

CONFIGURATION AND DEMONSTRATION OF 433-MHZ WIRELESS GAUGE READER



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The Cypress Wireless Gauge Reader is commercially available in 900-MHz and 2.4-GHz versions, which are already deployed at numerous facilities. For the purposes of this demonstration project, a 433-MHz version was created for the Electric Power Research Institute (EPRI). The 433-MHz band is potentially attractive because it has lower path loss than higher frequencies; for the same transmission power, 433-MHz devices have roughly double the range of 915-MHz devices and four times the range of 2.4-GHz devices. Using the 433-MHz band can also avoid frequency overcrowding with the many other wireless solutions that use 900 MHz or 2.4 GHz.

Technical Overview of the Wireless Gauge Reader

The wireless gauge reader (WGR), shown in Figure 1, is an “electronic eyeball” that can be clamped onto the front face of a dial gauge to digitize its reading. It is an Internet of Things (IoT) sensor that enables IoT applications at industrial sites at minimal disruption and cost.



Figure 1 – Wireless gauge reader

This patented WGR technology (U.S. patents US20090190795, US8594368, and US8411896) uses an optical sensor, built-in illumination, and image recognition firmware to convert the dial image to a digitized value that is transmitted wirelessly. It is capable of reading round dial gauges for pressure, temperature, flow, humidity, and so on. A WGR is installed non-invasively in minutes, without the need to cut pipes, shut down processes, perform leak checks, run wires, and so on, and is rated for both

indoor and outdoor use (IP66/NEMA 4 enclosure). The unit is battery-operated, with a typical battery life of three to five years at a 15-minute sampling rate.

The WGR has three main parts—the gauge reader sensor unit, the mounting adapter, and a calibration tool. Figures 2 and 3 show the following key components of the sensor unit:

- Charge-coupled device camera
- Microcontroller
- LED illumination, which acts as a flash for image capture
- Wireless transceiver module with antenna
- Desiccant pack to prevent condensation inside the unit
- Two CR123A batteries with 3 amp-hours each, which cost approximately \$2 per cell

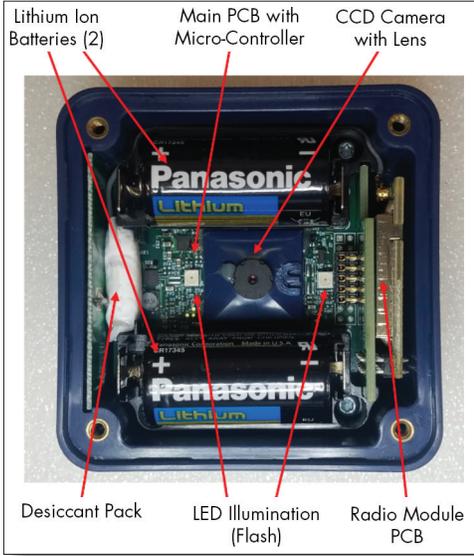


Figure 2 – Components of gauge reader sensor unit

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Configuration and Demonstration of 433-MHz Wireless Gauge Reader

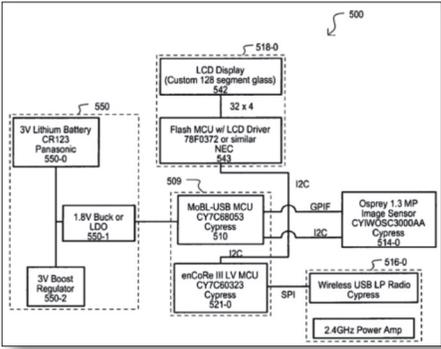


Figure 3 – Main electronic parts

The WGR's front panel, shown in Figure 4, includes a display and three buttons that enable the user to select multiple menu functions and settings. The letter labels in Figure 4 correspond to the following elements:

- **A: Sample icon.** Displayed when a new reading is being captured and converted.
- **B: Error icon.** Displayed when an error condition is detected.
- **C: Bar graph.** Indicates percent of full-scale reading.
- **D: Numeric display.** Displays the converted reading value.
- **E: Antenna icon.** Displayed when wireless communication is successful.

