Laser characterization and modelling for the development of the Super LHC versatile transceiver

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Project background

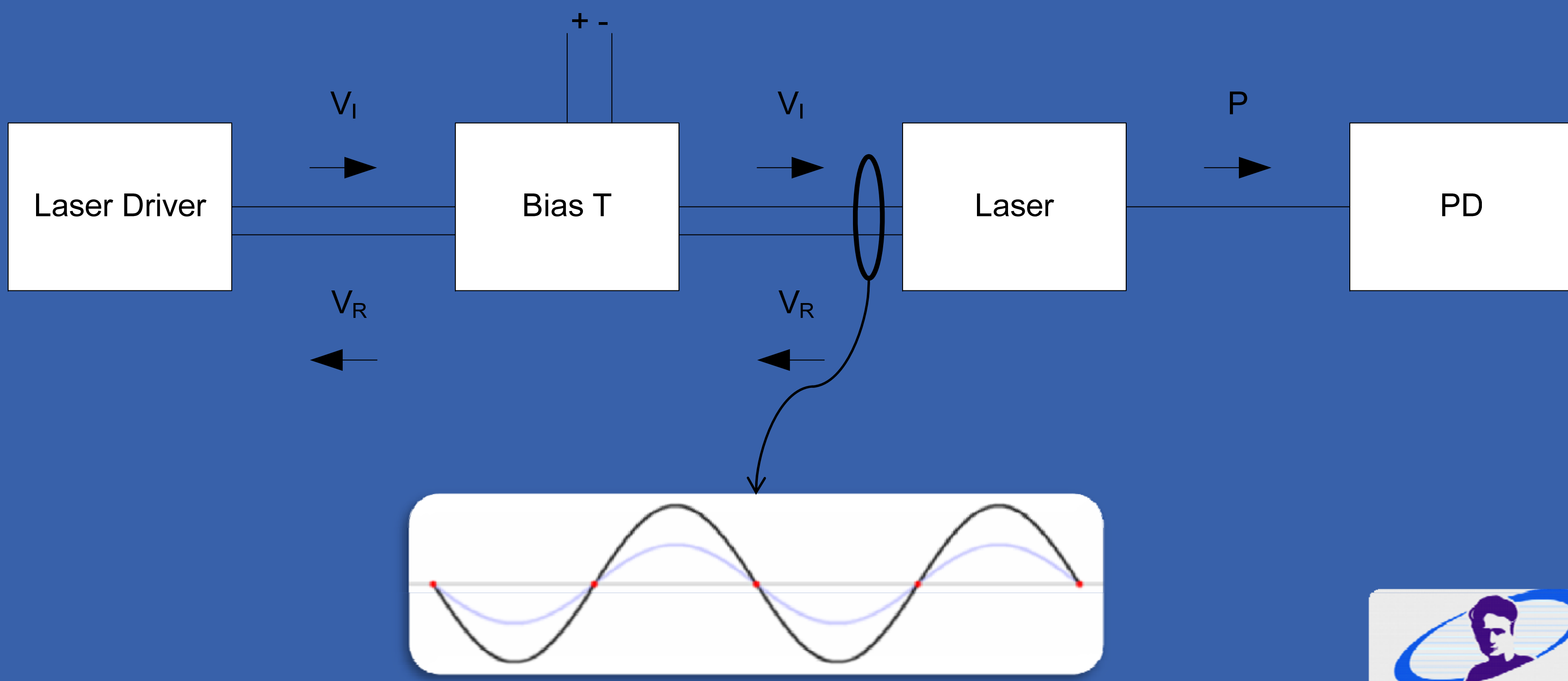
- An upgrade of the current LHC (super LHC or SLHC), planned for 2013-18, is expected to increase the luminosity by an order of magnitude to 10^{35} particles/cm^2/s.
- A tracking detector operating at the SLHC will require ten times more readout data bandwidth and radiation tolerance than at the current LHC detectors.
- Design a digital transceiver capable of operating at high speed (multiple GBits/s) and endure:
  - High radiation levels
  - High magnetic fields
  - Low temperatures

Why characterize LASER devices

- With a device characterization one can:
  1. Evaluate the LASER device
  2. Predict interaction between LASER, driver and connection network:
     - Design matching network
     - Peaking circuit / Pre-Emphasis
     - DC electrical interface (Bias-T)
  3. Predict performance degradation with environment conditions (temperature, radiation)
  4. **Design better systems**

Why characterize the LASER devices

- Interaction between LASER, driver and connection network:
  - Electrical impedance mismatch should be kept < 10%

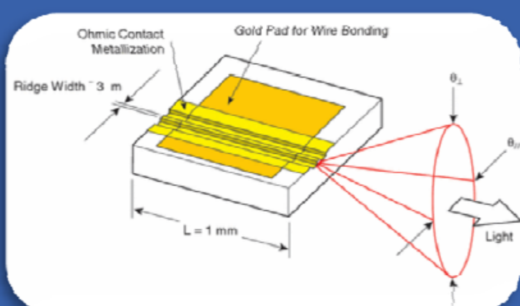


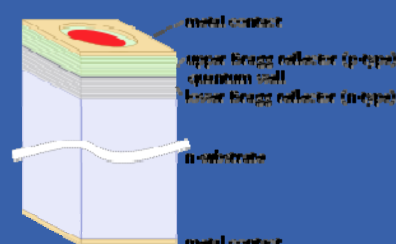
What to characterize in the LASER device

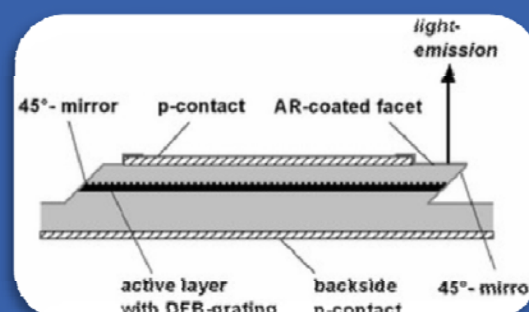
- Laser characterization
  - Power / Current / Voltage Curves
  - S-Parameters
    - Direct measurements
    - Static values obtained for a finite number of device working conditions
- Then, using input from characterization, make model
  - Predict device behaviour
    - Current threshold, BW & wavelength changes
      - Temp
      - Radiation
    - Device package modifications

Types of LASER devices

- Semiconductor LASER devices:
  - FP (Fabry-Perot LASER)
  - DFB (Distributed Feedback LASER)
  - DBR (Distributed Bragg Reflector LASER)
  - VCSEL (Vertical Cavity Surface Emitting LASER)
  - HCSEL (Horizontal Cavity Surface Emitting LASER)

