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Temperature Effects in Automotive-Grade High Speed Interconnects (poster)

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Temperature Effects in Automotive-Grade High Speed Interconnects

J. Rafael del-Rey, Zabdiel Brito-Brito, José E. Rayas-Sánchez, and Nicolás Izquierdo

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0. Abstract

This work discerns the frequency response (up to 15 GHz) of several automotive-grade microstrip transmission line structures over a temperature span from −40 to 105 Celsius degrees. To ensure precise measurements, S-parameter responses from several test PCBs based on Cu over FR4 substrate are attained through a vector network analyzer in a controlled environment. Results show that temperature has a major impact on these high speed interconnects in frequencies above a few GHz, setting the need of employing accurate multi-physical models.

1. Introduction

The automotive industry is currently undergoing major and accelerated changes. Stricter government regulations, pollution constraints, more driving assistance and an increasing awareness of safety and security are driving the development of the so-called connected car [1]. Along with the potential of making lives more convenient, journeys safer, and vehicles greener [2], the automotive market is shifting towards greater connectivity.

To fulfill this trend, fully digitized automobile vehicles with 5G connectivity, advanced infotainment systems (Fig. 1.), real-time location services and advanced driver assistance systems, require powerful computing entities with state of the art interconnects. These interconnects should be able to withstand automotive temperature ranges alongside single-digit parts per million (PPM) in quality while maintaining the typical cost-effectiveness relationship required by this market.

Nevertheless, current automotive computing design is mostly based on semiconductor vendors' methods and models, typically neglecting temperature effects on interconnects. The effects of temperature performance have been studied mainly for antenna applications with Teflon based materials such as Polytetra Fluroethylene (PTFE) and Tetra Fluroethylene (TFE) as in [3], and also with Poly Vinylidene Fluoride (PVDF) materials which performance is studied in [4]. It's important to remark that Teflon based materials are not cost-effective for automotive electronics' applications.

Fig. 1. State of the art automotive driver information systems

In this paper we assess these temperature effects by considering five different FR4-based microstrip transmission lines (TLs). We built three test printed circuit boards (PCBs), intending to spot the sensibility to temperature through different microstrip geometry relationships: two TLs with same length but different widths and two TLs with same width but different lengths. These TLs are designed with a characteristic impedance of approximately 50 ohms. We also consider the Samtec Golden Standard [5] as trustworthy reference to control environment setup and calibration, and particularly useful as a test case for temperature effects on near-end and far-end crosstalk. These interconnects are shown in Fig. 2.

2. Trans. Line Structures

Transmission lines with different widths were built in the same PCB anticipating a homogeneous behavior between them. A four layer FR-408 PCB stackup (see Table I) was chosen in order to create a planar TL geometry from layers 1 to 2 and another one from layers 1 to 3. TL lengths were fixed at 1.7”. According to the PCB manufacturer, the PCB substrate has an εr of approximately 3.6 and a loss tangent of 0.0117 [6].

TABLE I
4-LAYER TEST PCB STACKUP

Layer	Thickness (mil)	Material	Tolerance (mil)
	1	Solder resist	± 0.2
1	1.4	1 oz. Cu	
	6.7	FR408 prepreg	± 0.67
2	0.7	0.5 oz. Cu	
	47	FR408 core	± 4.7
3	0.7	0.5 oz. Cu	
	6.7	FR408 prepreg	± 0.67
4	1.4	1 oz. Cu	
	1	Solder resist	± 0.2

Initial impedance matching was calculated using APLAC1. A more accurate estimation was performed with Sonnet2 using a thick metal model due to the 1 oz. outer conductor layer thickness in the PCB stackup. TL widths were calculated at 13.5 mils and 117.5 mils, respectively. Connectors used in this test PCB were Samtec part number SMA-J-P-H-ST-MT1, being chosen for its temperature range, from −65 to 125 °C, and also because of its geometry, due to the absence of via interconnects in signal path which simplifies simulation models.

