AKL-PT2 6 GHz Passive Probe Operator Manual

Antikernel Labs

April 1, 2021

Contents

1 Overview

1.1 Manufacturer

Antikernel Labs
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https://www.antikernel.net/
sales@antikernel.net

1.2 Warranty

Antikernel Labs warrants this probe to meet published specifications during ordinary laboratory use and operation for a period of one (1) year from date of shipment and will repair or replace, at its sole option, any defective product. This warranty covers manufacturing and assembly defects only. Damage caused by negligence, misuse, accident, alterations, or exceeding published operating limits is specifically not covered. The solder terminals at the probe tip are consumable and are expected to degrade over time from repeated soldering and desoldering; damage from ordinary wear and tear is not covered.

Antikernel Labs's maximum liability under this warranty is limited to the replacement value of the probe. Antikernel Labs will not be liable for any direct, indirect, special, exemplary, or consequential damages (including, but not limited to, procurement of substitute goods or services, loss of use, data, or profits; or business interruption) arising in any way out of the use of this probe, even if advised of the possibility of such damage.

1.3 Open Hardware

The most up-to-date design files for this probe may be found on GitHub under the 3-clause BSD license, including:

- KiCAD schematic
- KiCAD board layout
- Fabrication notes including stackup and impedance
- Sonnet field solver models

The current location of design files as of this writing is: `https://www.github.com/azonenberg/starshipraider/`.

1.4 Testing Note

All AKL-PT2 probes (unless sold under student/hobbyist discount pricing) are soldered to a test fixture during the manufacturing process using lead-free SAC305 solder in order to verify that they meet all published specifications. Excess solder and flux is removed prior to shipment, however a small amount of tinning residue remaining on the castellations is normal.

1.5 Sponsors

Development and prototyping of this probe was made possible by support from Symbiotic EDA.

Symbiotic EDA

1.5.1 Disclaimer

Antikernel Labs has terminated its relationship with Symbiotic EDA. The above acknowledgement is required by contract to remain in the manual and on all probes manufactured prior to April 2023 and should not be construed in any way to imply endorsement of Symbiotic EDA by Antikernel Labs.

2 Safety Information

To avoid personal injury, damage to the probe, or damage to the attached instrument, it is important to understand and follow the warnings and specification limits in this document.

- Only personnel familiar with the safe use and operation of electronic test equipment should use this probe.
- Do not connect the ground terminal of this probe to any voltage other than earth ground.
- Do not exceed operating limits in the specifications section of this document.
- Do not over-tighten the SMA connector. Antikernel Labs recommends using a properly calibrated torque wrench to torque the connection to 5 lbf-in (0.57 Nm) while holding the connector body across the flats with a wrench. Do not apply torque without securely holding the connector body.
- The coverlay on this probe is *not* rated for insulation against hazardous voltages, and conductive elements are exposed at the tip and connector. Do not use this probe on any circuits which may contain voltages exceeding 30 Vrms, or the touch-safe voltage limit in your organization's standard operating procedures if this is lower.
- Do not operate in damp or wet conditions, or under temperature/humidity extremes in which condensation is likely.
- Do not operate this probe in a flammable or explosive atmosphere.
- Wear eye protection and ensure good ventilation when soldering.
- The SMA connector center terminal is made from beryllium copper (BeCu) alloy. While exposure to beryllium is expected to be insignificant during ordinary use of this product as the BeCu is in solid form and covered by gold plating, hazardous dust could potentially be generated if the contact material is ground or abraded.

  CA PROP 65 WARNING: This product can expose you to beryllium, which is known to the State of California to cause cancer.

3 Theory of Operation

Tha AKL-PT2 probe is a *transmission line probe* and works very differently from high-impedance passive or active probes many engineers are familiar with. It is intended primarily for probing relatively low impedance (50Ω range), high bandwidth digital signals, which ordinarily require expensive active probes to properly examine.

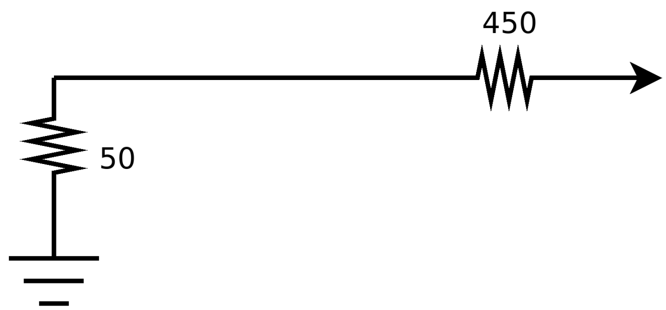

Figure 1: Simplified probe schematic

The signal is split off from the DUT at the point of contact and travels through the probe castellations, then passes through a precision resistor array. This array is a series string of several resistors of different values summing to 450 Ω, carefully selected to cancel out frequency-dependent effects from L/C parasitics and ensure maximal flatness across the operating frequency range.

