Design and Validation of a Strain Gauge Simulator



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About Me..

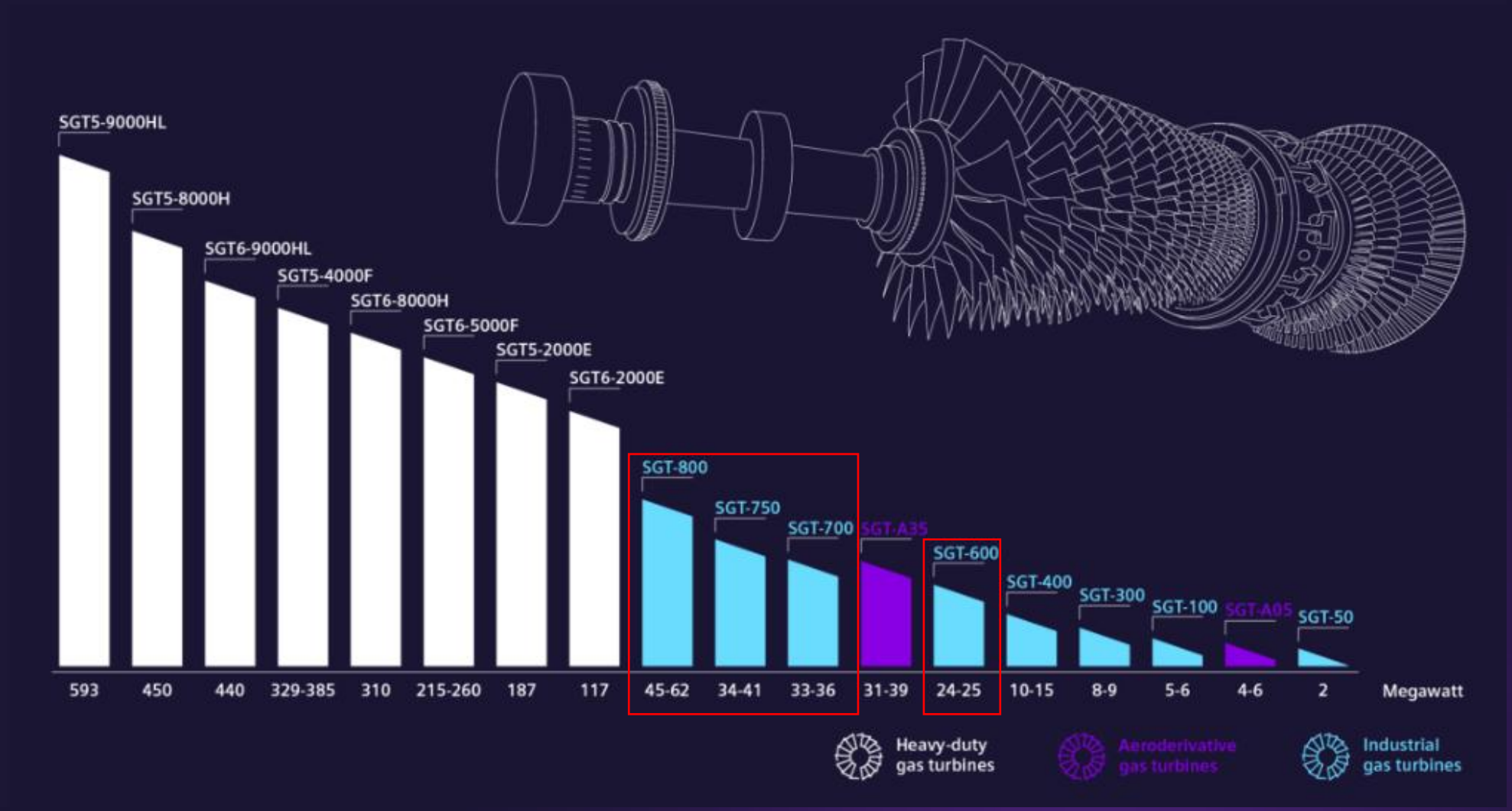
• Born in India,Living and working in Sweden for almost 11 years
• Master’s degree in Electronic Engineering
• Nearly 7 years of experience at Siemens Energy
• Working as an R&D Test Professional within gas turbine testing
• Responsible for the complete strain gage measurement chain, from sensor to data acquisition and analysis
• Responsible for all dynamic measurement signals, including strain, pulsation, acceleration and other dynamic test measurements
• Focused on measurement quality, troubleshooting, validation and developing reliable test solutions



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The Siemens Energy gas turbines portfolio:



