Python Automation of Measurement and Multi-Dimensional Plotting of DC and AC Bias Sensitivity of MLCCs

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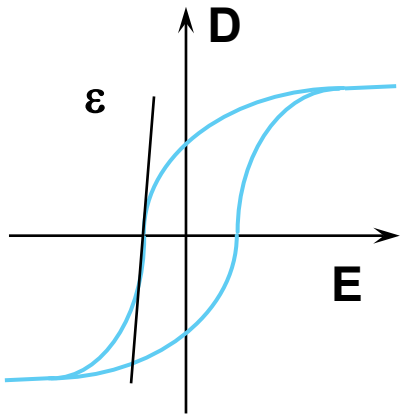
Introduction

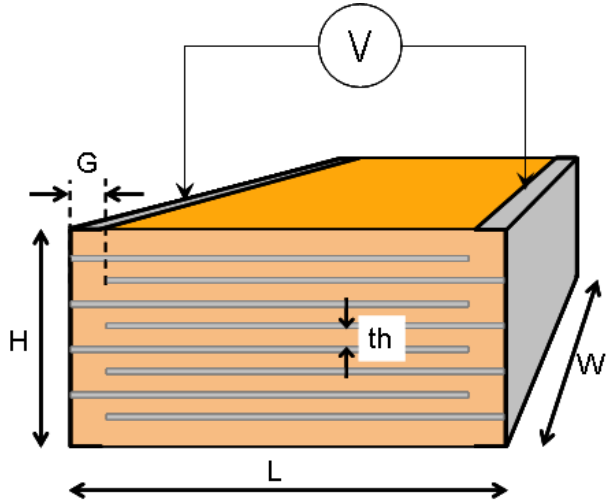


Class II and higher ceramic materials are ferroelectric

Ferroelectric materials have saturated hysteretic D-E curves

DC and AC bias changes ε and through ε also C

- Layer count
- N = H/th



$$D = \varepsilon E$$

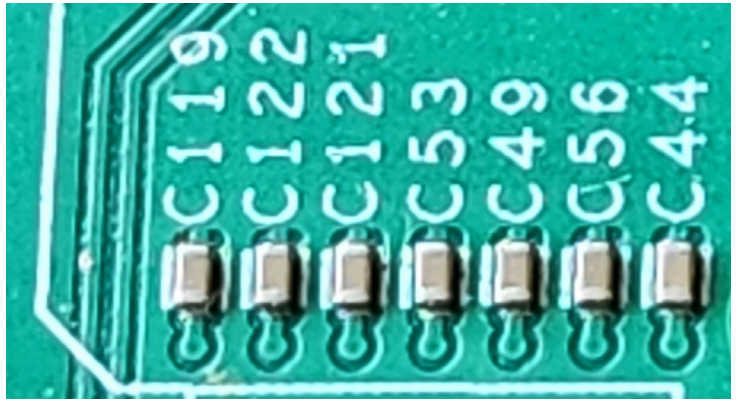
$$C = \varepsilon_0 \varepsilon_r N \frac{W(L-2G)}{th}$$

$$E = \frac{V}{th}$$

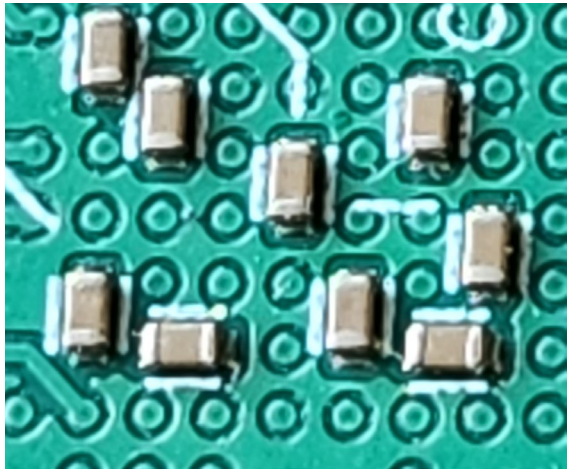
In extreme cases we may lose 60-80% capacitance due to DC and AC bias effects!

Why Do We Care for Capacitance?

DC blocking capacitors in high-speed signaling standards may have capacitance specification or recommendation



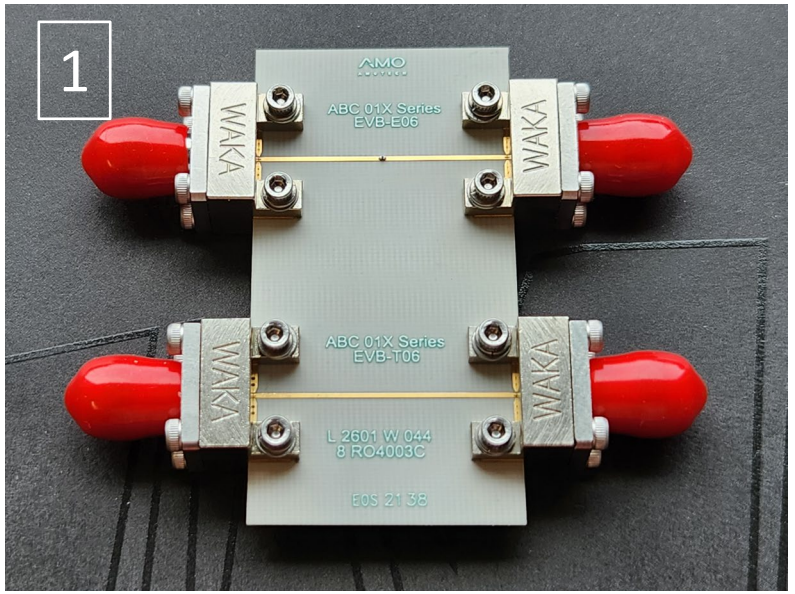
Regardless of design methodology, PDN designs depend on (among others) the capacitance of bypass capacitors

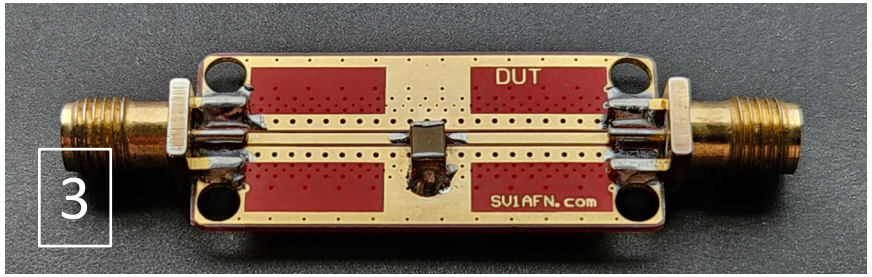


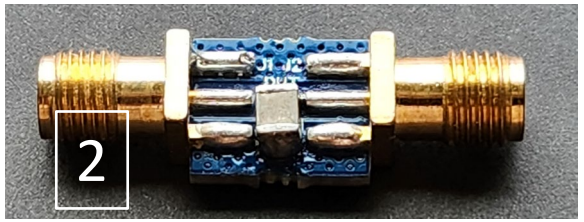
Measurement Setup: The Fixture

1. ABCUC 101 01X 224K 0201-size fixture by Amotech for series DC-blocking applications with reference THRU trace
2. Picotest DTBK01 1210-size fixture with TY AMK325ABJ337 MLCC for parallel topology
3. HAM-radio fixture for parallel topology
4. Home-made SMA fixture for parallel topology

For electrically short fixtures there is no need for deembedding







Measurement Setup

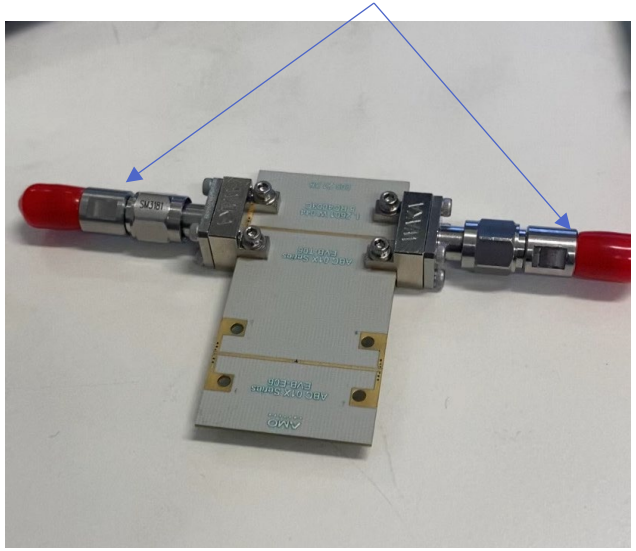
Electronic calibration (Ecal) was used on all active channels at -15dBm

Reference plane is at the end of the cables

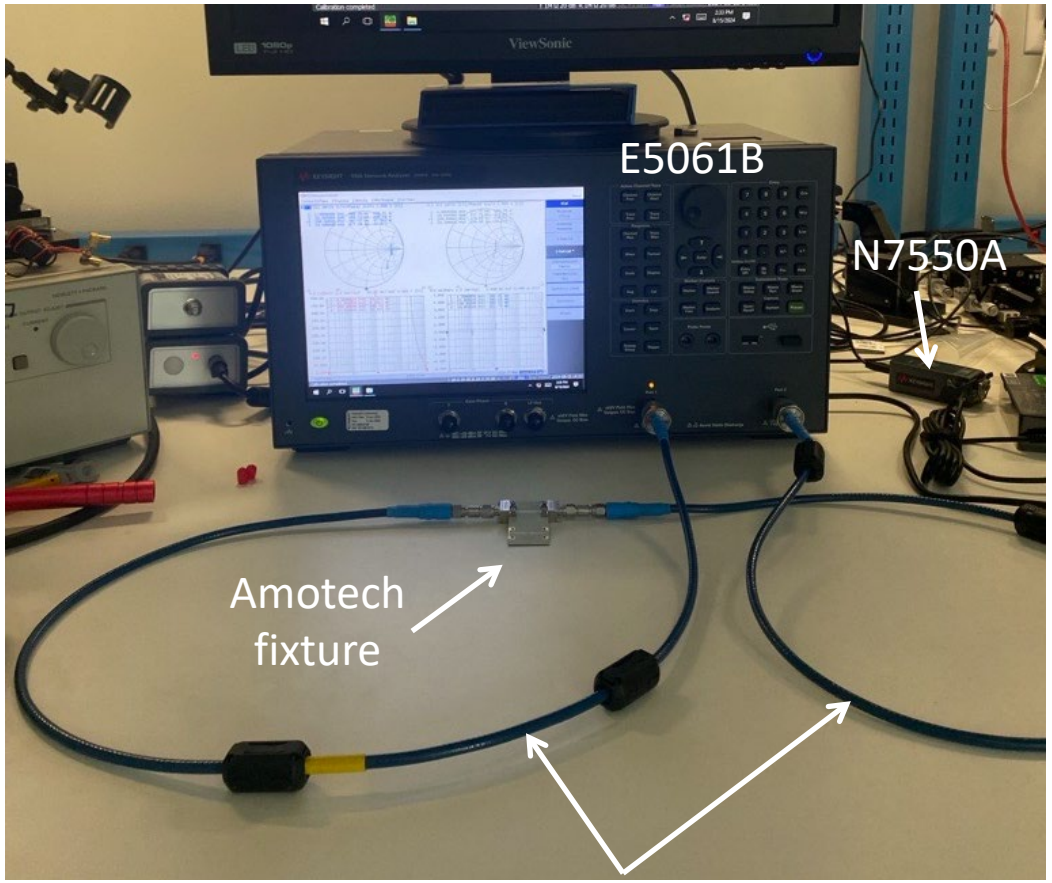
Traces, connectors, adapters are not deembedded

