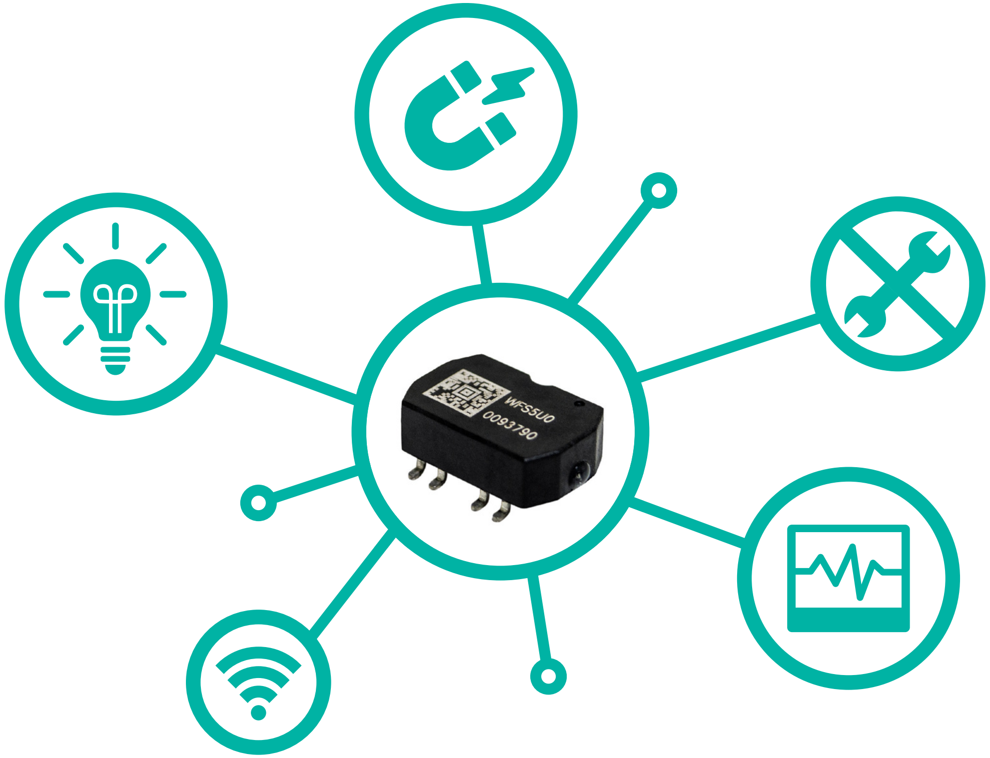
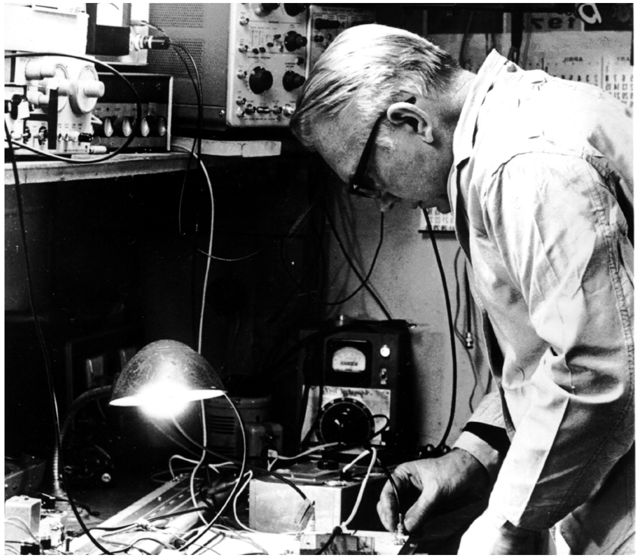
The Wonderful Wiegand Wire:
Energy Harvesting, Motion Sensing and More