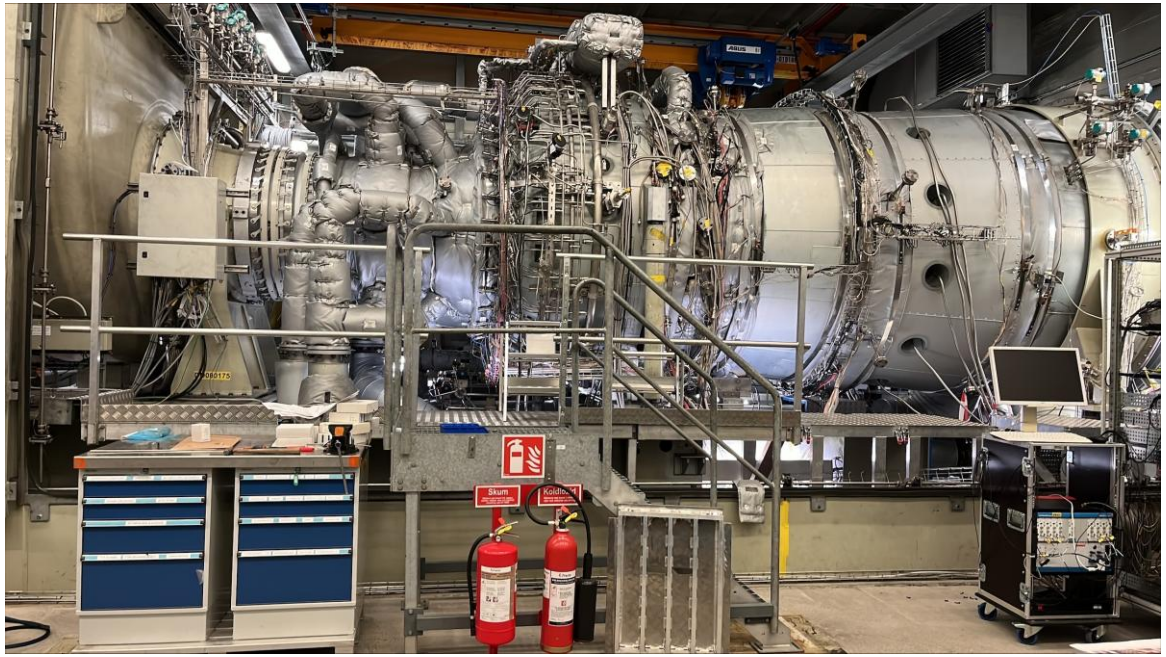
Power Generation / Mechanical Drive, Performance at ISO conditions

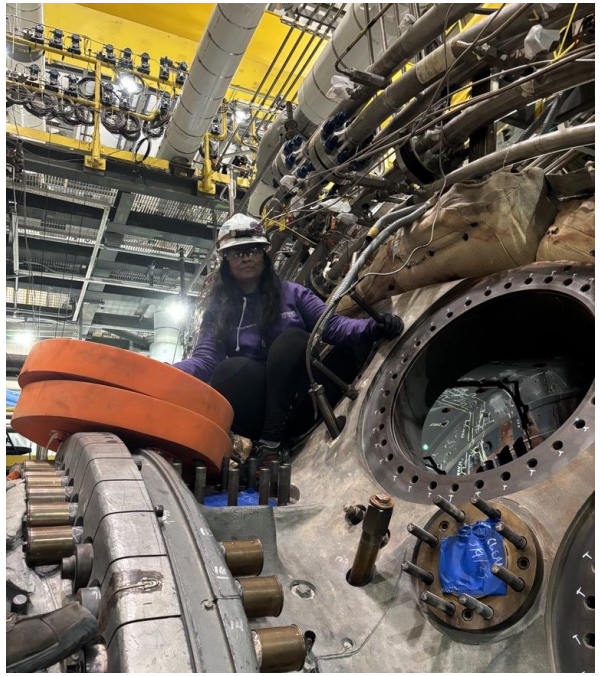
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SGT-800 GT2 and SGT 6-9000 HL

SGT-800 GT2 Measurement System: 1500 physical measurement points and the resulting 4500 calculated measurements values
SGT-9000 HL2 : Over 6000 sensors with dynamic signals of about 520



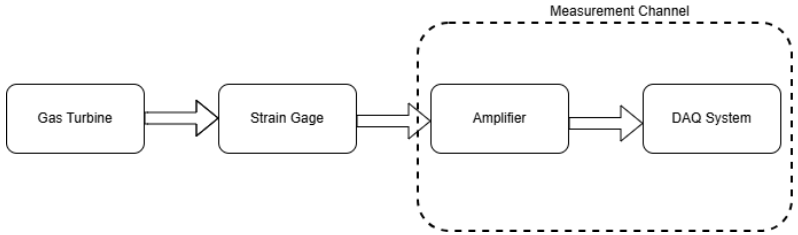


Dynamic strain gages – 107 st
Dynamic strain gages (telemetry) – 191 st
Accelerometer – 132 st
Pressure sensors – 70 st
Vibrational velocity – 13 st

