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Dear Ladies and Gentlemen,

My name Dr. Thomas Theil.

I work most of my time as an independent consulting engineer or inventor.

This presentation is a collaboration with Broadcom, Eltra and Nemicon and the decision was made to use English. But it is not my mother language. Therefore please forgive any mistakes in pronunciation or spelling.

A presentation copy will be available later on the homepage of Eltra. The link will be on the last slide.

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If you may have noticed on the trade show, many companies propagated position sensors using a Wiegand-wire.

Due to the short time available, I want to focus more on this technology's mostly unknown history and background rather than so much on the technical aspects.

After remembering the origin of the wire, a short overview of the available magnetic sensors at that time, and the projected and realized applications for the wire, I want to explain why it fell into oblivion.

And that is why, more than 30 years later with the change of conditions for automation and the progress of technologies it came to a new life and is now so successful.

I want to finish my speech with a concise overview of the product development for encoders using the Wiegand technology and a conclusion.

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In 1974 John R. Wiegand filed a patent describing the procedure to produce a bistable magnetic wire, later known as the Wiegand-wire. By twisting and stretching a wire of Vicalloy, he got a wire with two different magnetic properties. With a soft magnetic core and a hard magnetic shell and this composition gave the wire the desired magnetic properties. It can be found in the literature, which describes the magnetic process itself; therefore I don’t want to explain it in all detail here.

The so called “macroscopic Barkhausen jump” of some magnetic materials under physical stress like tension or pressure was already known at this time. The electric pulse generated in a simple coil wrapped around such a wire was used for scientific measurements, for example, by “Sixtus & Tonks”.

The problem with Pulse-wires for industrial applications was that the mechanical stress has to be maintained over time and this was challenging with temperature and other environmental influences.

John R. Wiegand was therefore looking for a way to produce a bistable magnetic device which could be used for industrial applications and he found this in the way he described in the patent.

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Most used for magnetic measurements in 1970 were induction coils, but these could only be applied for alternating magnetic fields down to a certain minimum frequency.

For the measurements of permanent magnetic fields, the Hall-Effect was known. However, only the signal was minimal and the effort to amplify with discrete components was high. It was, therefore, quite big, expensive and still not very stable over temperature.

But the advantages of magnetic sensors had been clearly recognized. First, the possibility to act in a contactless mode was highly demanded by many applications. And also, the easy and possible complete isolation of the measurement unit from the DUT was a frequently needed feature.

So for a lot of simple switching applications, the Reed-contact was used. Due to the mechanical construction the switching frequency and the contact bounce were problems.

The Pulse-wire was not used so much due to the previously mentioned mechanical stress issues.

And with this background, the invention of Wiegand was a real breakthrough in 1974 and got a lot of attention.

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After the publication of the patent, a big amount of applications for the Wiegand-wire were published. It started from contactless keys to encoder and position sensors. Also the possibility to use the voltage generated by the Wiegand-wire to power direct a light pulse with a LED and to transmit the data over an optical fiber cable or to use some Wiegand-wires sealed inside a card to generate a specific code for security cards was planned or visualized.

For industrial and automotive applications the main features were the functionality of the Wiegand-wire over a very large temperature range from -190° up to +260°C and the simple connection to electronic devices. Without the need for an own power supply a simple 2-wire cable connection could be used.

Unfortunately, after some time, only the application in security cards was a real success for the Wiegand-wire. The reason for this is easy to explain.

The Wiegand-wire, once it was produced, was very stable over time and temperature but the manufacturing process of the wire itself remains very complicated. From the alloy's melting to the twisting and stretching of the wire, there were a lot of critical parameters.

Worldwide only a few suppliers for the Wiegand-wire were available and this was on one side good for the security card application because copying was very complicated and needed a high effort, but it could have been better for industrial or automotive applications.

In addition to all these manufacturing problems, the chip technology made speedy progress and soon the use of Hall elements with dedicated evaluation electronics became so common, small and very cheap and could be much easier integrated in most applications that nobody wanted to use the Wiegand-wire anymore.

And the end came for security cards based on Wiegand-wire too, even with a delay of some decades of years. Today the use of transponder technology is cheap and safe and has so many advantages that the production of Wiegand wires was mostly completely stopped around the year 2000. Only in the name of the often used Wiegand-protocol for the safe transmission of data Wiegand is still alive today.

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But as most people already may have noticed, the world continues to spin around and so with time the requirements changes.

With all the environmental problems we fight today, and I fear it will worsen, new parameters become more important. This could be seen with the introduction of ESG in 2004.

This was an attempt to define the responsibility of companies and economies to take care of the environment and the people. Today this is necessary and has become almost a quality criterion for companies and investments.

Related to multiturn encoder applications, the most relevant conditions for an environmentally friendly development are:

… Gears always need space and as more turns you want to count as bigger the space becomes

… A lot of the materials used by batteries come from countries where the concept of human rights is unknown. Furthermore, even if most of the chemicals can be reused, this is valid only if you can (next point)

… And I would not be sure if this is valid worldwide. Even in Europe, you can still find a lot of batteries in waste bins. And the problems with plastic today should be known to everybody.