Huber-Suhner Sucoflex 1-meter coaxial SMA to N cables

SMA to 1.85mm adapters



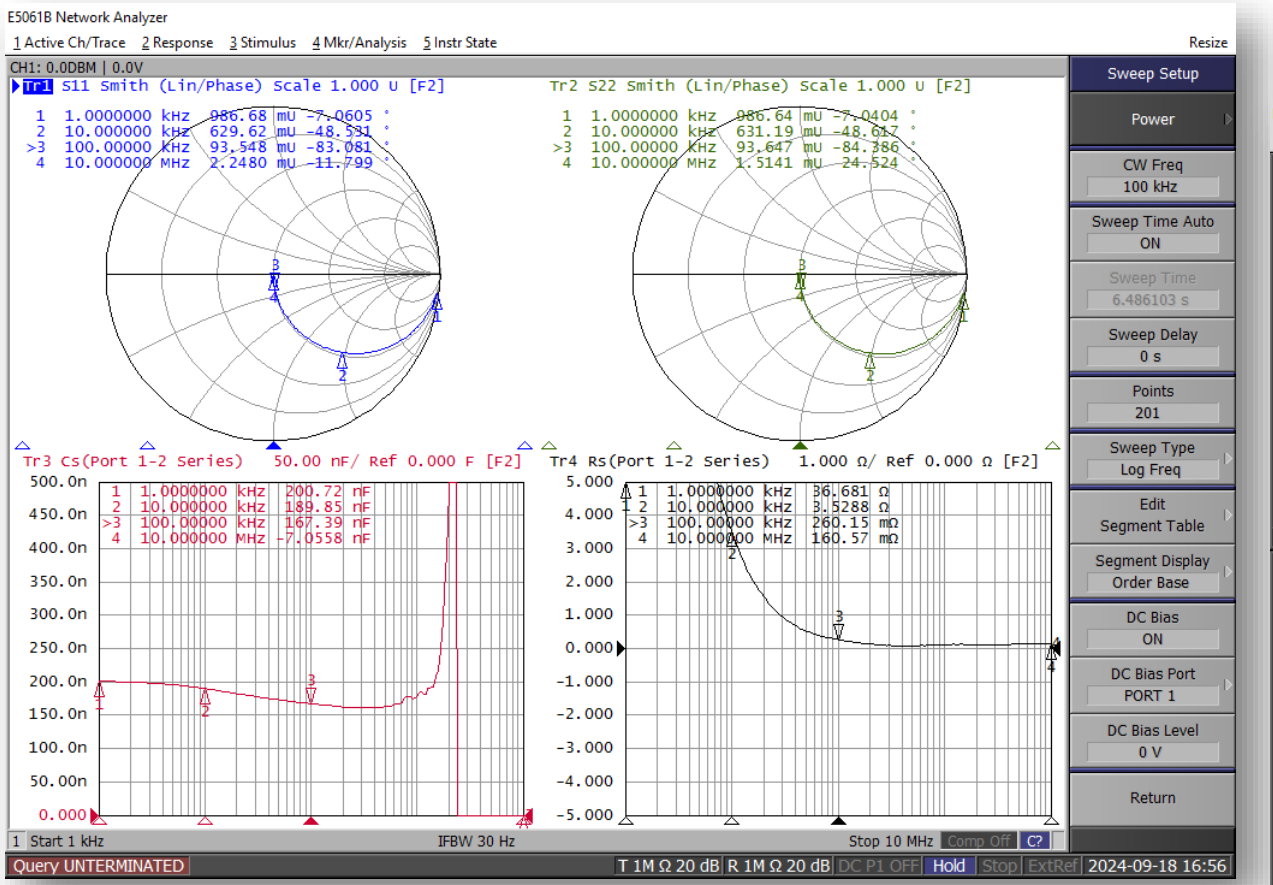
Amotech test fixture with reference THRU trace



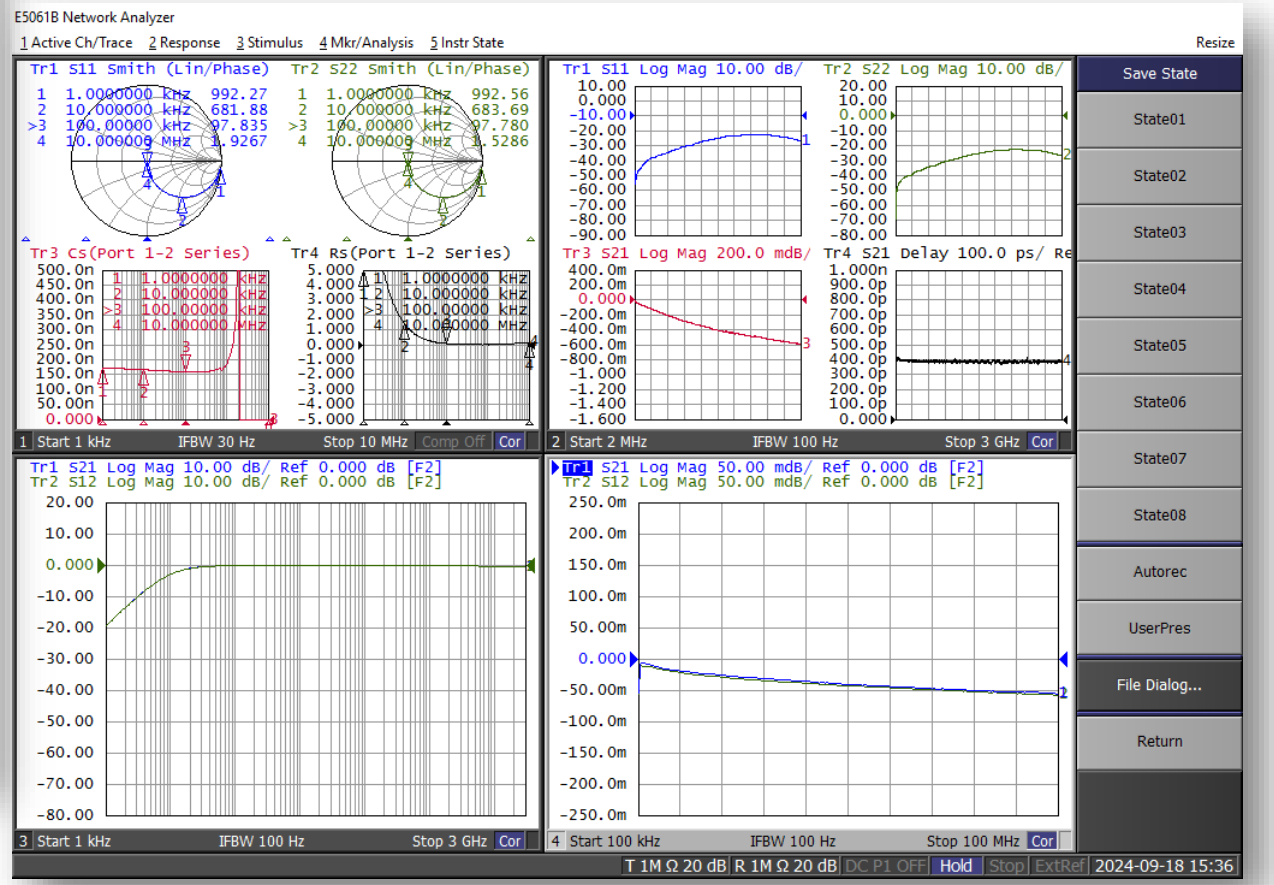
Coaxial cables with ferrite absorbers

Measurement Setup

One-channel view with extracted C and ESR from series topology



Four-channel VNA screen with extracted C and ESR from series topology



Measurement Automation

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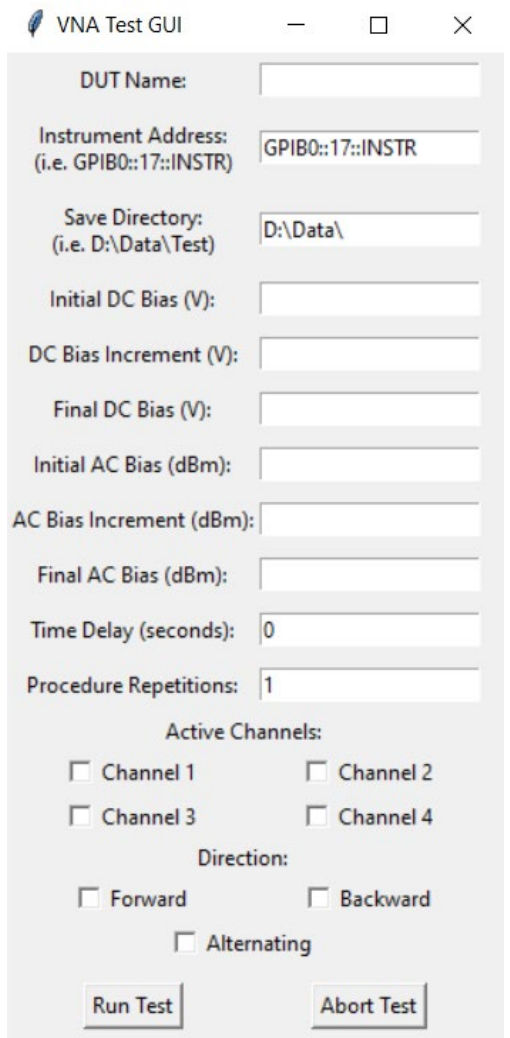
The first program takes the following steps in order to run a defined measurement procedure on a list of DC and AC bias points generated by user-entered parameters.

- It takes an initial, increment, and final value for both biases (closed interval), DUT name, instrument address, save directory, time delay, active channels, and direction of sweep.
- Firstly, the list of DC and AC test points is generated by using the numpy arange function (or a custom function if alternating), stores the current power levels of each channel and turns on the DC bias.
- The program then iterates through each DC point, and at each DC point it iterates through every AC point, runs a frequency sweep, saves the touchstone file, dumps the screen image.
- Waits for the remainder of the given time delay if there is time remaining, then moves to the next point.
- Procedure repetitions is the number of times the generated measurement procedure will be repeated
- Finally, returns the channels back to their original power levels and turns the DC bias off.
- Abort test allows the user to close the program in case of an emergency.



Measurement Procedures

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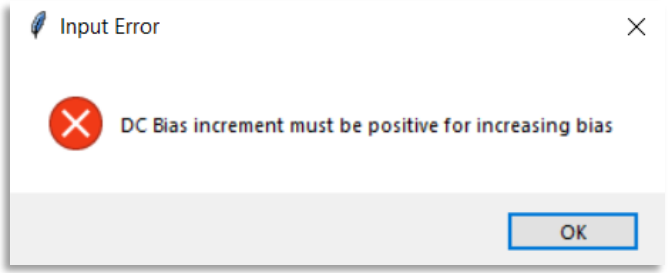
Examples

- Forward, start = 0, increment = 1, end = 4
  → [0, 1, 2, 3, 4]
- Backward, start = 0, increment = 1, end = 4
  → [4, 3, 2, 1, 0]
- Forward Alternating, start = 0, increment = 1, end = 4
  → [0, -1, 1, -2, 2, -3, 3, -4, 4]
- Backward Alternating, start = 0, increment = 1, end = 4
  → [4, -4, 3, -3, 2, -2, 1, -1, 0]

Rules

- For increasing bias range, the increment must be positive
- For decreasing bias range, the increment must be negative
- For a constant bias the increment must be 0
- If the increment violates the above requirements, an error box will appear
- User cannot enter fractions
- DC bias has resolution of 0.01
- AC bias has resolution of 0.05



