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Adaptive RF Pigtail Probe Modeling for De-embedding of RF Measurements

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Adaptive RF Pigtail Probe Modeling for De-embedding of RF Measurements

ABSTRACT

This disclosure describes techniques for accurate estimation and de-embedding of the effects of pigtail probes in circuits. An adaptive pigtail model is developed and described that can accurately de-embed the effects of pigtail probes in digital circuits. Example parameters are identified that include pigtail length, tip length, pigtail tilt degree, ground distance, and solder amount. A pigtail simulation model is developed to model the soldered pigtail probe. The dependency of circuit impedance on the identified parameters is determined by experimentation which indicates that circuit performance can be boosted by short ground distance lengths, low tilt angles, thick support wires, short pin and cable lengths, and thick support wires. The pigtail model can be utilized to derive de-embedded results for different pigtail probe configurations without a need for explicitly measuring de-embedded results for those configurations.

KEYWORDS

- De-embedding
- High frequency circuit
- Smith chart
- Radio Frequency (RF) trace
- Trace Impedance
- RF probe
- Vector Network Analyzer (VNA)
- Coaxial connector
- SubMiniature version A (SMA) connector

BACKGROUND

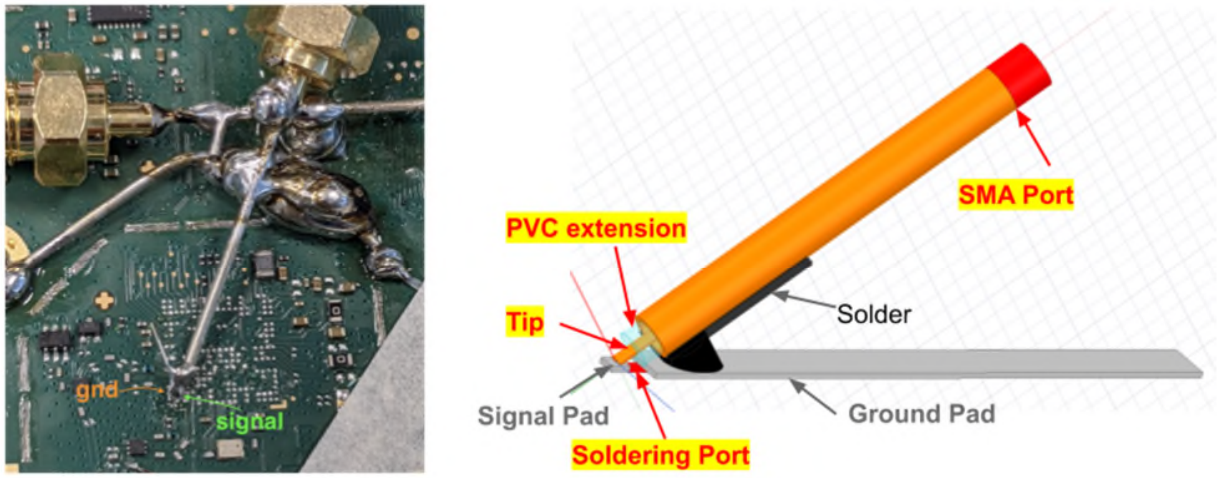
Proper operation of high speed digital circuits within printed circuit boards (PCB) depends on accurate impedance matching. For efficient signal transfer, a target characteristic impedance is usually specified, e.g., 50 Ω. The target characteristic impedance is sought to be realized at key points in the circuit, such as component connections, transmission line junctions, terminators, etc.

A prerequisite to matching and tuning a PCB is the determination of an impedance of the traces. Circuits that do not include a standard connector mounted on the board pose challenges for the measurement of radio frequency (RF) parameters. For such circuits, RF pigtail probes (semi-rigid cables) are commonly soldered onto the board to enable measurement of RF parameters. However, accurate measurement of trace impedance requires compensation (de-embedding) of the effects introduced by the RF pigtail probe.

Port extension techniques can be utilized to de-embed the effects of pigtails, which entail shifting a measurement reference plane by the addition of an electrical delay in the circuit. A vector network analyzer (VNA) is typically utilized in performing the port extension techniques. However, traditional port extension methods by utilizing a VNA can only be performed for calibration of an open circuit version and neglects the effect of soldered pigtails on the PCB. The error from traditional port extension methods is particularly magnified in PCBs that include high frequency circuits.