The signal then travels on 50 Ω transmission line through a low-loss coplanar waveguide, SMA connector, and coaxial cable to the oscilloscope, which terminates the signal with 50 Ω to ground. The tip resistor and termination form a 10:1 voltage divider, so the oscilloscope sees the incident signal attenuated by a factor of 10 (-20 dB). *Note that a 50 Ω termination at the instrument is required. This probe cannot be used with lower-cost oscilloscopes that only have 1M Ω terminations.*

The tip resistor and scope-side termination in series present a total loading of 500 Ω on the DUT. While this is a significantly lower DC impedance than conventional probes, the resistive input stage has extremely flat frequency characteristics with much less capacitance than conventional passive probes. This means that the impedance of the probe remains comparatively constant across the entire operating range, rather than greatly decreasing at higher frequencies.

4 Usage Instructions

Proper soldering and desoldering technique is crucial to getting the best performance and lifetime from your probe.

4.1 Probe Coupling

Transmission line probes such as the AKL-PT2 have significantly higher DC loading than a standard $10M\Omega$ passive probe, and may interact poorly with pull-up/pull-down resistors or level shifters with automatic direction sensing. Consider AC coupling (using an industry standard SMA inner DC block between the probe and coaxial cable), or use of a different type of probe for these applications.

4.2 Test Point Design

The probe tip is designed to mate with a signal and ground contact on the DUT at 1.0 mm spacing. The suggested test point layout is shown in Fig. 2. A 1.0 mm long aperture as shown in the diagram is preferable if space permits, but this may be reduced to 0.5 mm in space-constrained applications. The diagonal trace shows one potential layout of the signal approaching the test point; arbitrary routing above or below the soldermask aperture is acceptable as long as the trace is straight within the aperture.

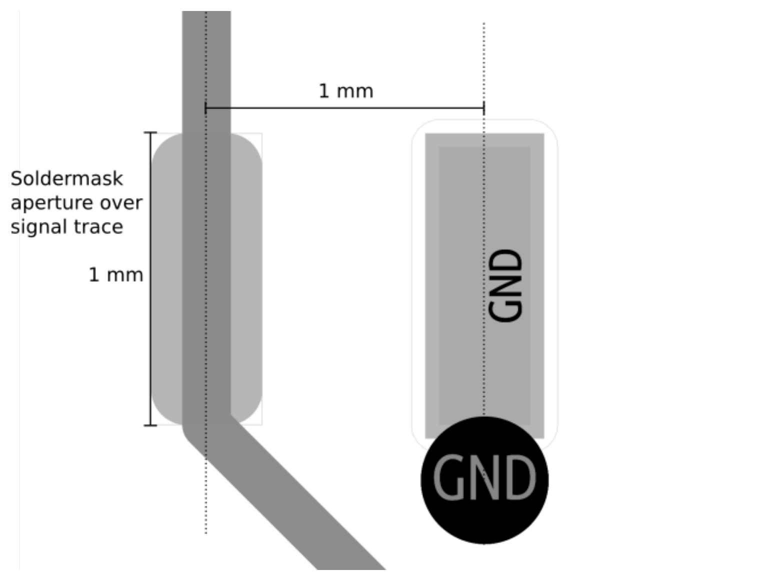

Figure 2: Suggested test point layout (probe entering from bottom)

Avoid placing test points in confined spaces between components or in other difficult-to-reach locations. The tip of the probe is nominally 3.0 mm wide so at least 1.5 mm of clearance to either side of the signal/ground contacts is required for the tip to fit while providing room for tolerances of PCB edge routing. Additional space beyond this will likely be needed for effective soldering.

Consider the relative orientation of the signal and ground contacts on the probe when designing test points. If the probe is oriented with the SMA at the left and the tip at the right, the upper contact is signal and the lower is ground.

