Improving Electric Motor Performance, Efficiency and Safety with Embedded Torque and Temperature Sensing

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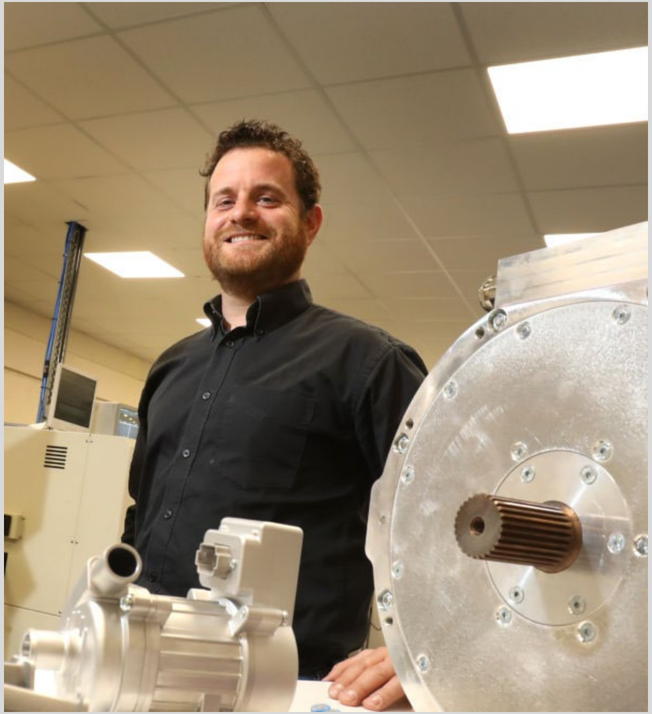
#TBS22 #EVT22

Ryan Maughan - Background

- Professional engineer and a Fellow of the IMechE
- Founded AVID Technology in 2004, powertrain components and systems solutions for electric and hybrid vehicles
- Sold sensor and drive by wire controls business to major German T1and span out battery systems business in 2012
- Acquired EVO axial flux motor technology IP and business from GKN in 2018. Exited AVID in 2021
- Strategic Advisor to Transense Technologies since Jan ’21 joined main board in ‘Nov 21
- In addition to Transense, projects in cutting edge motors, drives and battery systems development and manufacturing



Company

transense technologies plc

Strategy and Vision:

Develop and supply robust and reliable wireless sensor technology and systems utilising patented SAW technology that measures torque, temperature, pressure and strain to improve efficiency, reliability and safety in critical propulsion and drive systems

Key Facts:

Founded 1991

Listed on AIM 1999

>£30m invested in technology

>50 granted patents

2015 EMERSON
Licence for Sensing HV Switch Temperature

2016 GE
TMS Licence for Vertical Lift Propulsion

2020 BRIDGESTONE
Licence for Off Highway Tyre Monitoring

2021 McLaren APPLIED
TMS Joint Collaborative Agreement

The Motor Development Cycle

- Motor torque is proportional to B field current in line with the motor torque constant K_t
- Motor properties and loss mechanisms affect the relationship and current control
- In order to calculate motor output torque we characterise motor over a range of operating points and create look up parameter tables and control variables
- Current is measured by hall effect sensors in the motor controller (inverter) and this forms a control loop inside the inverter for torque estimation
- Dynamic nature of loss mechanisms, signal filtering required on current sensors and manufacturing tolerances motor control is complex and has to accommodate all of these parameters
- **What if there was a better way to characterise and control electric motors?**

Dyno Image Courtesy Marposs EDC

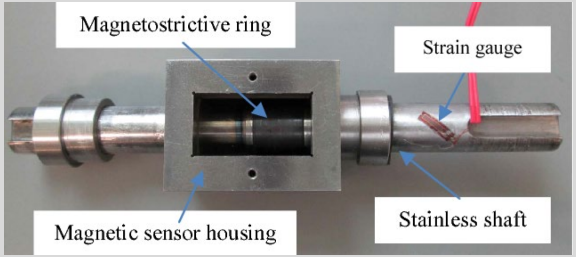
Alternative Sensor Technology

Why do we not fit torque sensors into every electric motor today?

