Tapered pad to trace transition & Diving board structure
For inner layer routing, via stub length shall be minimized to be less than 1.3mm [5 mils] for 50GHz. 0.5mm [20 mil] via stub will cause non-linear effects on insertion loss and return loss.

**Via stub impact**

**Drill diameter**
- Signal: 0.25mm [10mils]
- Ground: inner ring 0.25mm [10mils]
- outer ring 0.3mm [12mils]

2.4 mm coaxial connector

27.4mm [1080 mil] strip line

Megtron 6 (Dk : 3.6, Df : 0.004)

**Leftover via stub**

\[ L < \frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}} \]

- \( L \): Via stub length
- \( \lambda_0 \): Wave length of electromagnetic wave in free space.
- \( \varepsilon_{eff} \): Effective dielectric constant.
When substrate is drilled, damaged glass fibers and separation in the glass fibers to the resin leave holes. Because of migration of copper salt into the glass fibers of insulation material, these holes will be filled with copper during the electro-plating process. It will cause a discrepancy between design and actual PCB. To compensate for copper wicking, 5% to 10% of diameter is added to diameter of signal via model.

Damaged glass fibers

Via anode side (+)  Via cathode side (-)

Drill size

Tiny clearance

Cross section of via

Wicking example
Stitching via space recommendation for CPWG

- For CPWG structures, stitching ground vias with 0.5mm [20 mil] space on both sides of the CPWG micro-strip trace are required to prevent the grounds on both sides from resonating.

**Drill diameter**
- Signal: 0.25mm [10mils]
- Ground: inner ring 0.25mm [10mils]
  / outer ring 0.3mm [12mils]

2.4 mm coaxial connector

27.4mm [1080 mil] strip line

Megtron 6 (Dk : 3.6, Df : 0.004)

Stitching ground vias

\[ s < \frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}} \]

- \( s \) : Via space
- \( \lambda_0 \) : Wave length of electromagnetic wave in free space.
- \( \varepsilon_{eff} \) : Effective dielectric constant.

Measurement
Stitching via separation recommendation for CPWG

- The via separation should be a minimum of 3 strip widths. When vias are placed too close to edge of trace, they affect impedance. At the same time, if the via separation is too large, unwanted propagation modes can be excited, which affect performance.

Drill diameter
Signal: 0.25mm [10mils]
Ground: inner ring 0.25mm [10mils]
/outer ring 0.3mm [12mils]

1.17mm [46 mils] / 2.17mm [85 mils]

\[ d > 3w \]
\[ d < \frac{\lambda_0}{2\sqrt{\varepsilon_{eff}}} \]

- \( d \): Via separation
- \( w \): Trace width
- \( \lambda_0 \): Wave length of electromagnetic wave in free space.
- \( \varepsilon_{eff} \): Effective dielectric constant.
Substrate thickness between 2 GND planes

If substrate thickness is too large, unwanted spurious wave propagation can occur. It can interfere with the desired wave on the circuit.

$t < \frac{\lambda_0}{2\sqrt{\varepsilon_{eff}}}$

$t$ : Substrate thickness
$w$ : Trace width
$\lambda_0$ : Wave length of electromagnetic wave in free space.
$\varepsilon_{eff}$ : Effective dielectric constant.
### Anti-pad optimization (thick PCB)

**Antipad size is optimized at every layer by considering dielectric layer thickness and via pad size.**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Anti-pad dia.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>1.5mm / [59 mils]</td>
</tr>
<tr>
<td>2</td>
<td>1.5mm / [59 mils]</td>
</tr>
<tr>
<td>Layer 3-24</td>
<td>0.94mm / [37 mils]</td>
</tr>
<tr>
<td>Layer 25</td>
<td>1mm / [40 mils]</td>
</tr>
<tr>
<td>Bottom</td>
<td>Microstrip line out</td>
</tr>
</tbody>
</table>

**PCB stackup**

*2.4 mm coaxial connector*

Megtron 6 (Dk : 3.6, Df : 0.004)
Anti-pad optimization (thin PCB)

- Antipad size is optimized at every layer by considering dielectric layer thickness and via pad size.