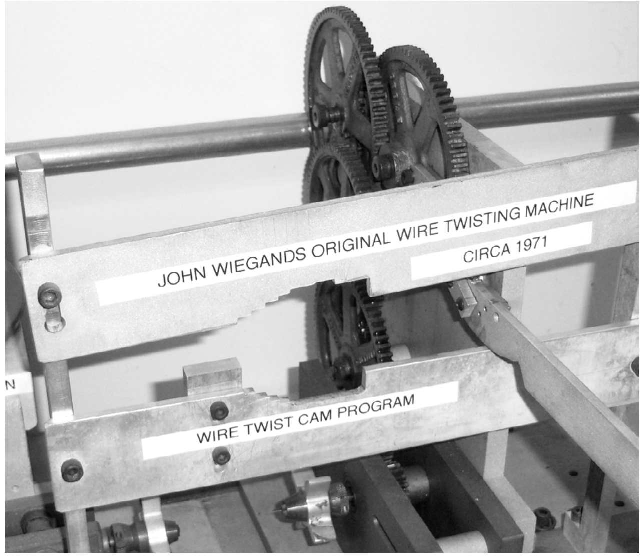
The “Wiegand effect” was discovered almost fifty years ago and has been used successfully in several specialized applications. However, its full potential for energy harvesting and signal generation has received only limited recognition. With recent enhancements to the energy output from Wiegand devices and the emergence of a new generation of ultra-efficient electronic chips for wireless communications, the technology is showing significant promise, especially in the exciting new area of the Internet of Things (IoT). UBITO, a member of the FRABA Group of technology companies, is leading research and development projects aimed at fulfilling this promise.



An energy harvesting technology of limited recognition, that has found its niche and is now coming of age.



John Wiegand at work in his lab



The original wire production machine designed by John Wiegand

John Wiegand discovered a physical phenomenon in the 1970's, which led to today's Wiegand sensors.

About the Wiegand Effect

The Wiegand effect is a physical phenomenon discovered in the 1970's by John Wiegand, an American inventor who found that by repeatedly stretching and twisting a piece of ferromagnetic wire, he could alter its magnetic properties. When a sample of "Wiegand wire" is exposed to a reversing external magnetic field, it will initially retain its original magnetic state. However, when the strength of the external field reaches a critical threshold, a region of the wire that is magnetically soft will undergo an abrupt reversal of its polarity. This transition takes place within a few microseconds and can be harnessed to induce a pulse of electric current in a fine copper coil wrapped around the wire.

The combination of a short length of Wiegand wire and a surrounding copper coil is referred to as a Wiegand sensor. These are available commercially from UBITO in SMD (surface mountable device) packaging.

UBITO

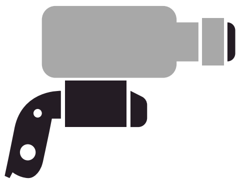
How is the Wiegand Effect Different?

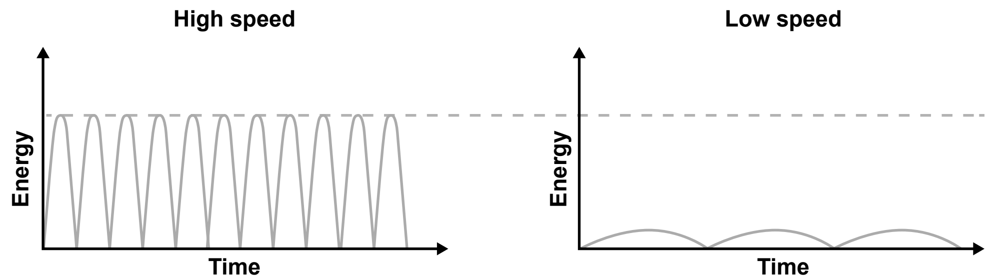
The electric pulse generated by a Wiegand wire is very brief, but its strength stays nearly constant, regardless of how quickly or slowly the external magnetic field changes. This is what makes the Wiegand effect special: while simple dynamos – which also use electromagnetic induction – are effective at converting rotary motion into electrical energy, their output power varies with the speed of rotation. When a dynamo is turned slowly, power levels can be too low to be useful. With a Wiegand wire however, the amount of electrical energy generated with each reversal of the magnetic field remains consistent over a wide range of speeds.

The electrical energy generated with each reversal of the magnetic field remains consistent over a wide range of speeds.