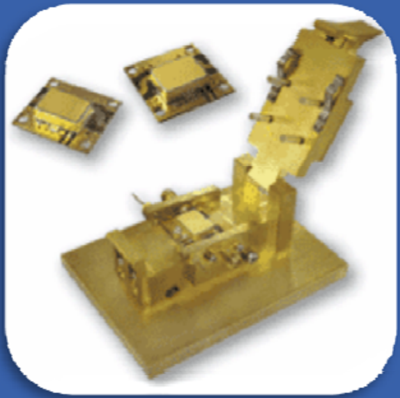






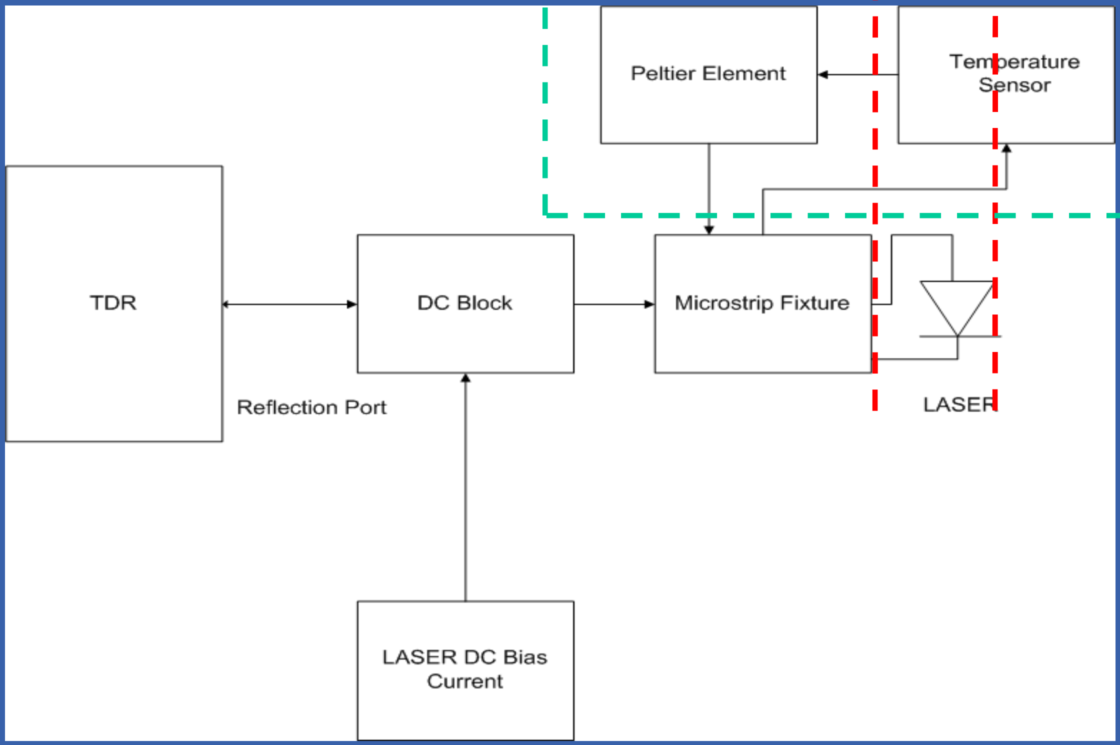
Measurement setup

- TDR Setup

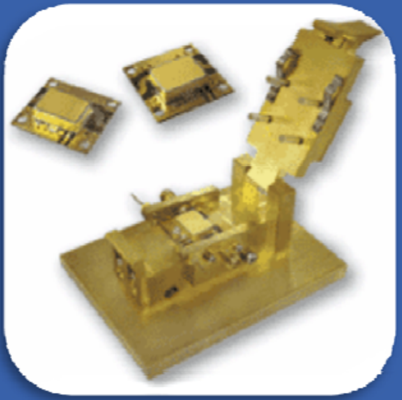


Calibrate here

Cooling system



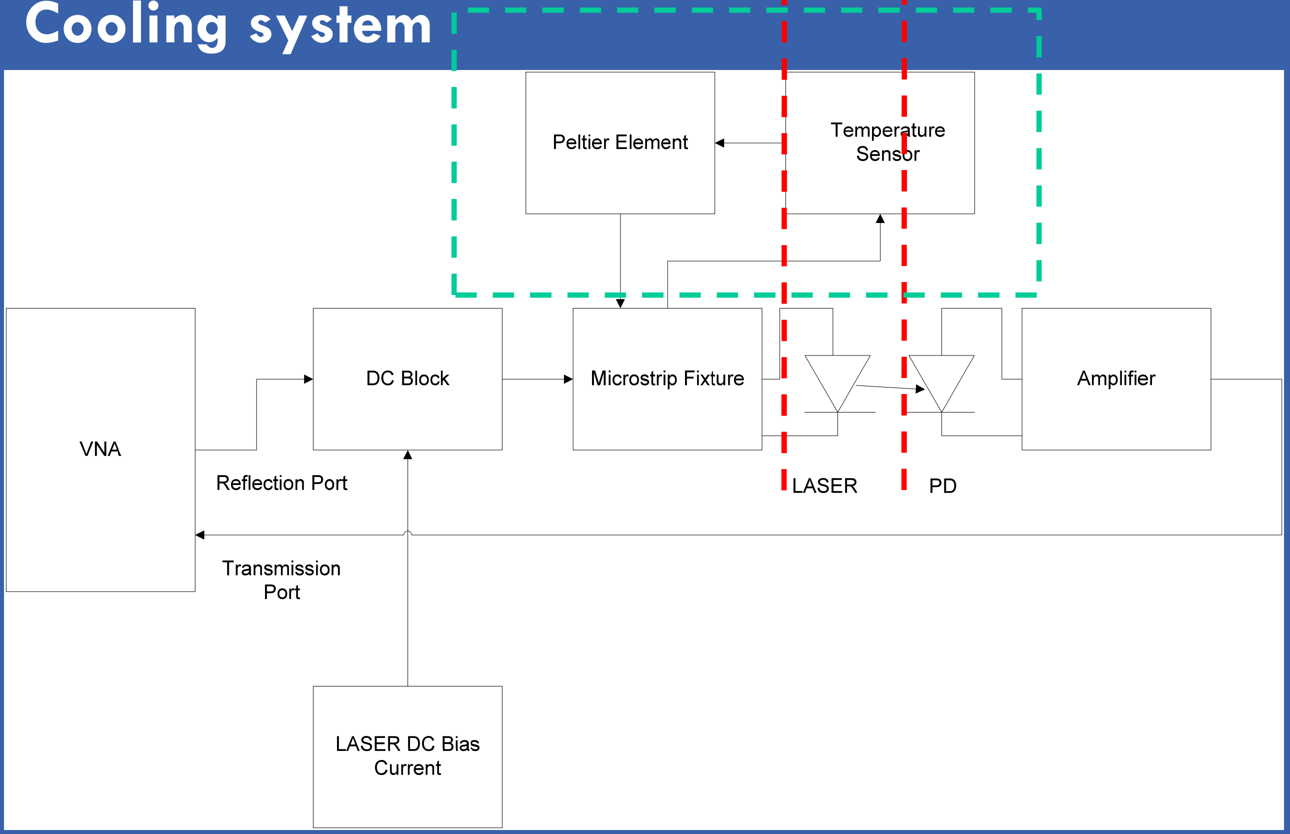
Measurement setup



- VNA Setup

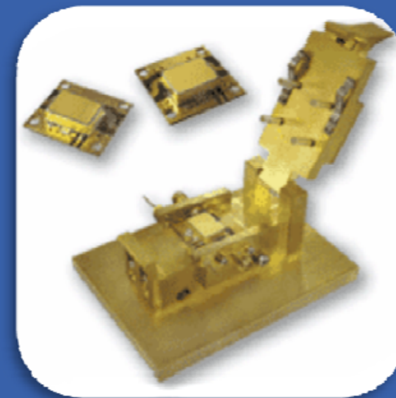
Calibrate here

Cooling system

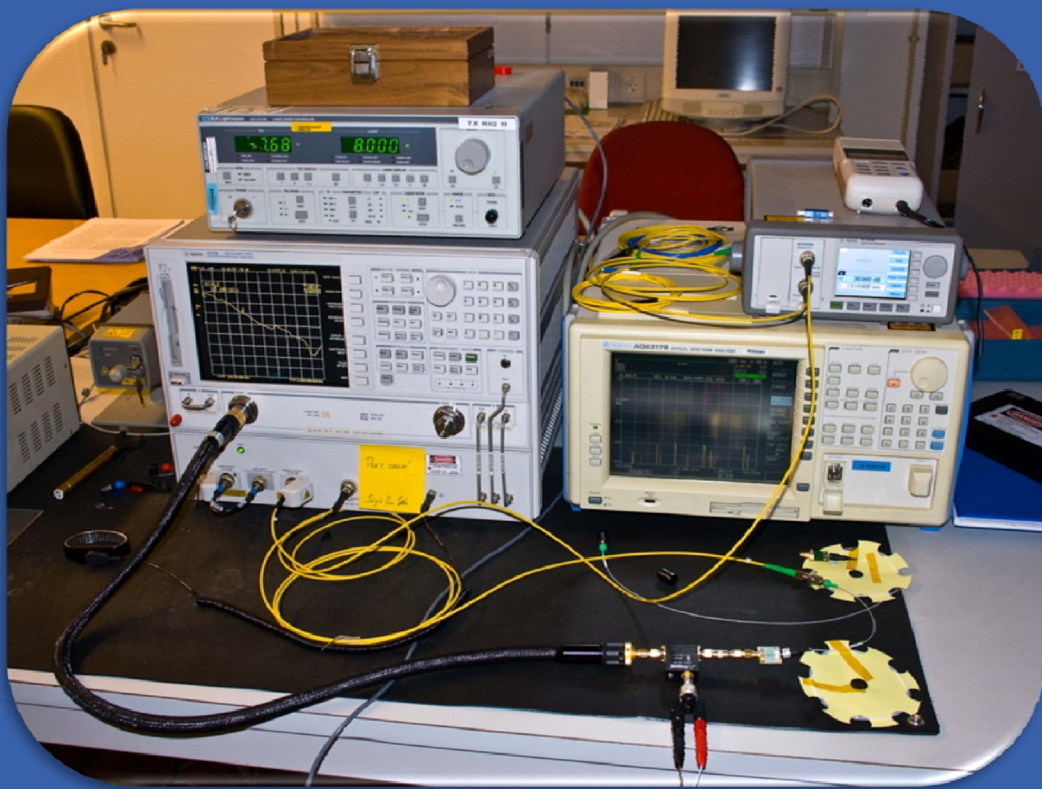


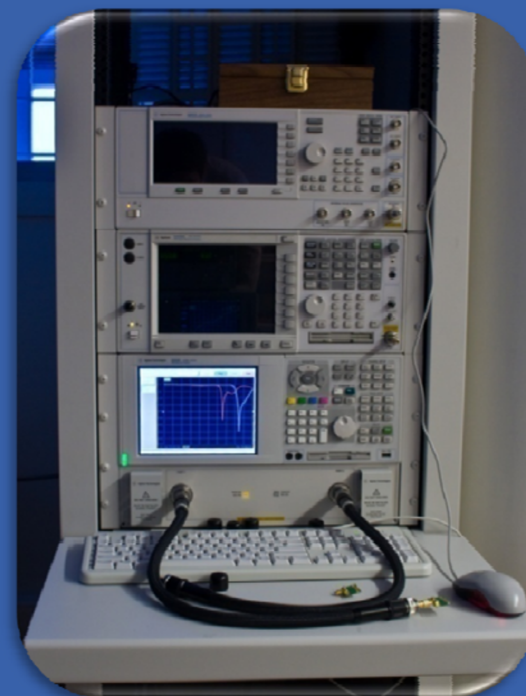
MARIE CURIE ACTIONS

Measurement setup



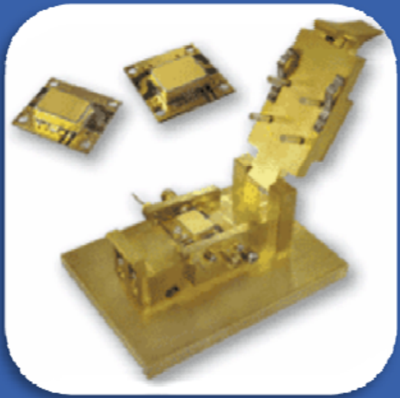
- VNA Setup