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Background

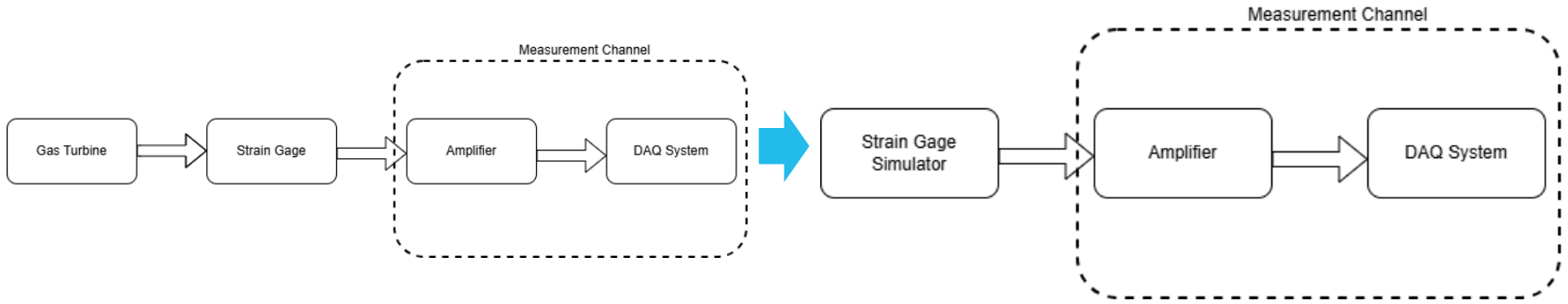
- Strain gauges convert mechanical deformation into a measurable electrical resistance change.
- Gas turbine components experience high mechanical stress, rapid temperature swings, and continuous vibration.
- Strain is monitored continuously to detect overload and fatigue during operation.
- The measurement chain must be calibrated and verified without operating the turbine itself.



Standard strain measurement chain in a gas turbine

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Concept of the Simulator



Conventional setup — requires operating the turbine

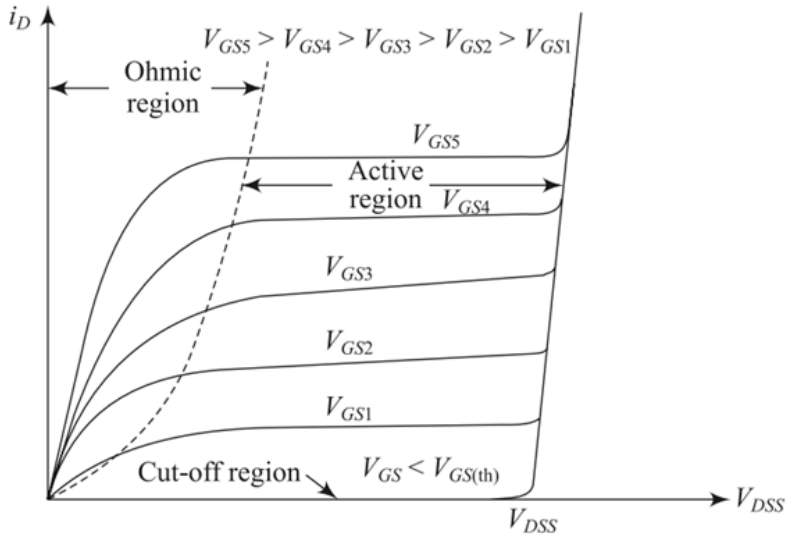
Simulator replaces the gauge — safe, repeatable calibration

The simulator injects a resistance change equivalent to a real strain signal directly into the measurement chain, eliminating the need to physically load or operate the turbine for calibration.

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MOSFET Operating Principle

- In the ohmic (linear) region, a MOSFET's drain-source channel behaves like a voltage-controlled resistor
- Varying the gate-source voltage adjusts the effective channel resistance
- This makes the MOSFET suitable for generating the small, controlled resistance changes needed to emulate a strain gauge
- Operation must stay within the ohmic region across the full drive range — the boundary differs per device



MOSFET operating regions

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MOSFET Selection Criteria

- Temperature Stability - Reliable operation up to 80°C.
- Resistance Range - Support strain-gauge equivalent resistance variation of 0.07 Ω to 0.7 Ω, Corresponding to 100 με to 1000 με.
- Linearity in the Ohmic Region - Predictable resistance behavior, Accurate strain signal reproduction.
- Robustness & Compatibility - Suitable drop-in replacement for the existing IRF710-based design, Long-term reliability and component availability.

MOSFET	Vgs	BVdss	Rds(on)
2N7000	±30V	60V	5Ω
ZVN3310A	±20V	100V	10Ω
IXTH02N450HV	±20V	4500V	625Ω
IXTP02N120P	±20V	1200V	75Ω
VN2450N3G	±20V	500V	20Ω
IXTH02N250	±20V	2500V	450Ω

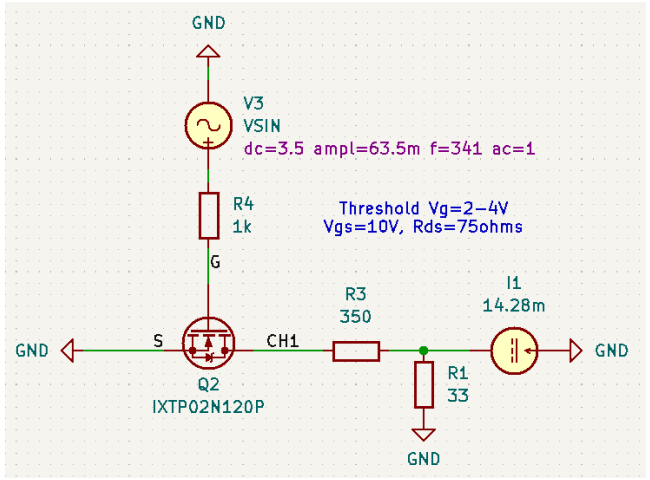
These were the MOSFETs which were able to fulfill the above criterias