Similarly, transmission lines with different lengths were implemented with separate machine milled PCBs in a standard FR4 substrate. The short trace TL is laid out with a length of 2”, while the long trace TL is defined at 6” long. Impedance match is achieved using Saturn PCB Calculator3 with an εr of 4.6 and a loss tangent of 0.018. Under those circumstances, TL width is calculated at 122 mils. Connectors used are Molex part number 0732511150, selected in order to attach the microstrips directly at connector launch and due to its temperature range, from −65 to 165 °C.

The last transmission line structure tested was the Samtec Golden Standard, which is an accurately matched 100-ohm microstrip differential pair with a length of 6”. Its geometry is described in [7] and has been thoroughly modeled in [8]. Its end launch SMA connectors are Johnson Components part number 142-0701-851 and are rated at an operating temperature of −65 to 165 °C, which makes the Samtec Golden Standard an ideal candidate for this work.

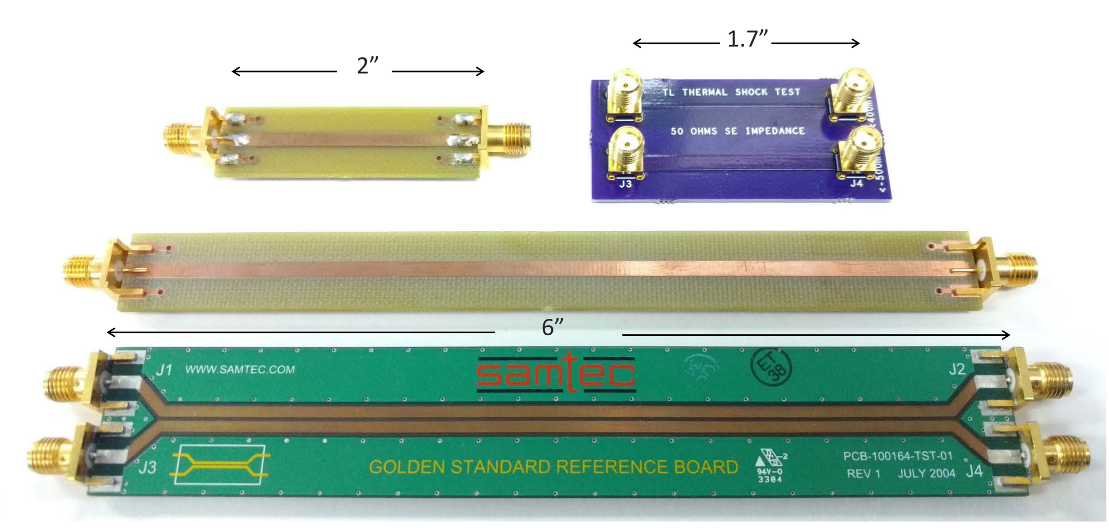

Fig. 2. Tested transmission line structures. From top to bottom and left to right: 1) 2” long FR4-STD TL; 2) 1.7” long FR408 13.5 mil and 117.5 mil width TLs; 3) 6” long FR4-STD TL; 4) Samtec Golden Standard with 6” long 100 ohm differential impedance.

3. Test Set Up

To perform the measurements, a 20 GHz Keysight E5071C vector network analyzer (VNA) was used for broadband frequency measurements from 0.5 to 15 GHz. The VNA was calibrated with a Keysight 8052B Calibration Kit, rated from 0 to 20 GHz.

Device under test (DUT) was placed inside a Thermotron Industries model S-1.5-3800 environmental test chamber and connected to the VNA through Semflex 2121-DKF-0036 3.5 mm coaxial assembly cables. These cables were chosen since they are rated up to 26 GHz and have a temperature range from −65 to 200 °C.

Even though the environmental test chamber calibration was professionally tested beforehand, a thermocouple was attached to the bottom surface of test PCBs (see Fig. 3) in order to discard any temperature mismatch. Thermocouple maximum resolution is 0.001 °C.