Factors to consider:

- Cost
- Need to make shaft flex to create a measurable strain/torsion
- Poor accuracy, not suitable for control
- Position of sensor and electronics
- Size & mass
- Wireless
- Response rate
- Position of sensor
- Durability
- Shaft material
- Calibration durability

Magnetostrictive



Strain Gauge

SAW Technology

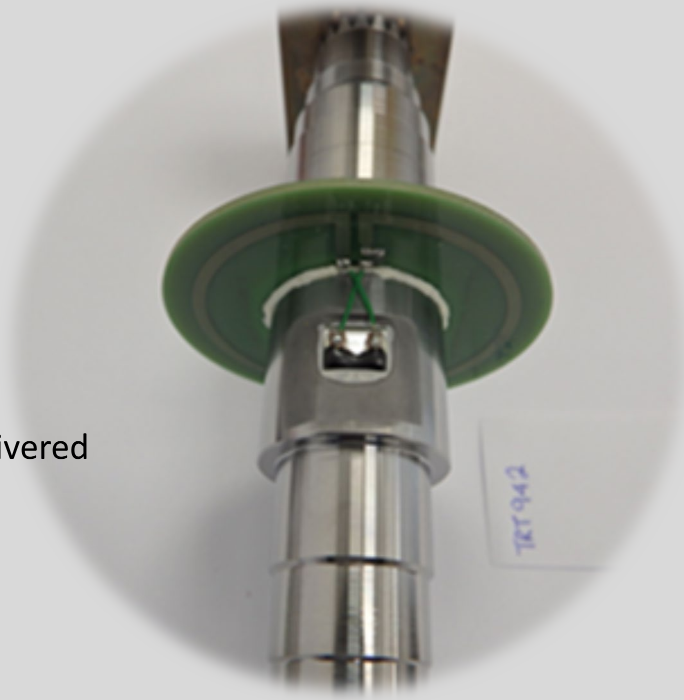
SAW technology provides, robust, accurate, real time measurement of:

- Torque
- Pressure
- Strain
- Temperature

Improved measurement technology enables:

- Improved motor efficiency and performance by real-time torque and temperature measurement
- Improved safety integrity with redundant, dissimilar verification of delivered torque
- Real-time monitoring of machine performance
- Load and condition monitoring

A real time dynamometer in every motor!



SAW Sensor System

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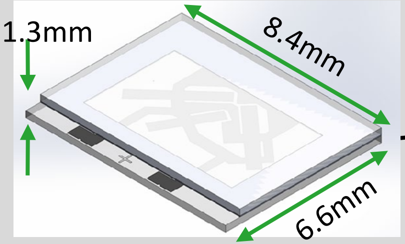
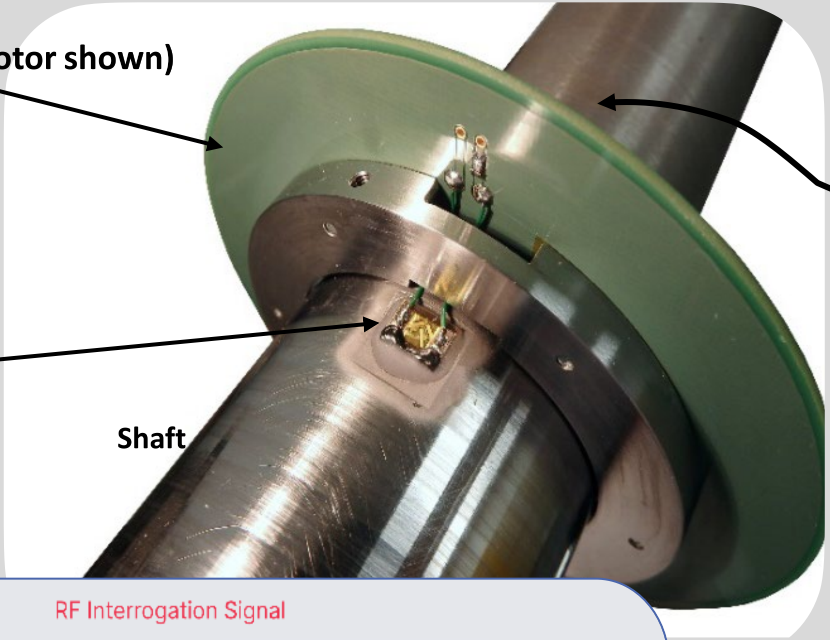
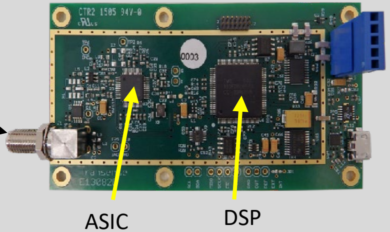
1. AQP