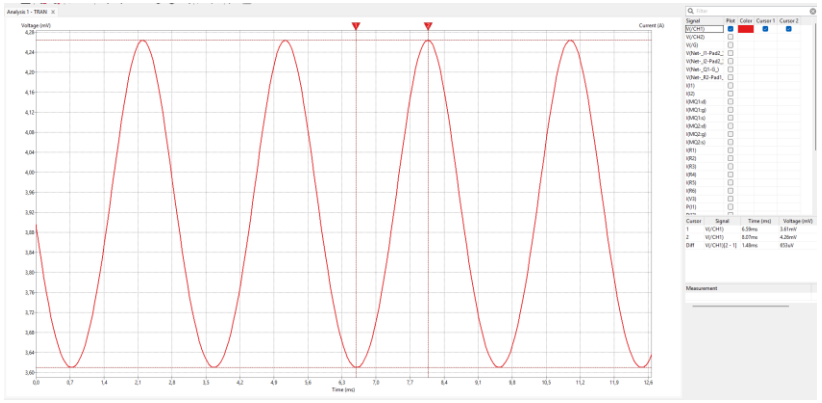
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Circuit Simulation and Verification

Simulation Verification & Results

- Feasibility of the selected strain gauge simulator design was verified through simulation.
- Function generator output requirements remained within the available operating range.
- Required strain-equivalent resistance variation was successfully achieved.
- Simulated output reproduced the desired sinusoidal strain signal.
- Similar simulation procedures were applied to all candidate MOSFETs, with device-specific operating parameters selected for each device.

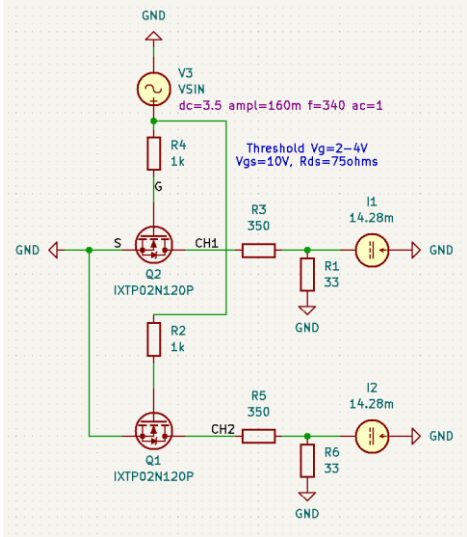




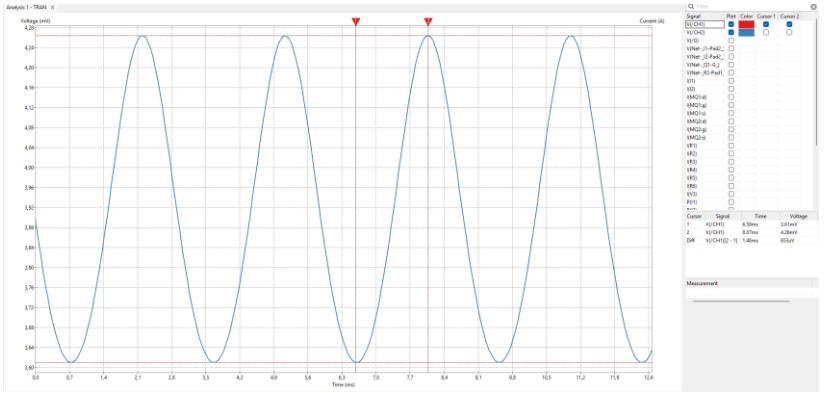
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Dual Channel Prototype Development

- Design Objective - Extend the validated single-channel design into a dual-channel strain gauge simulator capable of generating simultaneous, independent strain-equivalent signals.
- **MOSFET: IXTP02N120P -** Selected based on simulation results and comparison against five candidate devices.
- Gate resistor: 1 kΩ (±1%)
- Shunt resistor: 33 Ω (±1%, metal film)
- Gauge resistance: 350 Ω / 120 Ω selectable
- Drive: 14.28 mA constant current, matching the FE-527-SGA instrumentation amplifier
- Extended to a dual-channel configuration for simultaneous, independent strain signals