Example error message box

Data Collection

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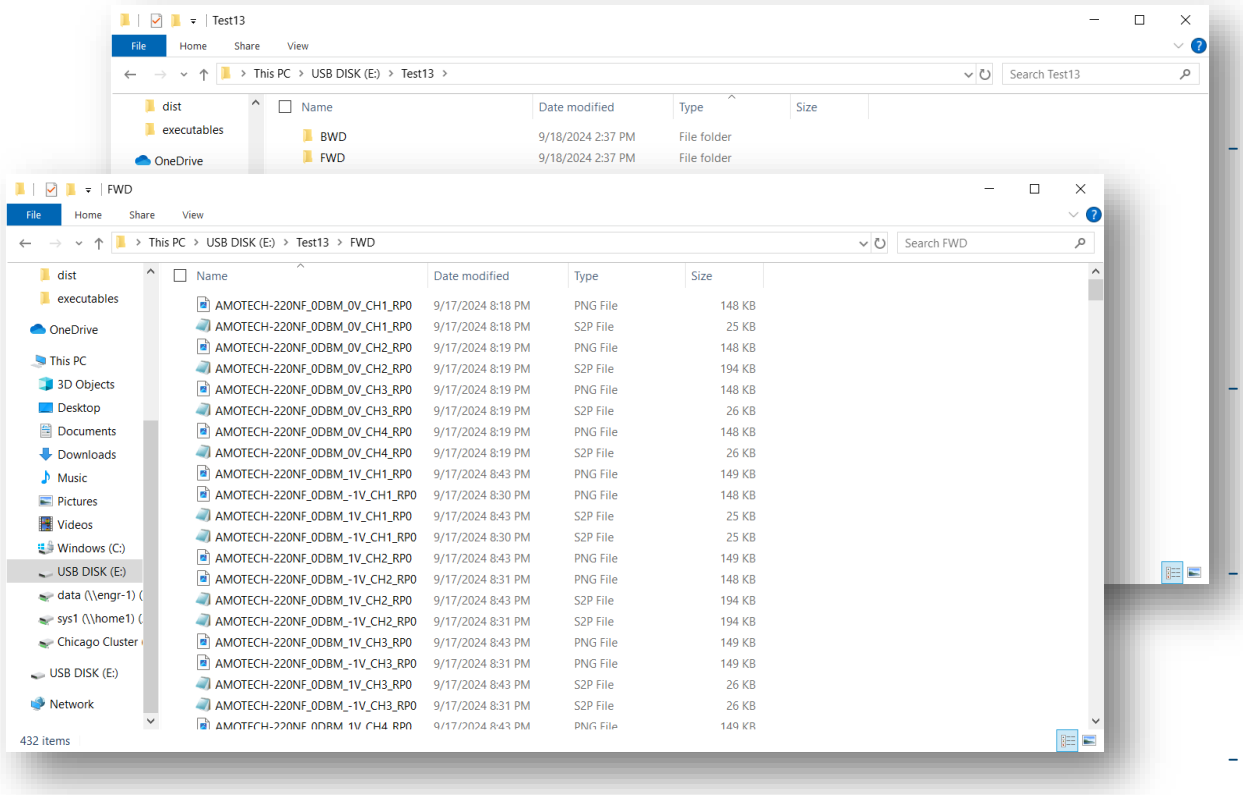

- After each measurement, the program saves the touchstone file storing the s-parameters as well as a PNG storing the screen image taken at the end of the measurement
- The user-entered save directory must contain a folder called “FWD” and another called “BWD” within it before starting the program. If not, the program will show an error message box.
- The naming convention of the files is: “DUT-NAME_AC-BIAS_DC-BIAS_CHx_RPx.S2P” & “DUT-NAME_AC-BIAS_DC-BIAS_CHx_RPx.PNG”
- The naming convention is generic by having “CHx” and “RPx” at the end to indicate what channel and repetition the data was saved from.
- The touchstone and image files are saved into the “FWD” and “BWD” folders in order to avoid overwriting data when a forward test and backward test are run.

Data Analysis

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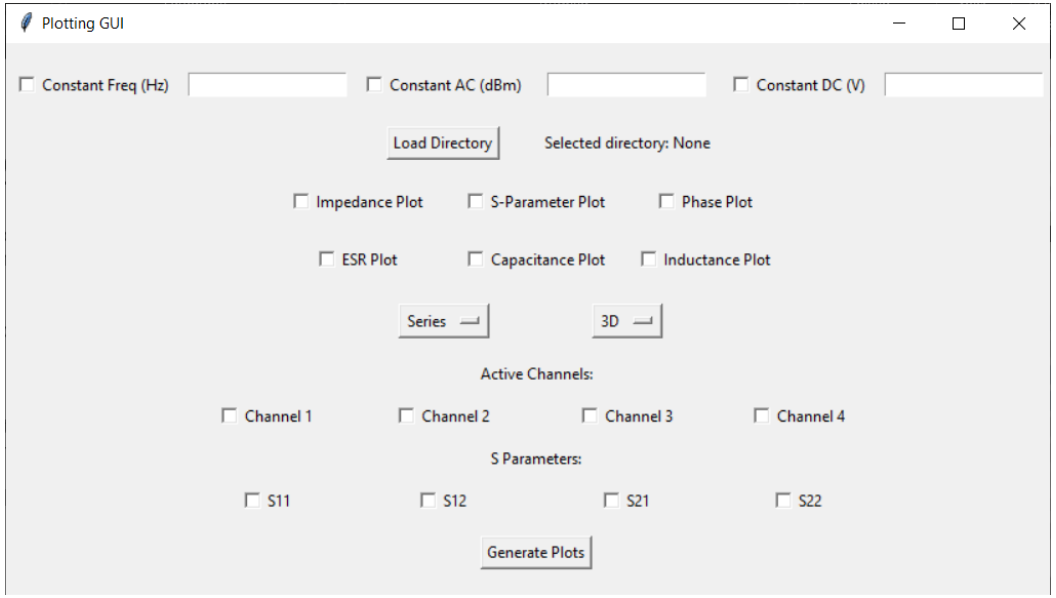
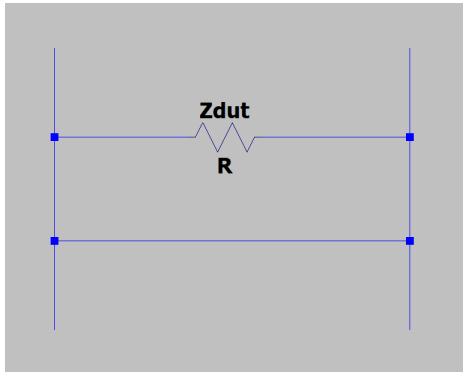
The second program was developed to generate plots from a chosen directory that contains data gathered from the automated measurements script.

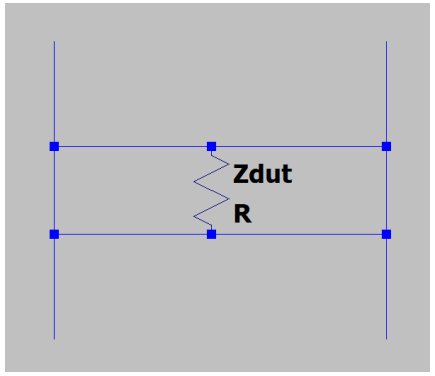
- It allows the user to select between series or parallel topologies, as well as whether the user wants to display the data in 3D or 2D plots (with overlapping curves and legends).
- The program generates 3D or 2D plots at a constant frequency, or AC bias, or DC bias
- The visualization parameters are selected by checkboxes in the GUI with current support for generating plots to show impedance magnitudes, s-parameter magnitudes, s-parameter phase, extracted equivalent series resistance (ESR), capacitance, and inductance.
- The user may select whether they want to show derived values from S21 only or all four s-parameters.



Series Topology



Parallel Topology



How it Works

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DERIVING THE VALUES

- When deriving the values for the complex impedance of these measurements, we use different formulas if the DUT is in the series or parallel path between Port1 and Port2.

$$Z = 2Zo\frac{S_{11}}{1-S_{11}} \qquad Z = 2Zo\frac{1-S_{12}}{S_{12}}$$

$$Z = 2Zo\frac{1-S_{21}}{S_{21}} \qquad Z = 2Zo\frac{S_{22}}{1-S_{22}}$$

Series ← Parallel →

$$Z = \frac{1}{Re\{Y_{in}\} - \frac{1}{Z_0} + jIm\{Y_{in}\}} \qquad Y_{in} = \frac{1}{Z_0}\frac{1-\Gamma}{1+\Gamma}$$

$$Z = \frac{Z_o}{2}\frac{S_{21}}{1-S_{21}} \qquad Z = \frac{Z_o}{2}\frac{S_{12}}{1-S_{12}}$$

- Impedance = absolute value of z complex
- ESR = the real component of z complex
- Capacitance = $-\frac{1}{2\pi f X}$
- Inductance = $\frac{X}{2\pi f}$

DISPLAYING THE DATA

- Data is displayed in the form of 3D or 2D plots generated using the matplotlib library in python.
- The program takes a directory of touchstone files and then extracts the AC and DC bias from the name of each file and stores all the s-parameters.
- Then it calculates all of the necessary data to be displayed (complex impedance, ESR, capacitance, inductance, etc.).
- Then either one or four subplots are created in a window for each selected visualization parameter in order to show a 3D or 2D plot for each s-parameter's derived values.

3D Impedance and ESR at 10kHz

Series topology, Amotech 220nF MLCC, from S11, S12, S21 and S22

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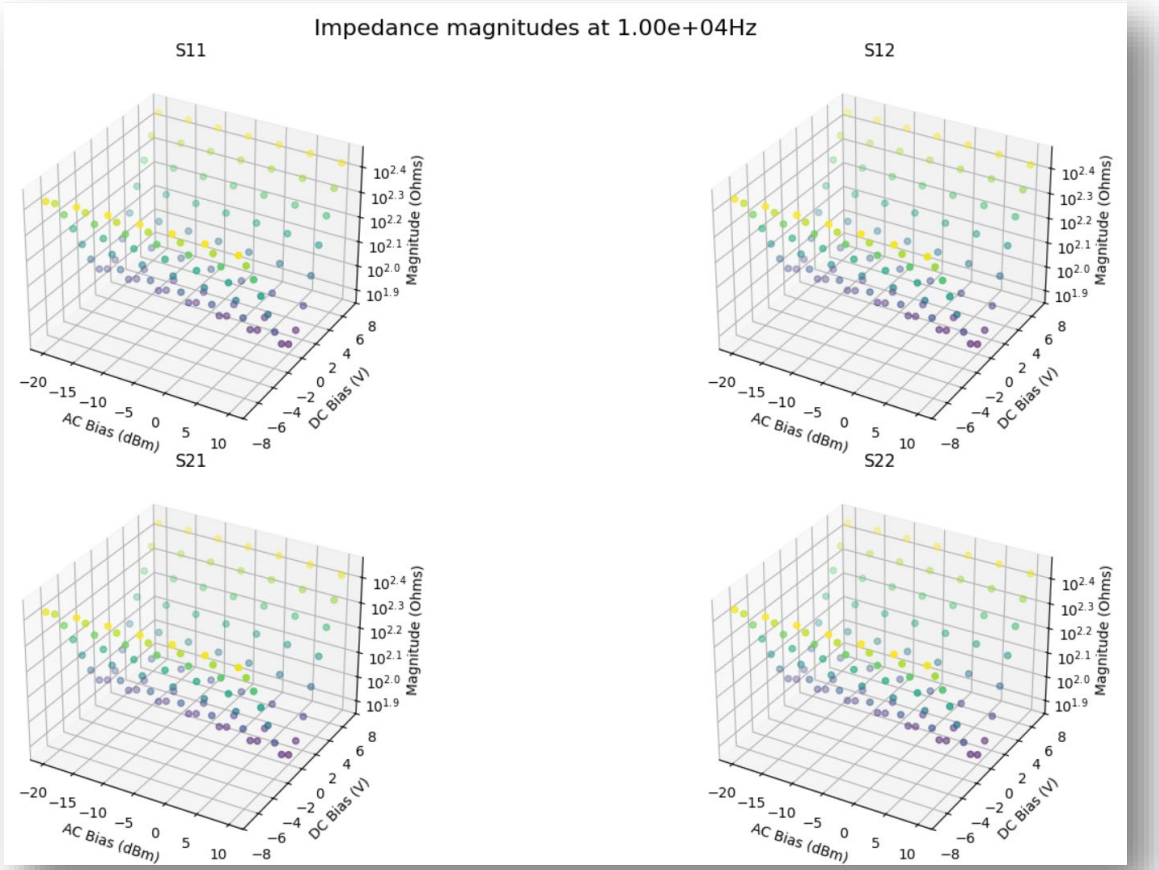

