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SPINpad

In the advent of increasing demand for even more electric vehicles on the roads to meet customer requirements it is becoming increasingly more important to optimise their range and efficiency. One method to achieve this is through optimum control of the rotor position of their motor. Outlined in the paper below is AB Elektronik's non-contact inductive rotor position sensor technology, SPINpad. The technology offers, amongst other features: high speed sensing of up to 480,000rpm; a sensor linearity (electrical) in the order of <0.5°; and a functional safety classification of up to ASIL C (D).

Introduction

SPINpad is developed from AB Elektronik's successful Autopad® sensor technology range and uses a similar topology. To date there are over 80 million Autopad® sensors in the field; these developments have generated the extensive modelling capabilities and knowhow that forms AB Elektronik's decades of experience that underpins SPINpad technology.

SPINpad uses the same custom tools developed in house for Autopad® systems. Sensors proceed through a rigorous design, development and testing cycle using: sophisticated modelling tools (both analytical and finite element analysis); state of the art evaluation tools for prototypes (A,B,C and production ready samples), ensuring performance and environmental specifications are met; and state of the art manufacturing methods. Exploiting such methods, in addition to working with IC suppliers with extensive experience in the automotive industry, allows AB Elektronik to provide systems meeting the required ISO 26262 rating.

This allows AB Elektronik to offer a viable cost effective alternative for high speed rotary position sensing, for both automotive and industrial systems, to traditional sensing techniques. SPINpad is flexible, has a short lead time, and is capable of operating in almost all environments. Its electrical angle accuracy is in the order of <0.5° whose corresponding mechanical accuracy is given by:

$$Mechanical\ Accuracy = \frac{Electrical\ Accuracy}{Number\ of\ electrical\ periods\ per\ mechanical}$$

For rotors in electrical machines the number of electrical periods usually corresponds to the number of pole pairs of the motor.

SPINpad applications are wide and varied and include variable reluctance (VR) resolver replacements. In comparison, SPINpad systems are lighter, have a thinner form factor with similar or smaller radial extent, and have the option to avoid the full 360° topology needed by a VR system. Applications include but are not limited to:

- Rotor position sensing for electric and hybrid electric (EV/HEV) motors and generators for automotive applications.
- Motor / generator rotor position sensing for industrial applications, such as e-bikes and industrial machinery.
- Applications where space and weight (and hence cost) are strict constraints.
- Linear topologies

The sensing system forms part of a larger system where the outputs (V_{sin} and V_{cos}) of the sensor are supplied to a control unit (for example that of a motor or engine) and the electrical angle (φ_e) is calculated using the CORDIC[1] algorithm. φ_e is given by:

$$\varphi_e = arctan\left(\frac{V_{sin}}{V_{cos}}\right)$$

This angle is then fed into a control algorithm that is used to control the respective units, as shown in Figure 1. Within the control unit the voltage signals from the sensor may be normalised and/or have their offset removed (amplitude and offset compensation) to optimise their linearity.

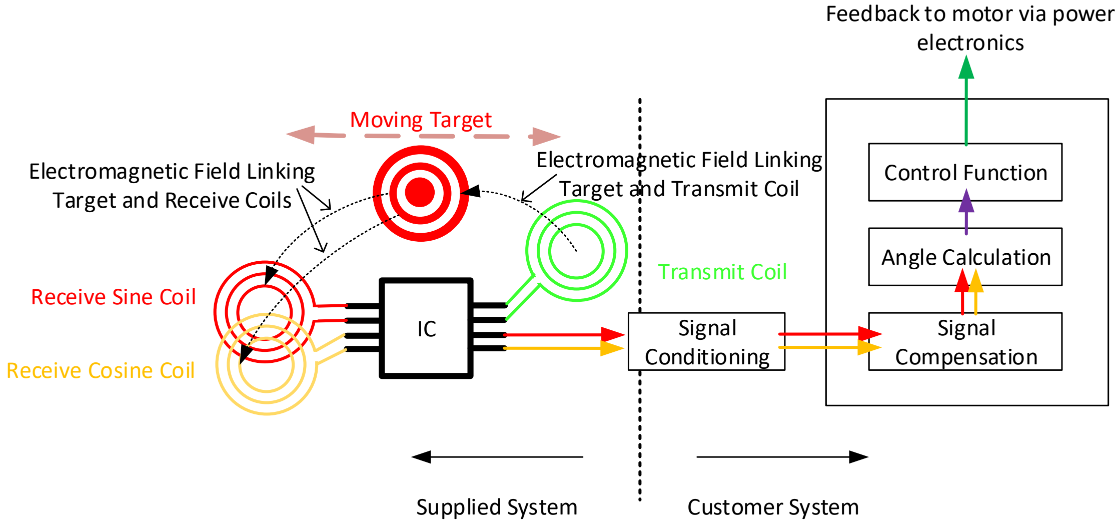

***Figure 1: SPINpad sensing** as part of a larger system*

[1] CORDIC - COordinate Rotation DIgital Computer algorithm used to calculate trigonometric functions