Dual-channel prototype schematic

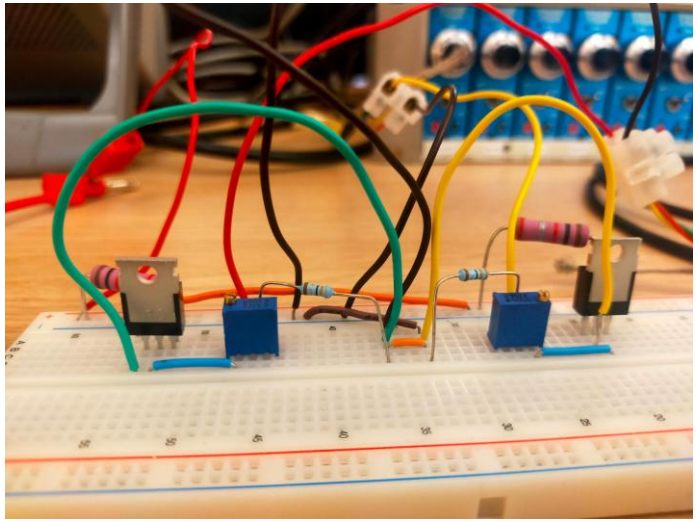


Dual-channel prototype simulation results

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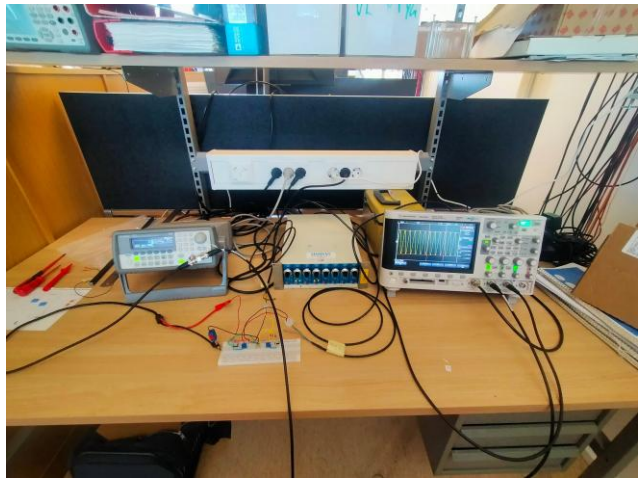
Breadboard Implementation

- Dual-channel prototype assembled using IXTP02N120P MOSFETs.
- 350 Ω / 120 Ω gauge resistance achieved through potentiometer adjustment.
- Tested using the FE-527-SGA instrumentation amplifier, providing a 14.28 mA excitation current representative of the intended application.
- Prototype constructed to verify the simulated design prior to PCB development.

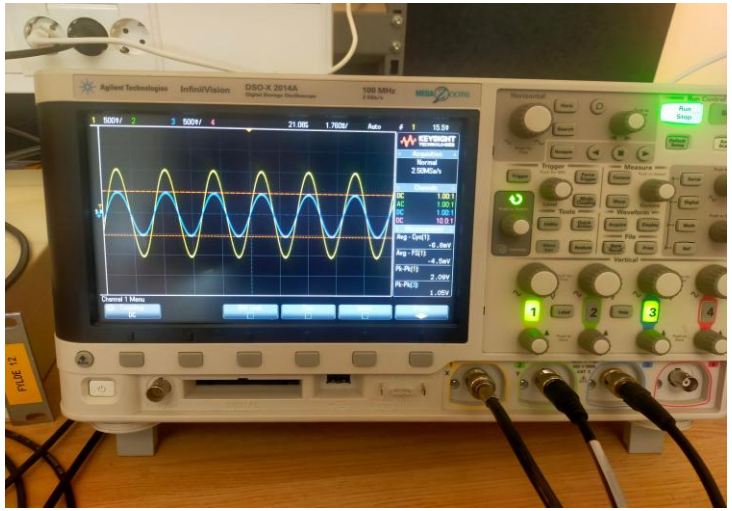


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Breadboard Experimental Validation



Experimental Setup



Output at 700mV input signal amplitude

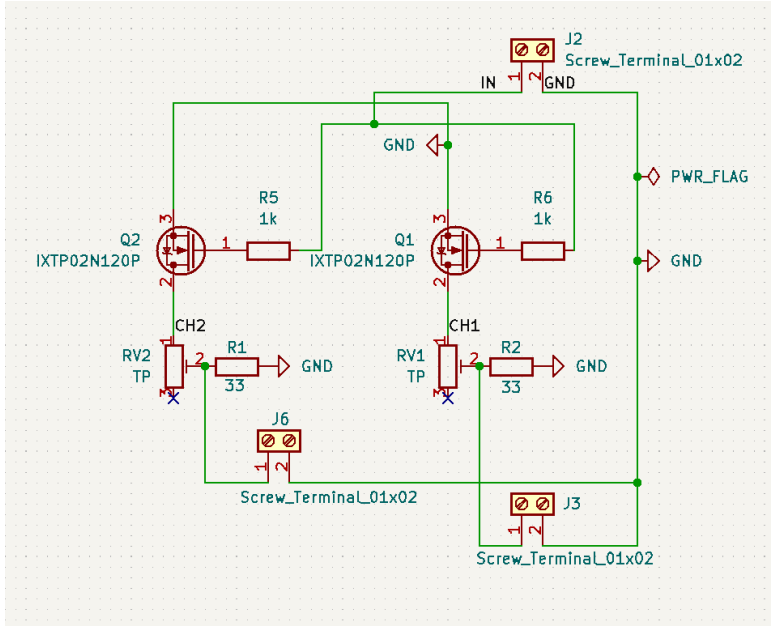
CH1 (120 Ω) – Yellow trace
CH2 (350 Ω) – Blue trace

- Successful generation of dual-channel sinusoidal strain-equivalent signals.
- 120 Ω channel: approximately 2.09 Vpp output.
- 350 Ω channel: approximately 1.05 Vpp output.
- Stable operation achieved with a 700 mV gate-drive signal.
- Experimental results were consistent with the expected channel response.
- Breadboard validation confirmed the viability of the design prior to PCB implementation.