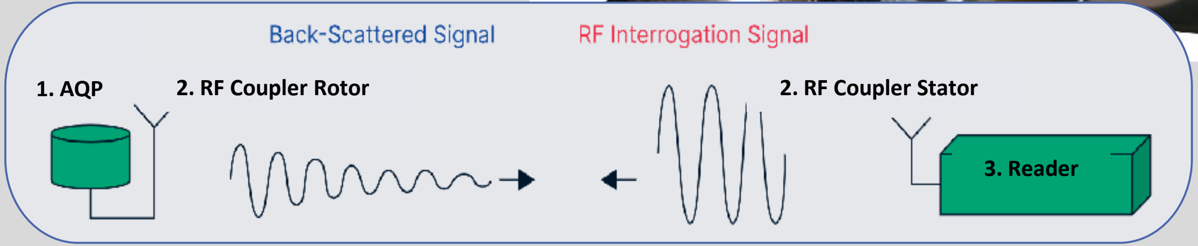


2. RF Coupler (rotor shown)

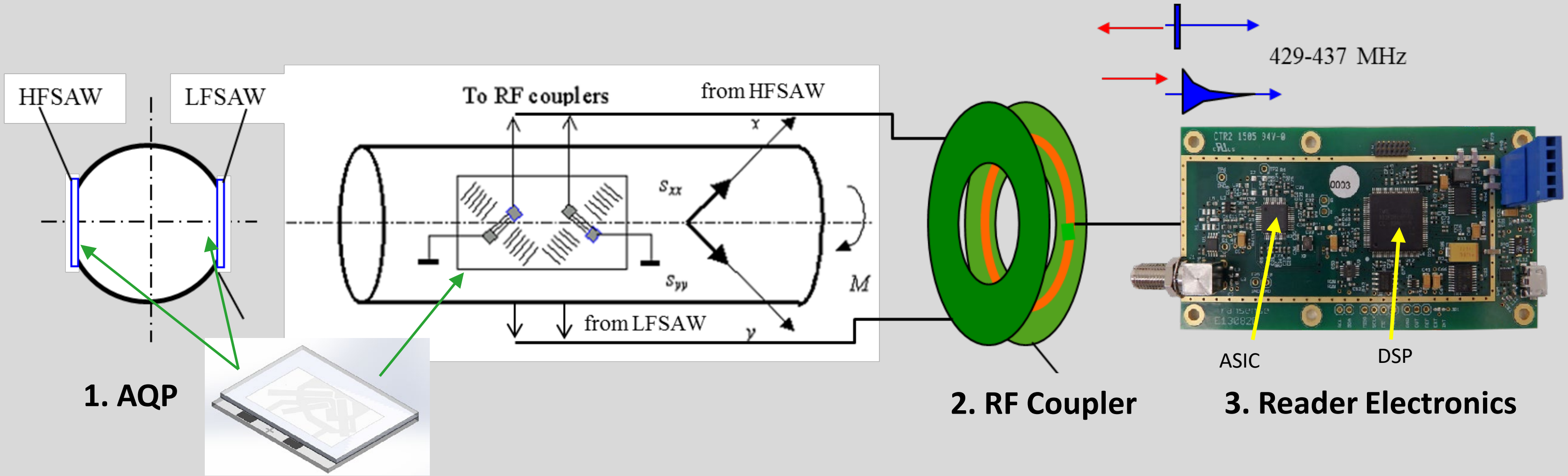


3. Reader Electronics





SAW Technology



- Torque M applied to the shaft changes the two SAW resonant frequencies in the opposite directions since they are strained differently
- Using HF and LF SAW AQP's allows compensation of axial forces and bending moments

CAPABILITIES
Torque Measurement System (TMS)

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- **Wireless**
- **Battery-less**
- **Non-Contact**
- **Small size and mass**
- **Not susceptible to magnetic forces**
- **Suitable for high volumes production**
- **Torque measurement capability**:
  - 0 to +/- 50KNm+
  - Option for bending compensation
  - Update frequency up to 6.67KHz
  - Accuracy <+/1% FSD
- **Suitable for wide range of Shaft types**
  - Steel, Aluminum, alloys
  - Ø20 ~ 250mm+
  - Hollow or solid
  - Any cross section

- **Environmental operating limits**
  - -40 to > +125^{o}C
  - Immersion in oil/oil mist is OK
  - Protected from water/moisture/debris
  - High shock/vibration tolerance
- **Connectivity and power supply**
  - Low voltage ~1W power supply
  - Dedicated CANBUS/Analogue or wireless output
- **Calibration requirements**
  - Torque & temperature (+/- 1% FSD)
  - Torque only (+/- 5% FSD)
- **Sensor Operating strain range**
  - Preferred range +/-350 µstrain
  - Max measurement +/-480 µstrain
  - Safe operating limit 1200 µstrain
  - Shaft design/adaptors used to mange strain range vs torque range