Operating Principle and Topology

SPINpad technology operates using the principles of electromagnetic induction. As electromagnetic induction requires an alternating magnetic field, the system is fundamentally immune to static magnetic fields, such as permanent magnets in motors. SPINpad technology can be used for both linear and rotary sensor position systems.

The sensor comprises of a stationary transmit coil, two stationary receive coils, and a moving target as shown for a linear sensor in Figure 2(a). The transmit coil and the receive coils are usually arranged on a printed circuit board (PCB) – offering a low cost product. The geometry of the receive coils is such that one coil produces a sine waveform and the other produces a cosine waveform in response to linear (rotational) motion of the target (Figure 2(b & c)), yielding a corresponding angular position for the target (Figure 2 (d)). The target is either metal (typically non-magnetic) or a patterned PCB and moves in a plane parallel to the coil structure.

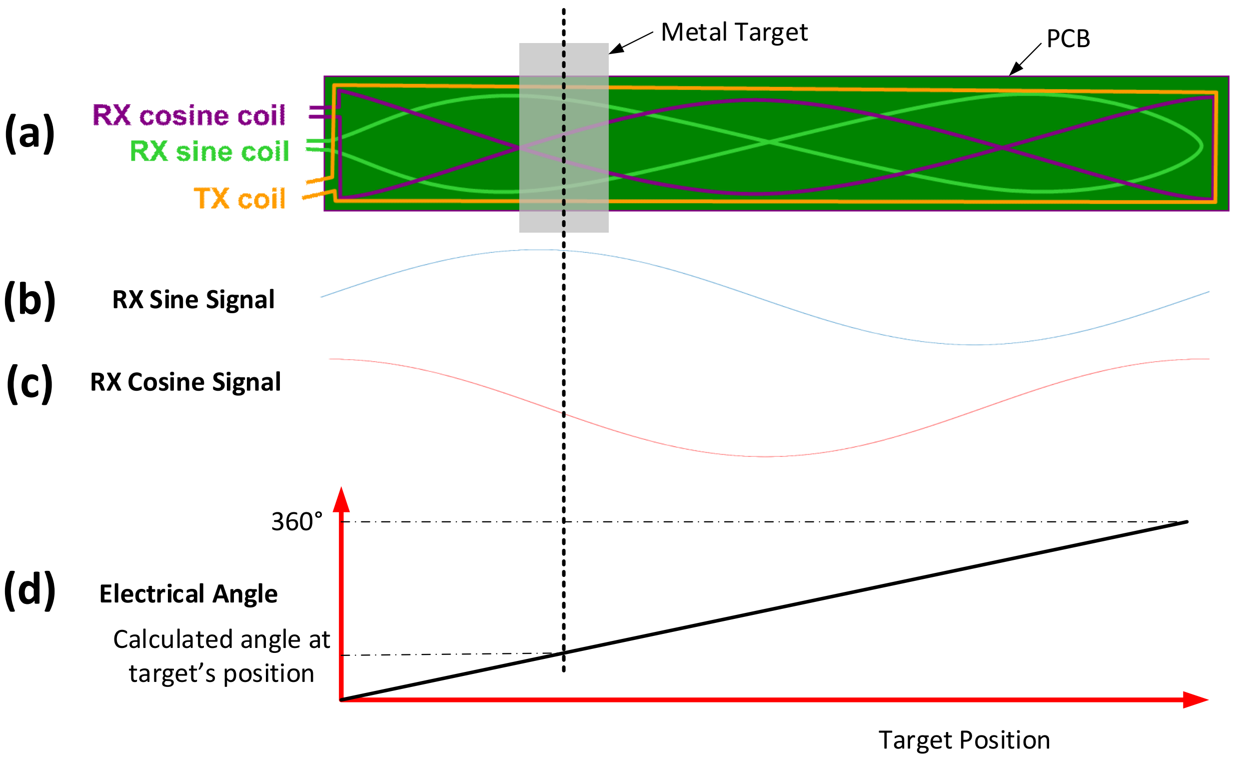

Figure 2: Linear Representation of SPINpad topology *- For simplicity (a) shows a linear representation of a SPINpad topology. (b) and (c) show the received demodulated signals from the sine and cosine channels as a function of position of the target (d) shows the calculated electrical angle in the controller unit*