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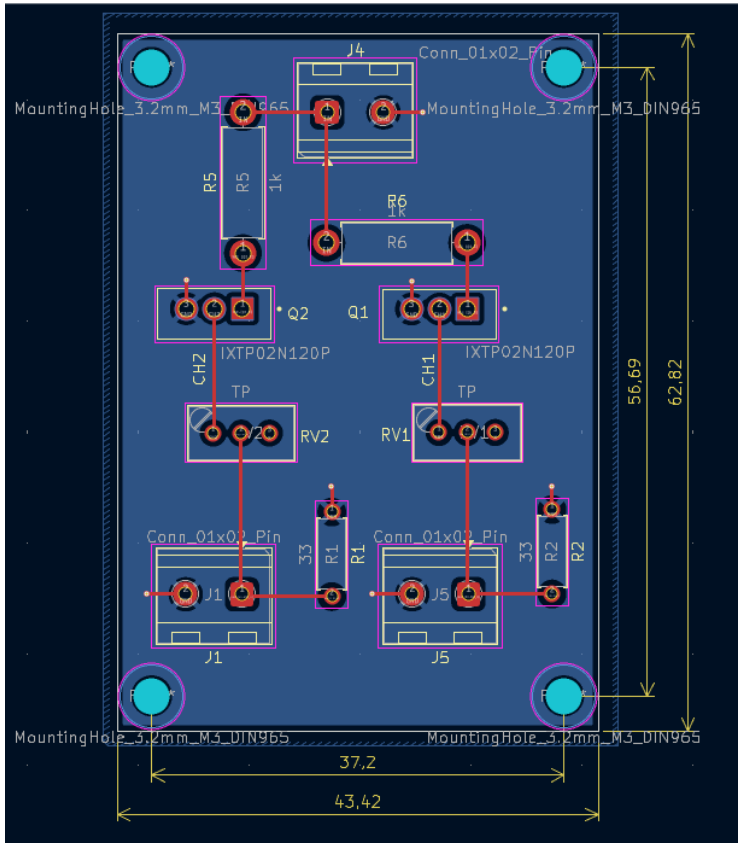
PCB Schematic Design

- Breadboard-validated design converted into a PCB-ready schematic using KiCAD.
- IXTP02N120P MOSFETs retained for both channels.
- Integrated input and output screw terminals for simplified interfacing.
- Adjustable potentiometers(RV1 and RV2) used to emulate 120 Ω and 350 Ω strain gauges.
- Electrical connectivity verified before PCB layout generation.



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PCB Layout Design



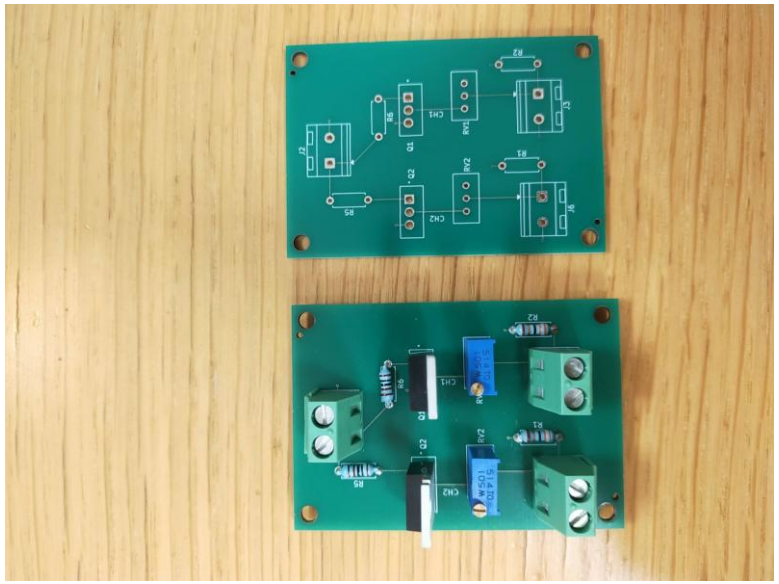
Final PCB layout developed in KiCAD

- PCB layout developed from the verified schematic design.
- Compact dual-channel architecture implemented on a 43.42 mm × 62.82 mm PCB.
- Mounting holes incorporated to facilitate enclosure integration.
- Component placement optimized to simplify routing and assembly.
- Symmetrical channel layout adopted to minimize layout induced channel to channel variations.
- Layout verified prior to PCB fabrication.

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PCB Implementation

- 2-layer FR-4, 43.4 × 62.8 mm, 1.6 mm thickness, 1 oz copper
- Dedicated ground plane — eliminates the floating-ground behaviour seen on the breadboard.
- Bourns 3296W trimmer potentiometers (500 Ω, ±10%) set the 120Ω/350Ω gauge resistance
- Screw terminals interface directly with the FE-527-SGA amplifier
- PCB fabricated and assembled for experimental validation.