4.3 Placing and Securing

The tip castellations are fragile and can be easily damaged by applying even a small amount of force to the solder joint. When working with any solder-in probe, it is critical to provide a firm mechanical attachment *before* soldering the tip. Securing a probe operating at microwave frequencies, such as the AKL-PT2, requires additional care to avoid degrading the performance of the system.

Antikernel Labs recommends use of removable double-sided tape, such as Scotch® part number MMMR103B tape squares or 3M Command® strips, to secure the probe from the underside. Thick foam/gel tape such as these is preferable to conventional double-sided tapes based on thin plastic films, since increasing the spacing from probe to DUT reduces capacitive coupling between surface conductors on the DUT and the ground plane on the underside of the probe. An example of a properly secured probe is shown in Fig. 3.

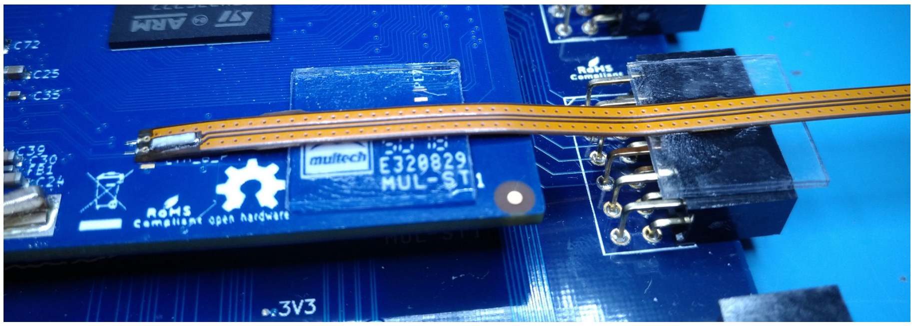

Figure 3: AKL-PT2 probe secured to DUT with double-sided adhesive squares

Securing the probe from the bottom side avoids placing any dielectric material over the signal trace, which could cause the impedance of the probe to shift. If the probe must be secured from the top side, use narrow strips of thin Kapton® tape to minimize the amount of dielectric added over the signal trace.

To minimize coupling between the probe's ground plane and the DUT, avoid running the probe directly over signal traces when possible. The tip area is unshielded directly under the resistors and is especially sensitive to EMI. Good results can often be obtained by securing the probe to the top of an IC package, heatsink, or connector shield, then bending the end of the probe downward so the castellation contacts the test point at an angle (minimizing the portion of the probe's length in close proximity to the surface of the DUT). The probe includes a polyimide stiffener under the resistors and epoxy staking on the top side of the board to reduce the risk of cracking the solder joints, however deliberate flexing of the probe under or close to the resistors may still cause damage and should be avoided.

The SMA cable attached to the probe should also be secured to prevent applying excessive force to the probe body. Any method providing adequate mechanical support may be used; an example setup using polyimide tape is shown in Fig. 4.

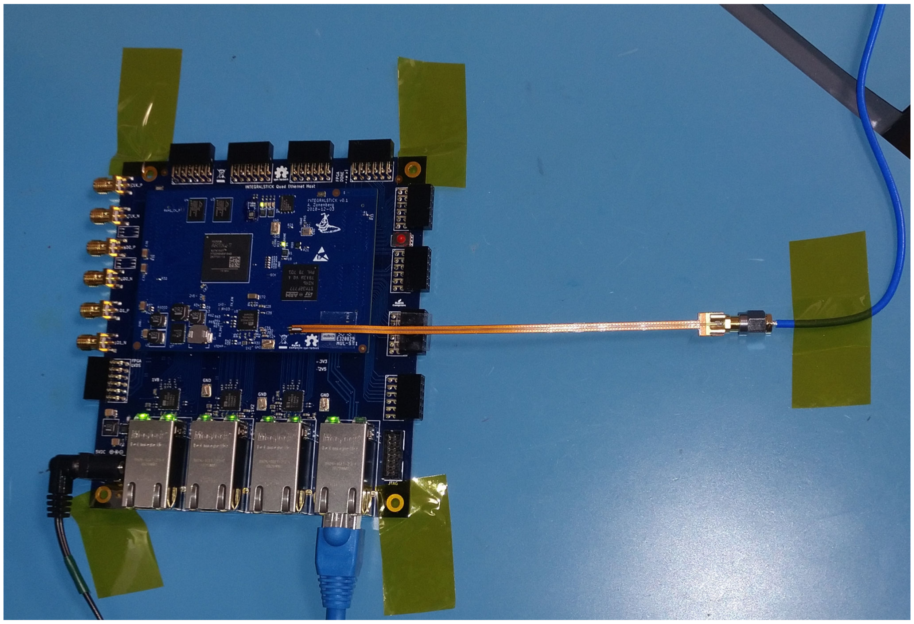

Figure 4: Securing cable and DUT to lab bench with polyimide tape

4.4 Soldering

Secure the probe body firmly to the DUT, then apply a small amount of flux to the test points. Using a fine point iron and thin solder wire, solder the signal and ground contacts. Work quickly to avoid overheating the castellations, which can cause them to delaminate.