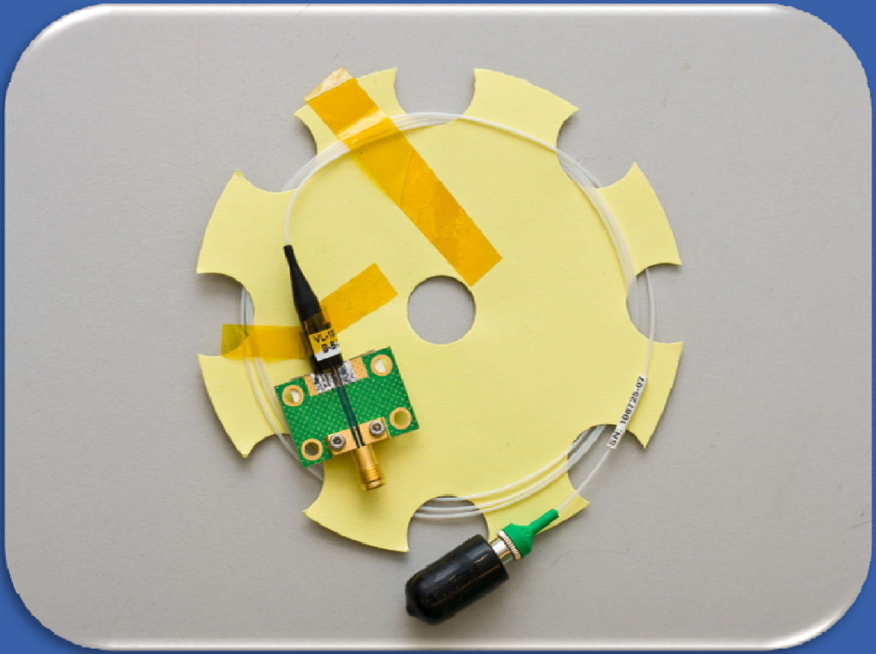


MARIE CURIE ACTIONS

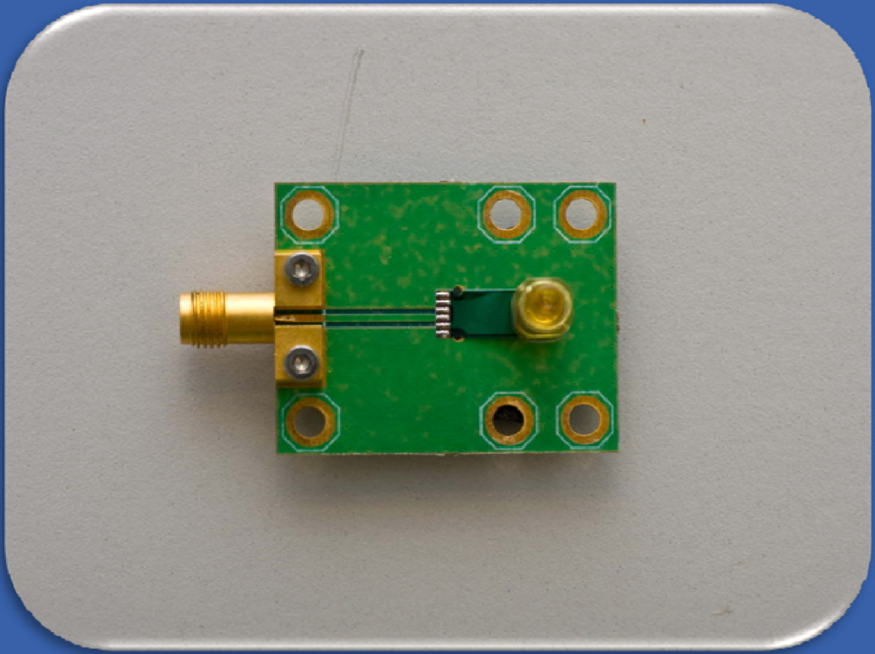
Measurement setup



- Laser assembly

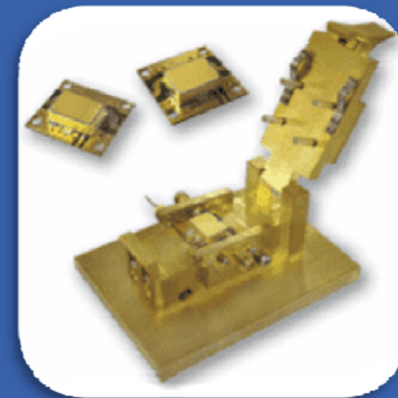


Wired Laser

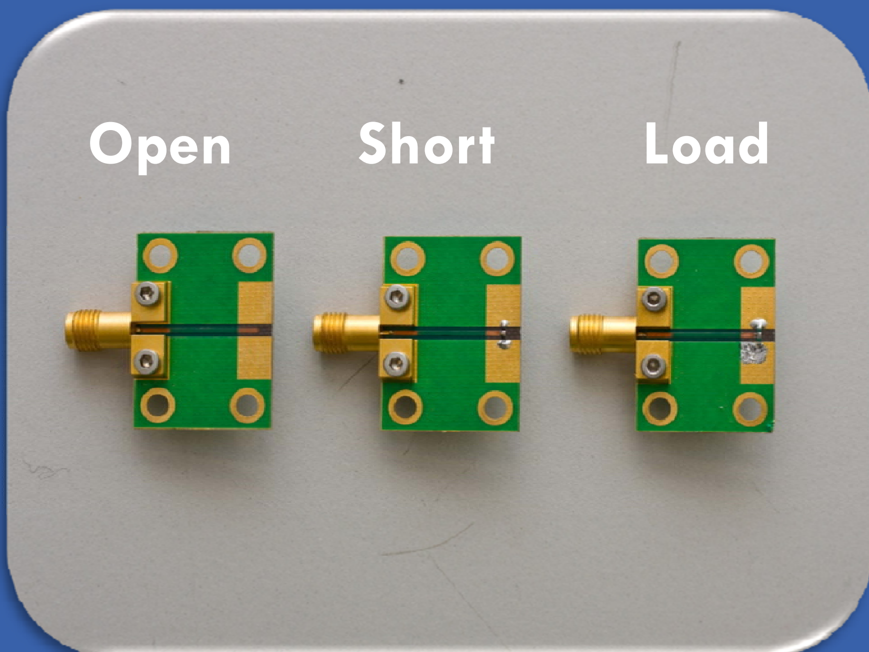


Flex Strip Laser

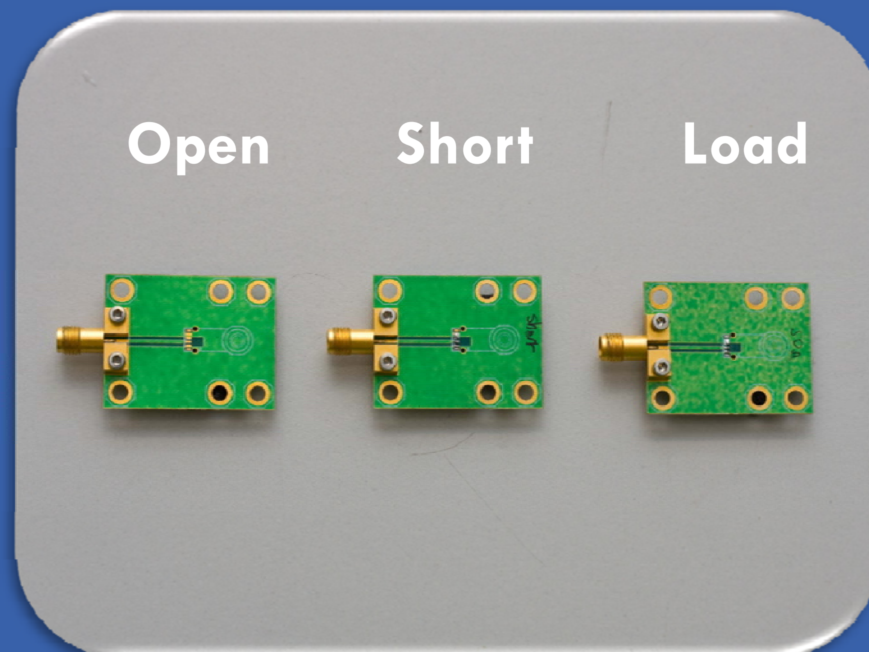
Measurement setup



- Test fixture calibration set

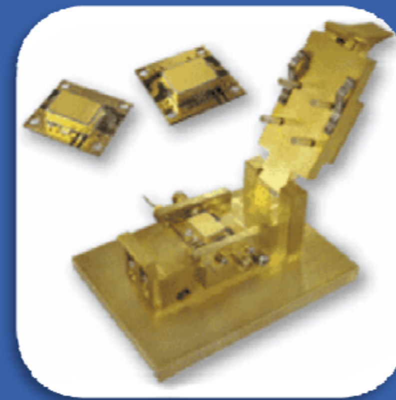


Wired Lasers

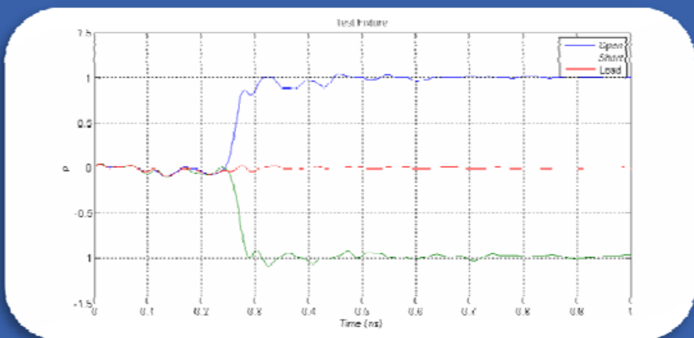


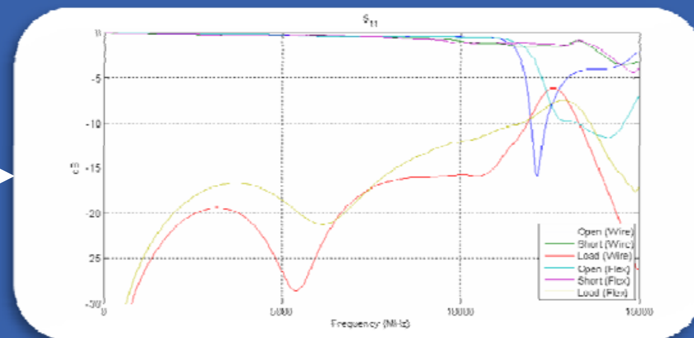
Flex Strip Lasers

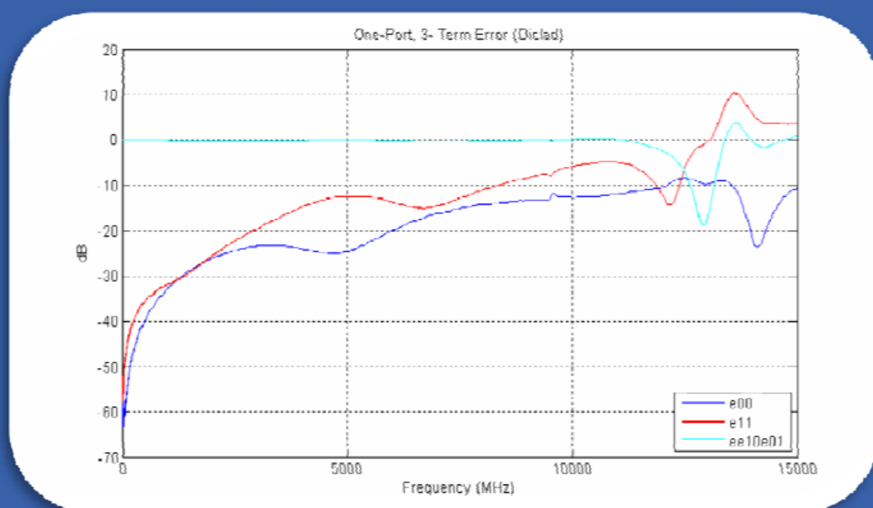