- **F: Battery level.** Displays percentage of battery life remaining.
- **G: Alphanumeric display.** Displays the reading units or diagnostic messages.
- **H: Left button.** Menu navigation and decreases values.
- **I: Center button.** Requests immediate updated reading and menu navigation.
- **J: Right button.** Menu navigation and increases values.

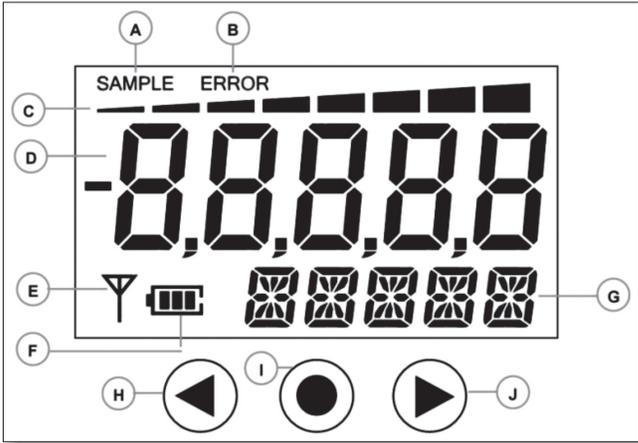


Figure 4 – Display panel and push buttons

Figure 5 shows the main press-menu structure for the user to access the available functions.

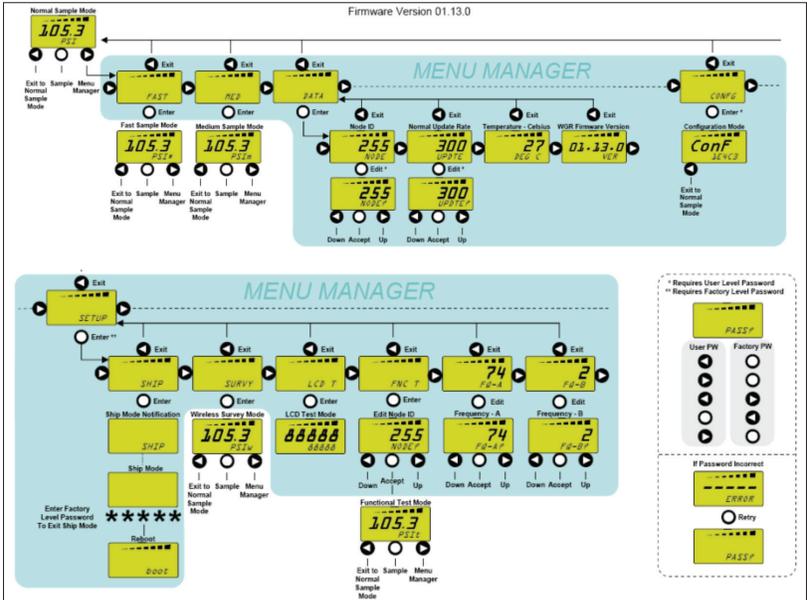


Figure 5 – Front buttons menu

The various functions and displays labeled in Figure 5 are as follows:

- **Normal Sample Mode:** Standard WGR operating mode. The time between samples is set up using the HH.
- **Fast Sample Mode:** WGR will sample every 5 seconds for 5 minutes. It will automatically return to Normal Sample Mode. This mode is useful for short-term diagnostics.
- **Medium Sample Mode:** WGR will sample every 30 seconds for 8 hours. It will automatically return to Normal Sample Mode. This mode is useful for medium-term diagnostics.
- **Node ID:** The node ID of the WGR. This can be viewed and edited.
- **Normal Update Rate:** The update rate for Normal Sample Mode. This can be viewed and edited.
- **Temperature—Celsius:** Displays the current temperature reading at the WGR. Read-only.
- **Ship Mode:** Effectively powers down the WGR. The WGR is in an ultra-low power consumption state. Used when storing or transporting WGRs.
- **Wireless Survey Mode:** Used when performing a wireless survey at a site. To save battery power, the WGR sends dummy samples without capturing an image.
- **LCD Test Mode:** Used during manufacturing test.
- **Functional Test Mode:** Used during manufacturing test.
- **Frequency—A:** Frequency A can be viewed and edited.
- **Frequency—B:** Frequency B can be viewed and edited.