**PCB stackup**

**Layer**

- **Top**
  - 1.7mil (Copper foil + Plating)
  - 4mil (Megtron 6 #3313)
  - 2.76mil (Megtron 6 #1080)
  - 0.6mil (Copper foil)
  - 7.87mil (Megtron 6 #3313)

- **2nd**
  - 0.6mil (Copper foil)
  - 2.76mil (Megtron 6 #1080)

- **3rd**
  - 0.6mil (Copper foil)

- **4th**
  - 18mil (Copper foil)

- **Bottom Routing layer**
  - 7.87mil (Megtron 6 #3313)
  - 1.7mil (Copper foil + Plating)

**Anti-pad dia.**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Anti-pad dia.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>1.54mm/ [60.6mils]</td>
</tr>
<tr>
<td>2</td>
<td>1.15mm/ [45.3mils]</td>
</tr>
<tr>
<td>3</td>
<td>0.97mm/ [38.2mils]</td>
</tr>
<tr>
<td>4</td>
<td>1.09mm/ [42.9mils]</td>
</tr>
<tr>
<td>Bottom</td>
<td>1.02mm/ [40.2mils]</td>
</tr>
</tbody>
</table>

**2.4 mm coaxial connector**

Megtron 6 (Dk : 3.6, Df : 0.004)
The effect of Glass Weave style

- Uneven glass cloth causes a large impedance variation and skew due to unevenness of dielectric constant.
  To use flat type glass cloth or to route trace tilting 10 to 20 degrees against glass weave orientation brings more stable performance.
## Typical glass weave styles