All VNA connections to DUT were carefully tighten at 0.90 N-m with a Keysight 8710-1765 torque wrench. Error introduced for cables' length was removed using short-open-load-thru (SOLT) calibration with the cables inside the environmental test chamber at 25 °C. To verify the behavior of test setup, a measurement in different temperatures was performed without DUT (cables only connected to themselves).

Fig. 3. DUT setup inside environment test chamber.

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Results of this measurements in Fig. 4 show that no effect is introduced by the test setup due to the temperature change, even though some behavior in S_{11} will be added to the DUT response since we are focusing in the temperature change or difference in the response and not in the final waveform.

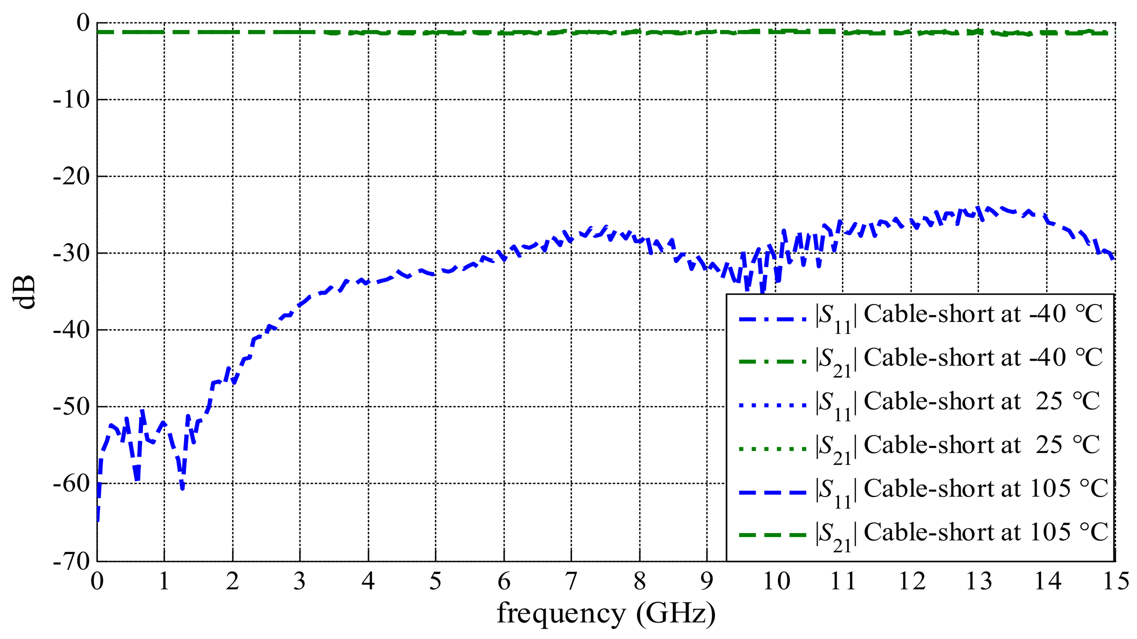

Fig. 4. Cable only test (without DUT) S-parameter responses at different temperatures.

4. Test Procedure

For guaranteeing the repeatability of the results, three different temperatures in a six step sequence was set for S-parameters capture: 25 °C, 105 °C, −40 °C, 25 °C, −40_°C, 105 °C. To eliminate any uncertainty in the measurements, each temperature was measured twice and with a tolerance < 0.1 °C. Additionally, the test sequence was applied uninterruptedly to each DUT PCB in order to maintain homogeneous humidity and atmospheric pressure conditions

TABLE II
MAX CHANGE IN S-PARAMETERS (0.5 to 15 GHz)
FROM −40 TO 105 °C

DUT	$\lvert S_{11}\rvert$ (dB)	$\lvert S_{21}\rvert$ (dB)
Thin TL	8.81	4.37
Thick TL	7.25	4.66
Short (2”) TL	19.08	5.87
Long (6”) TL	13.56	8.39
Samtec Golden Standard (SE)	22.39	40.19

5. Results

Besides S-parameters, impedance was measured with the TDR functionality of E5071C VNA. The thin TL impedance measured 58 ohms while the thick TL impedance measured 43 ohms. This mismatch from ideally calculated impedance resulted from the broad tolerances given by PCB manufacturer and the connectors effects.