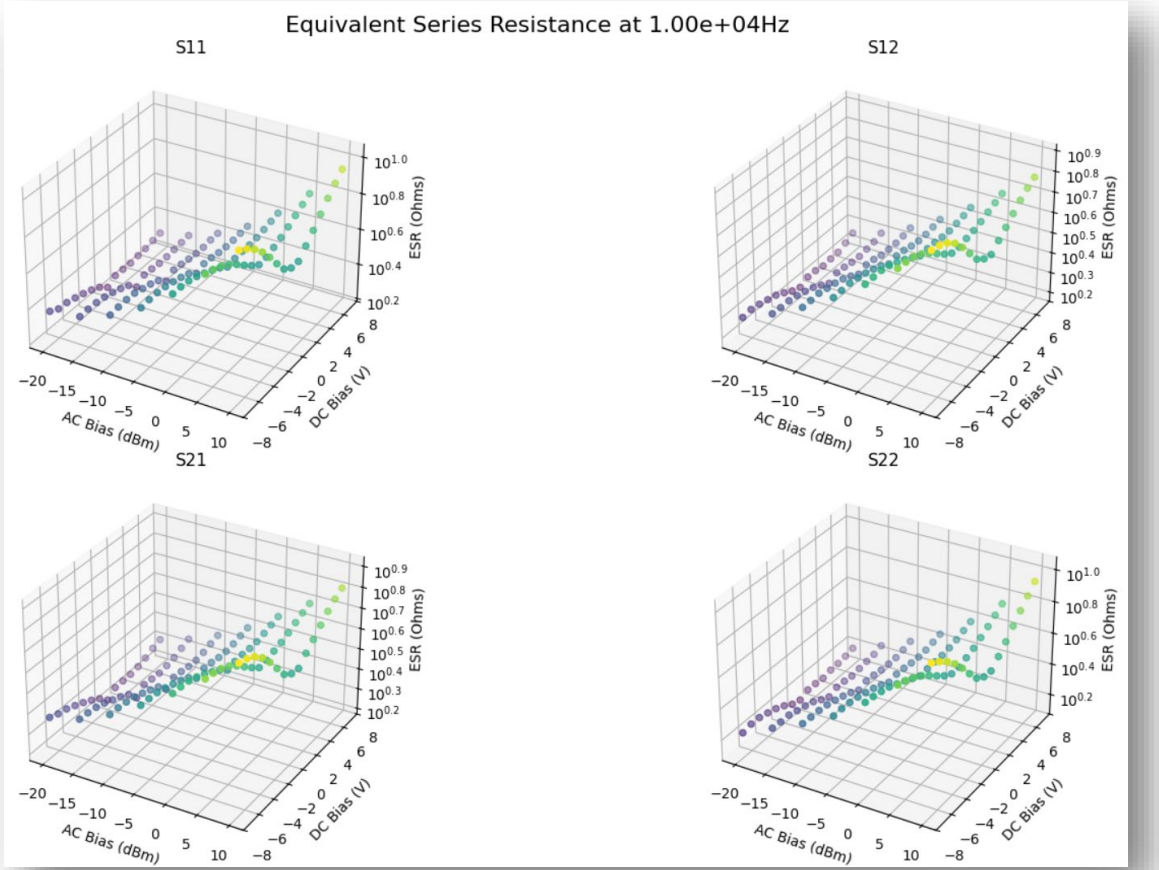

3D Impedance and ESR at 10kHz

Series topology, Amotech 220nF MLCC, from S21 only

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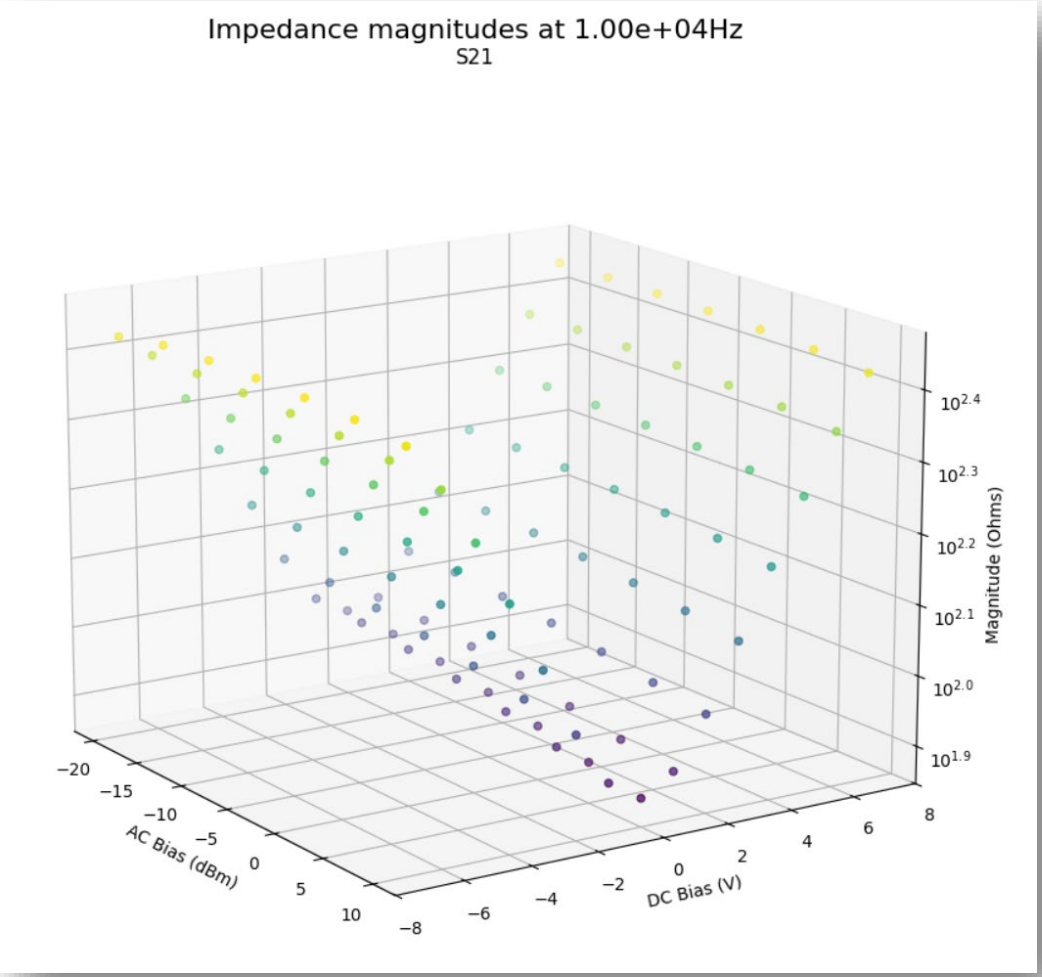

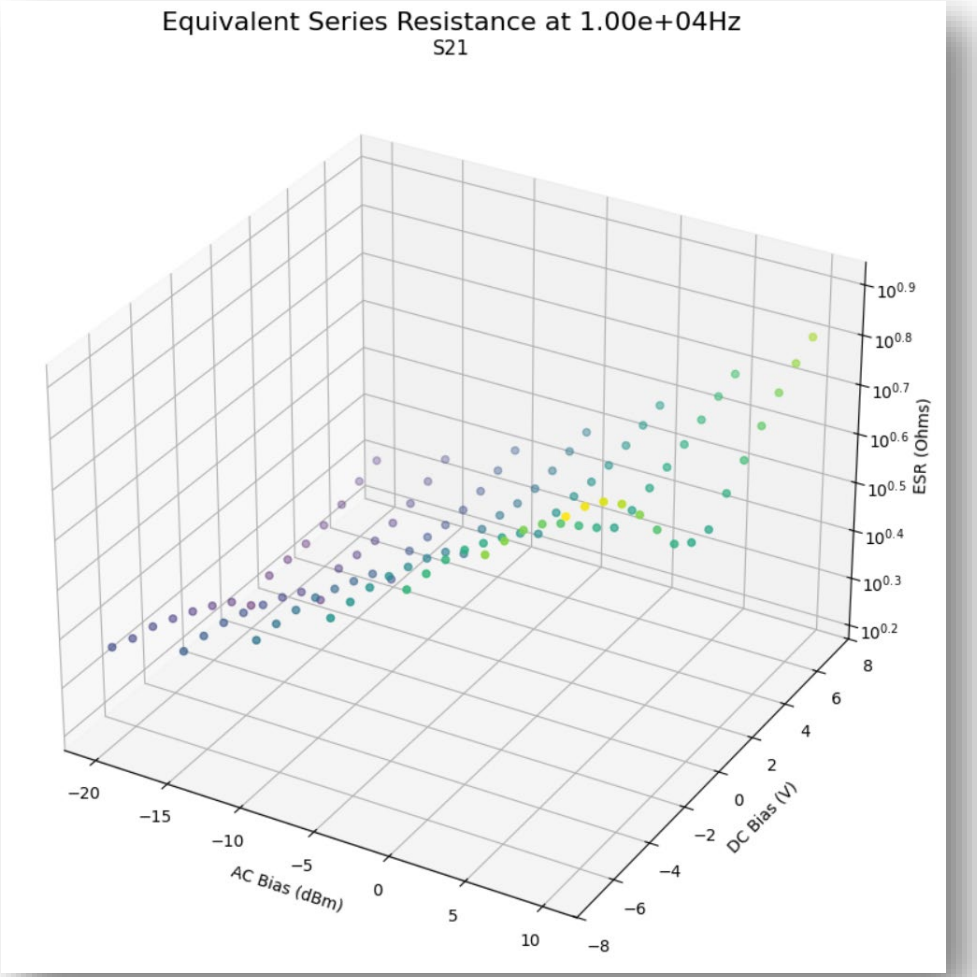

3D ESR Plots

Series topology, Amotech 220nF MLCC, from S21 only

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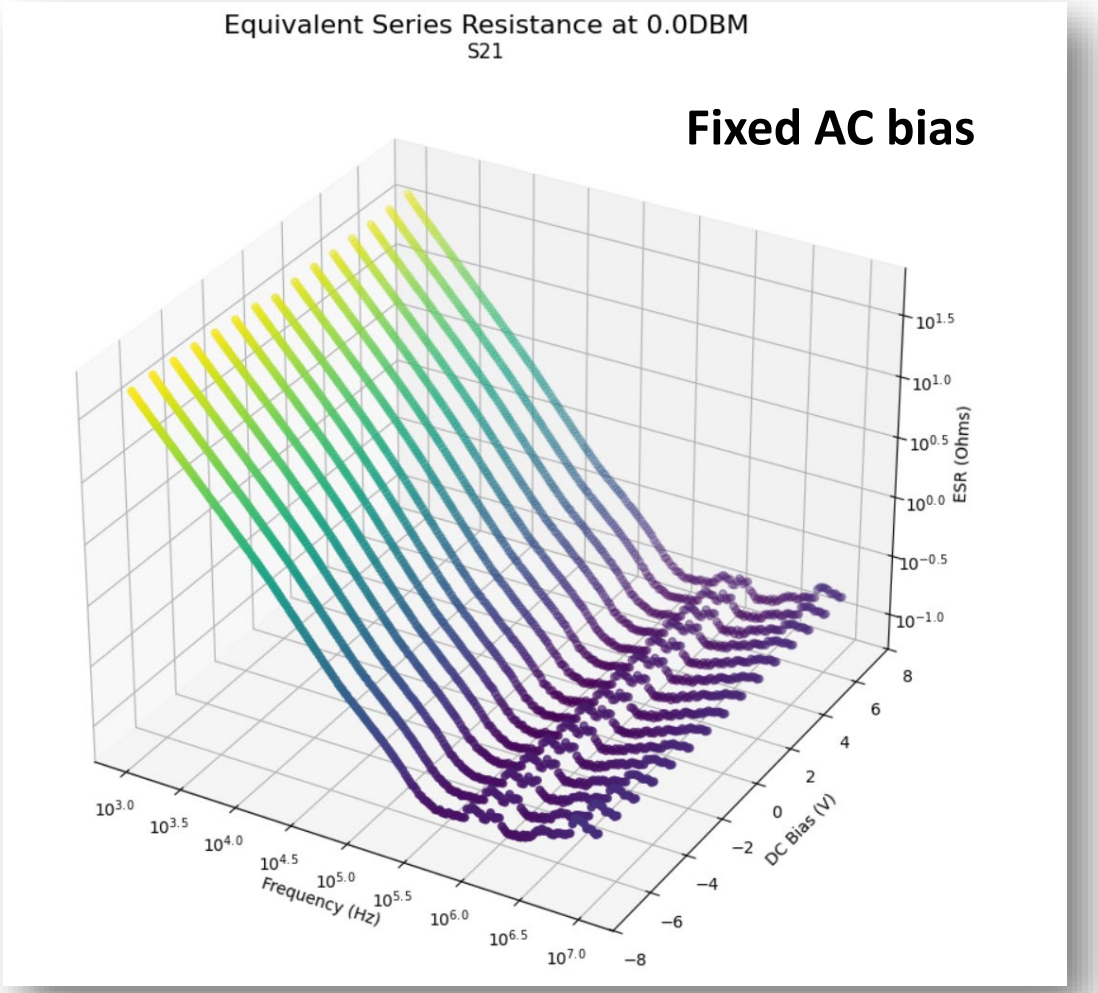