Figure 6 shows the various sizes and types of mounting adapters available to fit on different gauges.



Adapter Size	Dimensions		
	ID at Gauge Interface	Max. OD of Gauge	Min. OD of Gauge
Mini	1.955 in.	1.955 in.	1.600 in.
	(49.66 mm)	(50.67 mm)	(40.64 mm)
Small	2.350 in.	2.390 in.	1.995 in.
	(59.69 mm)	(60.71 mm)	(50.67 mm)
Medium	2.782 in.	2.822 in.	2.390 in.
	(70.66 mm)	(71.68 mm)	(60.71 mm)
Large	3.245 in.	3.285 in.	2.820 in.
	(82.42 mm)	(83.44 mm)	(71.63 mm)
Extra Large	3.675 in.	3.715 in.	3.285 in.
	(93.35 mm)	(94.36 mm)	(83.44 mm)
Grande	4.083 in.	4.123 in.	3.715 in.
	(103.71 mm)	(104.72 mm)	(94.36 mm)
Extra Grande	4.600 in.	4.680 in.	4.181 in.
	(116.84 mm)	(118.87 mm)	(106.20 mm)

Figure 6 – Sizes and types of mounting adapters

Typically, the mounting adapter is clamped onto the gauge using a hose clamp, as shown in Figure 7. The proper size and type of adapter must be selected to mount the WGR sensor on the gauge.

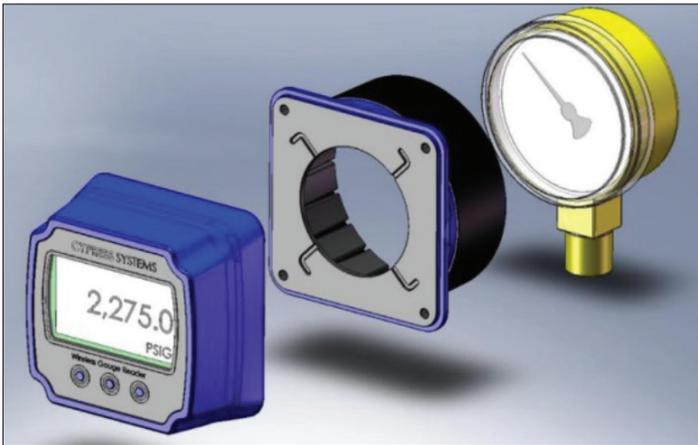


Figure 7 – WGR sensor (left), mounting adapter (center), and gauge (right)

The sensor unit attaches to the mounting adapter with a quarter-turn quick-disconnect, as shown in Figure 8. The quick-disconnect makes for easy removal and reattachment of the WGR, allowing the user to see the underlying gauge.



Figure 8 – Convenient access to gauge through quick-disconnect

Figure 9 shows the calibration tool that is used once during the initial installation to “teach” the sensor unit how to read the gauge.

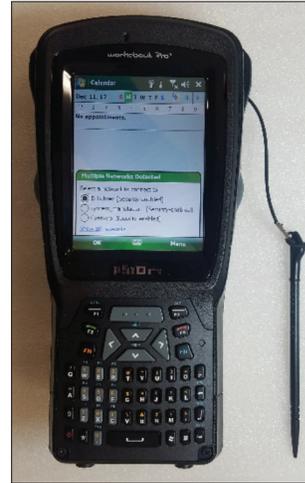


Figure 9 – WGR calibration tool

The calibration procedure usually takes about 5–10 minutes and involves setting five parameters for each gauge, plus selecting a series of circles to detect the needle. Figure 10 shows the variables that need to be manually configured for initial operation—the gauge’s minimum and maximum angles, minimum/maximum needle travel angle, needle rest correction, and gauge tilt angle.