An IC drives the transmit coil and interfaces the receive coils. The frequency of the current in the transmit coil is of the order of several MHz, and this alternating current generates an electromagnetic field (Figure 3(a)) which induces eddy currents in the moving target. These eddy currents in turn generate an electromagnetic field (Figure 3(b)) that induces a current in the receiver coils. As the target moves the high frequency component of the voltage/current from the sine and cosine coils is amplitude modulated by the geometry of the coils to give a lower frequency sine and cosine waveforms, which represent the position of the target (Figure 3(c&d)). The coupling (mutual inductance) between the target and coils varies as a sine and cosine function of the target's position. The coupling between the target and the transmit coil is a constant function of position.

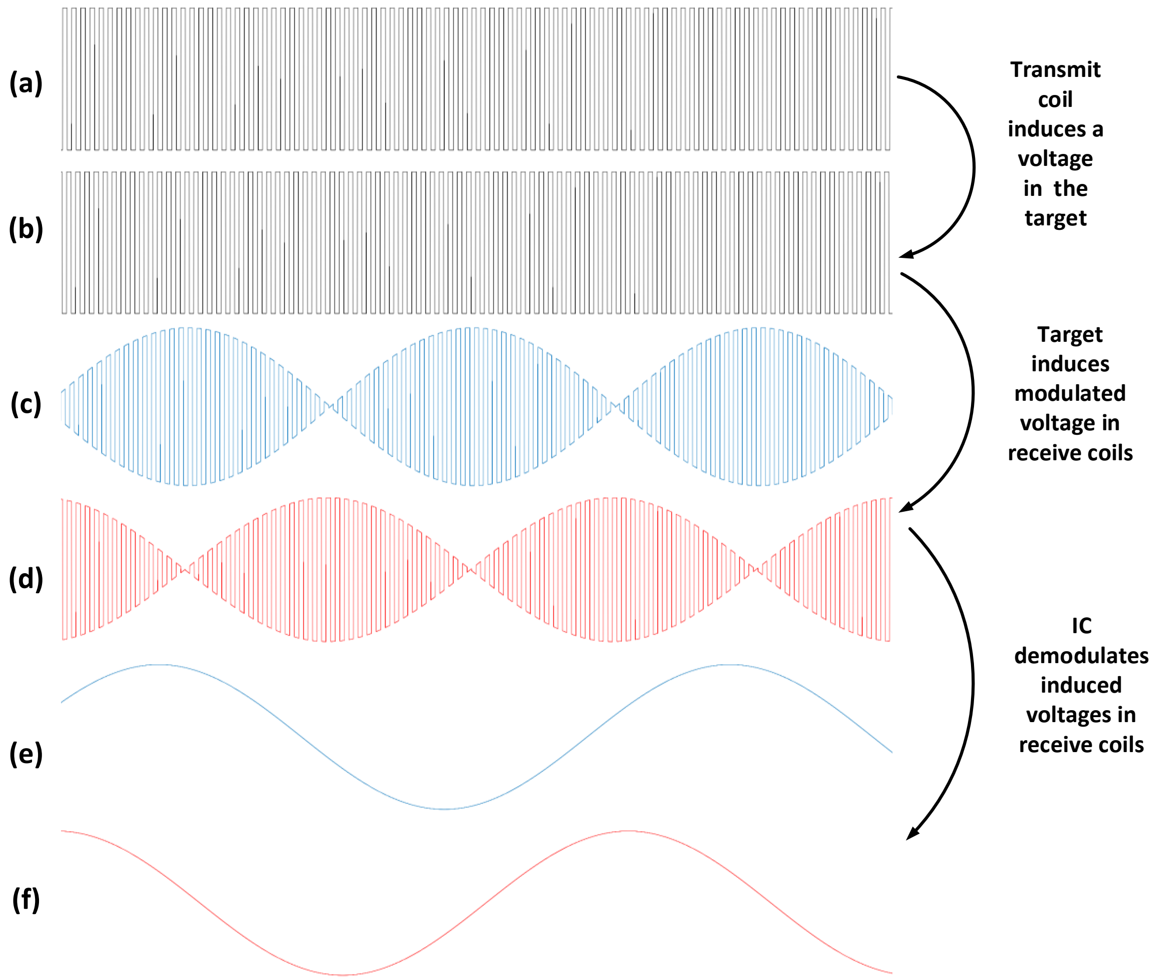

Figure 3: Generated waveforms *(a) shows a representative voltage across the transmit coil (b) shows the induced voltage in the target in response to the transmit signal (c) shows the induced voltage in the sine receive coils (d) shows the induced voltage in the cosine receive coils; (e&f) are the demodulated voltages of (c&d) respectively.*