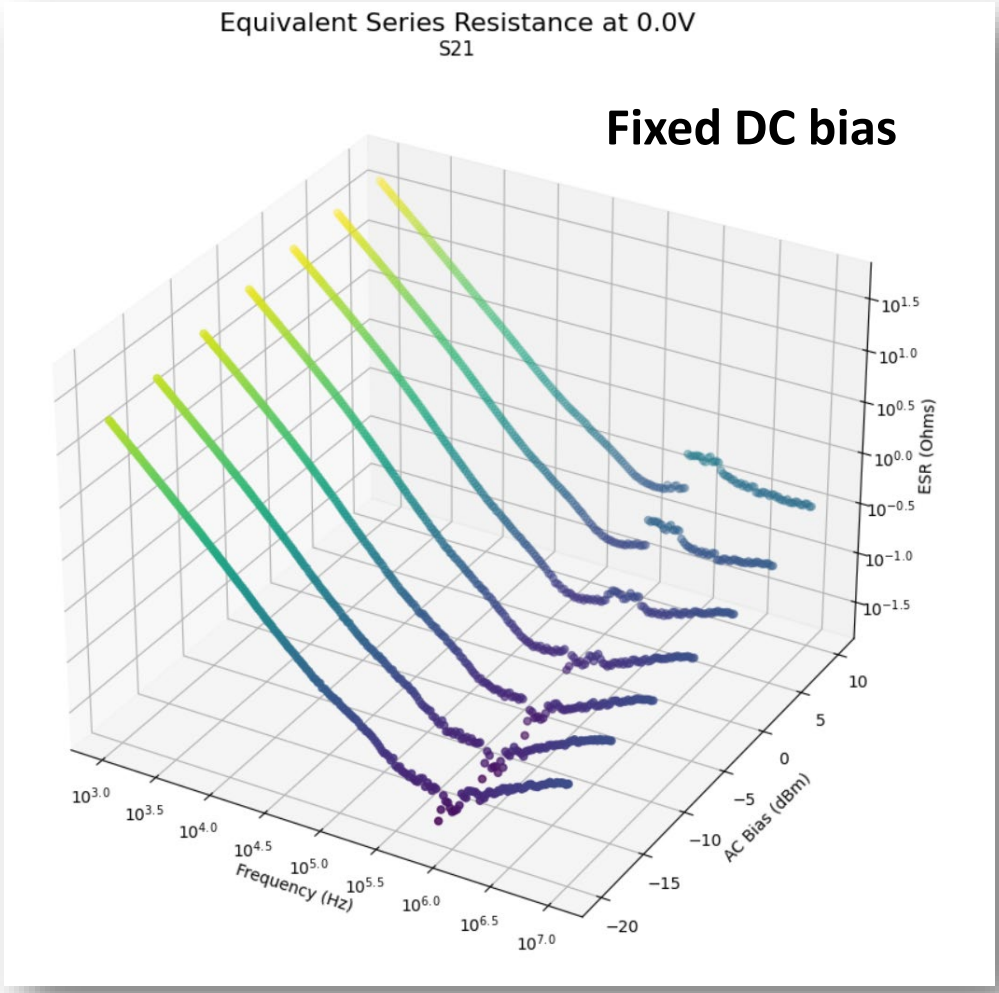

3D Capacitance Plot at 10kHz

Series topology, Amotech 220nF MLCC, from S21, S12, S21 and S22

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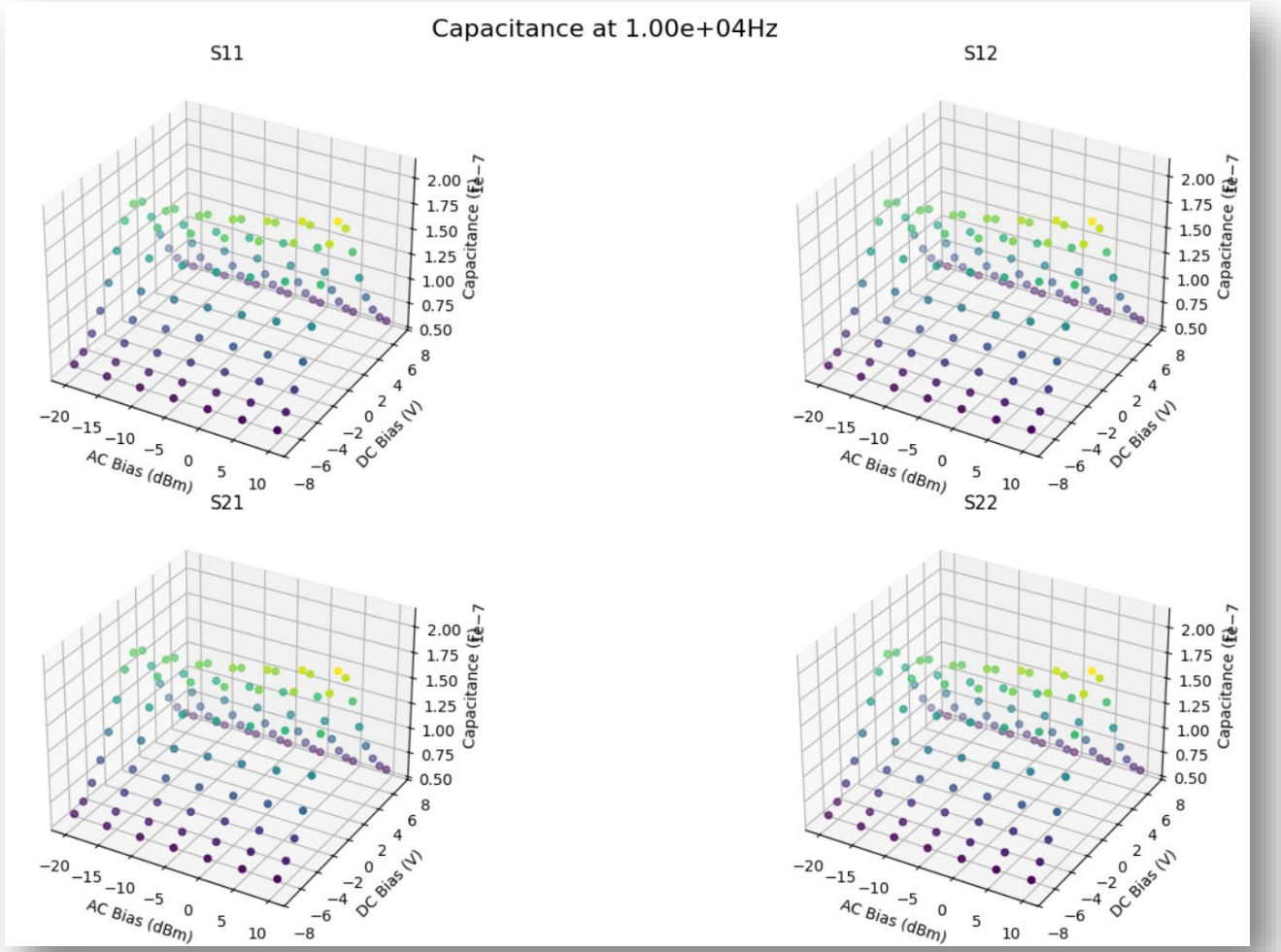

2D Capacitance Plot at 10kHz

Series topology, Amotech 220nF MLCC, from S21 only

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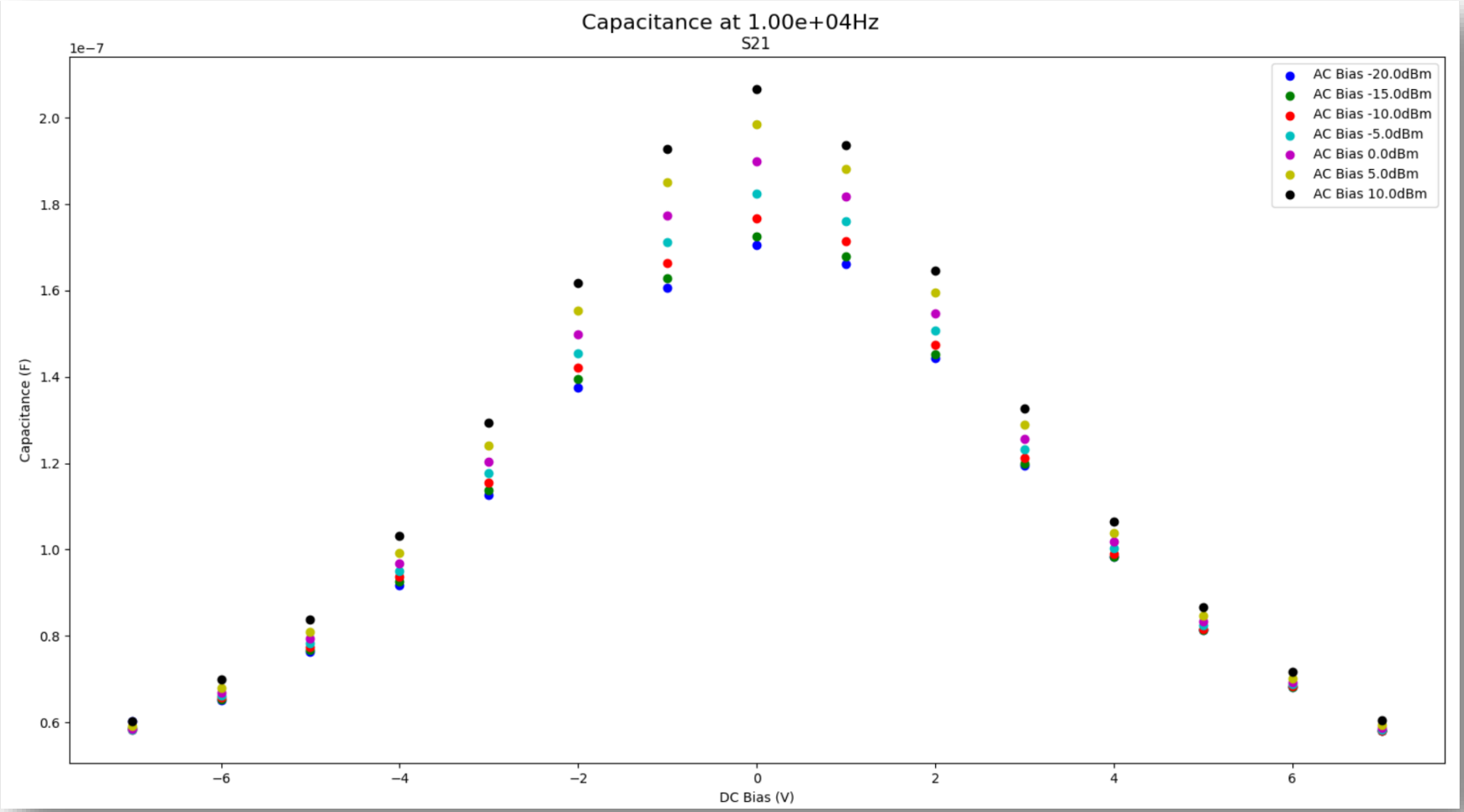