Fabricated 2-layer PCB from JLCPCB

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Enclosure Integration



- PCB integrated into a custom enclosure for improved protection and handling.
- Enclosure dimensions selected based on the final PCB footprint.
- External interfaces exposed for signal input and output connections.
- Final assembly provides a compact and portable platform for measurement-chain verification.

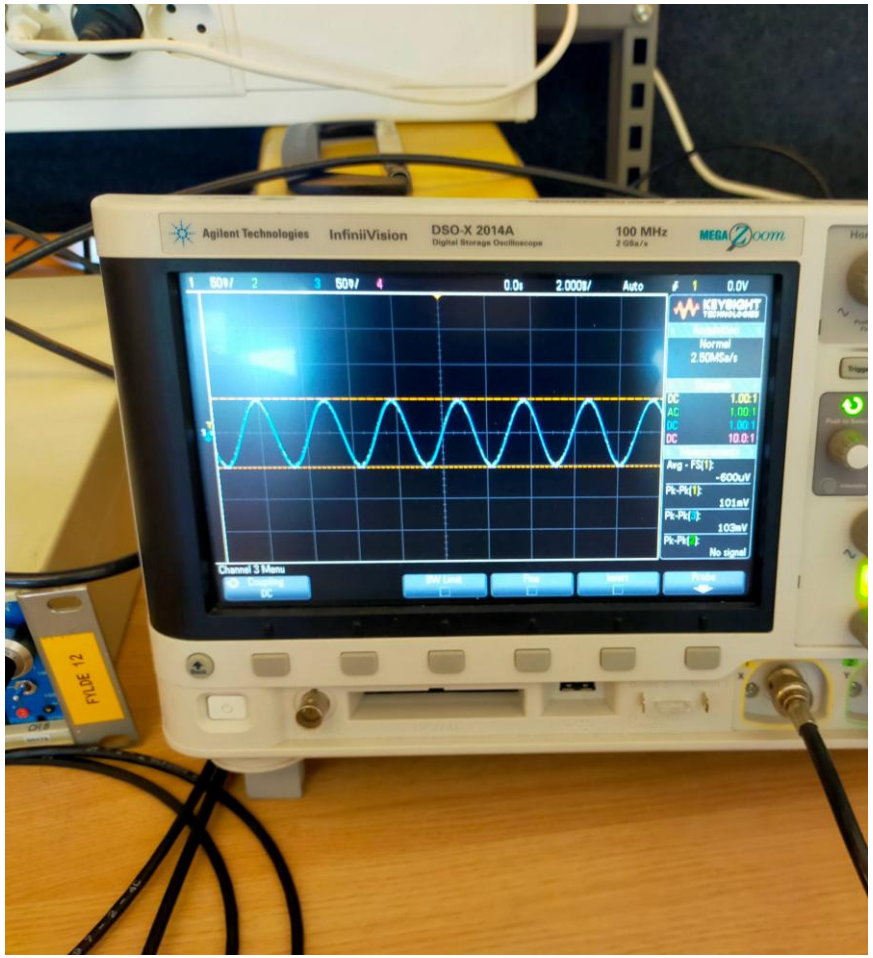
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PCB Experimental Validation

Input Parameters

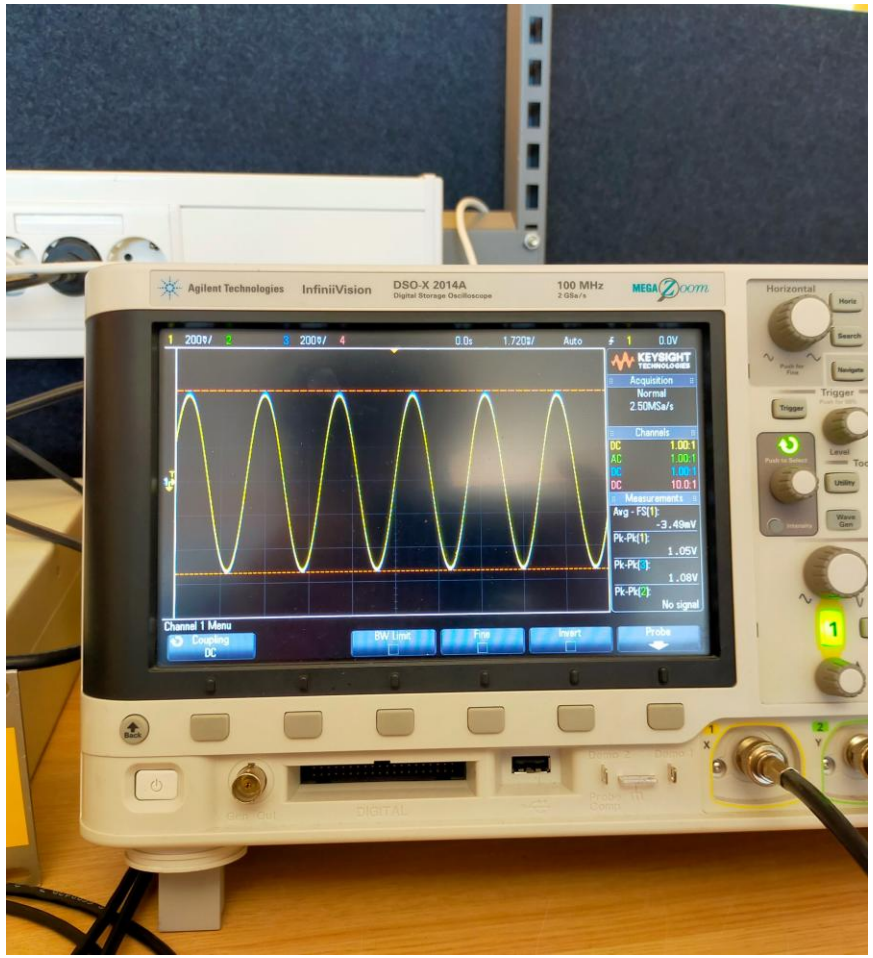
- Vdc = 3.5 V
- f = 341 Hz
- A = 63.5 mVpp