<table>
<thead>
<tr>
<th>Style</th>
<th>Fabric Count Warp x Fill (Per cm)</th>
<th>Yarn (SI)</th>
<th>Thickness (mm) (Reference Only)</th>
<th>Nominal Weight (g/m²)</th>
<th>Weight Tolerance (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>29.5 x 29.5</td>
<td>5 2.75 1x0 5 2.75 1x0</td>
<td>0.024</td>
<td>16.3</td>
<td>15.2 - 17.3 1</td>
</tr>
<tr>
<td>104</td>
<td>23.6 x 20.5</td>
<td>5 5.5 1x0 5 2.75 1x0</td>
<td>0.028</td>
<td>18.6</td>
<td>18.0 - 19.3 1</td>
</tr>
<tr>
<td>106</td>
<td>22.0 x 22.0</td>
<td>5 5.5 1x0 5 5.5 1x0</td>
<td>0.033</td>
<td>24.4</td>
<td>23.4 - 25.4 1</td>
</tr>
<tr>
<td>1078</td>
<td>21.3 x 21.3</td>
<td>5 11 1x0 5 11 1x0</td>
<td>0.043</td>
<td>47.8</td>
<td>46.8 - 49.2 1</td>
</tr>
<tr>
<td>1080</td>
<td>23.6 x 18.5</td>
<td>5 11 1x0 5 11 1x0</td>
<td>0.053</td>
<td>46.8</td>
<td>45.1 - 48.5 1</td>
</tr>
<tr>
<td>1081</td>
<td>27.6 x 23.6</td>
<td>5 11 1x0 5 11 1x0</td>
<td>0.06</td>
<td>58.3</td>
<td>56.4 - 60.6 1</td>
</tr>
<tr>
<td>11280</td>
<td>23.6 x 23.6</td>
<td>5 11 1x0 5 11 1x0</td>
<td>0.056</td>
<td>52.9</td>
<td>51.5 - 54.2 1</td>
</tr>
<tr>
<td>1500</td>
<td>19.3 x 16.5</td>
<td>7 45 1x0 7 45 1x0</td>
<td>0.149</td>
<td>164.1</td>
<td>157.7 - 170.5 1</td>
</tr>
<tr>
<td>1501</td>
<td>18.1 x 17.7</td>
<td>7 45 1x0 7 45 1x0</td>
<td>0.14</td>
<td>165</td>
<td>158.0 - 171.0 1</td>
</tr>
<tr>
<td>1504</td>
<td>23.6 x 19.7</td>
<td>6 33 1x0 6 33 1x0</td>
<td>0.125</td>
<td>148</td>
<td>142.8 - 153.2 1</td>
</tr>
<tr>
<td>1651</td>
<td>20.0 x 10.8</td>
<td>9 33 1x0 9 74 1x0</td>
<td>0.135</td>
<td>146.2</td>
<td>142.1 - 150.3 1</td>
</tr>
<tr>
<td>1652</td>
<td>20.5 x 20.5</td>
<td>9 34 1x0 9 34 1x0</td>
<td>0.114</td>
<td>138.3</td>
<td>133.6 - 143.1 1</td>
</tr>
<tr>
<td>1674</td>
<td>15.7 x 12.6</td>
<td>9 34 1x0 9 34 1x0</td>
<td>0.097</td>
<td>96.6</td>
<td>92.9 - 100.4 1</td>
</tr>
<tr>
<td>1675</td>
<td>15.7 x 12.6</td>
<td>6 33 1x0 6 33 1x0</td>
<td>0.101</td>
<td>96.3</td>
<td>92.6 - 100.0 1</td>
</tr>
<tr>
<td>1678</td>
<td>15.7 x 15.7</td>
<td>9 34 1x0 9 34 1x0</td>
<td>0.091</td>
<td>103.5</td>
<td>102.7 - 111.6 1</td>
</tr>
<tr>
<td>2113</td>
<td>23.6 x 22.0</td>
<td>7 22 1x0 7 22 1x0</td>
<td>0.079</td>
<td>78</td>
<td>75.6 - 80.4 1</td>
</tr>
<tr>
<td>2114</td>
<td>22.0 x 18.9</td>
<td>7 22 1x0 7 22 1x0</td>
<td>0.084</td>
<td>90.9</td>
<td>88.5 - 93.2 1</td>
</tr>
<tr>
<td>2116</td>
<td>23.6 x 22.8</td>
<td>7 22 1x0 7 22 1x0</td>
<td>0.094</td>
<td>103.8</td>
<td>100.7 - 106.8 1</td>
</tr>
<tr>
<td>2117</td>
<td>26.0 x 21.7</td>
<td>7 22 1x0 7 22 1x0</td>
<td>0.095</td>
<td>108</td>
<td>104.8 - 111.2 1</td>
</tr>
<tr>
<td>2125</td>
<td>15.7 x 15.4</td>
<td>7 22 1x0 9 34 1x0</td>
<td>0.091</td>
<td>87.5</td>
<td>82.7 - 90.9 1</td>
</tr>
<tr>
<td>2157</td>
<td>23.6 x 13.8</td>
<td>7 22 1x0 9 68 1x0</td>
<td>0.13</td>
<td>148</td>
<td>144.0 - 152.0 1</td>
</tr>
<tr>
<td>2165</td>
<td>23.6 x 20.5</td>
<td>7 22 1x0 9 34 1x0</td>
<td>0.101</td>
<td>122.4</td>
<td>116.3 - 126.1 1</td>
</tr>
<tr>
<td>2166</td>
<td>23.6 x 15.0</td>
<td>7 22 1x0 9 68 1x0</td>
<td>0.14</td>
<td>155</td>
<td>150.0 - 160.0 1</td>
</tr>
<tr>
<td>2313</td>
<td>23.6 x 25.2</td>
<td>7 22 1x0 5 11 1x0</td>
<td>0.084</td>
<td>81.4</td>
<td>79.0 - 83.7 1</td>
</tr>
<tr>
<td>3070</td>
<td>27.6 x 27.6</td>
<td>6 16.5 1x0 6 16.5 1x0</td>
<td>0.078</td>
<td>93.6</td>
<td>90.9 - 96.3 1</td>
</tr>
<tr>
<td>3080</td>
<td>20.0 x 12.0</td>
<td>6 16.5 1x0 6 16.5 1x0</td>
<td>0.059</td>
<td>53.4</td>
<td>51.5 - 55.3 1</td>
</tr>
<tr>
<td>3313</td>
<td>23.6 x 24.4</td>
<td>6 16.5 1x0 6 16.5 1x0</td>
<td>0.084</td>
<td>81.4</td>
<td>79.0 - 83.7 1</td>
</tr>
<tr>
<td>7628</td>
<td>17.3 x 12.2</td>
<td>9 68 1x0 9 68 1x0</td>
<td>0.173</td>
<td>203.4</td>
<td>198.0 - 208.9 1</td>
</tr>
<tr>
<td>7629</td>
<td>17.3 x 13.4</td>
<td>9 68 1x0 9 68 1x0</td>
<td>0.18</td>
<td>210</td>
<td>204.5 - 215.3 1</td>
</tr>
<tr>
<td>7635</td>
<td>17.3 x 11.4</td>
<td>9 68 1x0 9 102 1x0</td>
<td>0.201</td>
<td>232.3</td>
<td>226.5 - 238.0 1</td>
</tr>
<tr>
<td>7642</td>
<td>17.3 x 7.9 (texturized)</td>
<td>9 68 1x0 9 136 1x0</td>
<td>0.254</td>
<td>227.8</td>
<td>221.1 - 234.7 1</td>
</tr>
</tbody>
</table>

※Quotation from IPC-4412

<table>
<thead>
<tr>
<th></th>
<th>Good flat type is available</th>
<th>Flat type is available</th>
</tr>
</thead>
<tbody>
<tr>
<td>515x41</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Surface roughness of copper foil

- At high frequencies, rough copper foil will cause large attenuation. Choosing smoother copper foil will provide improved quality on high frequency transmission line. However, smoother copper foil has less peel strength between substrate and copper. So, it is important to choose suitable copper foil by balancing mechanical issue and electrical issue.