Amotech Data, Capacitance vs Temperature and DC Bias

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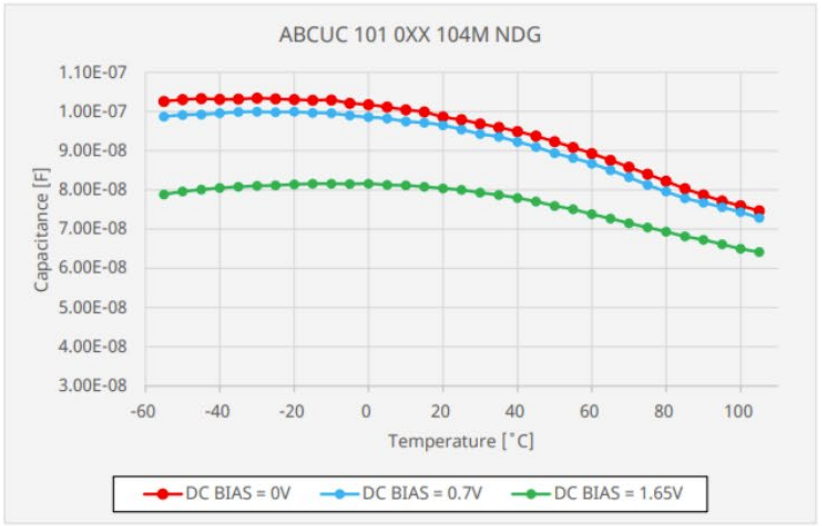
Broadband Capacitor

Bias TCC Characteristics

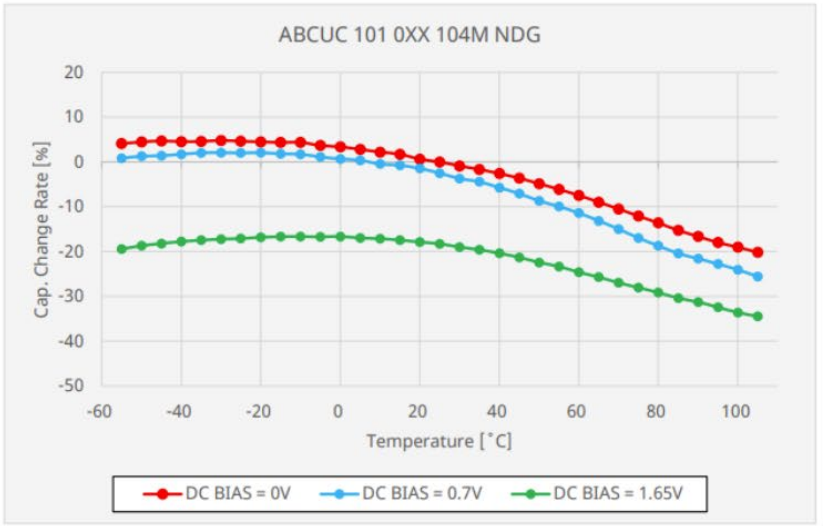
AMO AMOTECH

- ✓ DUT Part No. : ABCUC 101 0XX 104M NDG
- ✓ Check the change according to temperature while applying DC voltage
- ✓ DC bias step = 3 steps(0V, 0.7V, 1.65V), Temperature range = -55 °C to 105°C

[Capacitance value on temperature and DC bias voltage]



[Capacitance change rate on temperature and DC bias voltage]



3D Impedance and ESR Plots at 10kHz

Parallel topology, Taiyo-Yuden 330uF MLCC, from S11, S12, S21 and S22

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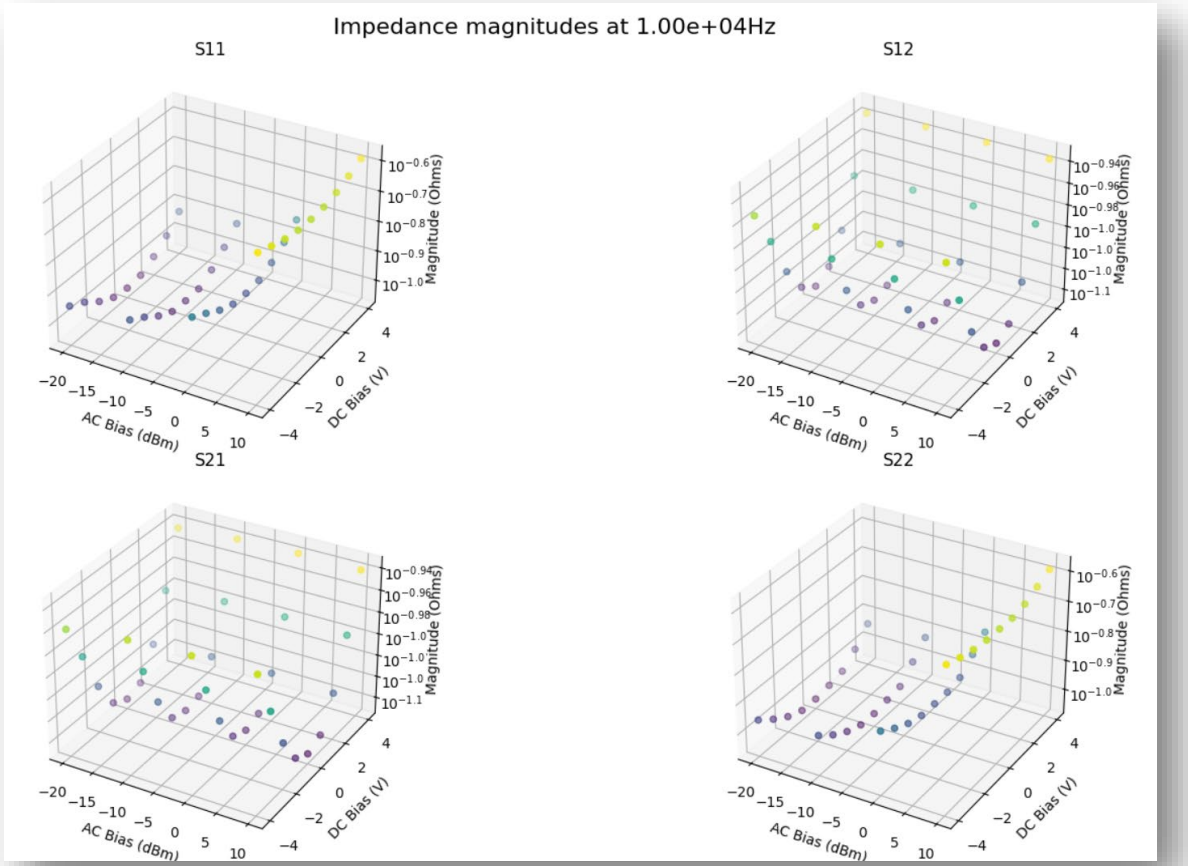