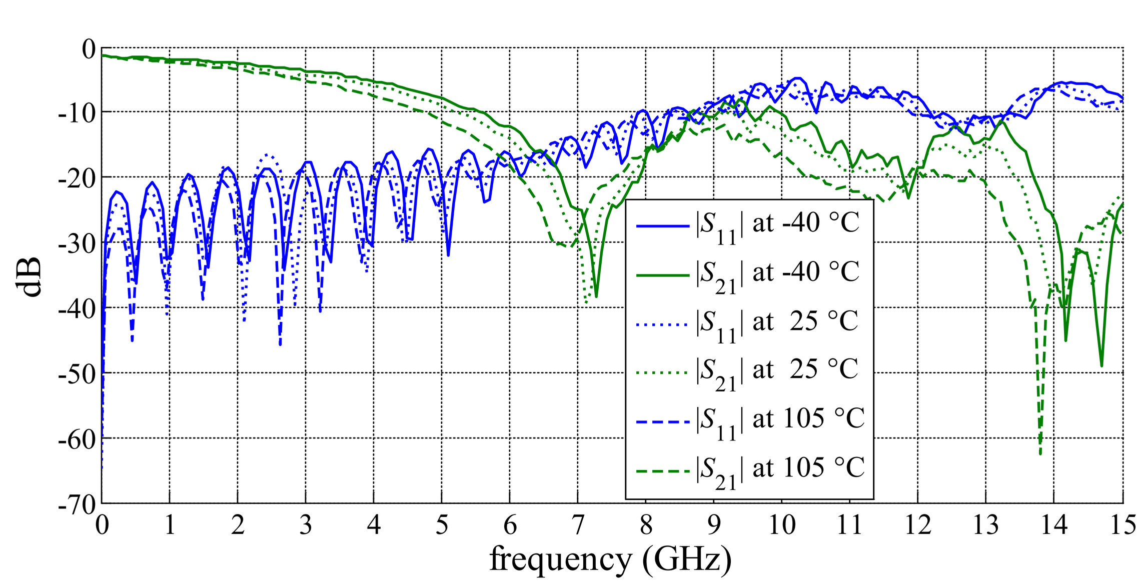

Fig. 5. Samtec Golden Standard S-parameter responses at different temperatures.

The short and long TLs resulted both at 50.2 ohms, since they were built in the same process.