For best accuracy and lowest loading, remove flux from the probe tip area after soldering.

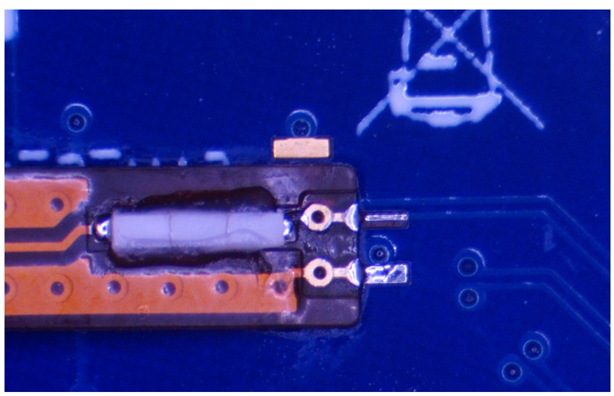

Figure 5: AKL-PT2 tip soldered to test point

4.5 Extending the Leads

If a pre-designed test point is not available, either the signal or ground contact may be extended to fit the board by means of a short length of 30 AWG (0.255 mm) round copper wire, or flat copper foil wires such as the Circuit Tracks sold by CircuitMedic® .

For best performance and lowest loading it is crucial to minimize the length of the stub between the test point and the signal contact; soldering the signal castellation directly to a trace or component lead (as shown in Fig. 6) is ideal. While excessively long ground leads will degrade performance as well, the probe is far more tolerant of long ground leads than long signal leads. When extending the ground lead, short and wide wires are preferable to minimize inductance.

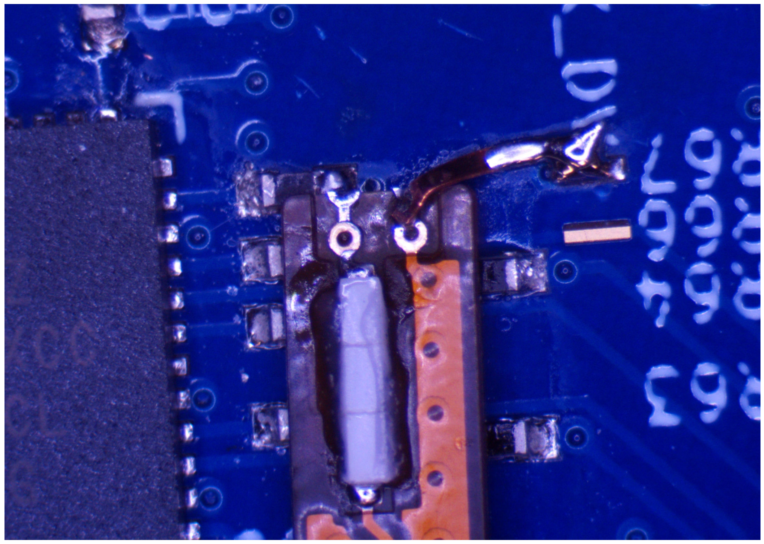

Figure 6: Extending the ground lead with 0.381 mm (15 mil) flat copper wire

If extending the signal or ground contact is necessary, place the wire horizontally on top of the probe tip and solder it to the exposed contacts, then bend the wire as needed and solder to the test point.

4.6 Desoldering

Use an iron and desoldering braid to remove as much solder from the tip and ground contacts as possible. If the probe tip does not come free at this point, gently heating with a hot air rework station may be necessary to melt residual solder on the bottom-side contacts. Once solder on both terminals is visibly melted, gently lift the tip of the probe away from the board with tweezers and let it cool before removing the tape securing the probe body to the DUT.