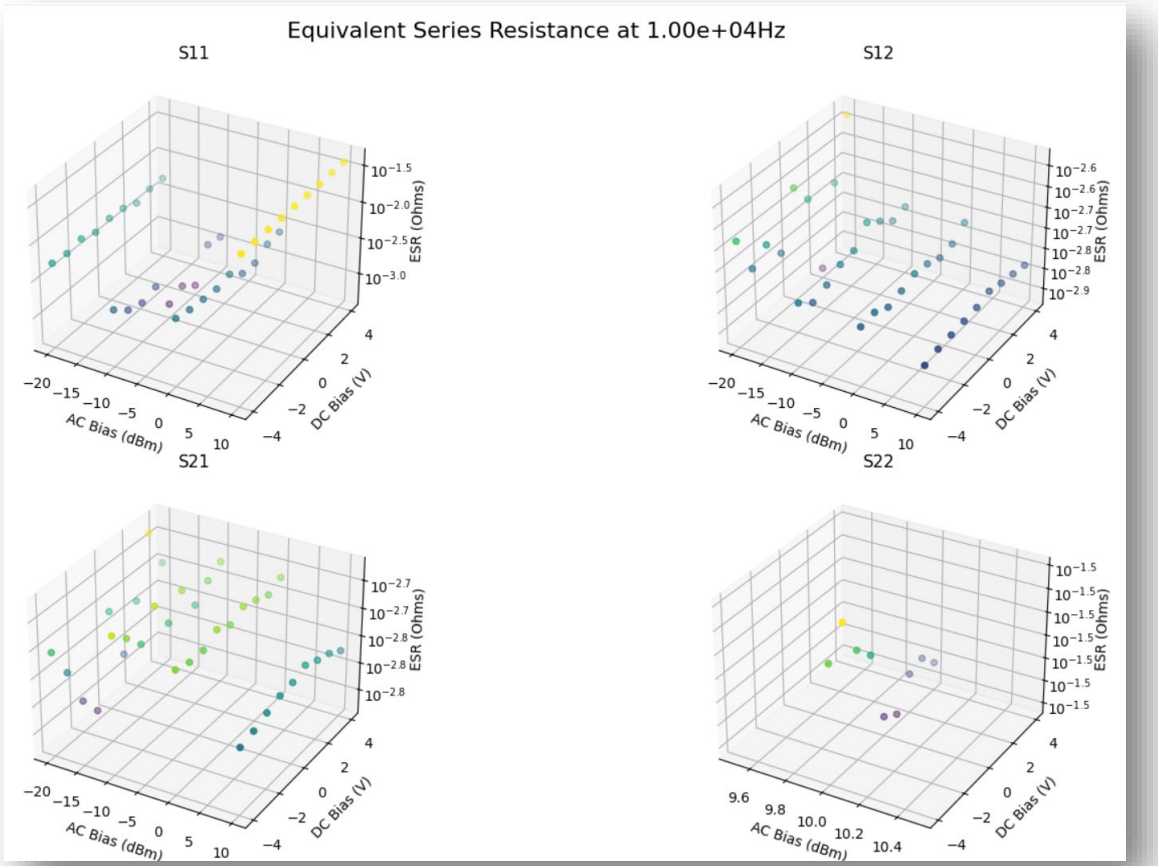

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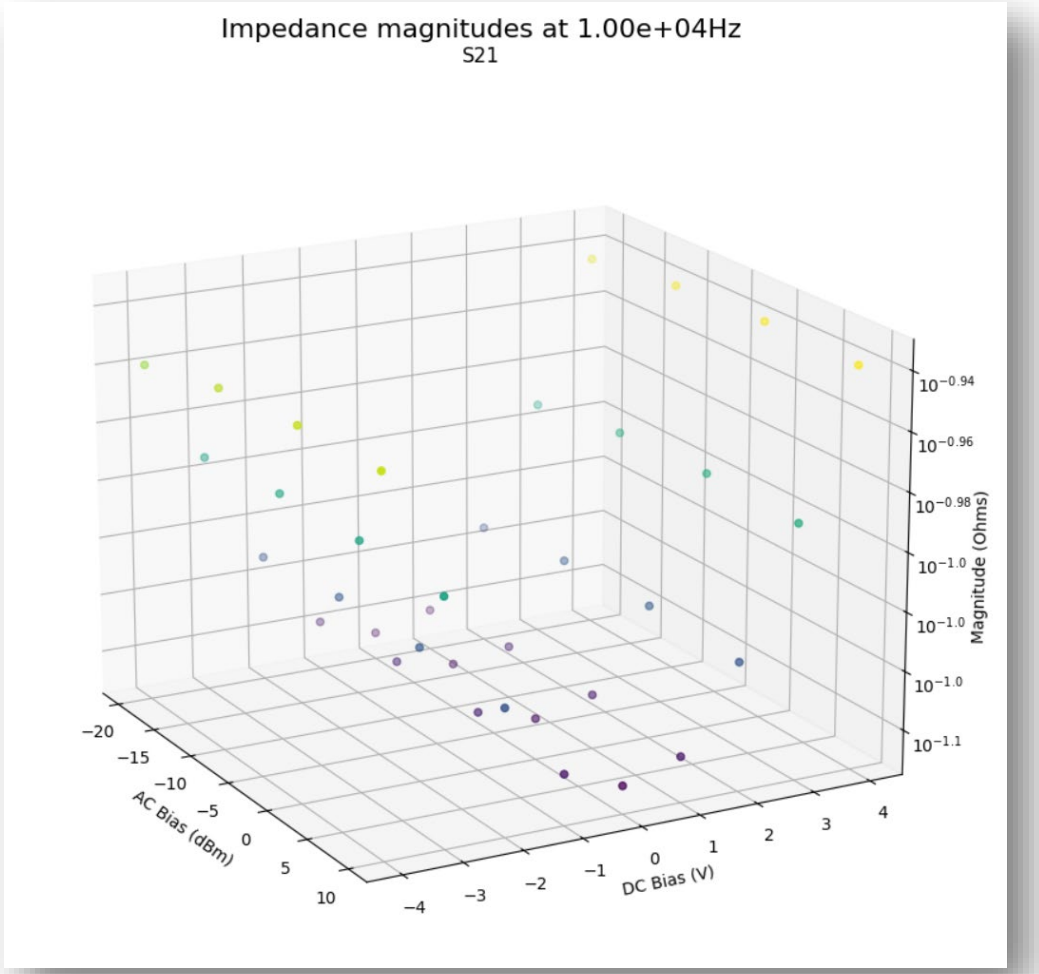

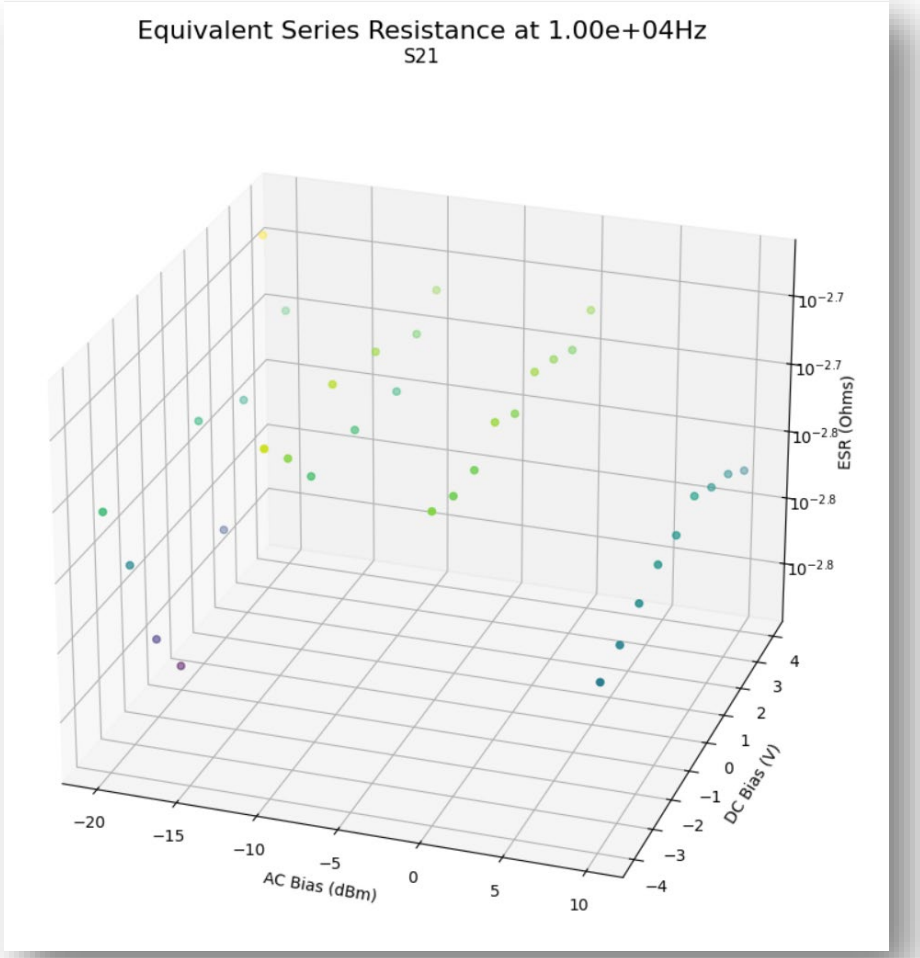

3D ESR Plots

Parallel topology, Taiyo-Yuden 330uF MLCC, from S21 only

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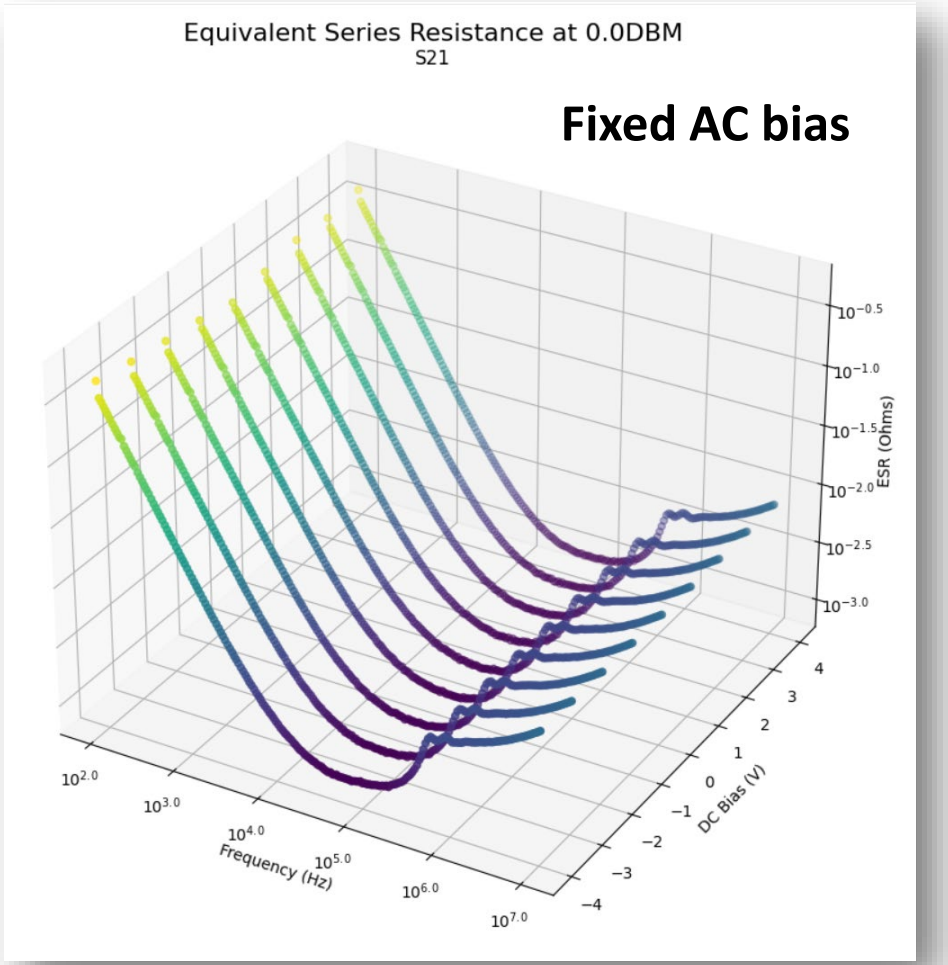