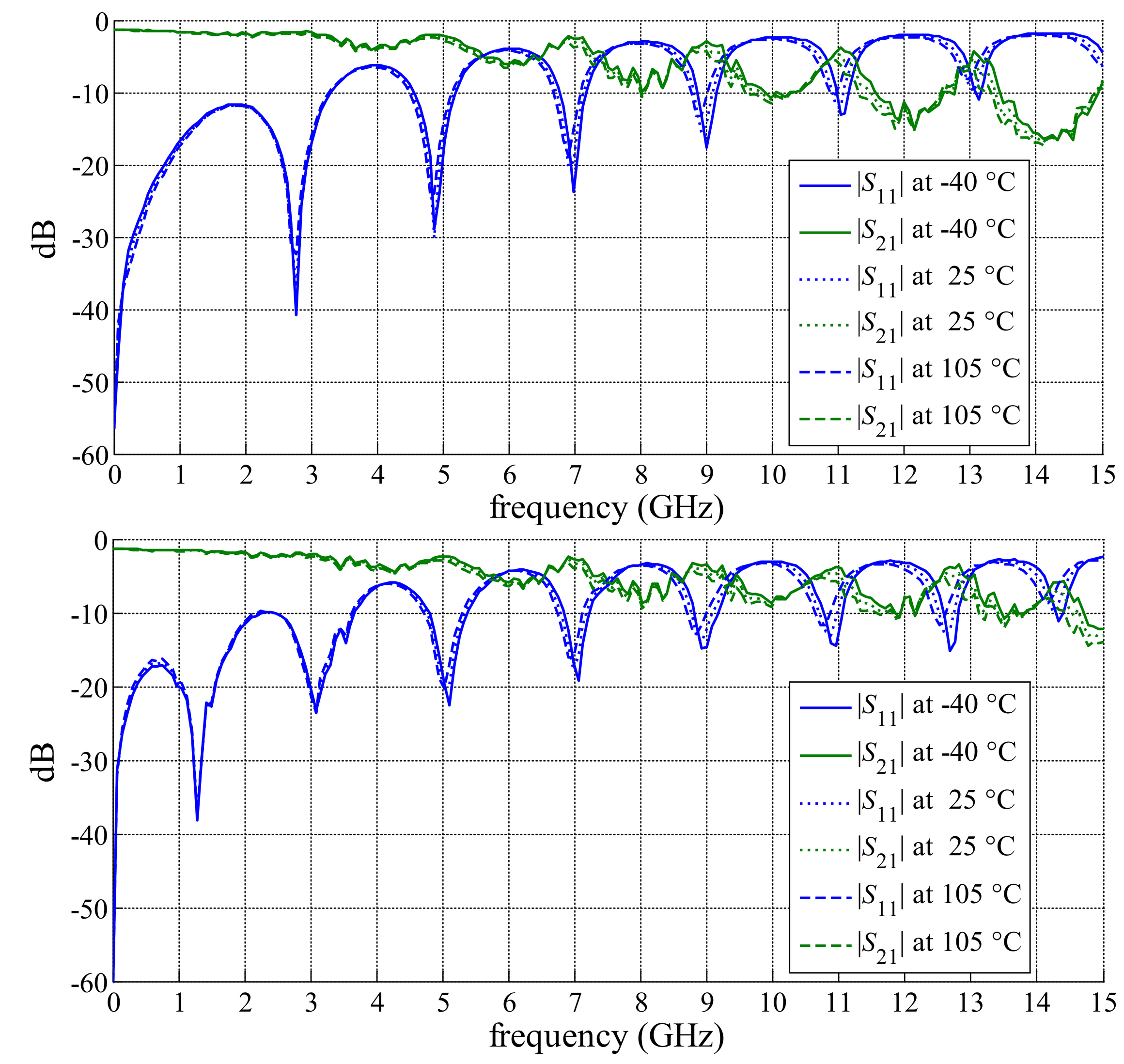

Fig. 6. Cable only test (without DUT) S-parameter responses at different temperatures.

Measured S-parameters and temperature differences can be seen in Figs. 5-8. Fig 5 shows the Samtec Golden Standard responses in Single Ended S-parameters (although 4 ports S-parameters were measured) in which differences bigger than 20 dB are noticeable above 13 GHz. Fig 6 shows the thin (13.5 mil width) and the thick (117.5 mil width) responses in which we can spot differences of up to 5 dB above 10 GHz. Fig 7 shows short (2”) and long (6”) transmission lines S-parameters responses in which differences of up to 10 dB are spotted above 14 GHz.