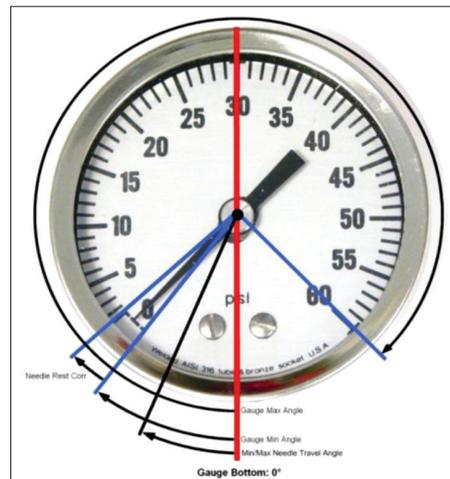


Figure 10 – Variables manually configured during calibration

Features such as the minimum value, start angle, and units vary from one gauge to another; accordingly, the user must configure the WGR to work with a specific gauge. The gauge characteristics do not depend on how the WGR is rotationally mounted on a gauge. All angles are defined with respect to the gauge face. In Figure 10, refer to the red line: all angles start from 0° and turn clockwise to 359°.

The WGR looks for the pointer along user-defined concentric circles (see Figure 11). The circles must be set up to avoid as much background as possible while still overlapping the pointer. Writing, markings, graphics, and so on that are dark enough can be picked up by the software as part of the pointer, which could create uncertainty or error in the reading. Center Points X and Y and Radiuses 1–5 define the size and location of the circles. In Figure 11, the concentric circles are improperly set up—note how they overlap the PSI symbol, the numbers, the graphic in the center, and even the rivets at the bottom.

Related HH Variables:

- Center Point X
- Center Point Y
- Radius 1
- Radius 2
- Radius 3
- Radius 4
- Radius 5
- Zoom Enable
- Zoom X Offset
- Zoom Y Offset
- Tip Width
- Tail Width
- Circles

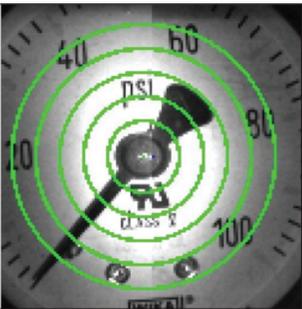




Figure 13 – Properly set-up concentric circles

Figure 11 – Improperly set-up concentric circles

Figure 12 is the same as Figure 11, except that the green pixels represent what the image processing algorithm considers the pointer. The green pixels outside of the pointer could confuse the image processing algorithm and distort the reading.

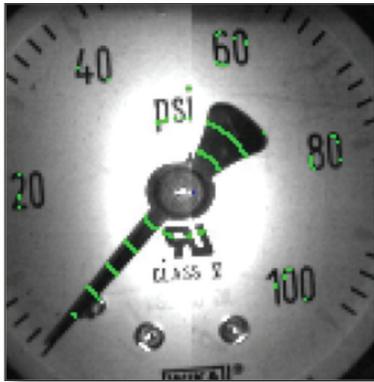


Figure 12 – Potentially problematic green pixels

Figure 13 is an example of properly set-up concentric circles. The image processing algorithm will ignore the numbers, rivets, and large graphic. However, portions of the PSI sample and the top of the “100” marker are still overlapped.

FCC Regulations for 433-MHz Devices

In the United States, 433 MHz is not a general-purpose ISM band. It is intended for amateur radio and specific remote-control applications. U.S. Federal Communications Commission (FCC) 15.231 imposes many restrictions on the use of the 433-MHz band—most notably, on transmission time. For example, 15.231.a.3 prohibits scheduled periodic data transmissions, but it does allow polling transmissions (with data) that cannot exceed 2 seconds of transmission time per hour. Second, 15.231.e allows more frequent periodic polling transmissions, as long as “the duration of each transmission shall not be greater than one second and the silent period between transmissions shall be at least 30 times the duration of the transmission but in no case less than 10 seconds.”

The current design of the WGR relies on scheduled periodic transmissions, which would violate the first requirement. Polling transmissions are not supported, so the second requirement does not apply. To use the 433-MHz frequency, the wireless transmission power must be significantly reduced to effective isotropic radiated power (EIRP) of -22.4 dBm. At this level, the FCC allows unrestricted use of this frequency, but it is extremely low power (that is, compared with the 900-MHz allowable limit of 30-dBm EIRP). Because of the significantly lower power output, the range of a 433-MHz transmission will be much less than what the FCC allows for 900 MHz.