Measurement setup



- Testing & de-embedding of the test fixture:







3-Term Error Matrix

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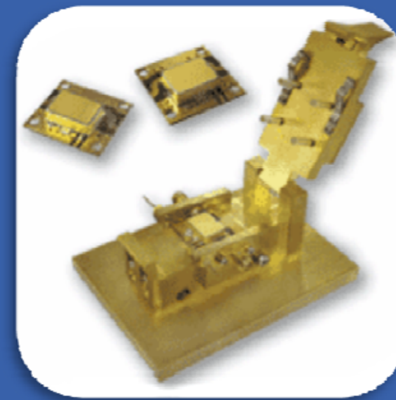
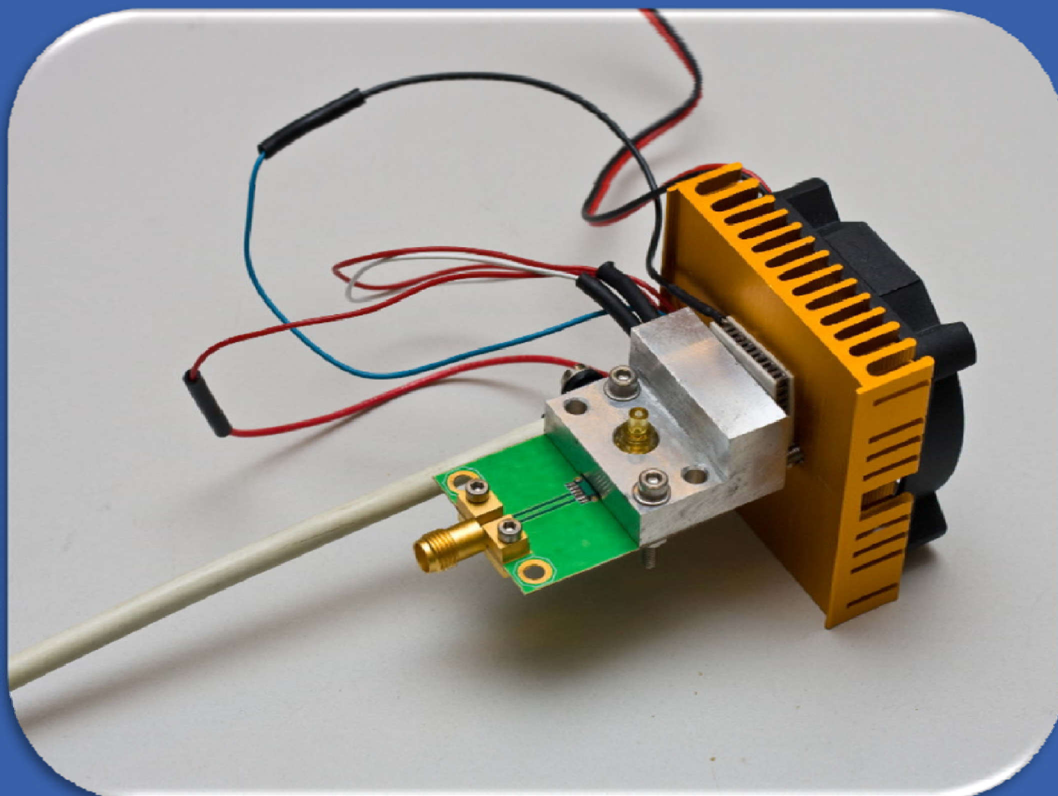
Measurement setup

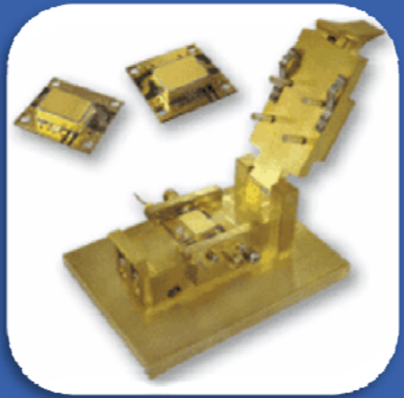


- Temperature control system:

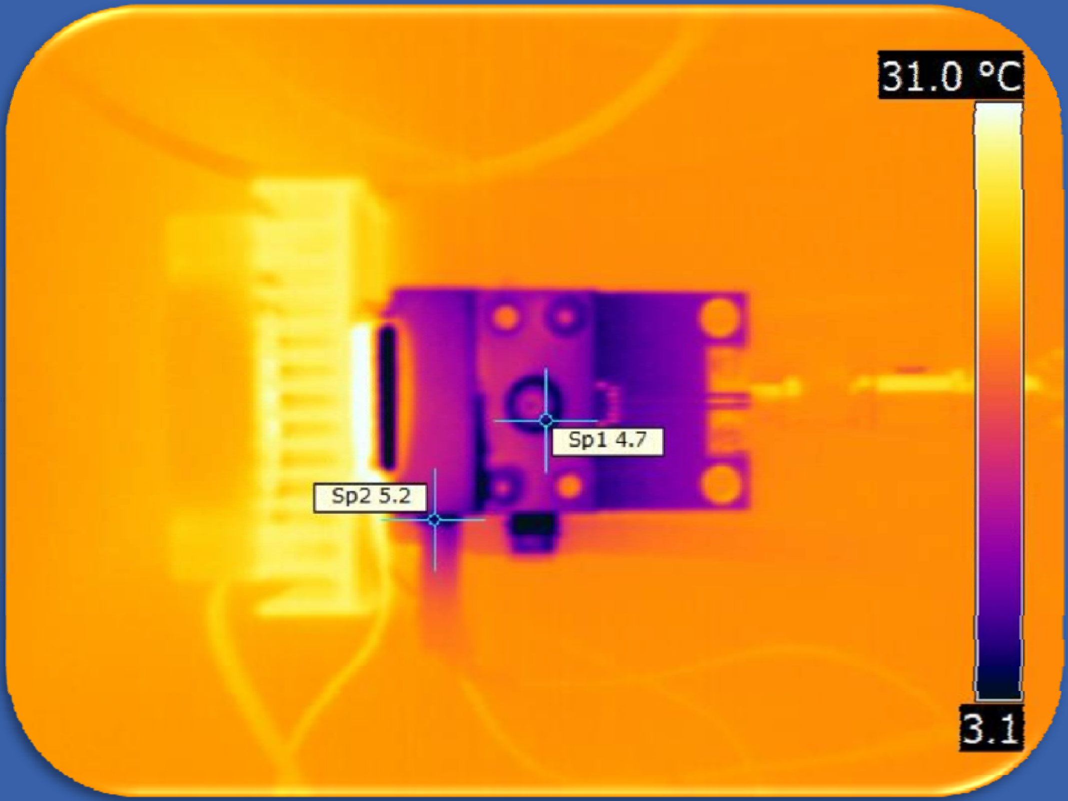


Peltier based thermo-electric laser cooling system

Measurement setup



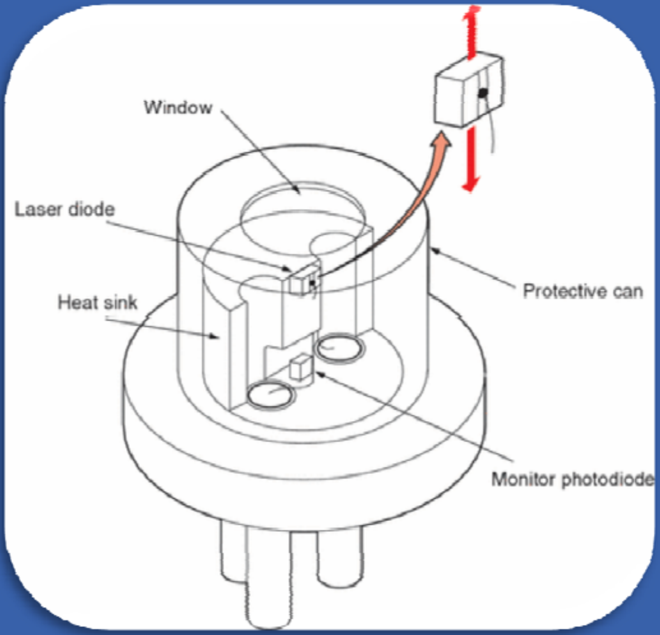
- Temperature control system:



Thermal image of the laser & cooling system set to 5°C

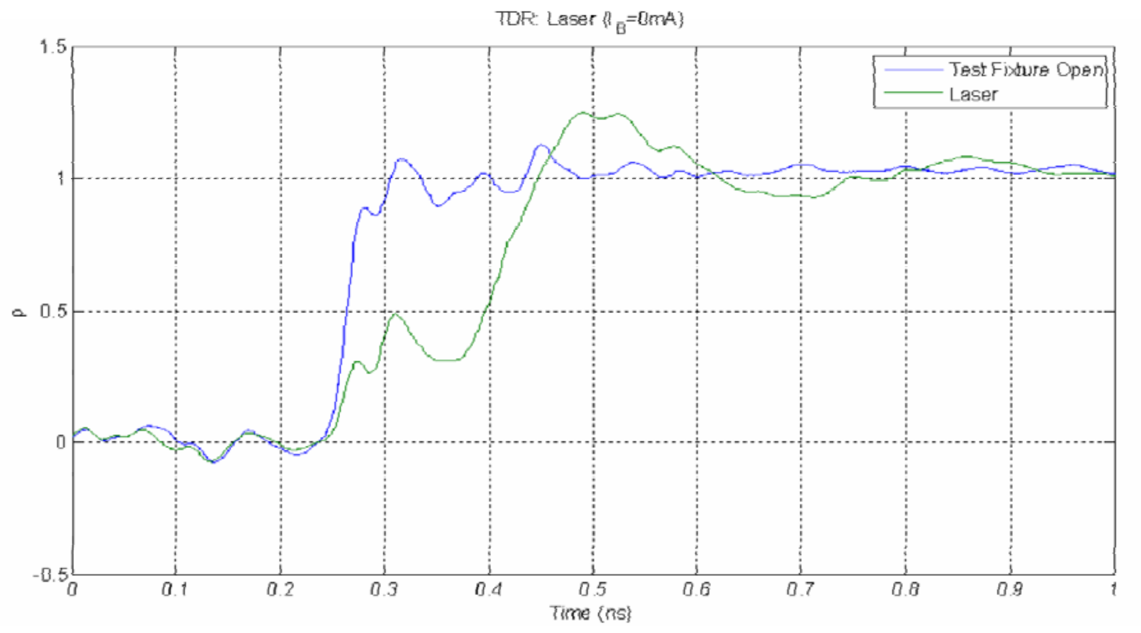
LASER model

- Measurements lead to simplified laser model
  - Chip & Package model
  - Intrinsic Laser
    - Large signal model
      - DC model
      - Large modulation currents
    - Small signal
      - Signal model
      - Small modulation currents



LASER model

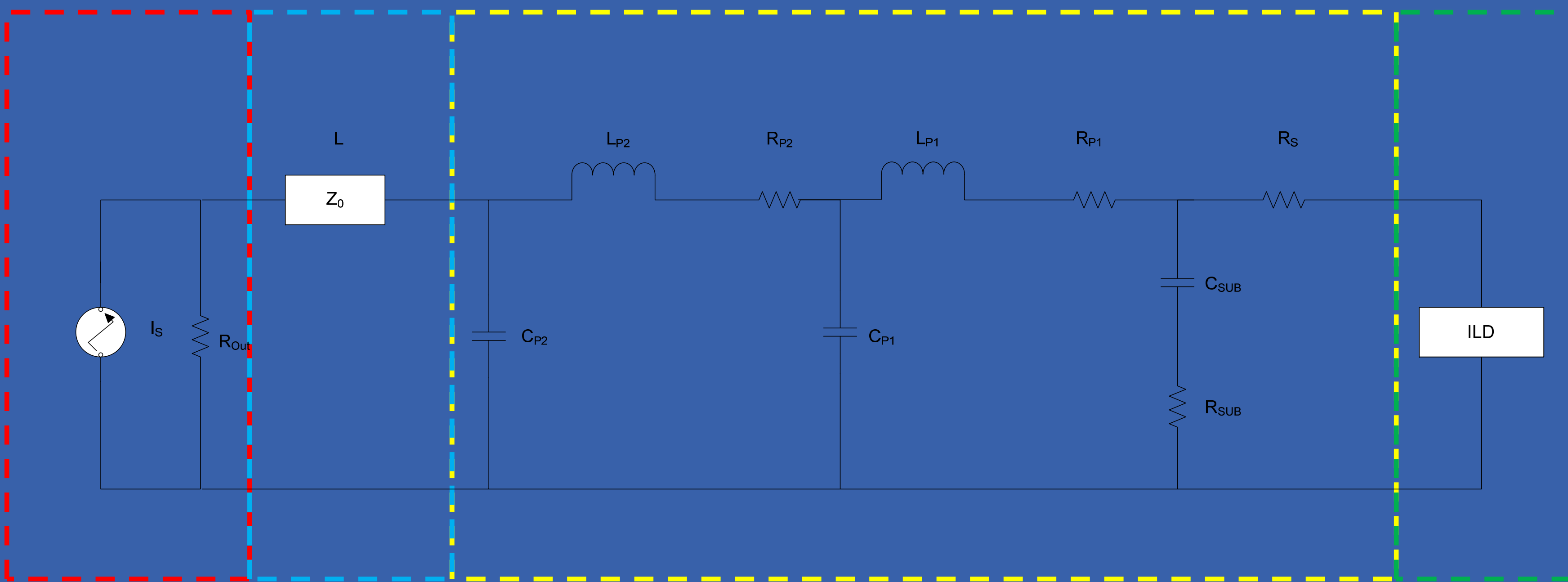
- Laser TDR measurement (I_{bias} = 0 mA)



(VL-1310-5G-P2-P4\108725-07)

LASER model

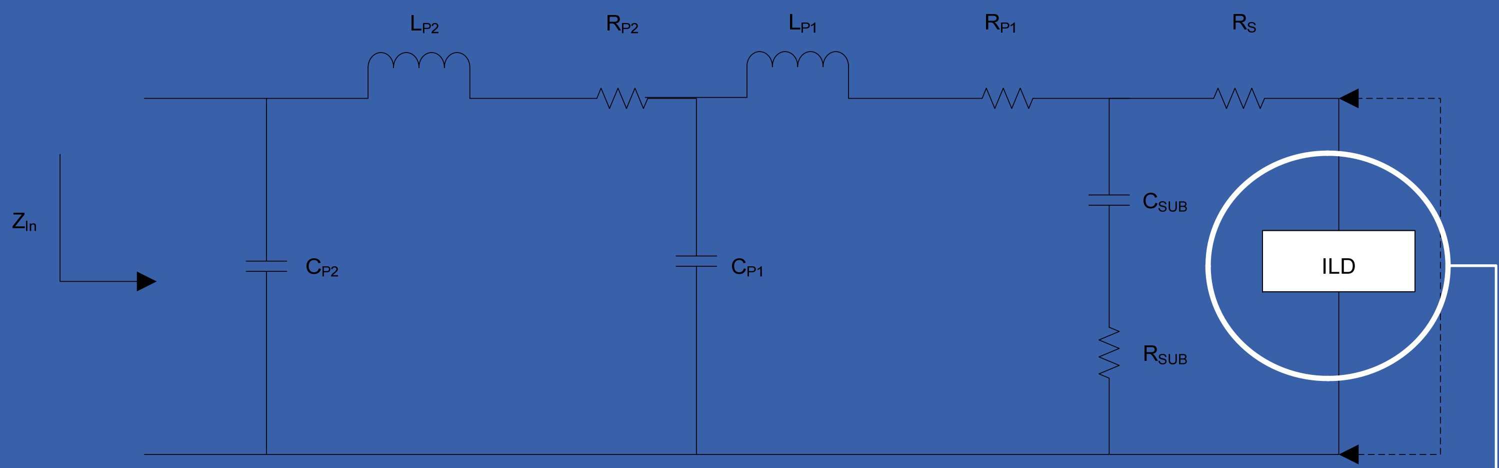
- Model used



Source **Test Fixture** **Chip & Package** **Intrinsic Laser**

LASER model

- Parasitic circuit model



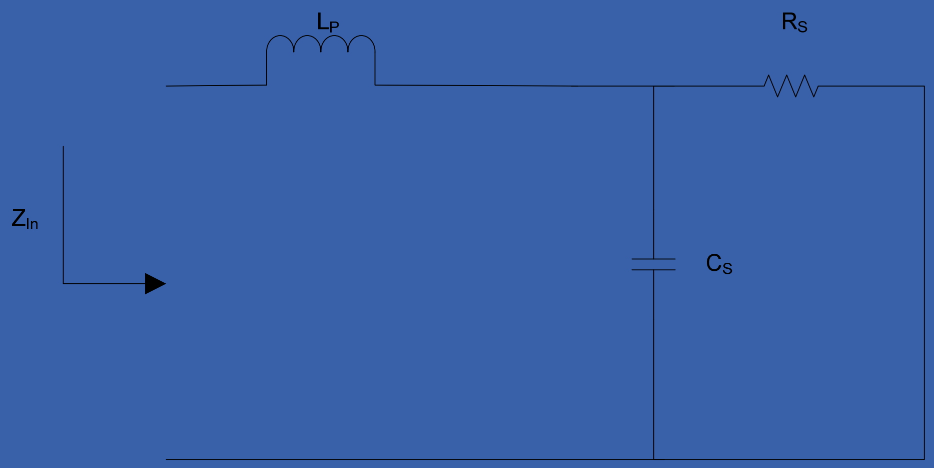
$$S_{11}(f) = \frac{Z_{In}(f) - R_0}{Z_{In}(f) + R_0}$$

Bias current should have a negligible effect in S_{11}: extract the parasitic model parameters using this data

