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ECU Test Methods

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HFCircuits

Goals related to stability of electronic calibration units (ECU):

- Describe methodology to test stability of ECUs (document)
- Collect and analyze test data (data)
- Write Best Practice Guide (document)

Done by METAS, PTB, SP

Purpose of stability tests

1. Understand long and short term stability of ECUs
   - Stability of ECU states
   - Repeatability of switching
   - Sensitivity to temperature variations
   - Connector repeatability

2. Give advice to end users
   - Recalibration intervals
   - Best practice, handling

Target audience for ECU stability tests

- NMIs
- Manufacturers of ECUs
- Ev. calibration labs

Effects to be considered

- Heat flow between ECU and VNA
- Connector repeatability due to stress and imperfections
- Stability of ECU states
  - during operation
  - due to ageing

Which quantities to look at

Possibilities:

- S-parameters of ECU states
- VNA error terms
- S-parameters of a DUT

- T tests: Heat flow primarily affects error terms of VNA → record changes in VNA error terms
- Stability of ECU states: record changes in S-parameters of ECU states

Requirements:

- Control of switching states of ECUs
- Calculation of VNA error terms from ECU measurements

Basic preparations

- Select VNA test ports to avoid connector resonance effects
- Check basic stability of measurement system
- Measurement setup: Minimize cable movements
- VNA setup:
  - IF BW low to reduce noise
  - Set source power to avoid compression

Temperature stability (TS) tests

- Test port and ECU are at different temperature.
- Changes in VNA error terms occur when ECU and test port are connected until equilibrium is reached.
- Perform tests to determine size of effect and time constants related to T changes
- Investigate dependency on setup: with / without cable

Test TS1a

A test port cable is installed between the VNA port and the ECU.

The following procedure is carried out at one single frequency or a reduced number of frequencies to keep the time interval between measurements reasonably short.

1. ECU is turned on and ready.
2. Connect ECU and immediately start measuring ECU states repeatedly. Use the measurements of the ECU states to determine the VNA error terms and record their drift over time.

TS1b: the same but without test port cable

Test TS2

With test port cable between VNA port and ECU.

Do reduced number of frequencies (timing!)

1. Connect ECU and wait until the system is in temperature equilibrium.
2. Perform a one port VNA calibration with the ECU.
3. Disconnect ECU and immediately connect a mechanical short standard.
4. Immediately start measuring mechanical standard repeatedly and record drift over time.

Repeat for mechanical load and open standard. Avoid heating from human skin contact.

Test TS3

1. Place the ECU inside a temperature controlled chamber while the VNA stays outside. One port of the ECU is connected through a test port cable to the VNA. The test port cable should be kept outside the chamber, to be affected by temperature changes in the chamber as little as possible.
2. Perform a one port calibration of the VNA with the connected ECU at nominal lab temperature $T_0 = 23C$ in chamber.
3. Set temperature in chamber to $T_0 + \Delta T$. Wait until temperature equilibrium is reached in chamber.
4. Make measurements for all states of the ECU.
5. Repeat 4 to 5 for different ΔT. Record changes as a function of ΔT.

Connector repeatability (CR) tests

- Determine influence of connection between ECU and test port during measurement
- Measurements at different connector orientations
- Deembed S-parameters of connector from VNA error terms
- Influenced by quality of test port connectors

Test CR1

1. Directly connect ECU to VNA test port cable in horizontal orientation, wait until temperature equilibrium is reached
2. Do measurements of all ECU states to determine VNA error terms $\mathbf{E_1}$
3. Repeat measurements of all ECU states at different connector orientations and determine new VNA error terms $\mathbf{E_2}, \mathbf{E_3}, \ldots$.
4. De-embed the mean of all error terms $\langle \mathbf{E} \rangle$ from all subsequently determined error terms to calculate the change in S-parameters of the connector $\mathbf{C_1}, \mathbf{C_2}, \mathbf{C_3}, \ldots$.
   $\mathbf{E_i} = \langle \mathbf{E} \rangle \oplus \mathbf{C_i} \longrightarrow \mathbf{C_i} = \mathbf{E_i} \ominus \langle \mathbf{E} \rangle$ The operators $\oplus$ and $\ominus$ denote cascading and decascading, respectively.

Alternatively it is possible to look at pairwise differences:
$\mathbf{C_i} = \mathbf{E_i} \ominus \mathbf{E_{i-1}}$. This is less prone to drift.