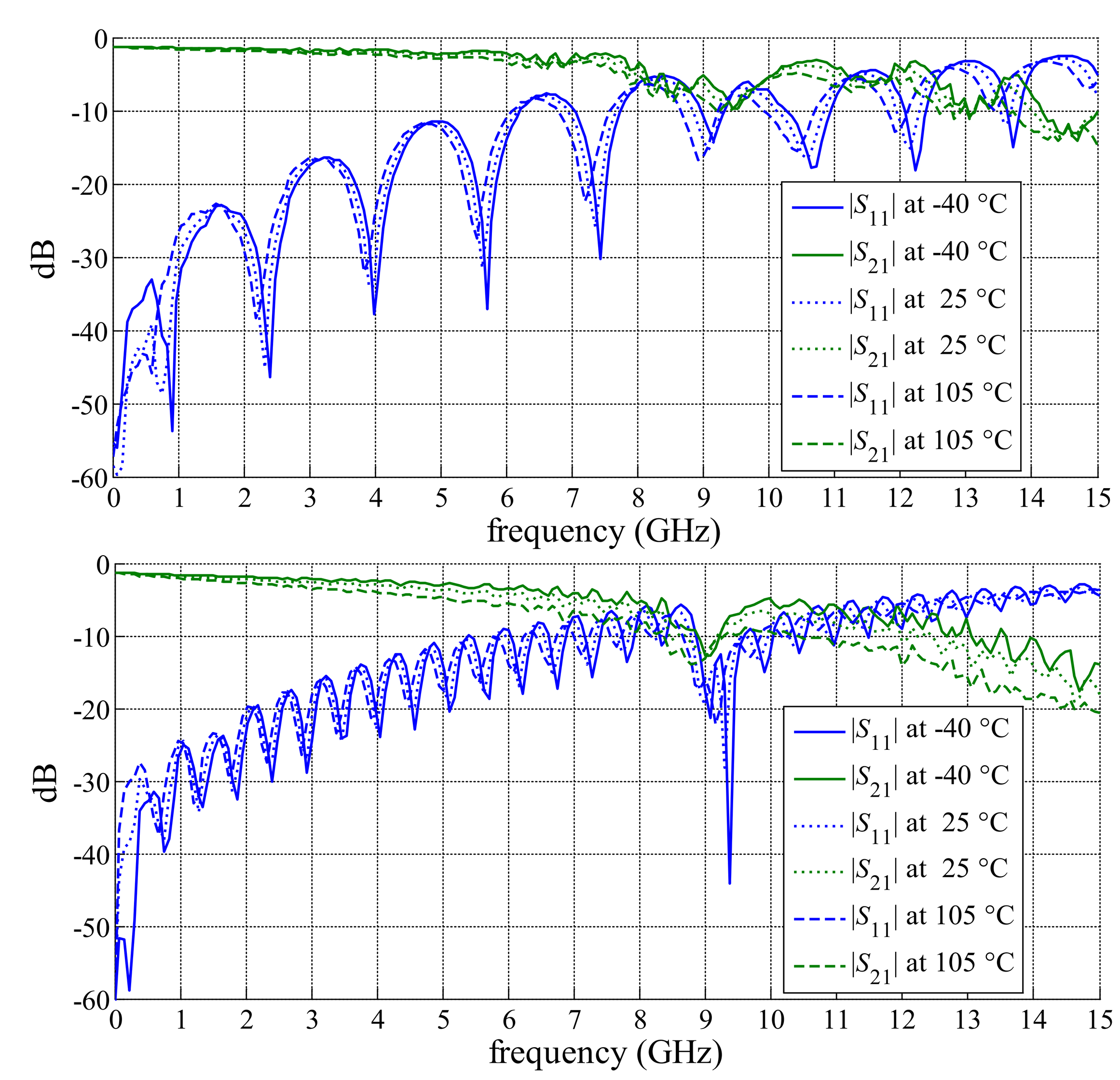

Fig. 7. Short and long TLs S-parameter responses at different temperatures. Top: short TL. Bottom: long TL.

Sensitivity of S-parameters to temperature is more noticeable above 3.5 GHz in most plots, especially for near-end crosstalk and far-end crosstalk (Fig. 8). It is seen that the Samtec Golden Standard, being a differential interconnect, presents the largest effects related to temperature at high frequencies on single-ended S-parameters.

Over temperature, the smallest changes in insertion losses were registered with shorter and/or thinner TLs, as confirmed in Table II. Conversely, the best performance for return losses was observed with thicker and/or longer TLs. Designing based on these observations must be subject to engineering criteria, since trading-off emissions and signal integrity performance is usually subject to equalization techniques available and EMC regulations.