Operation of a SPINpad sensor

The transmit coil, with inductance *L*, has a capacitor, *C*, in parallel forming an LC oscillator, that is driven by the IC, as shown in Figure 4. A large (several mA) alternating current flows around this circuit at the resonant frequency of the oscillator. Most ICs require a resonant frequency between 2-5MHz to operate. The resonant frequency (f_{res}) is given by:

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$$

With reference to Figure 4 the induced voltages in the receive coils are demodulated, within the IC, with a demodulation signal derived directly from the transmit stage. The received and demodulating voltages are in phase, giving optimum demodulation conditions. The demodulation process removes the high frequency modulated component (whose frequency is the same as that of the transmit frequency) from the received signal voltage leaving the modulating component (from Figure 3(c&d) to (e&f) respectively). These modulating components (Figure 3 (e&f)) represent the target position. After demodulation the signal is passed through a low pass filter and is then amplified by a specified gain to meet customer requirements.

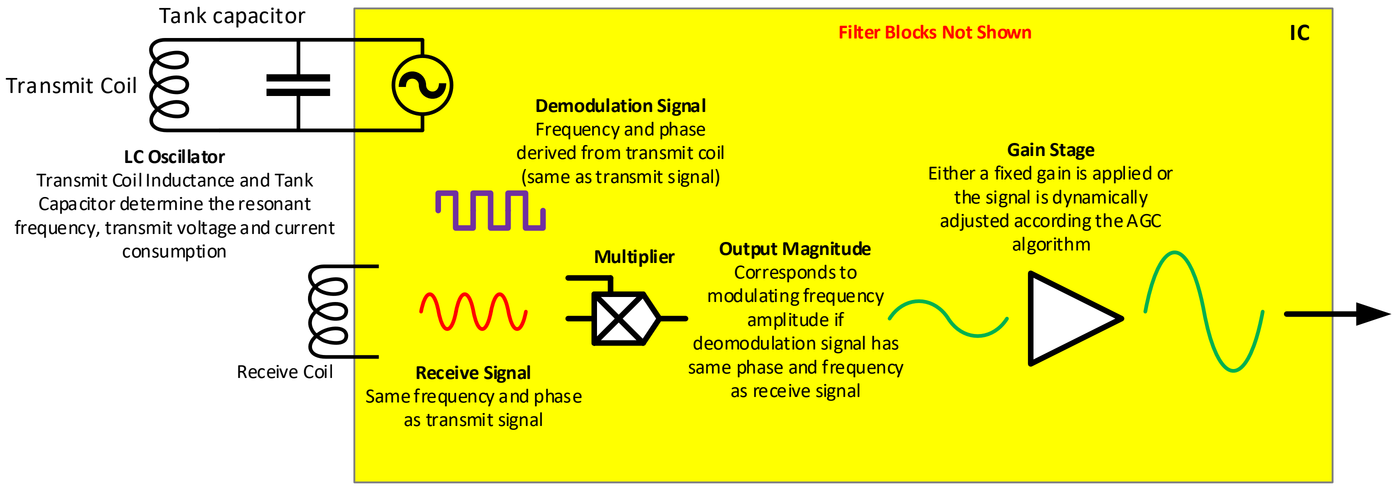

Figure 4: Block Schematic of the Sensor – *A representation of the various stages within the IC that condition the received signal to give a sine or cosine output, which represents the position. For clarity only a single channel is shown. The AGC (automatic gain control) is a feature some ICs have where the gain of the signal is adjusted depending on the input signal strength to maintain a constant amplitude output.*

Topologies

A typical SPINpad topology comprises of a rotating target and a fixed antenna structure. Shown in Figure 5 are the three main topologies for a SPINpad system. Other topologies, such as those exploiting flexible PCBs, linear configurations or other exotic arrangements are possible. Each of the topologies shown utilize a metal wheel target, either as a separate unit fixed onto the rotating shaft or as a machined part of the shaft. If a metal wheel is not feasible then a patterned PCB (or alternative equivalent structure) can be used. The number of castellations on the rotor corresponds to the number of pole pairs and hence the number of electrical periods per mechanical period the electrical output has. Figure 6 shows a target wheel for an eight pole pair machine.