… Low inertial mass means that the motor driving the encoders needs less energy

… Gears have a problem with high speeds and fast direction reversals. During the endurance tests of our systems, we had to replace a lot of mechanical encoders used as a reference

… The problems with batteries are complex. They are much better today but they still have a relevant self-discharging. Therefore the battery must be mounted in a replaceable way, which needs contacts and openings and leads to sealing and vibration sensitivity. And a fixed-mounted and sealed battery means that the whole system becomes hazardous waste at the end of the battery lifetime. Some products are still developed today this way but this is no sustainable solution and should not be supported.

And I want to point to another, secondary negative effect of battery-based systems, which is ignored because it is a problem for the end user and not for the manufacturer.

If the system is designed so that the battery “can” be changed, the replacement must be done in time before the system's function cannot be guaranteed any more. This means that many batteries are changed before they are empty. And the time and effort to change the batteries is also a waste of time, money and energy.

These aspects are mostly ignored because they are not visible directly and not included in the price of the product itself but in the end we all have to pay for it.

It is not a big thing to save one small battery per sensor but only to get an idea: If all of the multiturn sensors produced worldwide last year used a battery, the estimated weight would be 40 to 90 Tons each every year.

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As a conclusion of the before mentioned conditions, I can say:

1. For multiturn applications, there are only two possible ways of operation due to mathematical reasons. One is using a reduction gear and the other is counting the revolutions.
2. The requirements of the industries are always getting tougher. For example, the rotational speed and the number of turns become more, but the sensor size should become smaller.
3. Gear-based systems have a limited speed and count, which will exclude gear-based systems from many future applications.
4. Battery-based systems have a limited lifetime or need at least some maintenance intervals.

In the end, there is only one possible solution. A multiturn encoder can use many different technologies for the angle measurement in the range from 0 to 360 degrees but for the measurement and counting of the turns only a self-powered counter will be able to fulfil all of the current and future conditions.

And here comes the reason for the resurrection of the Wiegand-wire. With this technology it is easily possible to extract a small amount of energy from the movement itself, cumulate, store and finally convert this energy at predefined positions to an electrical pulse. With approximately less than 150nC this energy seems to be very small but with the proceedings in the chip technology it is today possible to power up a digital logic, to read the last position from memory, to count with the correct sign and to store back the new position in nonvolatile memory. This procedure today is named “use of energy harvesting”.

There were already some solutions for encoders with Wiegand-sensors before but they were not self-powered and needed at least two sensors for full functionality.

But size matters and in contrast to daily life where “big is beautiful”, you know, everyone wants a big salary, a big house, a big car and so on, the main condition for sensors is “small is nice”. For this, it is necessary to operate with only one single Wiegand-sensor and not with two or more.

This is necessary because a Wiegand-sensor's size cannot be reduced so much. For physical reasons, the Wiegand-wire doesn’t work if the wire is too short and the coil and the housing need space too.

And, also very important, the Wiegand-sensor is the most expensive single component of the encoder and the use of more than one will collide with the last point on the list.

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But I would only be here to talk about this presentation if we found a solution to solve this problem. Ironically it was a solution with the use of the same Hall-technology, which once was the substitute for the Wiegand-wire and the reason for not being such a success 50 years before. Within our IPs it is described more in detail how the counter works with the use of only one single Wiegand-sensor and how was solved the problem to synchronize the counter value with the singleturn position to a full multiturn encoder for every possible situation, but I list here on this slide only the two most important IPs.

The result is a straightforward system with only three main components. At least one magnet, the Wiegand-wire as a power supply and as a sensor for the counting and some ICs or ASICs for the signal and data elaboration.

The example here shows the combination of a Wiegand-counter with an optical singleturn but for the singleturn every solution is possible like optical, magnetically, capacitive, resistive or inductive.

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After first starting with the Wiegand technology in 2011 Broadcom, or at that time still named Avago Technologies in Malaysia, was only a licensee of us but in 2016 they acquired all our patents related to this application and Broadcom-INC is now the owner of the IPs and the related knowledge. Together with Eltra in Italy and Nemicon in Japan they developed multiturn encoders using the Wiegand-wire. They also developed their own wire and their own ASIC. Using a magnetic singleturn the whole electronic is integrated in just one single chip.

The first systems were housed encoders because only in this way the magnetic conditions needed for error-free working could be controlled. The encoders had a diameter of 40-60mm and a height of 40-50mm.

Today there are available not only much smaller housed encoders with diameters of only 36mm but also kits to integrate into user-specific applications, which save space and costs.

And the next generation will get even smaller, with diameters down to only 20mm and heights of 22mm. But they will return to housed encoders because the housing becomes an important magnetic component for the function at this small size. Prototypes are already working and under testing.

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Let me end my speech with the following conclusion.

Victor Hugo once said nothing is more powerful than an idea whose time has come.

And the shown history of the Wiegand-wire is good evidence that this is valid for social and technical ideas.

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Thank you for your attention and have a good time.