For $I_{Bias} > I_{th}$, $|Z_{ILD}| << R_S$

LASER model

- Parasitic circuit simplified model



Parameters can be calculated directly from measurement data

LASER model

- ILD model: rate equations (semiconductor LASERs):

$$\frac{dN(t)}{dt} = \frac{I(t)}{qV_a} - g_0 \frac{[N(t) - N_0]S(t)}{1 + \varepsilon S(t)} - \frac{N(t)}{\tau_n}$$ **Carrier density**

$$\frac{dS(t)}{dt} = \Gamma g_0 \frac{[N(t) - N_0]S(t)}{1 + \varepsilon S(t)} - \frac{S(t)}{\tau_p} + \frac{\Gamma \beta}{\tau_n} N(t)$$ **Photon density**

$$\frac{d\phi(t)}{dt} = \frac{1}{2}\left[\Gamma g_0 [N(t) - N_0] + \frac{1}{\tau_p}\right]$$ **Optical phase**

$$p(t) = \frac{S(t) V_a \eta_0 \hbar \upsilon}{2 \Gamma \tau_p}$$ **Optical power**

- Model ILD using:
  - Explicitly through differential equations
  - Linear approximation at bias point
    - For small signal model
    - Simpler simulations

LASER model

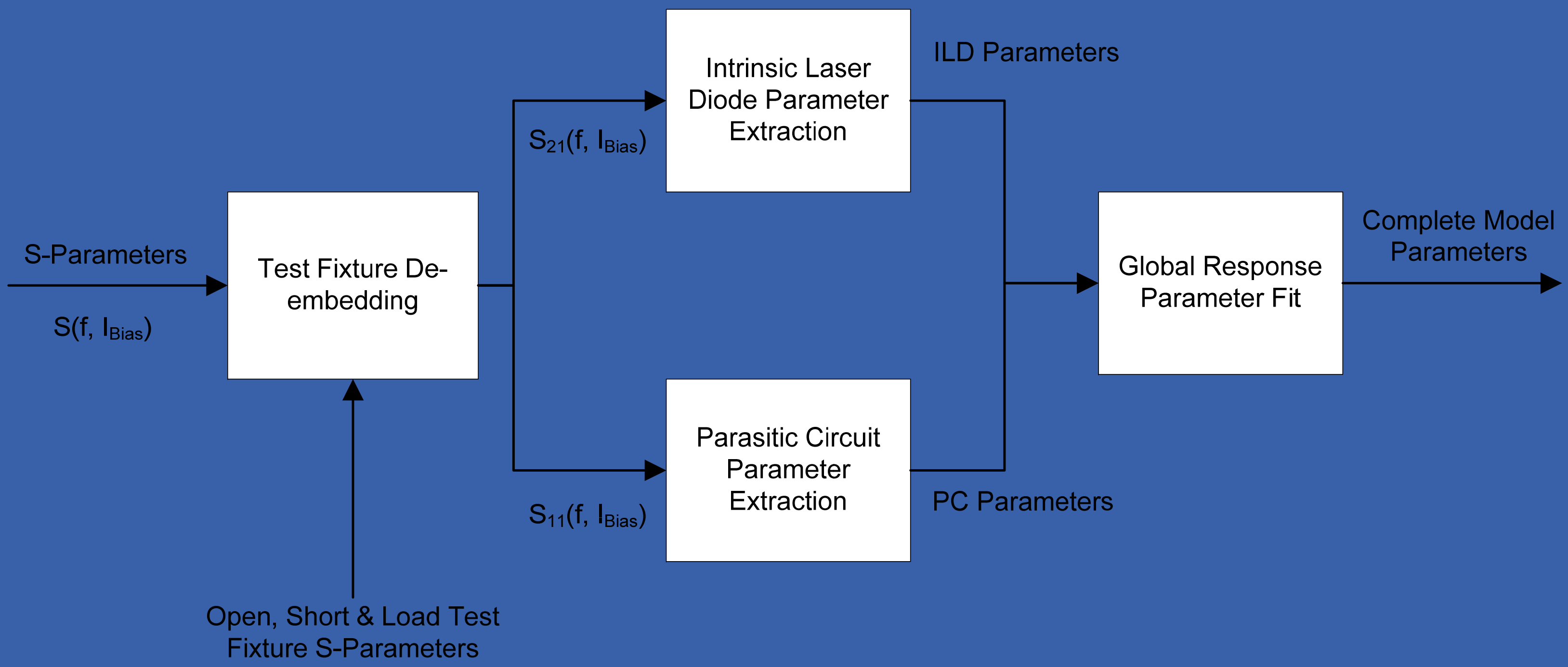
- Intrinsic Laser Diode Modelling

$$\frac{H_{Global}(f, I_{Bias})}{H_{Global}(f, I_{\text{Ref}})} = \frac{H_{ILD}(f, I_{Bias}) H_{PC}(f) H_{TF}(f)}{H_{ILD}(f, I_{Ref}) H_{PC}(f) H_{TF}(f)} = \frac{H_{ILD}(f, I_{Bias})}{H_{ILD}(f, I_{Ref})}$$

The ILD parameters can be extracted without the influence of the package parasitic effects

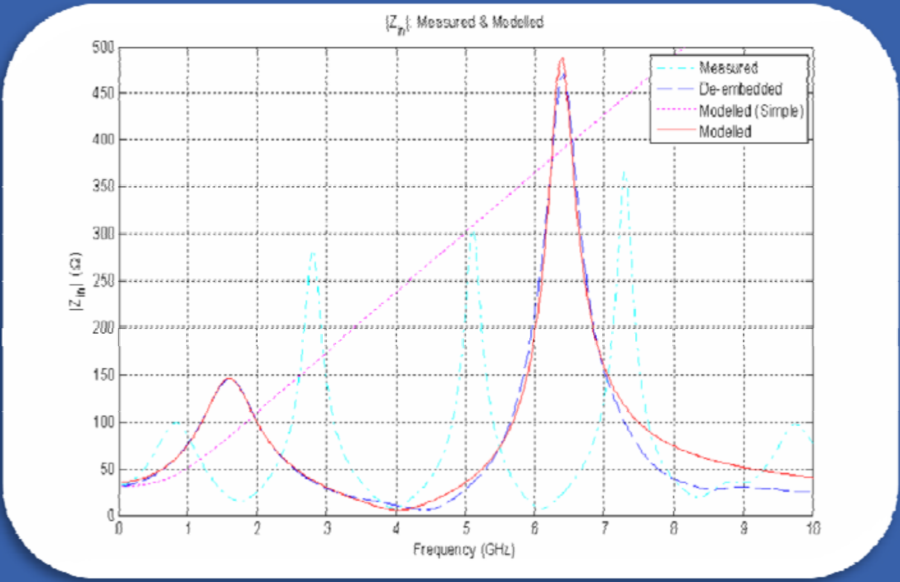
LASER model

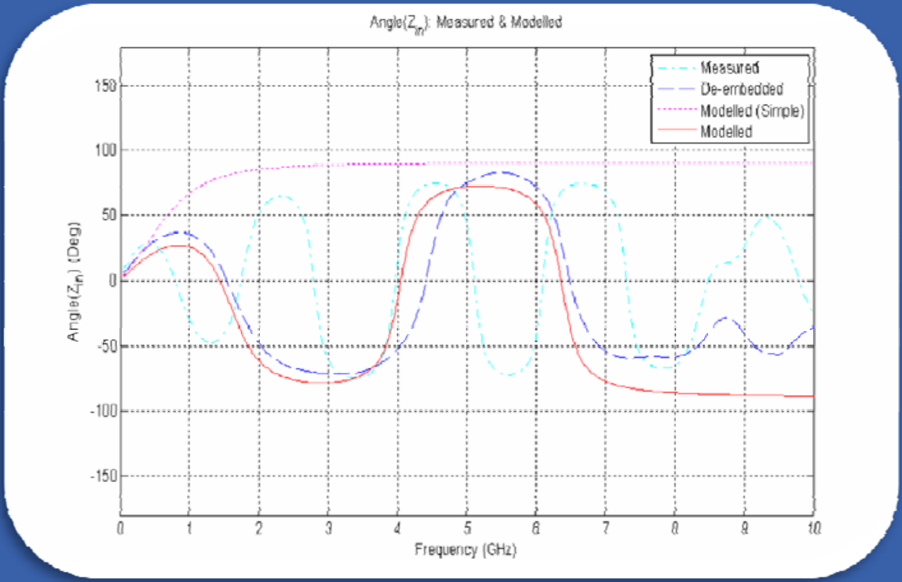
- Laser Model Parameter Extraction



LASER model

- Laser model : Input Impedance





Good fit in both magnitude and phase over the frequency range of interest

(VL-1310-5G-P2-P4\108725-07)

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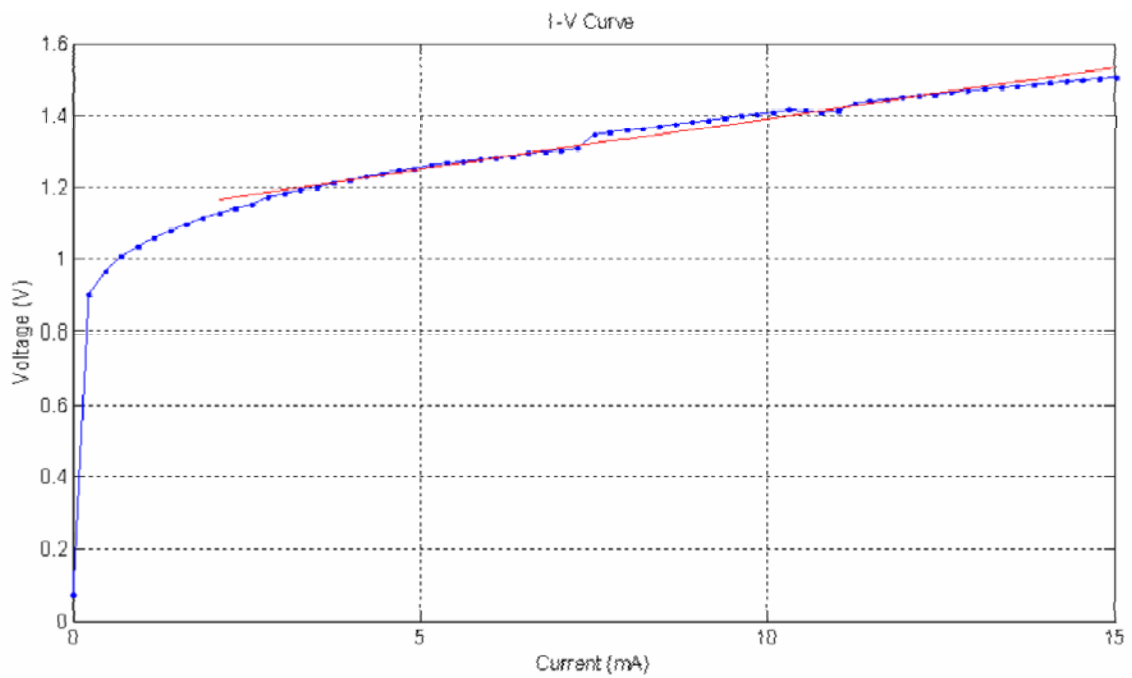
LASER model