Configuration and Demonstration of 433-MHz Wireless Gauge Reader

One practical limitation of 433 MHz is the scarcity of vendors and materials available in the marketplace. Compared with 900 MHz and 2.4 GHz—for which there is an abundance of equipment vendors for radios, protocol stacks, modules, gateways, and so on—very few vendor and product choices exist for 433 MHz. For example, there is no certified 433-MHz radio module for the LoRA protocol, nor are there any available LoRA gateways or routers. Therefore, developing a 433-MHz application would require more upfront engineering effort than for 900-MHz or 2.4-GHz designs.

Based on the FCC's severe restrictions on transmission power and transmission time as well as the limited vendor and product options, 433 MHz is overall a less flexible option for data acquisition. However, for the WGR application within a distributed antenna system (DAS) environment, the range limitations might not be a significant hurdle, as long as the WGRs are always located near a DAS antenna. The primary advantage of using the 433-MHz band is that it would alleviate anticipated congestion on the 900-MHz and 2.4-GHz frequencies.

Configuration of the WGR for a 433-MHz Radio

The objectives of this EPRI project are to demonstrate the feasibility of creating a 433-MHz version of the WGR and to operate it with a DAS. This effort involved the following three main tasks:

1. Modify existing 2.4-GHz WGRs to use a 433-MHz radio module:
 - Used Cypress 2.4-GHz units as a starting point (Artaflex AWA24R module).
 - Assessed available 433-MHz radio modules on the market. Selected microchip RN2483 based on form factor to fit within the existing WGR housing and to ease the integration with existing firmware APIs (via SPI physical interface) on the WGR.
 - Designed and fabricated a custom printed circuit board as daughterboard with RN2483 radio, which physically plugs into the same connector as the previous 2.4-GHz radio module onto the main WGR motherboard.
 - Designed, coded, and tested firmware to enable wireless communication.
2. Create a custom 433-MHz receiver to gather data from 433-MHz WGRs:

- No 433-MHz gateways/routers were commercially available for common protocols, so a custom receiver was designed and built.
 - A MOTE development board was modified to act as a receiver using LoRA modulation with a simple checksum protocol (not LoRA protocol).
 - This receiver has a coax input SMA connector that can be connected to a dipole 433-MHz antenna or a plant DAS.
 - This receiver has a USB output that connects to a Windows PC that can receive and display the data in near-real-time.
3. Create PC application to receive and display data from WGRs:
 - Wrote Windows application to receive data from receiver using USB COM port.
 - Application is installed on Windows 10 PC.
 - Application displays data from WGRs in near-real-time on a monitor connected to a PC.

For this demonstration, functionality for OPC or RESTful interfaces is **not** included, nor is the ability to store, trend, or alarm on process data. These interfaces allow the 433-MHz WGR system to share data with third-party supervisory control and data acquisition (SCADA), historian, or other applications. This functionality already exists for the 900-MHz and 2.4-GHz versions of the WGR—the 433-MHz version can be readily upgraded to include these features if needed.

Demonstration of Performance

The demonstration portion of this project involves installing and testing the 433-MHz WGRs at the EPRI lab in Charlotte. One key objective was to test the ability of the WGRs to use a DAS (which was recently installed at the EPRI-Charlotte facility).

The actual deployment of the three WGRs at the EPRI lab was accomplished on May 4, 2018, and took approximately 2.5 hours. The deployment included the following:

- Identification of the locations to install the WGRs
- Physical mounting of adapters to the selected gauges
- Calibrating the WGRs to read the selected gauges
- Setting up the receiver and the PC
- Connecting the receiver to the DAS

Configuration and Demonstration of 433-MHz Wireless Gauge Reader

Figures 14 and 15 show the gauges/locations where the WGRs were installed. For this demonstration, the receiver was located approximately 100 ft (30.5 m) away from the gauges monitored. Initially, we confirmed that we could receive the wireless transmission directly from the WGRs to the receiver without using the DAS. Then, we removed the external antenna from the receiver and connected to the DAS and confirmed reception using the DAS. Also, we took one WGR, walked to a location approximately 300 ft (91.4 m) from the receiver, and confirmed reception through the DAS. See Figures 16 and 17.