If the probe tip was bent into position during the soldering process, be aware that it may be under spring tension and rapidly stretch back to its natural shape when the solder melts. Use tweezers to support the tip during desoldering to minimize the chances of sudden tip motion. Allowing the tip to spring away from the board may damage the castellations if the solder is not fully melted, or fling droplets of molten solder into the air and pose a risk of operator injury.

4.7 Maintenance, Cleaning, and Storage

To avoid attracting dust or corroding the tip contacts, when the probe is being stored it is best to remove flux residue from the tip area. This may be done with isopropyl alcohol and a lint-free swab, or any other industry-standard flux remover suitable for the flux in question.

The SMA connector on the probe is gaged before shipment to ensure the pin and dielectric position are within tolerance, however it is good practice to gage the connector periodically to detect any gradual misalignments.

No other maintenance is normally required.

As with any other bare PCB, the probe should be stored flat and protected from mechanical damage.

4.8 Cables

The AKL-PT2 must be connected to the host instrument via a 50Ω coaxial cable rated for at least 7 GHz operation. Antikernel Labs recommends use of Mini-Circuits FL086 series flexible cable, 086 series hand-formable cable, or equivalents.

The cable should be taped to a lab bench or the DUT as shown in Fig. 4, or otherwise secured to prevent transferring any force into the probe. While hand-formable cables have greatly limited bend lifetime compared to flexible cables, their lack of springiness can be helpful when attaching to solder-in probes since there is no tendency for the cable to return to a neutral shape and exert force on the probe.

The probe-side connector is a brass SMA (Amphenol RF 901-10511-3). For best results, this connection should be torqued to 5 in-lbf (0.57 Nm). Over-tightening may damage the connector. When torquing the connector, hold the connector body across the flats with a wrench. Do not hold the probe by the PCB as this can put stress on the solder joints or flex circuitry.

5 Mechanical Specifications

Description	Typ	Units
Mass	2.09	g
Thickness (flex PCB)	0.3	mm
Length (PCB)	150.5	mm
Length (total)	160.3	mm
Width (tip area)	3.0	mm
Width (connector area)	8.0	mm

6 Electrical Specifications

Values in this section are typical / limit values. For measured values from a specific probe, please consult your calibration certificate.

6.1 Absolute Maximum Ratings

Exceeding these limits may result in permanent damage to the probe. Ratings in this section are stress ratings only and normal operation at these limits is not implied.

Parameter	Description	Limit	Units
T_{amin}	Minimum temperature	0	$°C$
T_{amax}	Maximum temperature	95	$°C$
I_{max}	Maximum sustained current	15.8	mA
V_{maxT}	Maximum sustained tip voltage	7.9	$Vrms$
V_{maxV}	Maximum instantaneous tip voltage	50.0	$Vrms$

ENGINEERING NOTE: The sustained current/voltage limits are thermally limited and based on the 50 mW power rating of the 200Ω tip resistors. Brief pulses or low duty cycle waveforms whose average power does not exceed these limits *may* be possible to probe safely with the AKL-PT2 as long as tip voltage does not exceed the instantaneous voltage limit at any time, however Antikernel Labs has not performed any testing of the probe under pulsed load conditions. Use of the probe with instantaneous power levels exceeding the thermal limits will void the warranty and customer assumes all risk of harm to personnel and equipment resulting from such usage.

6.2 Recommended Operating Conditions

While the probe will not be damaged by exposure to conditions outside the values in this section (but below the "Absolute Maximum Ratings" limits), tolerances may be temporarily exceeded.

Parameter	Description	Limit	Units
T_{min}	Minimum temperature	15	°C
T_{max}	Maximum temperature	45	°C

6.3 DC Characteristics

Parameter	Description	Min	Typ	Max	Units
G_{dc}	Gain across high-Z load*		0.1		V/V
R_{gnd}	Resistance from SMA shell to tip ground	0.15	0.35	0.55	Ω
R_{sig}	Resistance from SMA pin to tip contact	450.20	450.39	450.60	Ω
TCR	Temperature coefficient of resistance			±25	ppm / °C

* The tip resistors have ±0.1% accuracy which is significantly better than typical 50Ω instrument terminations. DC gain accuracy in actual use is largely dependent on tolerance of the termination at the oscilloscope, which is typically ±2%.

6.4 AC Characteristics

Data in this section is based on characterization in a 50Ω environment, with cable and fixture effects de-embedded, unless otherwise stated.