DESCRIPTION

This disclosure describes techniques for the accurate estimation and de-embedding of the effects of pigtail probes in circuits. An adaptive pigtail model is developed and described that can accurately de-embed the effects of pigtail probes in digital circuits. Per techniques of this disclosure, a pigtail probe is modeled based on different parameters that characterize the pigtail probe attachment to a circuit. The model includes consideration of parameters that are excluded in conventional port extension methods.



(a) (b)

Fig. 1: Pigtail probe attached to a printed circuit board (PCB)

Fig. 1 depicts an example pigtail probe attached to a circuit. As depicted in Fig. 1(a), a pigtail probe is soldered onto a PCB. A ground (gnd) and signal connections are labeled. Fig. 1(b) is a schematic representation of the pigtail probe connected to the PCB. The pigtail probe includes an SubMiniature version A (SMA) port, a tip, and a PVC extension, and is connected using a soldered joint to a signal pad. A ground pad on the PCB is also depicted. This setup is typically utilized during impedance matching of a PCB while optimizing its design for proper circuit function.

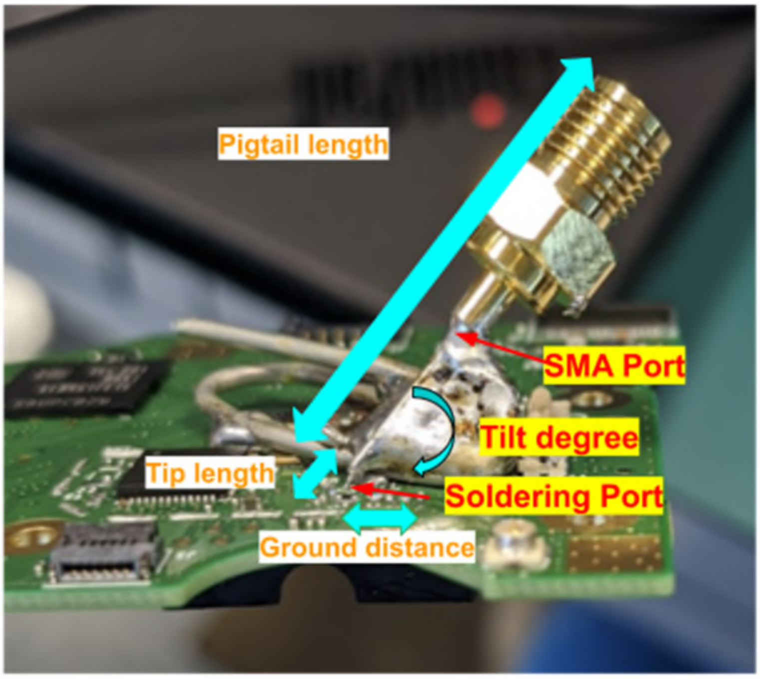


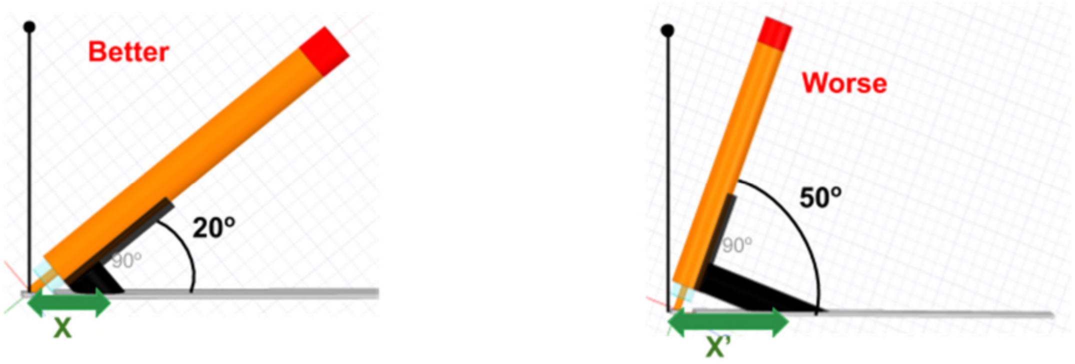
Fig. 2: Pigtail probe components and parameters

Fig. 2 depicts some example parameters utilized in characterization and modeling of the pigtail probe connection, per techniques of this disclosure. Example parameters that are considered include pigtail length, tip length, pigtail tilt degree, ground distance, and solder amount. Based on the identified parameters, a pigtail simulation model is developed that models the soldered pigtail probe.