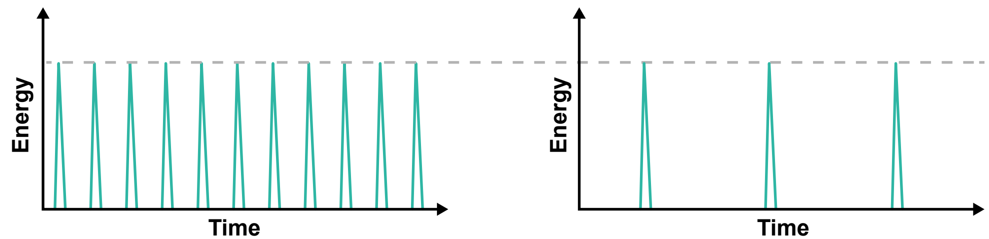
Watch video
HOW IS WIEGAND TECHNOLOGY DIFFERENT?

Dynamo
Conventional inductive generator. Energy depends on the rotation frequency.
Signal type: sinus

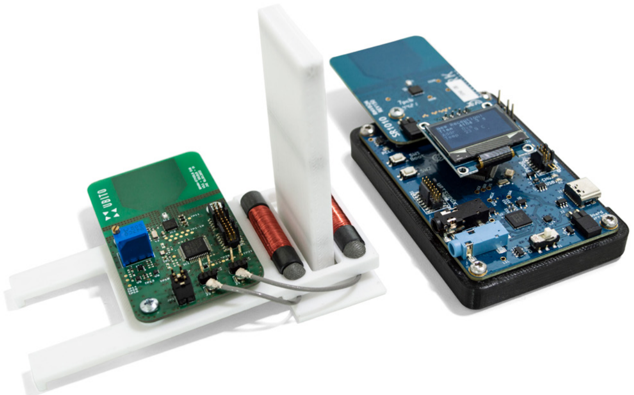




Wiegand Generator
Pulsing inductive generator. Energy does not depend on the rotation frequency.
Signal type: pulse



UBITO



UBITO laboratory prototype

Energy Harvesting: Power for Innovation

‘Energy harvesting’ refers to technologies that extract energy from the local environment to power electronic devices. Several are available, including photovoltaics (energy from light), thermoelectric and pyroelectric effects (energy from temperature variations) and Piezoelectric and electrostatic devices (energy from mechanical motion).

Wiegand sensors are also a good candidate for energy harvesting. In their basic form, these devices produced modest amounts of energy – about 200 nanojoules. However, recent developments have significantly increased energy output from Wiegand devices and opened possibilities for much more ambitious applications.

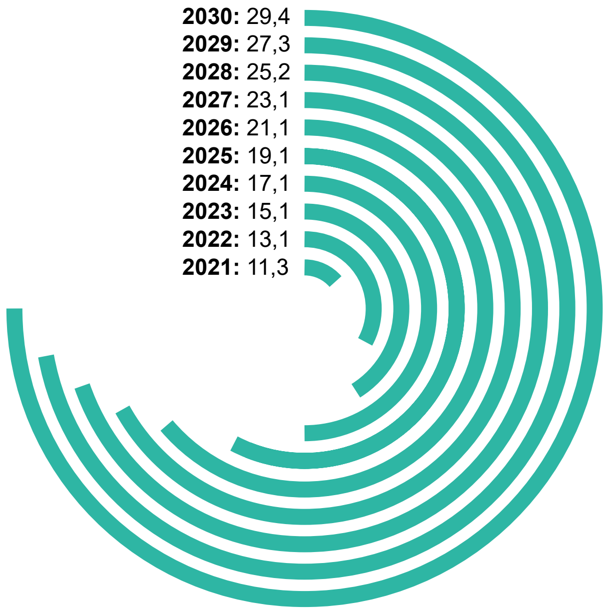
An R&D program, carried out by a team of researchers at FRABA’s technology center and the Rhineland-Westphalia Technical University with support from the German Ministry of Science and Technology, has developed enhanced Wiegand devices that are optimized for power generation. These are called “Wiegand harvesters”. The researchers have demonstrated that a set of Wiegand harvesters can generate up to 10 microjoules of energy (approximately 50 times the output from a commercial Wiegand sensor). This was sufficient to energize a low-power ultra-wide-band radio transceiver with a transmission range of 60 metres.

Recent innovations have achieved an increase of up to 50 times the energy output of a commercial Wiegand sensor.