Equivalent Strain ≈ 100 με



Measured output waveform for an equivalent strain of 100 με.

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Measured output waveform for an equivalent strain of 1000 με.

Input Parameters

- Vdc = 3.5 V
- f = 341 Hz
- A = 700 mVpp

Equivalent Strain ≈ 1000 με

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Calculation of Strain

- Known Parameters, Amplifier gain = 100x, Gauge Factor(GF) = 2, Current(I) = 14.28mA, Gauge Resistance(R)= 350 Ω
- When Oscilloscope shows 101mV(measured output from the amplifier),
- Actual Voltage, V = 101/100 = 1.01mV
- Resulting Resistance Change, ΔR = $V/I \rightarrow \Delta R = \frac{1.01\,\mathrm{mV}}{14.28\,\mathrm{mA}} \approx 0.0707\Omega$
- The equivalent strain is given by, $\epsilon = \frac{\Delta R/R}{GF} = \frac{\frac{0.0707}{350}}{2} \approx 101\,\mu\epsilon$ (Target Strain 100 $\mu\epsilon$)
- When Oscilloscope shows 1.05V(measured output from the amplifier),
- V = 1050/100 = 10.50mV
- Resulting Resistance Change, ΔR = $V/I \rightarrow \Delta R = \frac{10.50\,\mathrm{mV}}{14.28\,\mathrm{mA}} \approx 0.74\Omega$
- Equivalent strain, $\epsilon = \frac{\Delta R/R}{GF} = \frac{\frac{0.74}{350}}{2} \approx 1057\,\mu\epsilon$ (Target Strain 1000 $\mu\epsilon$)
- The calculated strains of 101 με and 1057 με closely match the target values of 100 με and 1000 με, validating the simulator's accuracy and functionality.

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Discussion

- IXTP02N120P was selected from six candidate MOSFETs due to its ability to cover the required resistance variation range (0.07 Ω to 0.7 Ω) and its close agreement between simulation and experimental results.
- The dual-channel prototype successfully reproduced the simulated behaviour, generating stable sinusoidal strain-equivalent signals on both channels.
- Transitioning from a breadboard to a PCB improved circuit robustness, eliminating the floating-ground behaviour observed during breadboard testing and providing a more reliable platform for validation.
- Equivalent strain values of approximately 101 με and 1057 με were achieved for target strains of 100 με and 1000 με, corresponding to errors of approximately 1% and 5.7%, respectively.
- The developed simulator successfully generated strain-equivalent signals within the required operating range, demonstrating its suitability for measurement-chain verification and calibration.
- The modular dual-channel design enables simultaneous verification of multiple measurement channels using a compact and low-cost implementation.

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Limitations

- Validation was limited to selected operating points within the target strain range.
- Further characterization across the full frequency and strain range could provide additional performance insights.
- Long-term operational stability was not investigated.
- Environmental factors such as temperature variation were outside the scope of this work.
- The current implementation supports two channels; scalability to additional channels was not evaluated.

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Future Work

- Extend the design beyond two channels to support simultaneous verification of additional measurement channels where required.
- Implement more user-friendly connectors and interfaces to reduce setup time and simplify integration with strain measurement systems.
- Evaluate performance across the full strain and frequency ranges to further validate simulator accuracy and robustness.
- Develop an enclosure with integrated controls and labeling to improve usability and portability.

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Conclusions

- IXTP02N120P was identified as the most suitable MOSFET for the application, successfully covering the required resistance variation range of 0.07 Ω to 0.7 Ω.
- A dual-channel strain gauge simulator was successfully designed, implemented, and validated through simulation, breadboard prototyping, and PCB implementation.
- Equivalent strain values of approximately 101 με and 1057 με were achieved for target strains of 100 με and 1000 με, respectively.
- Transitioning from a breadboard to a PCB improved system robustness, eliminating floating-ground issues while maintaining the desired functionality.
- The developed simulator demonstrated its suitability for strain measurement-chain verification and calibration by generating stable strain-equivalent signals for both 120 Ω and 350 Ω gauge configurations.
- Further validation across the complete frequency range and under elevated-temperature conditions remains future work.

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Questions?

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