Experiments are conducted based on different configurations of pigtail probes to validate the measurements against simulations using the model at different operating frequencies, and to determine optimal configurations. A determination of optimality is made based on comparison of a measured trace impedance with a predetermined target impedance, e.g., 50 Ω. Parameters of the pigtail probe connector are adjusted to identify dominant parameters.

Ground path

(a)

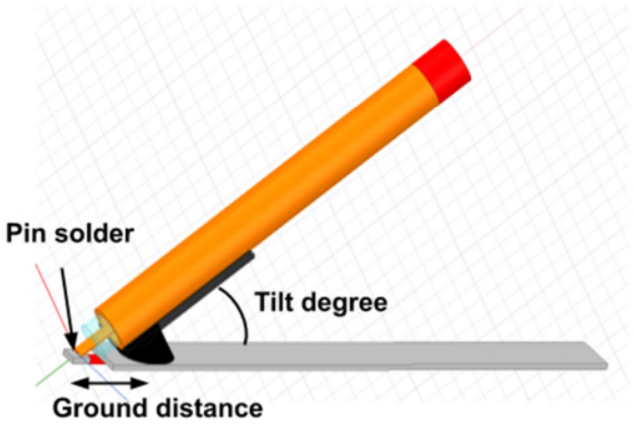


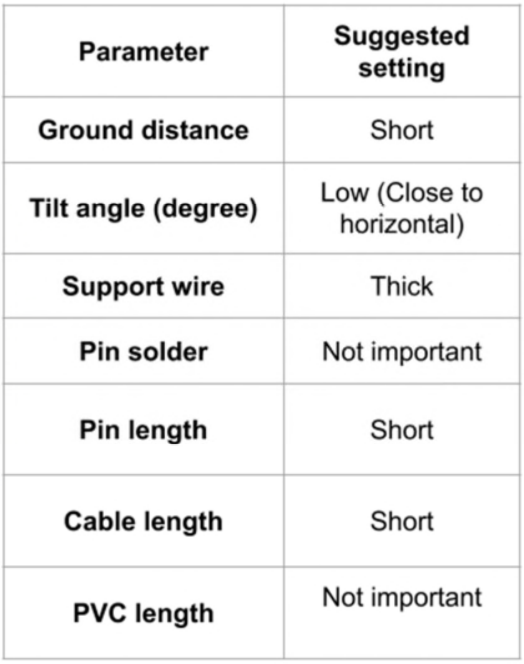
Pigtail tilt degree

(b)

Fig. 3: Identification of dominant parameters for the pigtail model

Fig. 3 depicts example configurations and experiments to determine the dependency of circuit impedance on the identified parameters. For example, various ground path distances between 1.5mm and 9.5 mm are studied before a determination is made that shorter ground distances are more optimal. Similarly, different pigtail tilt degrees between 20° and 50° before it is determined that a lower pigtail tilt degree provides optimal circuit performance.





Parameter	Suggested setting
Ground distance	Short
Tilt angle (degree)	Low (Close to horizontal)
Support wire	Thick
Pin solder	Not important
Pin length	Short
Cable length	Short
PVC length	Not important

Fig. 4: Suggested configuration parameters for optimal circuit performance

Fig. 4 depicts example parameters and a suggested setting for each parameter, based on studies performed per techniques of this disclosure. While the studies indicate that circuit performance is relatively unchanged for different settings for pin solder and PVC length, the studies indicate that circuit performance can be boosted by short ground distance lengths, low tilt angles, thick support wires, short pin and cable lengths, and thick support wires. Of these parameters, ground distance length, title angle, support wire thickness, and pin solder are typically not considered and/or modeled in traditional port extension techniques.