Read about
ENERGY HARVESTING

Building an Energy Self-Sufficient IoT Node

An increase in generated energy points to the feasibility of a new generation of entirely self-powered sensors that would be capable of monitoring a physical action – such as a rotary motion or the opening or closing of a door – and transmitting a signal, together with additional sensor data (e.g. temperature), to a monitoring system through wireless communications. This type of energy self-sufficient, maintenance-free devices could become important components in an Internet of Things (IoT). As Christian Fell, FRABA's head of technology development explains: "the vision of the IoT calls for thousands of smart sensors distributed through homes, commercial facilities, and digital factories, collecting data for monitoring, security and process optimization. If these devices can be made energy self-sufficient, harvesting electricity directly from their surroundings to power both their operation and a wireless communications interface, there will be enormous benefits in terms of simplifying network deployment and reducing maintenance costs – including the cost of installing, checking, and disposing of thousands of backup batteries." The Wiegand effect could provide an excellent power source for remote sensors wherever there are changing magnetic fields present.



Source: Transforma Insights © Statista 2022

Number of Internet of Things (IoT) connected devices worldwide 2021, with forecasts from 2022 to 2030

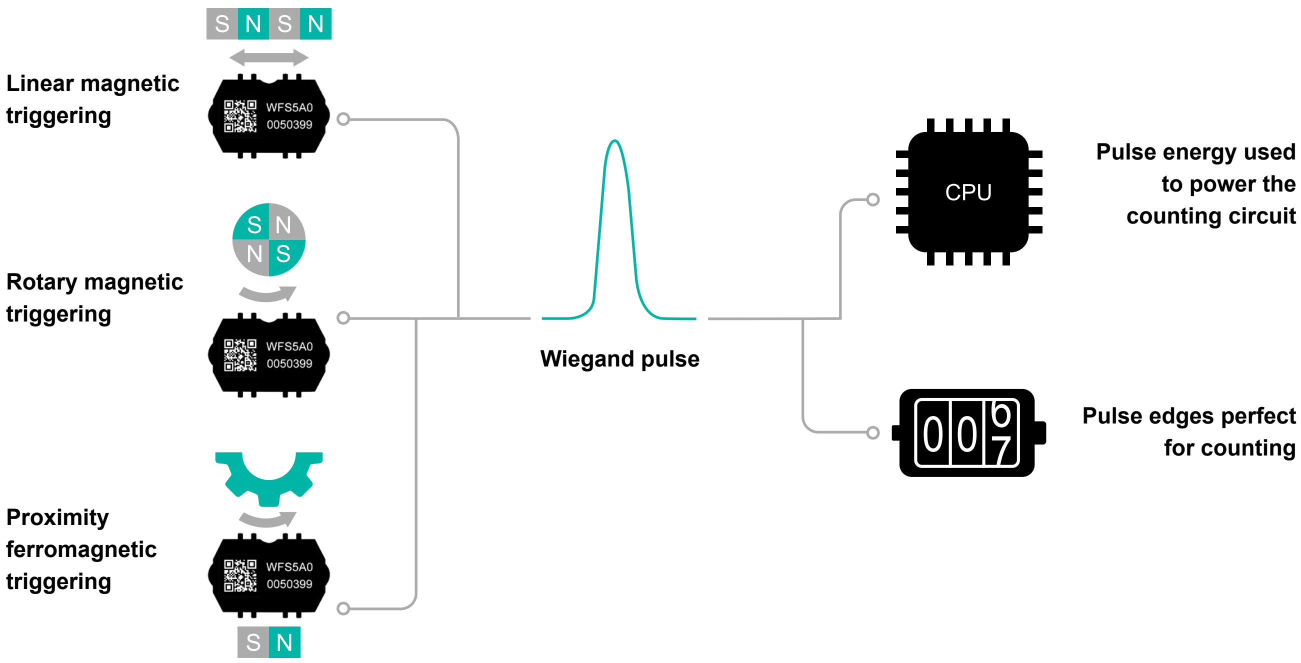
IoT calls for thousands of smart sensors distributed through homes, commercial facilities, and digital factories.

UBITO

Energy Harvesting for Self-Powered Sensors

Even for small Wiegand sensors, the electrical energy produced with each polarity change – while limited – is sufficient to activate a low-power electronic counter circuit. This form of energy harvesting has been used successfully in over a million encoders (rotation measurement instruments) built by POSITAL and other manufacturers. Thanks to Wiegand energy harvesting, these encoders' rotation counter systems are entirely self-powered with no need for external power sources or backup batteries, significantly reducing maintenance requirements.