Long term stability (LS) tests

- Record drift of ECU states due to ageing
- Comparison with a mechanical kit that is assumed to be stable
- Supported by verification

Test LS1

Keep both test port cables fixed. Leave enough space between test ports that ECU can be connected to both, but not more.

1. Perform VNA Calibration on port 1: Mechanical SOL.
2. Perform verification measurements with previously characterized components (Open, Short, Load) on port 1.
3. Connect ECU to port 1. Connect short to free ECU port. Wait until temperature equilibrium is reached.
4. Measure S-parameters of ECU one port states with 50 MHz resolution.
5. Remove ECU from port 1 and repeat steps 1 to 4 for the other ECU ports.

Test LS1 continued

6. Leave ECU connected to port 2 (in case of 2-port ECU) and move test port cable 2 to connect ECU also to port 1. Wait until temperature equilibrium is reached.
7. Measure all ECU two port states. Use the ECU Thru state with lowest attenuation to perform an Unknow Thru calibration.
8. Verification: Remove ECU. Measure known 10 dB attenuator. Measure mechanical Thru. Keep test port cable 1 fixed during verification, just move cable 2
9. Record drift of one port and two port ECU states over time.

Alternatively one could use the ECU measurements to determine the VNA error terms and record their variation with respect to the error terms from mechanical calibration

Short term stability (SS) tests

- Stability of ECU states in minutes or hours

Challenges:

- How to distinguish between ECU and VNA drift
- How to avoid reconnection of ECU

2 tests are proposed that should be able to seperate ECU drift from VNA drift, at least to a certain extent

If the tests really produce conclusive results needs to be demonstrated

Test SS1

Connect two ECUs in series to the test port: VNA - ECU1 - ECU2.

Limit number of frequencies (timing!)

1. Measure all ECU1 one port states → Raw S-parameters: $M_{11}^{ECU1}(t_1)$
2. Set ECU1 to Thru and measure all one port states of ECU2 → Raw S-parameters $M_{11}^{ECU2}(t_2)$
3. Keep repeating steps 1 and 2.
4. Determine error terms of the VNA for each of the ECU measurement: $\boldsymbol{E}(t_i)$
5. Error correct the raw S-parameter measurements using the error terms from the previous measurement. E.g. calculate $S_{11}^{ECU2}(t_i)$ from $M_{11}^{ECU2}(t_i)$ and $\boldsymbol{E}(t_{i-1})$.
6. Calculate differences $\Delta S_{11}(t_i) = S_{11}^{ECU1}(t_i) - S_{11}^{ECU2}(t_{i-1})$.
7. Record changes in $\Delta S_{11}(t_i)$ over time.

Test SS2

Connect a single ECU to a test port.

The following procedure should be done at a single frequency or a reduced number of frequencies to keep time intervals between measurements reasonably short.

1. Measure all ECU states repeatedly.
2. Calibrate the VNA based on all states with an over-determined technique where all states have the same weight.
3. Record the changes of the error corrected values of all ECU states with respect to the first measurement.

Inventory

METAS

Shortcut	Model
M:E01	ECU Agilent N4690C, 2 x Type-N (f-m), 300 kHz - 18 GHz
M:E02	ECU Agilent N4691B, 2 x 3.5 mm (f-m), 300 kHz – 26.5 GHz
M:E03	ECU Agilent N4693A, 2 x 2.4 mm (f-m), 10 MHz - 50 GHz
M:E04	ECU Agilent N4694A, 2 x 1.85 mm (f-m), 10 MHz - 67 GHz
M:E05	ECU Agilent N4694A, 2 x 1.85 mm (f-m), 10 MHz - 67 GHz

PTB

Shortcut	Model
P:E01	Rohde&Schwarz ZV-ZV52, 4 x 3.5 mm (f-f-f-f), 10 MHz – 24 GHz
P:E02	Anritsu 36585V, 2 x 1.85 mm (f-f), 70 kHz - 70 GHz
P:E03	Anritsu 36585V, 2 x 1.85 mm (f-f), 70 kHz - 70 GHz
P:E04	Agilent N4694A, 2 x 1.85 mm (f-m), 10 MHz - 67 GHz
P:E05	Agilent N4694A, 2 x 1.85 mm (f-m), 10 MHz - 67 GHz

SP

Shortcut	Model
S:E01	Agilent N4690B 2 x Type-N (f-m), 300 kHz – 18 GHz
S:E02	ECU Agilent N4691B: 2 x 3.5 mm (f-m), 300 kHz – 26.5 GHz

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