Existing Application - Motorsport

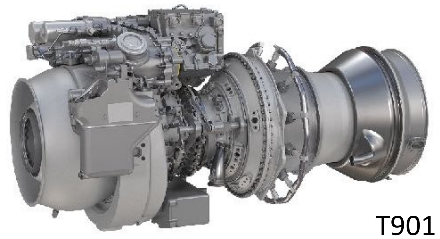
- McLaren Applied (MA) supply torque sensors as part of their motorsport data acquisition packages
- Transense instrument racing driveline shafts at low volumes <100 units PA
- MA previously used a complex magnetostrictive (MS) sensor
- Replaced MS sensor with SAW due to:
  - Need for higher accuracy +/-1% rather than +/-4% achieved by conventional sensor
  - Need to use different shaft materials - not possible with MS technology
  - MS was difficult to apply and required frequent re-calibration
  - MS technology was very expensive

Typical INDY CAR sensor specification:

Torque measurement max:	1000 Nm
Torque resolution (3σ)	< 1 Nm
Torque measurement combined error*:	< 1%FS
Overload:	3 kNm,
Torque reading update rate:	3.3 kHz
Temperature range:	up to 150°C
Speed of rotation	12000rpm

Existing Application - Aerospace

- Improved Turbine Engine Program (ITEP) by US Army to replace T700 Gas Turbine with T901. Target was to improve efficiency and reduce maintenance costs
- Transense SAW technology is built into **every** T901 engine to provide real time torque monitoring for control and safety functionality
- Replaced conventional displacement torque sensor due to:
  - Improved accuracy +/-1% rather than +/-4% achieved by conventional sensor
  - Higher speed measurement to be able to use in engine control loop rather than indication only
  - Conventional torque sensor known to get clogged up with soot between stator and torsion shaft. SAW is "fit and forget"



T901

Existing Application – Automotive, Specialist ePAS

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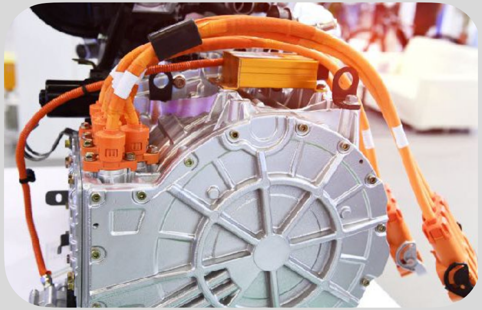
- Specialist high performance ePAS system
- Replacing inductive or optical displacement torque sensors
- Required a different sensor technology due to:
  - Improved accuracy +/-1% rather than +/-4% achieved by conventional sensor
  - Enables shorter shaft and tight packaging in the ePAS system
  - Enables stiff system, solves problems with torsion bar in conventional sensor giving vague steering feel

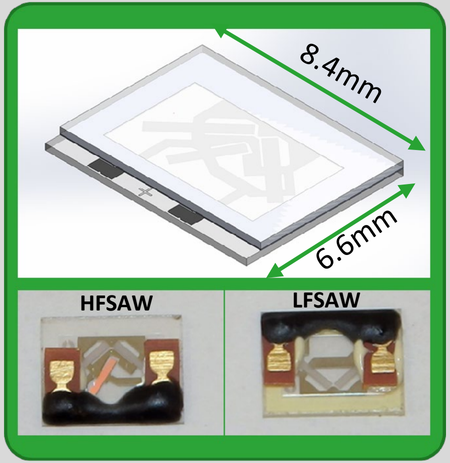
Typical EPAS sensor specification:

Torque measurement range:	± 10 Nm
Torque resolution (3σ)	< 0.03 Nm
Overload capability (die-shaft bond):	± (100…300) Nm
Torque measurement combined error*:	< ± 0.1 Nm
Hysteresis	< 0.06 Nm
Torque reading update rate:	2 kHz
Temperature range:	-40°C - +125°C
Dynamic torque:	> 5 Nm/ms

Automotive – eDrive Unit

- SAW technology will allow performance, efficiency and safety integrity to be improved complementing or replacing torque estimation
- The SAW technology will provide real-time measurement of shaft torque and temperature
  - Robust, Accurate, High speed, Stiff system, Relatively low cost
- Return on investment will be based on material cost savings and range increase
- Sensor cost will be same regardless of torque levels
- Greatest potential impact on larger, higher performance vehicles
  - Truck and Bus
  - Off-Highway machinery
  - SUV's and high power passenger car





SUMMARY

- Robust and reliable embedded torque, temperature, pressure and strain measurement
- Small, wireless, batteryless, non-contact
- Possible to fit a real time Dynamometer to every electric motor!
- Improving system efficiency, reliability and safety integrity
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- Web: www.transense.com