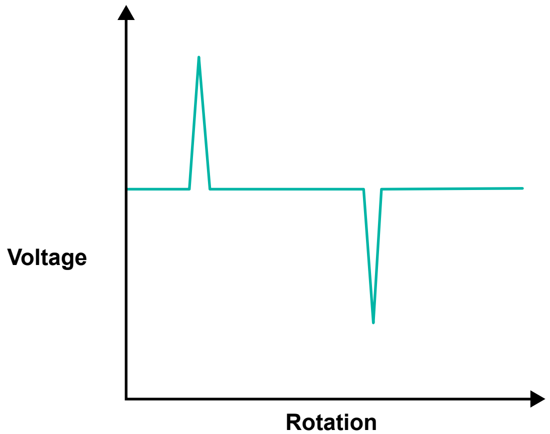
> **Wiegand Effect energy harvesting has already been used successfully in over a million encoders (rotation measurement instruments).**

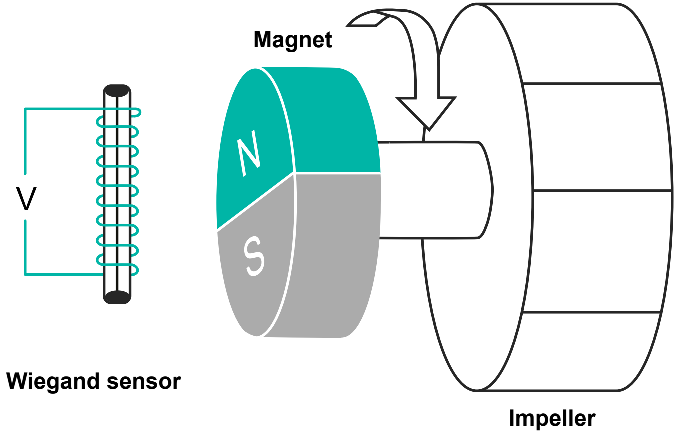


Clear Signals for Counting Operations

A similar principle has been used for water or gas meters. Here, a permanent magnet is mounted on the meter's rotating shaft, close to a Wiegand sensor. As the shaft turns, the rotation of the magnetic field triggers abrupt polarity reversals in the Wiegand wire, inducing electric current pulses in the copper coil. As the strength and duration of each current pulse is independent of how quickly or slowly shaft rotates, Wiegand sensors provide much higher signal-to-noise ratios than other analog magnetic sensors (e.g., Hall effect sensors). This ensures that the meter's counter circuit receives clear and unambiguous signals with each rotation of the shaft.

Wiegand sensors provide much higher signal-to-noise ratios than other analog magnetic sensors (e.g., Hall effect sensors).



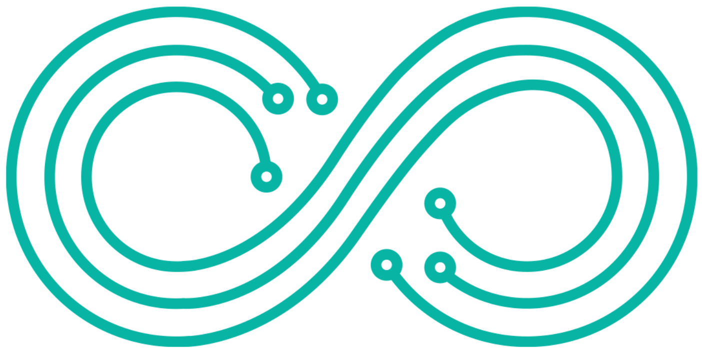


Non-Mechanical Contactless Sensing

Wiegand-based event triggering has also been used for tachometers and wheel-speed sensors. Here, the Wiegand sensor is located near two magnets with the opposite polarity. The presence of a large ferromagnetic (iron) body nearby can neutralize the effect of one of these magnets so that the magnetic field at the Wiegand sensor is dominated by the other magnet (N-S in the accompanying diagram). As the ferromagnetic body rotates, it will neutralize the other stationary magnet, reversing the field (S-N) and triggering a polarity flip in the Wiegand wire. Alongside operating reliably over a wide range of rotation speeds, with no mechanical contact between the sensor and the moving component, there is no wear, and the systems have service lifetimes of billions of operating cycles.