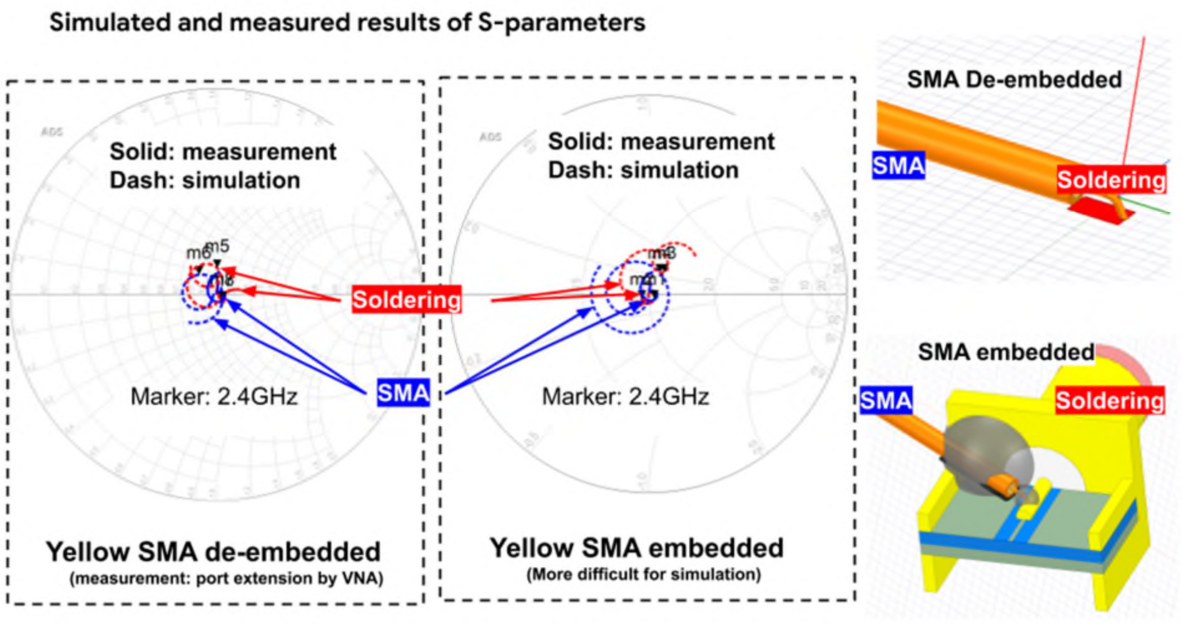
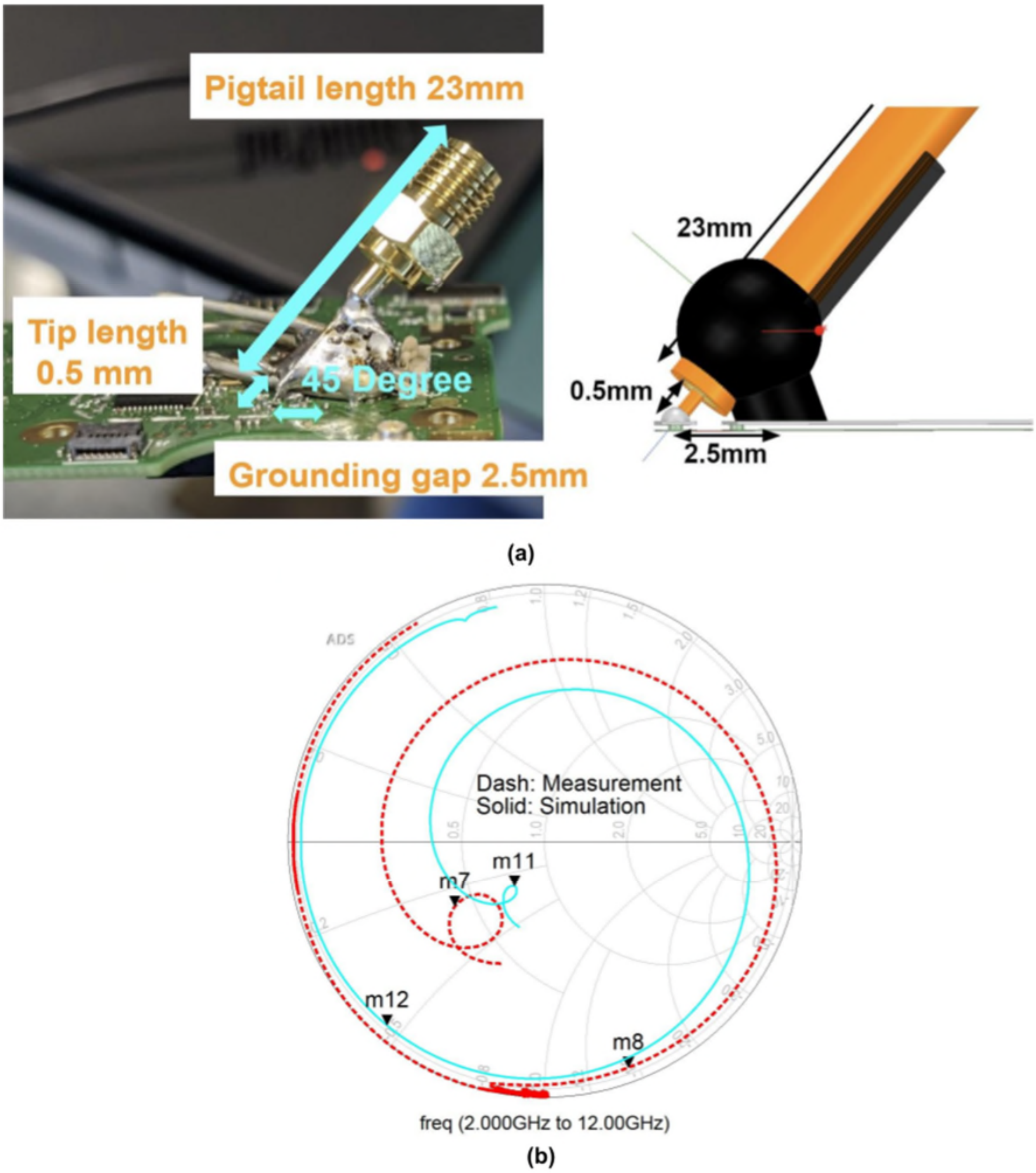