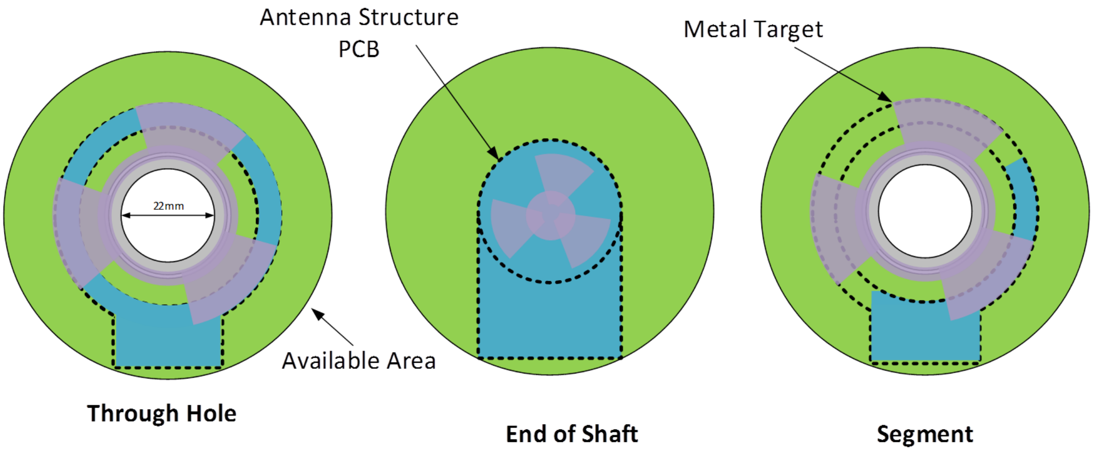

Figure 5: General SPINpad topologies

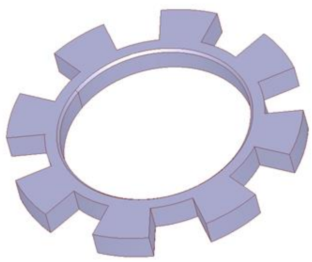

Figure 6: Target wheel for an eight pole pair machine

The choice of sensor topology usually comprises a trade-off of cost, required accuracy and tolerances, and application environment (location / assembly requirements). If PCB area is a premium, then novel coil topologies or multi-layered PCB boards can be employed to accommodate this.

SPINpad can be designed for a wide range of application sizes and this is reflected by the size of the outer diameter of the rotor. Rotor outer diameters from 20mm to 200mm have been designed for, and in each case a different sensor topology is more suitable due to cost and location drivers. Through hole solutions give good performance and are thinner than VR systems. End of shaft applications will usually give the best performance and cost value. They are small (typically <40mm rotor outer diameter) and have a 360° coil structure which gives the best immunity to tolerances. When considering large applications, typically > 75mm rotor diameter, a segment PCB is usually chosen - the cost of either an equivalent through-hole or end-of-shaft topology is too large.

Figure 7-Figure 9 show the solutions for an environment where all three types are viable. In this particular case the ratio of PCB areas required per sensor is 5.4 : 3.25 : 1 for a through hole : segment : end of shaft solutions.