- Laser model : Input Impedance



Agreement of DC internal resistance values between measures

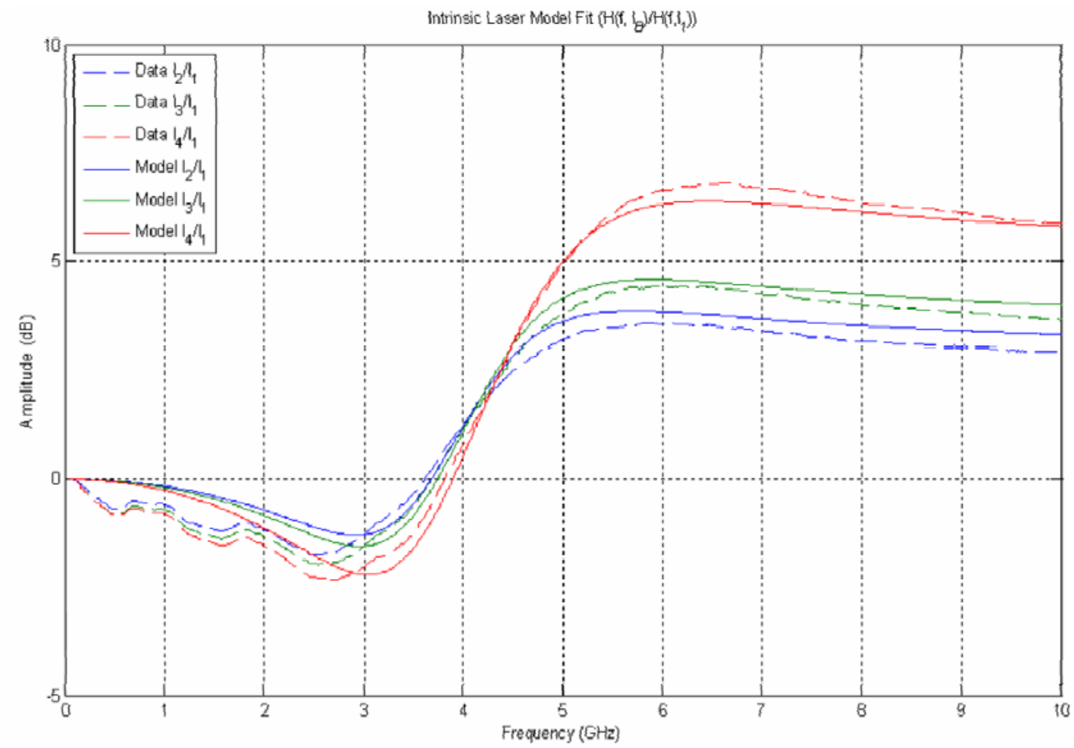
R_S=24 Ω (extracted from S_{11})
R_S=28 Ω (extracted from I-V)

(VL-1310-5G-P2-P4\108725-07)

MARIE CURIE ACTIONS

LASER model

- Laser model : Intrinsic Laser Model

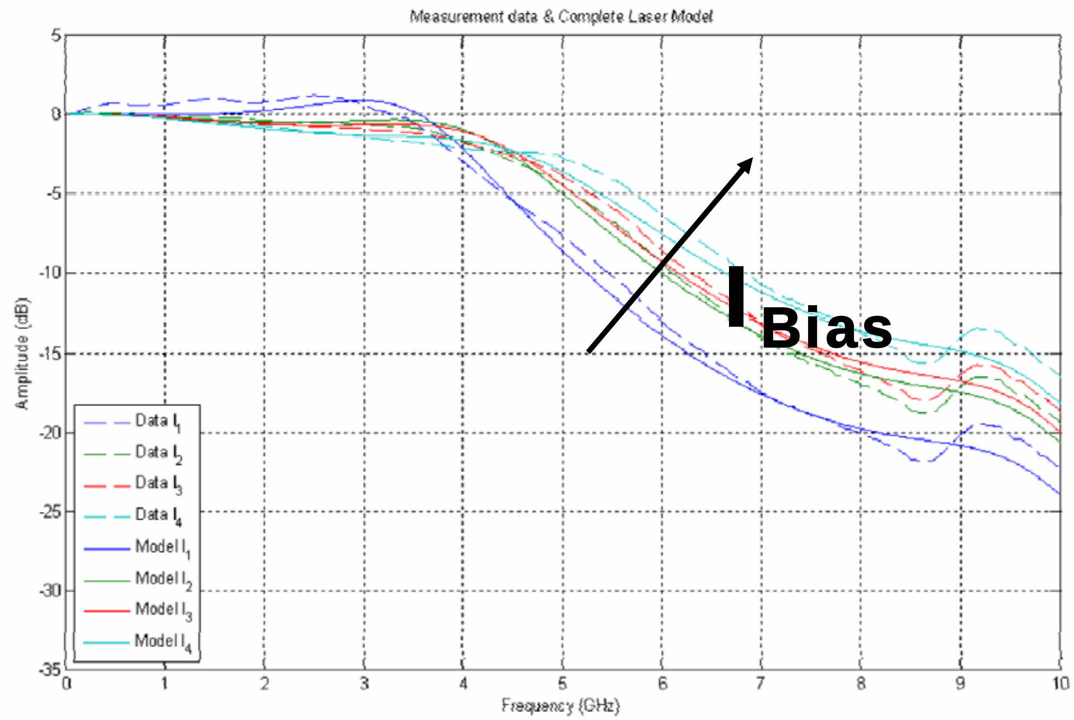


Good agreement between the curves obtained with the model and the measured data

(VL-1310-5G-P2-P4\108725-07)

LASER model

- Laser model : Global model (Transfer function)



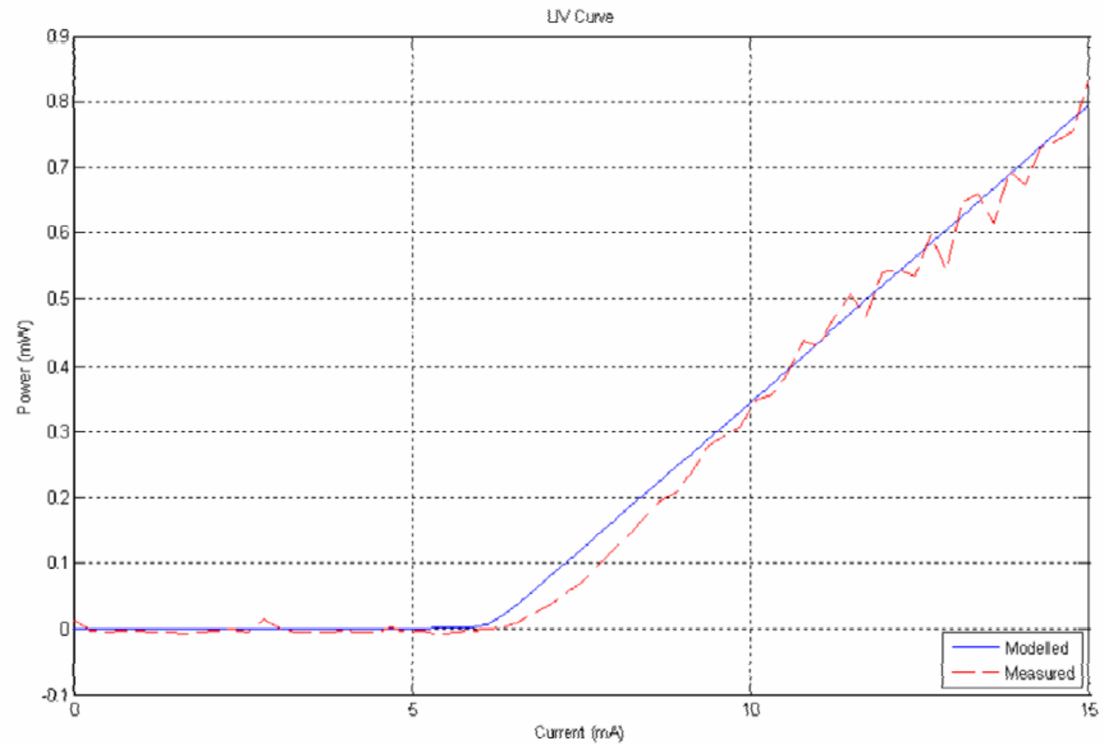
Good model fit:

- **Clear dependence on bias**
- **Bandwidth increases as bias increases**

(VL-1310-5G-P2-P4\108725-07)

LASER model

- Laser model : Global model (I-L Curve)