Parameter	**Description**	**Min**	**Typ**	**Max**	**Units**
S_{11o_low}	S_{11} across open circuit from DC - 4 GHz	-1.85	-1.75	-1.40	dB
S_{11o}	S_{11} across open circuit from DC - 6 GHz	-2.60	-1.75	-1.40	dB
S_{11_low}	S_{11} from DC - 4 GHz	-33.00	-22.00	-14.00	dB
S_{11_hi}	S_{11} from 4 - 6 GHz	-20.00	-11.00	-8.75	dB
S_{21}	S_{21} from DC - 6 GHz	-23.50	-21.95	-20.00	dB
S_{21_100}	S_{21} at 0.1 GHz	-20.50	-20.45	-20.40	dB
S_{21_500}	S_{21} at 0.5 GHz	-21.00	-20.85	-20.70	dB
S_{21_1000}	S_{21} at 1.0 GHz	-21.20	-21.00	-20.80	dB
S_{21_3000}	S_{21} at 3.0 GHz	-22.20	-21.95	-21.70	dB
S_{21_6000}	S_{21} at 6.0 GHz	-23.50	-23.10	-22.60	dB
BW	-3 dB bandwidth	6.00	6.50		GHz
$Rise_{90}$	Rise time (10-90 %)		99	101	ps
$Rise_{80}$	Rise time (20-80 %)		47	51	ps
Tpd	Propagation delay		925		ps