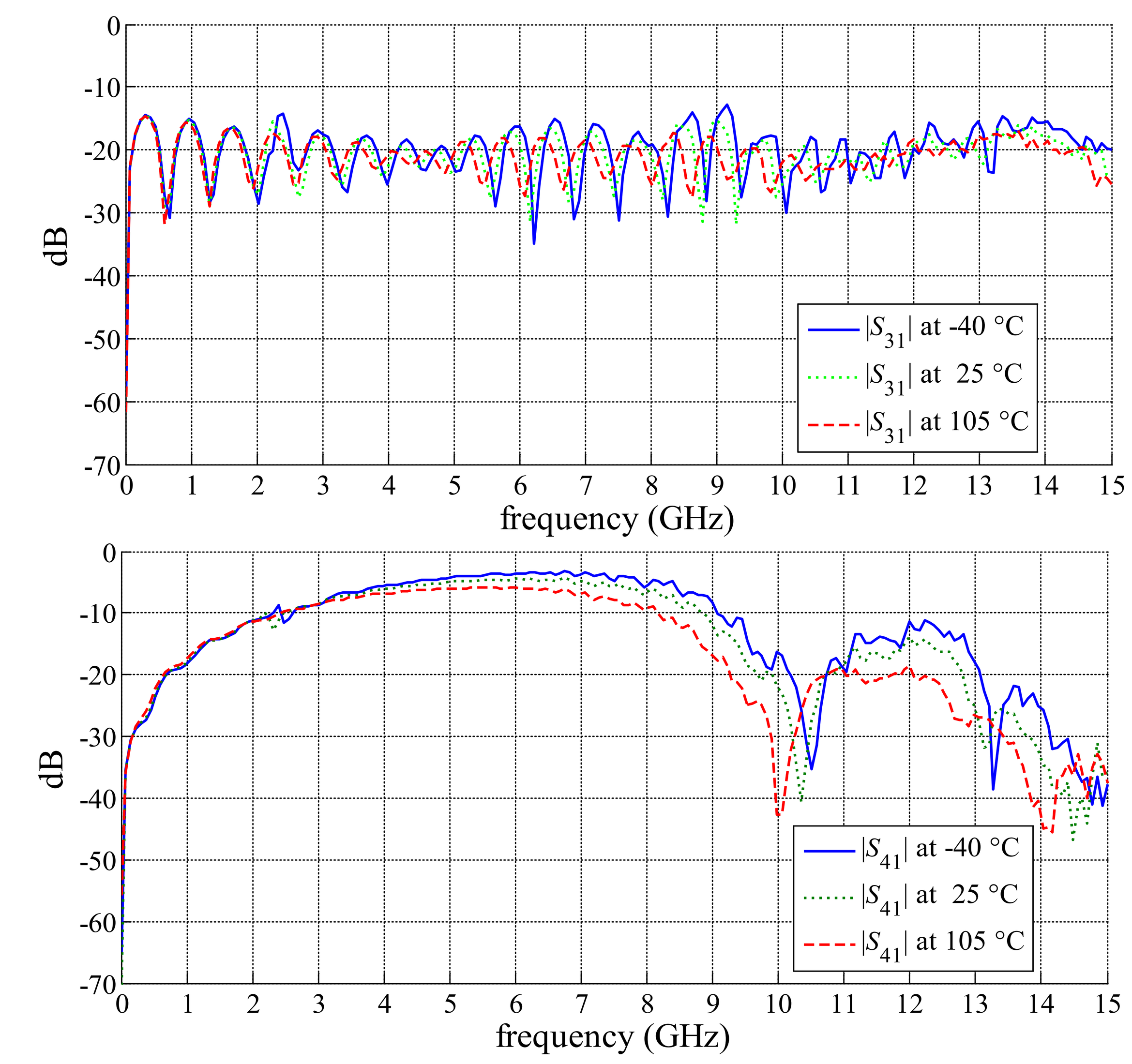

Fig. 8. Samtec Golden Standard S-parameter response at different temperatures. Top: near-end xtalk. Bottom: far-end xtalk.

6. Conclusions

Experimental measurement results in this work indicate that current cost-effective, FR4-based PCB technology might become vulnerable above a few GHz in typical automotive temperature ranges. The coupled EM-thermal behavior observed settles the necessity of implementing multiphysics models and simulations for future automotive computing interconnects, such as in the connected car.

8. References

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