Fig. 5: Comparison of simulated and measured S-parameters

Fig. 5 depicts an example comparison of scattering parameters (S-parameters) for an embedded and de-embedded soldered SMA pigtail probe. Smith charts derived from the simulated and measured results are illustrated for corresponding de-embedded and embedded configurations. While the embedded configuration shows a larger variation between the measured and simulated results, both configurations yield a satisfactory match between the simulated and measured results.



(a)

(b)

Fig. 6: The pigtail model can be used to de-embed measured results

Fig. 6 depicts an example of use of the pigtail model to de-embed measurement results. Fig. 6(a) depicts an example pigtail probe configuration and a corresponding schematic representation for the pigtail mode. Impedance measurements are made without a pigtail port extension. The configuration parameters are used in conjunction with the pigtail model to determine de-embedded results based on simulations performed using the model. De-embedded results are also obtained via measurements.

Fig 6(b) depicts a comparison (Smith chart) of simulated and measured results that is indicative of agreement of the measured and simulated results, thereby validating use of the pigtail model to derive de-embedded results for different pigtail probe configurations without a need for explicitly measuring de-embedded results for those configurations.

CONCLUSION

This disclosure describes techniques for accurate estimation and de-embedding of the effects of pigtail probes in circuits. An adaptive pigtail model is developed and described that can accurately de-embed the effects of pigtail probes in digital circuits. Example parameters are identified that include pigtail length, tip length, pigtail tilt degree, ground distance, and solder amount. A pigtail simulation model is developed to model the soldered pigtail probe. The dependency of circuit impedance on the identified parameters is determined by experimentation which indicates that circuit performance can be boosted by short ground distance lengths, low tilt angles, thick support wires, short pin and cable lengths, and thick support wires. The pigtail model can be utilized to derive de-embedded results for different pigtail probe configurations without a need for explicitly measuring de-embedded results for those configurations.

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