7 Performance Graphs

7.1 Insertion Loss

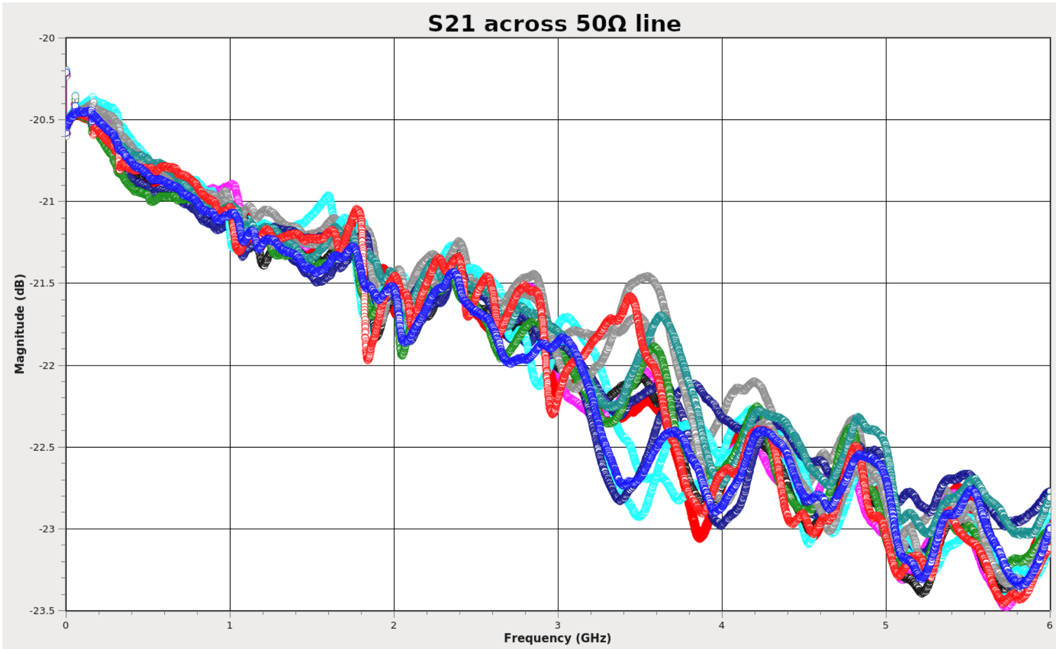

Figure 7: S_{21} range of probes across 50Ω termination

7.2 Group Delay

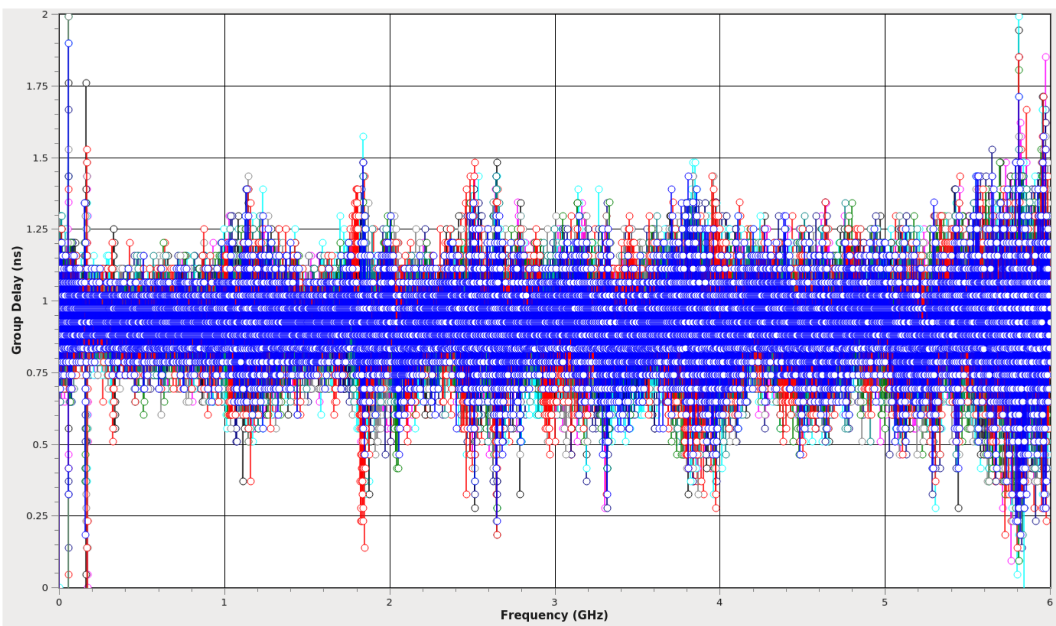

Figure 8: Group delay variation of probes

7.3 Return Loss

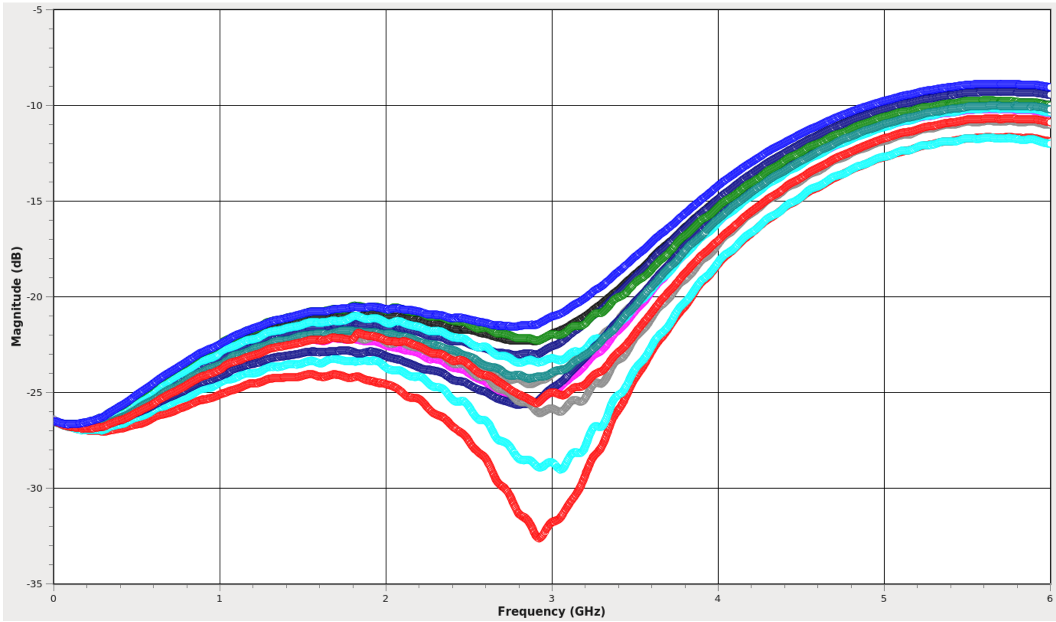

Figure 9: Variation in S_{11} of probes across 50Ω load

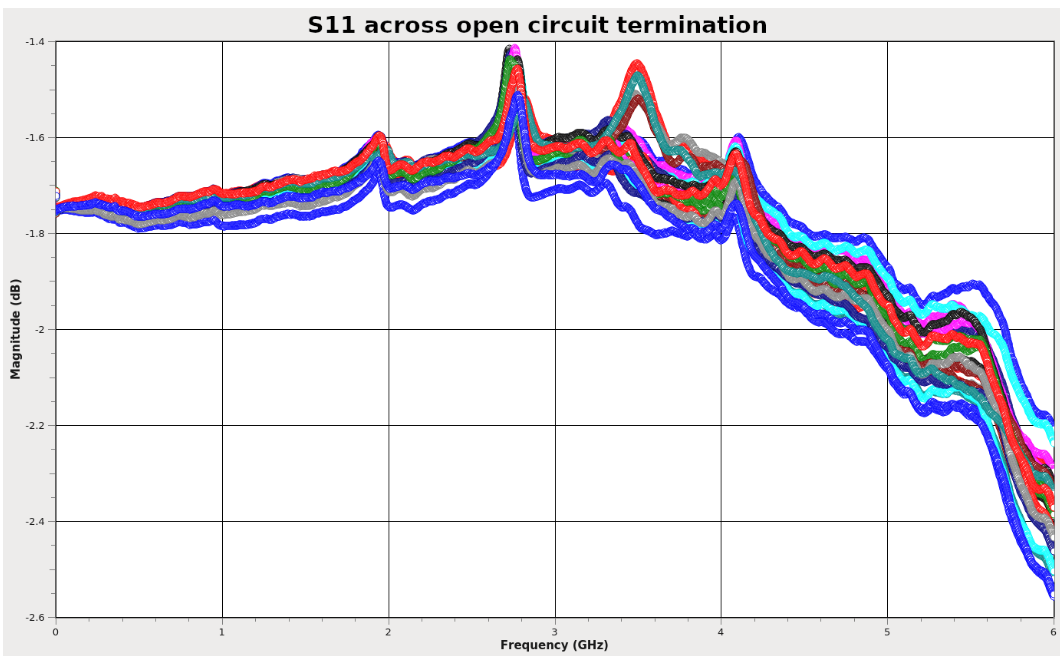

Figure 10: Variation in S_{11} of probes across open circuit

7.4 Step Response

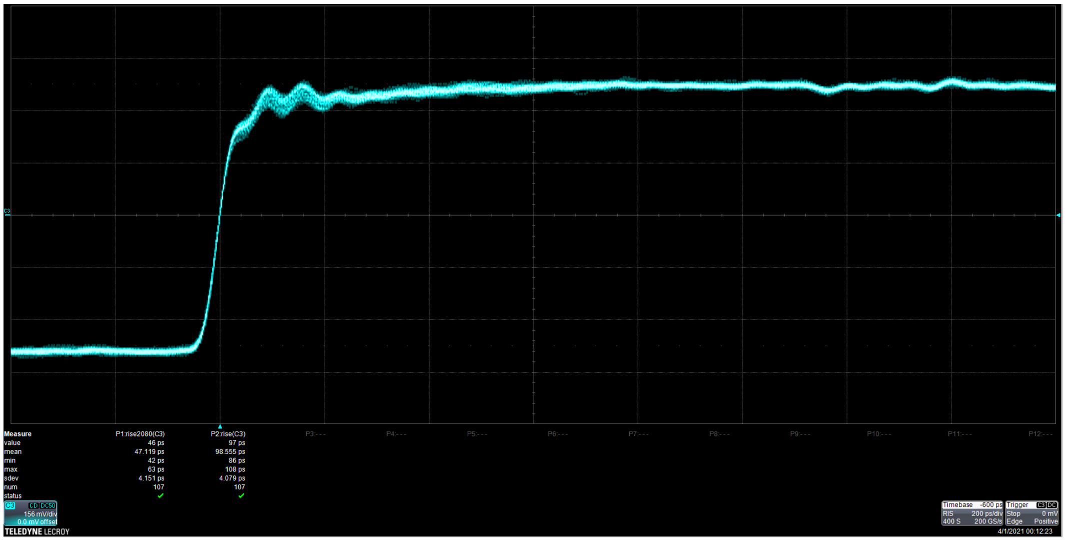

Figure 11: Typical response of AKL-PT2 to fast rising edge (200ps/div)

8 Performance Data

If you requested full characterization at the time of your order, test measurements are available at https://www.antikernel.net/downloads/AKL-PT2/caldata/ and searching for your probe's serial number. All measurements are de-embedded to the SMA connector or probe tip, as applicable.

The following S-parameter data files are provided:

- probe.s2p - probe soldered across 50Ω load
- zin.s1p - probe soldered across an unterminated line for input loading/impedance measurements

Touchstone port 1 is connected to the DUT side of the probe and port 2 (if applicable) is connected to the instrument side.