Figure 14 – WGR installed on pressure gauge

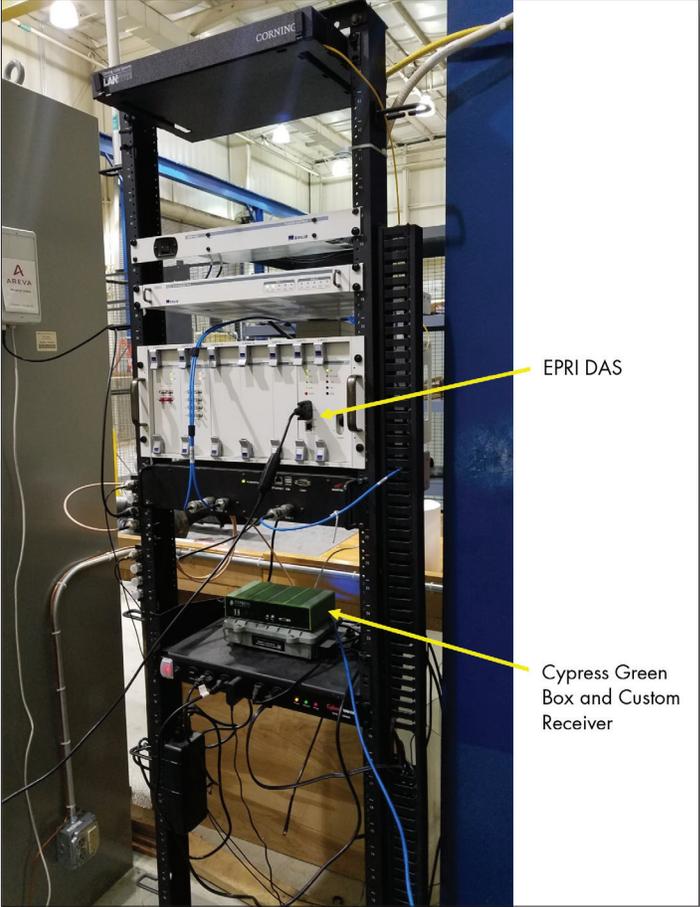


Figure 16 – Green box and receiver connected to DAS



Figure 15 – Two WGRs installed on temperature gauges

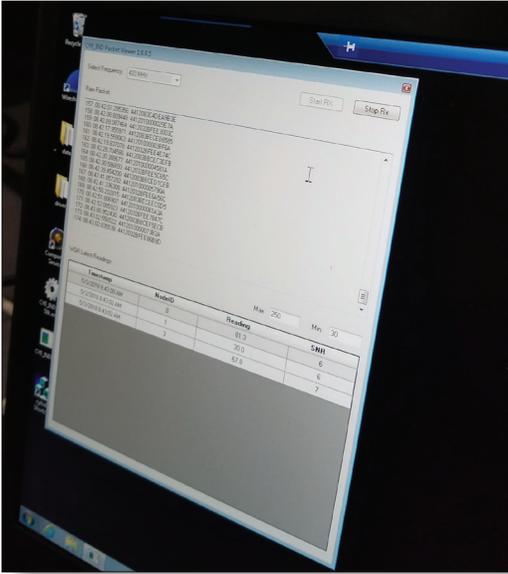


Figure 17 – PC application displaying data received from WGRs

Conclusions

The demonstration confirmed the viability and functionality of a 433-MHz version of the WGR, including using it with a DAS. As configured, the demonstration system can scale up to approximately 20 WGRs. It can also be upgraded to include OPC and/or RESTful API interfaces to share data with third-party systems, built-in history, and user interfaces for trending and alarming.

However, for the system to be deployed on a larger scale at 433 MHz, a more sophisticated protocol—ideally, LoRA for cybersecurity, device contention management, and so on—would have to be implemented. In the future, it would also be necessary to find suppliers to provide 433-MHz LoRA devices, such as gateways and routers.

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