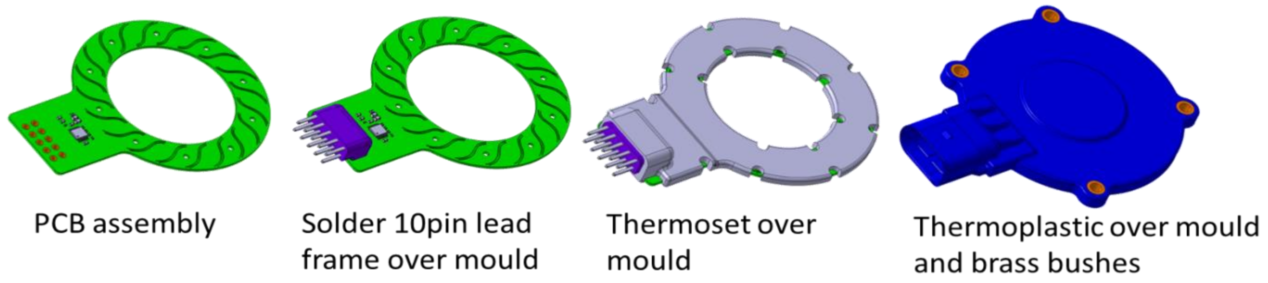

Figure 7: Through hole solution

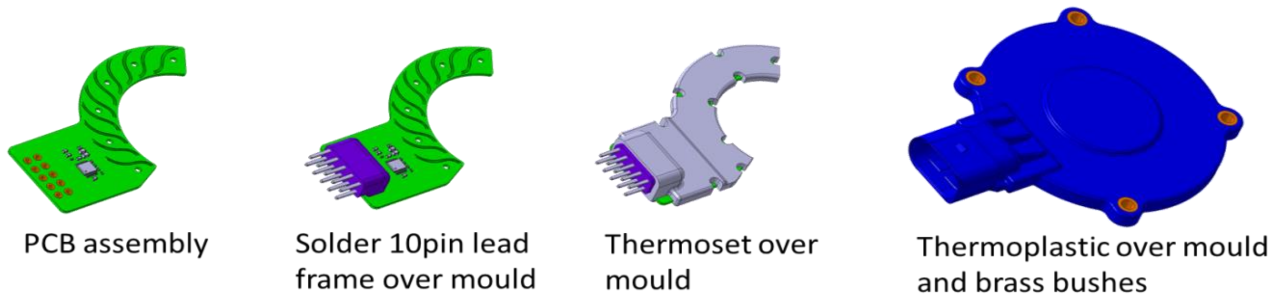

Figure 8: Segment Solution

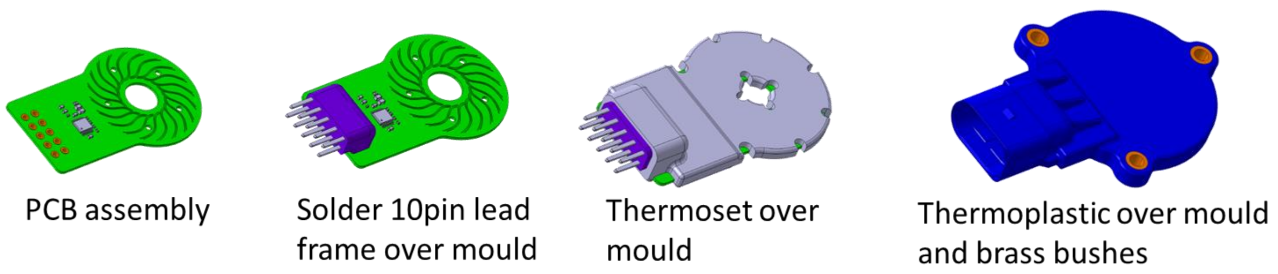

Figure 9: End of shaft solution

Comparison to alternative technologies

SPINpad provides a superior alternative to other resolver technologies, such as variable reluctance and HALL cell based systems. The following tables compare the two technologies, to that of SPINpad. A key benefit of SPINpad systems, aside from reduced cost, over the variable reluctance system is its ability to easily integrate redundancy. A SPINpad system can integrate a secondary sensing structure onto the same PCB, thereby occupying the same volume as a single sensing structure. To implement redundancy using a variable reluctance topology two separate systems need to be incorporated, thereby doubling the required volume. In comparison to HALL sensor systems, SPINpad systems do not have the concern with the effect of the environment on an expensive permanent magnet. High grade magnets have to be used in a HALL system to ensure performance over temperature, eliminating lower cost grades. Furthermore the incorporation of permanent magnets into the system implies a higher vulnerability to contamination.

Table 1: SPINpad and Variable Reluctance Resolvers

	Variable Reluctance Resolver	SPINpad
Size and Weight	---	+++
System Costs	--	++
Accuracy	++	++
Functional Safety	--	++
Redundancy	Not possible	Possible
Power Consumption	7V ~10kHz >20mA	5V DC <20mA
Topology	360°	360°, segment
Arrangement	Through hole	End of axis, off axis, through hole

Table 2: SPINpad and HALL cells

	HALL Cell	SPINpad
Stray field / B field	No impact	No impact
Arrangement	End of axis	End of axis, off axis, through hole
Output	Period corresponds to mechanical period	Period corresponds to pole-pair (electrical) period
Electrical angle error, e.g. for a 4 pole pair machine	2°-6° (mechanical error)	<0.5° (electrical error)
Speed	35,000rpm	30,000rpm for a 10 pitch system 480,000rpm for a 1 pitch system
Cost Implications	Permanent magnet +PCB	PCB + Metal target

Contact details for further discussions and questions

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