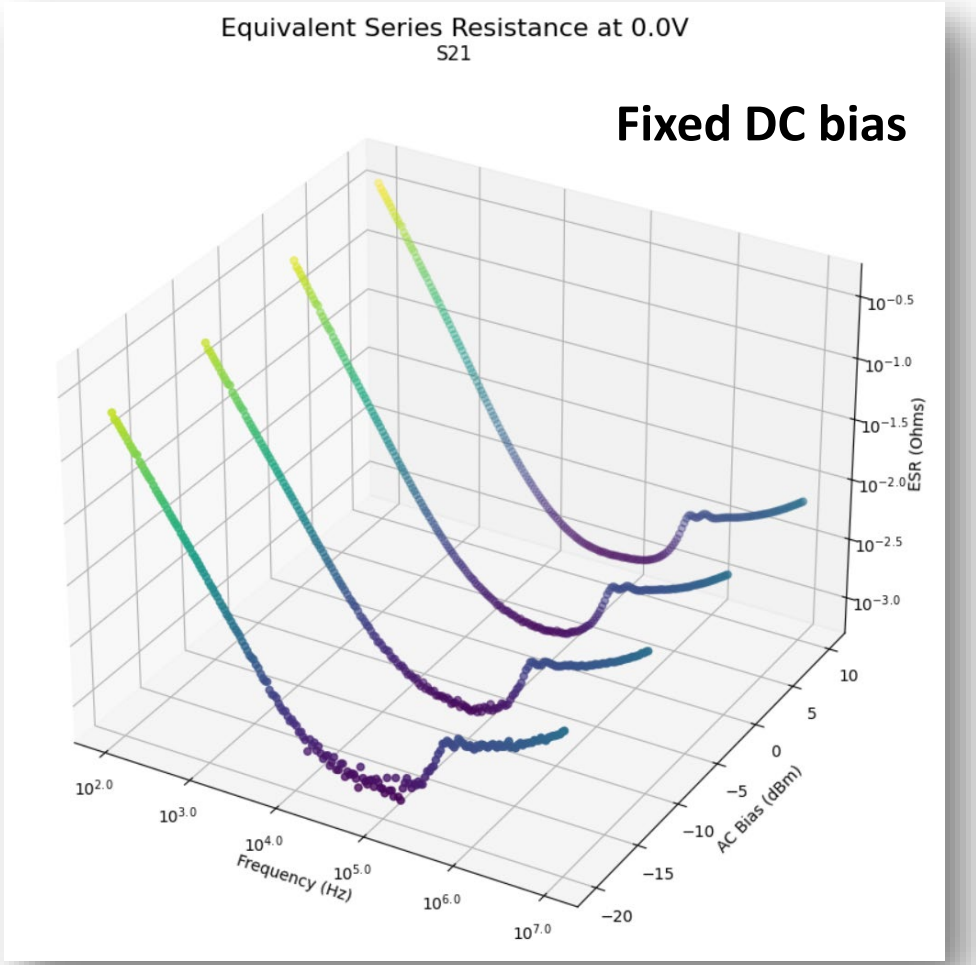

3D Capacitance Plots at 10kHz

Parallel topology, Taiyo-Yuden 330uF MLCC, from S11, S12, S21 and S22

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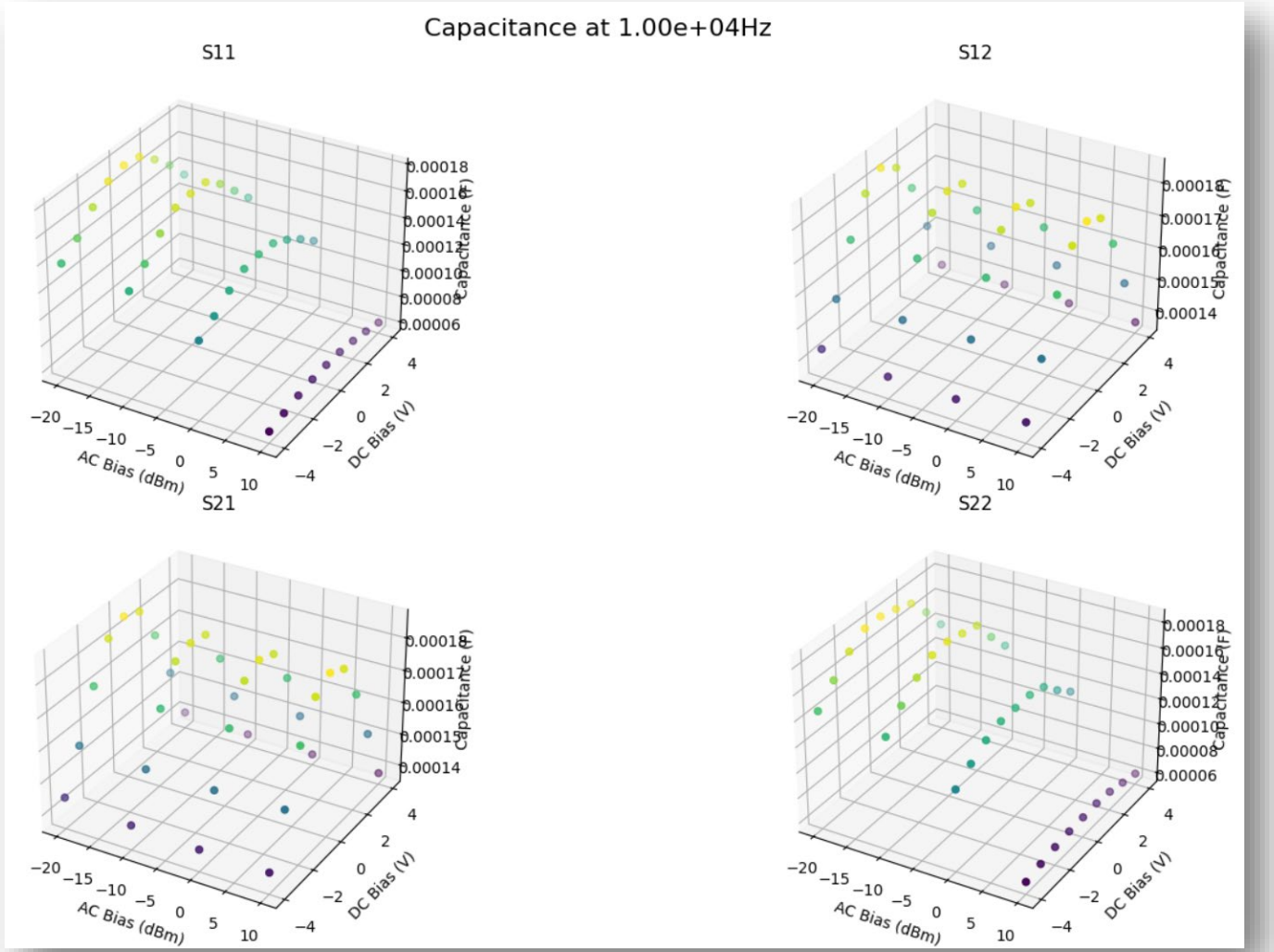

2D Capacitance Plot

Parallel topology, Taiyo-Yuden 330uF MLCC, from S21 only

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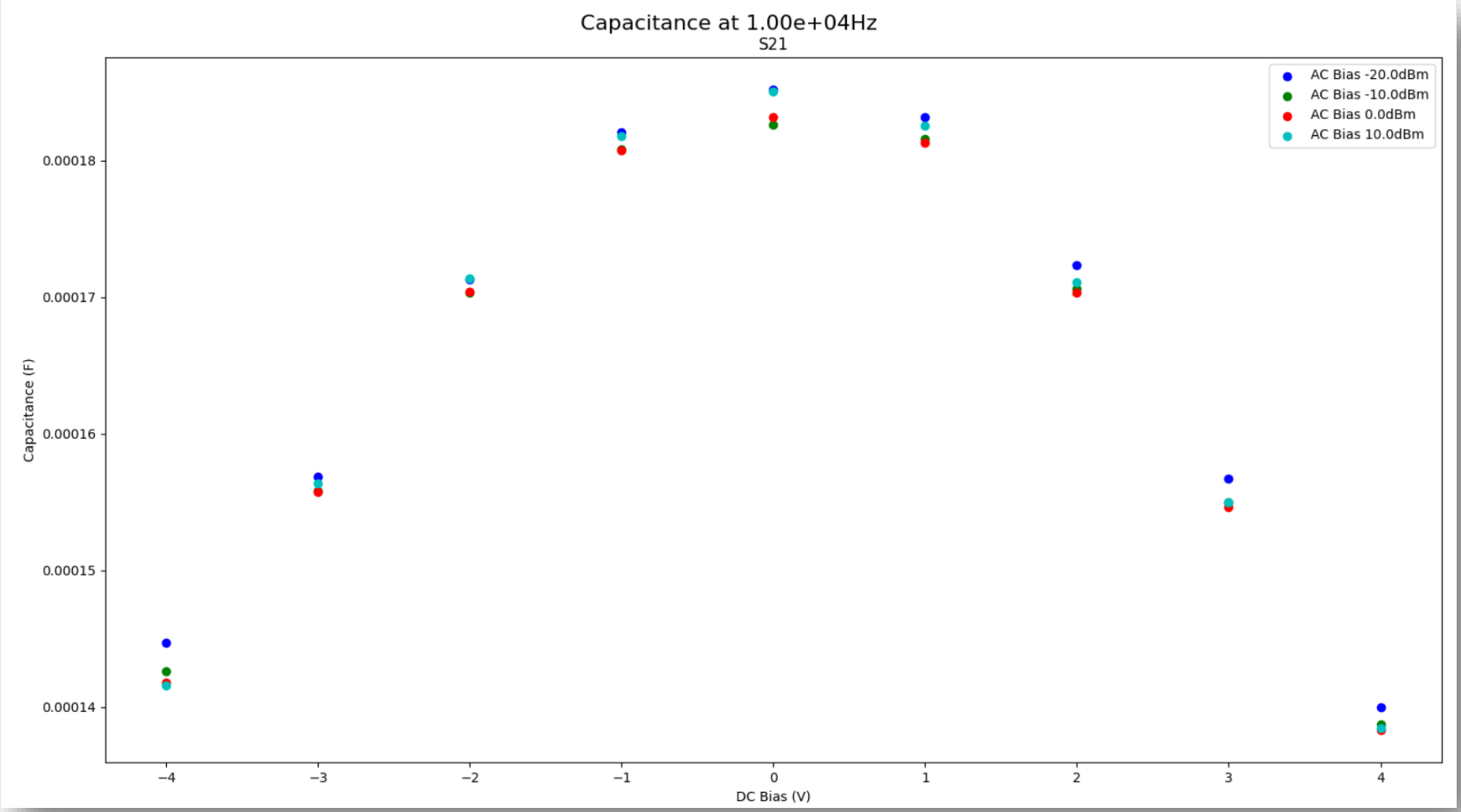

3D Capacitance Video

Series topology, Amotech 220nF MLCC, from S21 only

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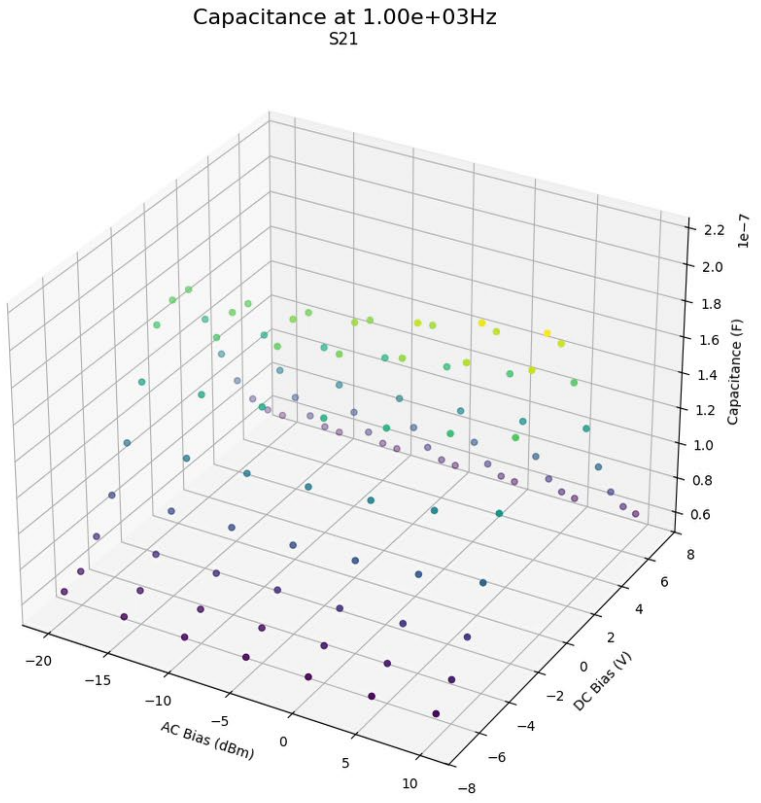

Summary and Conclusions

- Python automation code automates DC and AC bias sweeps
- Python code extracts series equivalent capacitor parameters assuming series or parallel topology
- Python code visualizes Touchstone files and extracted parameters in 2D and 3D plots
- Large data sets and rich visualization options enable deeper data mining and better characterization of parts
- The validity of calibration over the full selected sweep ranges has to be evaluated
- Cs and Ls can be uniquely solved only far from the series resonance frequency
  - In the valid frequency range, there is no need to de-embed small fixtures
  - De-embedding the fixture allows us to properly extract Ls and Rs above the series resonance frequency

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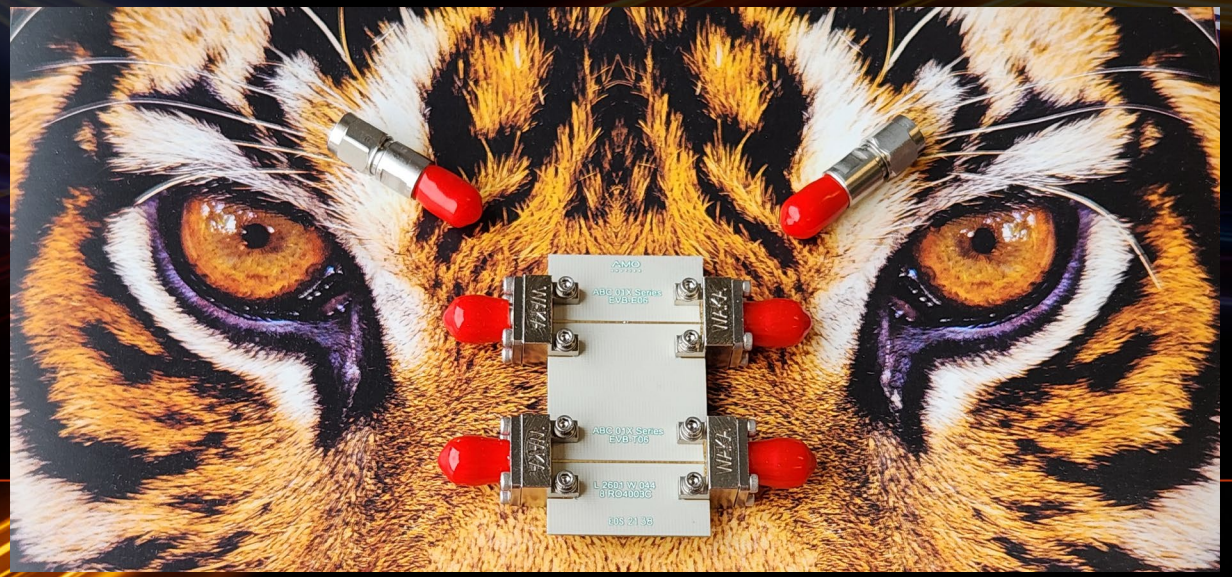
THANK YOU!



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