With no mechanical contact between the sensor and the moving component, there is no wear, and the systems have service lifetimes of billions of operating cycles.

BILLIONS OF OPERATING CYCLES



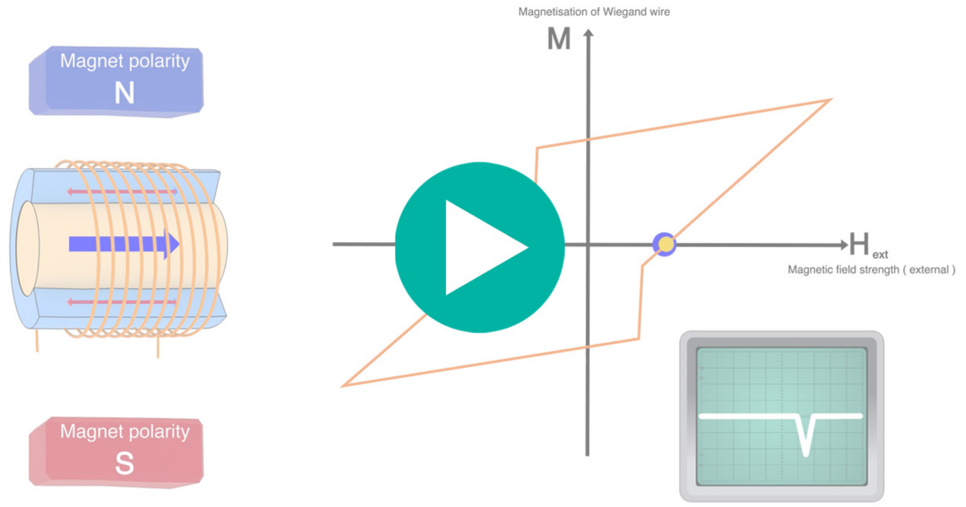
Inside the Wiegand Effect

The mechanical process used to produce Wiegand wires creates a combination of magnetically hard and soft layers in the wire, causing the wire to have a high level of magnetic hysteresis.

As the external magnetic field changes, the Wiegand wire will retain its initial polarity. However, when the strength of the external field reaches a critical threshold, the polarity of the magnetically soft zone of the Wiegand wire suddenly reverses. As the external field continues to strengthen, the magnetically hard zone will also reverse its polarity, so that the whole wire reaches a new magnetic state. When the external field changes back towards its original polarity, a sudden reversal of the soft material will occur again. The wire will eventually return to its earlier state.

These fast reversals in the magnetic polarity of the wire core will induce short pulses of electrical current in the fine copper coil wrapped around the Wiegand wire.

The magic of the Wiegand effect lies in the high level of magnetic hysteresis seen in the Wiegand wire.



Watch video
WIEGAND EFFECT

UBITO

Manufacturing Wiegand Wire

Wiegand wire is produced through a process that involves annealing a spool of Vicalloy wire (an alloy of vanadium, iron, and cobalt), then simultaneously stretching and twisting the wire. This aggressive cold working alters the crystalline structure of the metal and creates two regions – an inner core and outer shell – with significantly different levels of magnetic coercivity.

Coercivity is a property of ferromagnetic materials that defines how easily the material can be magnetized by and external magnetic field. Magnetically soft materials, such as mild steel, have low coercivity and change their magnetic state easily. Magnetically hard material, such as the alloys used to make permanent magnets, will retain their magnetic state unless they are exposed to very strong external fields. The interaction of these two regions causes the wire to have a high level of magnetic hysteresis.

The 'recipe' for producing a satisfactory batch of Wiegand wire was determined by John Wiegand and his collaborators through trial and error. The machine that they developed to produce Wiegand wire features a series of rotating frames that stretch, twist, then un-twist the wire at various rates. This machinery was acquired by FRABA, along with John Wiegand's lab notes. Since then, research carried out by FRABA and its partners has automated this process and optimized it for quality and consistency.

The original wire manufacturing process conceptualised in the 1970s has been optimised and automated by the FRABA Wiegand technology centre.