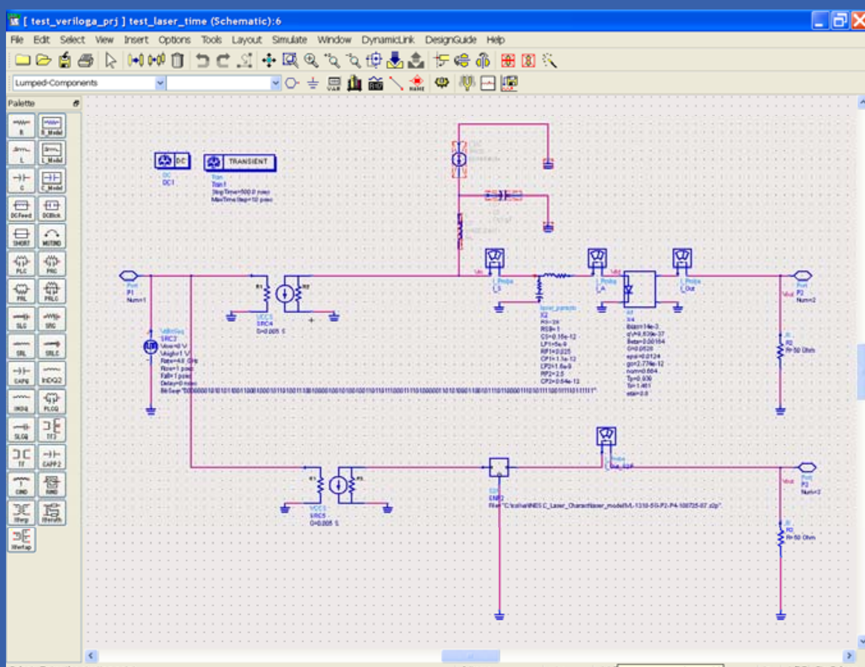


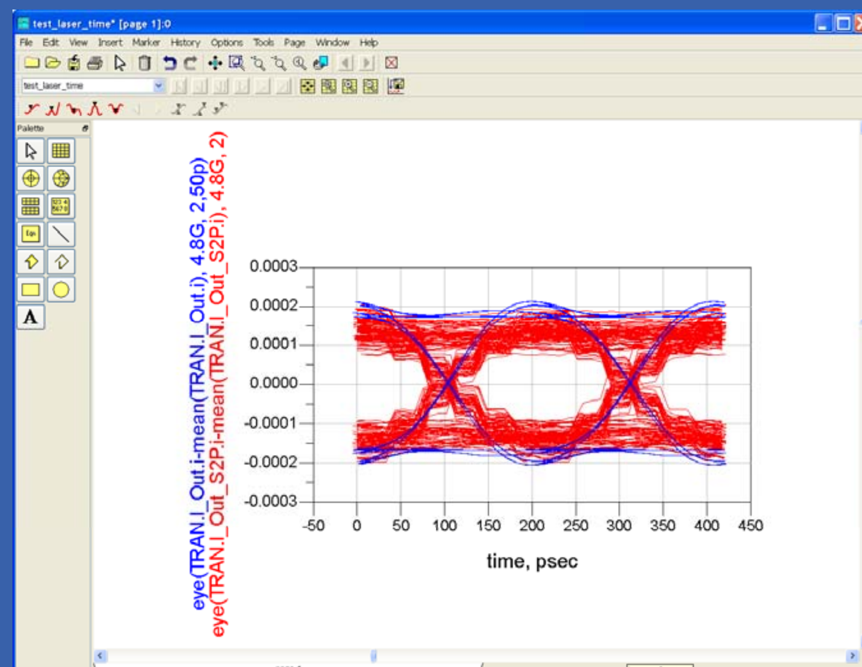
Model is able to predict back a quantity that was not included in the model fit

(VL-1310-5G-P2-P4\108725-07)

On going work

- Model tuning (evaluate model with transceiver designer):

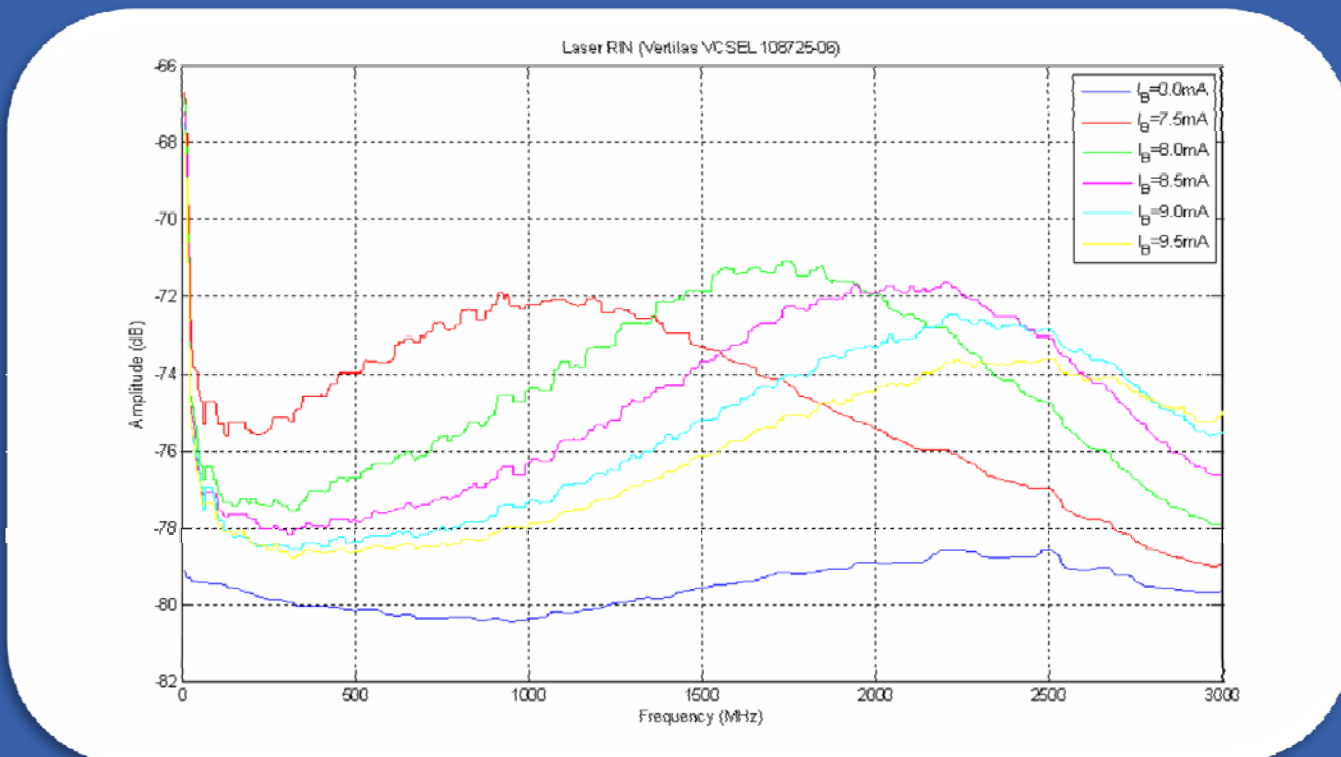




Simulation using the developed Verilog-A implementation of the laser model in ADS

On going work

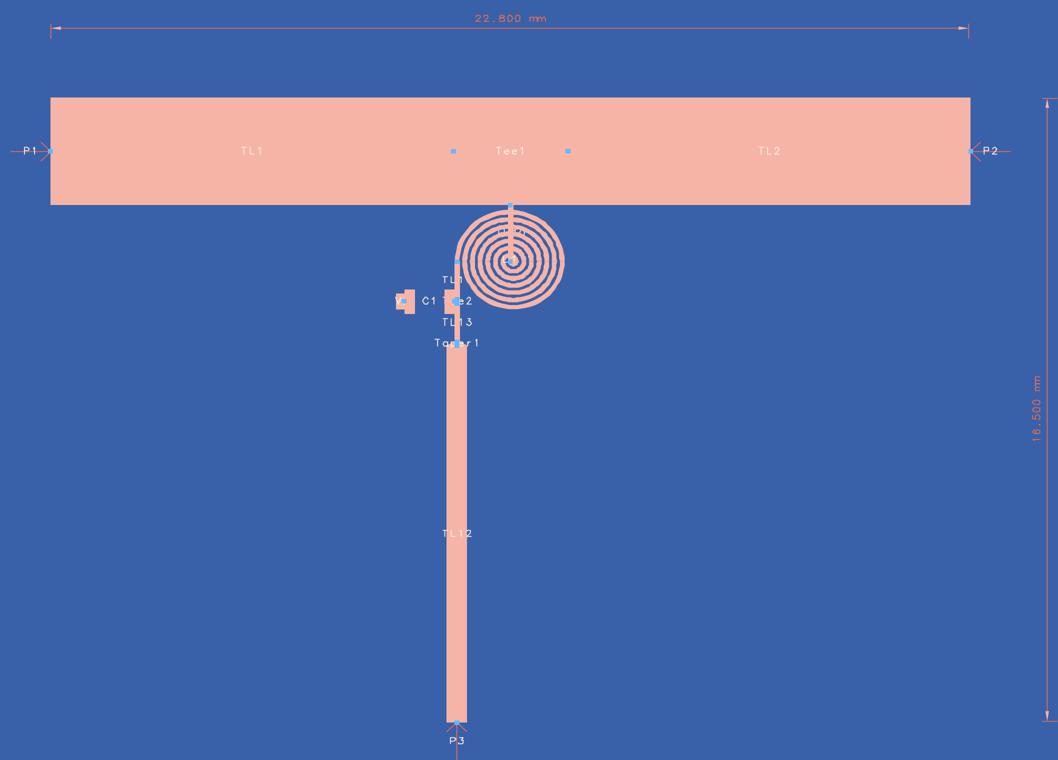
- Laser parameter extraction using noise (RIN) measurements:



(VL-1310-5G-P2-P4\108725-07)

On going work

- Microstrip Bias-T:



Conclusion

- A laser model suitable for large variety of laser was developed.
- Accurate modelling of the input impedance was achieved:
  - Essential for designing matching network and bias-T.
- Good agreement obtained between the ILD model and the measured data:
  - Transfer-function;
  - L-I curve;
  - Eye-Diagram.
- Development of good-practices in HF PCB layout.

Thank you for your attention!