- **Standard foil**
  - **ED**: Electrodeposited
  - **HTE**: High Tensile Elongation

- **Low profile**
  - **RTF**: Reverse Treated Foil
  - **VLP**: Very Low Profile

- **Very low profile**
  - **e-VPL**: Extra Very Low Profile
  - **H-VLP**: Hyper Very Low Profile

<table>
<thead>
<tr>
<th>Copper foil type</th>
<th>Peel strength</th>
<th>Stable impedance</th>
<th>Attenuation</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard foil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low profile</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very low profile</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

>10 microns

5 - 10 microns

<5 microns
A PTH to bottom micro-strip transition structure was examined.

Drill diameter
Signal: 10mils
Ground: 10mils

Signal pad diameter
Inner layer: 18mils
Outer layer: 20mils

2.4mm coaxial connector

Test sample  Simulation model
Appendix

- Cutoff frequency
- 2.4mm, 2.92mm comparison
- Conversion of VSWR to Return loss
Connector species have their own frequency limitation, which is determined by cutoff frequency. When frequency exceeds cutoff frequency, unwanted propagation mode (TE mode) will excite. This mode will degrade loss and VSWR.

\[
f_c = \frac{c}{\pi \sqrt{\varepsilon_r} \frac{D + d}{2}}
\]

- \(f_c\): Cutoff frequency
- \(\varepsilon_r\): Dielectric constant
- \(D\): Outer diameter
- \(d\): Inner diameter
- \(c\): Light speed

### Table: Connector species & Frequency Limit

<table>
<thead>
<tr>
<th>Connector species</th>
<th>Calculated cutoff frequency [GHz]</th>
<th>Frequency limit [GHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5mm</td>
<td>38.0</td>
<td>26.5</td>
</tr>
<tr>
<td>2.92mm</td>
<td>45.6</td>
<td>40</td>
</tr>
<tr>
<td>2.4mm</td>
<td>55.4</td>
<td>50</td>
</tr>
<tr>
<td>1.85mm</td>
<td>71.9</td>
<td>60</td>
</tr>
<tr>
<td>1mm</td>
<td>133</td>
<td>110</td>
</tr>
</tbody>
</table>

Representative connector species & frequency limit
2.4mm, 2.92mm comparison

Back to back measurement

Degradation due to unwanted mode

Degradation due to unwanted mode
# Conversion of VSWR and Return loss

## VSWR to Return loss

<table>
<thead>
<tr>
<th>VSWR</th>
<th>Return loss [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>1.05</td>
<td>-32.26</td>
</tr>
<tr>
<td>1.1</td>
<td>-26.44</td>
</tr>
<tr>
<td>1.2</td>
<td>-20.83</td>
</tr>
<tr>
<td>1.3</td>
<td>-17.69</td>
</tr>
<tr>
<td>1.4</td>
<td>-15.56</td>
</tr>
<tr>
<td>1.5</td>
<td>-13.98</td>
</tr>
<tr>
<td>1.6</td>
<td>-12.74</td>
</tr>
<tr>
<td>1.7</td>
<td>-11.73</td>
</tr>
<tr>
<td>1.8</td>
<td>-10.88</td>
</tr>
<tr>
<td>1.9</td>
<td>-10.16</td>
</tr>
<tr>
<td>2</td>
<td>-9.54</td>
</tr>
<tr>
<td>2.5</td>
<td>-7.36</td>
</tr>
<tr>
<td>3</td>
<td>-6.02</td>
</tr>
<tr>
<td>3.5</td>
<td>-5.11</td>
</tr>
<tr>
<td>4</td>
<td>-4.44</td>
</tr>
<tr>
<td>4.5</td>
<td>-3.93</td>
</tr>
<tr>
<td>5</td>
<td>-3.52</td>
</tr>
</tbody>
</table>

## Return loss to VSWR

\[
\text{VSWR} = \frac{1}{\frac{1}{\text{Return loss}^{20} + 1}} - 1
\]

\[
\text{Return loss} = -20 \log_{10} \left( \frac{VSWR + 1}{VSWR - 1} \right) \text{ [dB]}
\]