Wireless, hermitically sealed actuator and sensor platform with reconfigurable hardware

Juho Vesanen
Department of Intelligent Technology
Helsinki Metropolia University of Applied Sciences
Espoo, Finland
juho.vesanen@metropolia.fi

***Abstract*— Wireless sensor networks and Internet of Things are rapidly gaining momentum and ground in measurement and control applications. Typically these systems contain simple sensor elements networked together. However, the possibilities and applications of small and independent sensor and/or actuator devices are not yet fully explored and some research should be targeted towards more traditional systems.**

In this paper a novel platform for actuator and sensor applications is presented. The key features of the platform are wireless very short range communications, wirelessly charging using inductive coupling, in-application- and self-programming, re-configurable hardware and extremely simple electronic circuitry. The system is designed to be hermitically sealed.

With in-application programming and with re-configurable hardware the software and hardware configuration of the device can be altered even while the system is operating. This includes for example the analog signal pathway consisting of amplifiers, filters and AD converters. In fact, the system is designed to be installed before the actual operational parameters or the details of the target environment are even known.

Applications for presented platform range from industrial measurements to electronic fishing gear. The platform could be used e.g. in humidity, moisture, temperature and vibration measurement in applications where the measurement device needs to be implanted in the target - for example cast in cement. As a fishing lure the system could automatically detect the depth and change the parameters how it is attracting fish with blinking lights and vibrations.

Keywords—PSoC; reconfigurable hardware; sensor; actuator; inductive power transfer

I. Introduction

Wireless sensor networks have now been under research for more than a decade. Internet of Things (IoT) is projected to have 26 billion devices by 2020 [1]. Both of these emerging technologies are gaining momentum in different applications. In today’s world it is easy to forget traditional non-networked systems even if networked sensor and actuator devices have their own limitations and challenges especially in security and privacy [2]. Non-networked systems can be physically smaller, cheaper to manufacture and simpler to design and implement than e.g. IoT compatible devices.

Inductive power transfer (IPT) [2] provides a method to power remote devices. The limitations of this technology are low distance and low efficiency. However, IPT does provide a completely wireless solution which can be necessity for certain applications. For the past years this has been used mostly in consumer electronics. Wirelessly charging tables, PDAs and smart phones has been found very convenient. Other IPT applications include medical devices and biomedical implants, instrumentation systems and electric cars and trains.

II. Platform concept

The underlying idea was to develop a wireless platform that can act as a sensor, actuator or as both with a possibility to alter the hardware configuration without having a physical access to the device. Design goals also included a short-range wireless data communication, simple electronic circuitry and versatility. When long operational life is required together with limited battery size, the platform needs to be wirelessly chargeable.

This kind of measurement and/or actuator platform can be used in a variety of applications. Some of the application areas that were considered and identified during the design process are:

- Implantable medical measurement. For example performance of artificial joints could be analyzed with system similar to the developed platform.
- Structural parameter measurement. Implanting a sensor e.g. in concrete would allow measurement of temperature, moisture, physical movement and stress wirelessly.
- Sports equipment measurement. Wireless sensor could be integrated into sports equipment such as bats, clubs, rackets and ski poles. This would allow wireless data reception from e.g. acceleration sensors. The data could be used to analyze the performance and movement.

- Electronic fishing lures. Programmed sensor and actuator, that can be wirelessly charged, could be used in creation of intelligent fishing lures that could for example attract fish with different acoustic or visual signals.

Common factor on all of the precious concepts is that the hardware configuration of the system may have to be changed after the device is placed as the operational parameters and requirements may not be fully known in advance. Also systems operating for extended periods of time may face changing operational requirements. For example amplifiers and filters on analog signal pathway may need to be altered after the device is placed to the target environment.

In order to implement previously described system the core of the platform was chosen to be a PSoC microcontroller from Cypress Semiconductor based on its unique feature for hardware reconfiguration. Conceptual block diagram of the whole system is shown in Figure 1. The base station consists of a microcontroller controlled wireless power transmitter and wireless data transceiver. The platform contains units for power reception, data reception and transmission, power management and sensor interfacing. The key in the design is the hardware simplicity that allows miniaturization of the platform to suit different needs and applications.

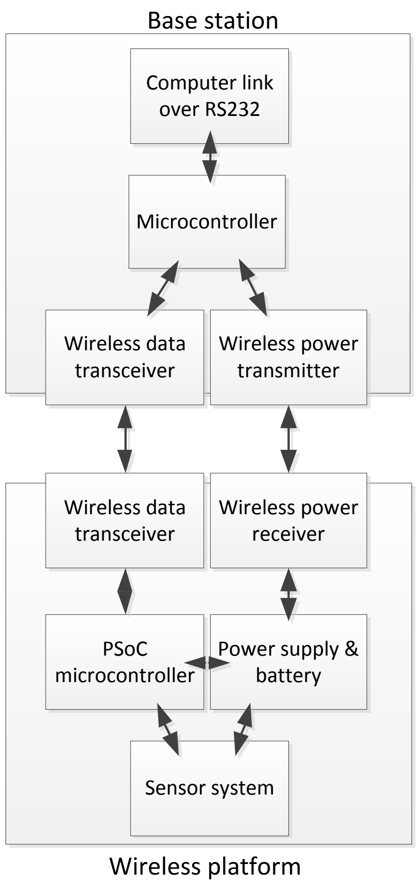

Figure 1 – Block diagram of the system

III. PSoC MICROCONTROLLER

PSoC (Programmable System on Chip) [3][4][5] is a family of microcontrollers (µC) by Cypress Semiconductor. In addition to having a typical microcontroller core, these devices contain an array of freely configurable analog and digital blocks. These blocks can be configured to perform a variety of analog and digital tasks. There are multiple different PSoC microcontroller families, but the most significant difference between these is type and architecture of the CPU core and physical size of the chip. In this paper PSoC 1 family µCs are used. The computational performance of a PSoC 1 family µCs is quite limited (< 3 MIPS), but for battery powered systems requiring long operational life the devices is suitable due to very powerful sleep modes and low sleep currents that are in the range of microamperes [6].

The configurable blocks in a PSoC can be configured quite freely with some limitations. The selection of block functions includes AD and DA converters, analog amplifiers, counters, timers and PWM modulators. Blocks can also perform communication tasks using serial interface such as I2C, SPI, 1-Wire or UART. Different kinds of analog filters, hardware-based pseudo random number generators and stochastic signal density modulator are examples of other functions. Signal routing between the blocks and physical pins of the chip has also a lot of freedom. The most interesting fact is that the blocks are totally independent from each other and from the CPU core. For example, the system can leave only a counter running, turn everything else off including the CPU core, and wake up after specified amount of input pulses have been counted. The hardware configuration can also be altered while the system is running. The internal configuration is designed using software called PSoC Designer. Figure 2 illustrates the PSoC Designer when designing the chip level – the configuration and connection of the modules – of a PSoC project.

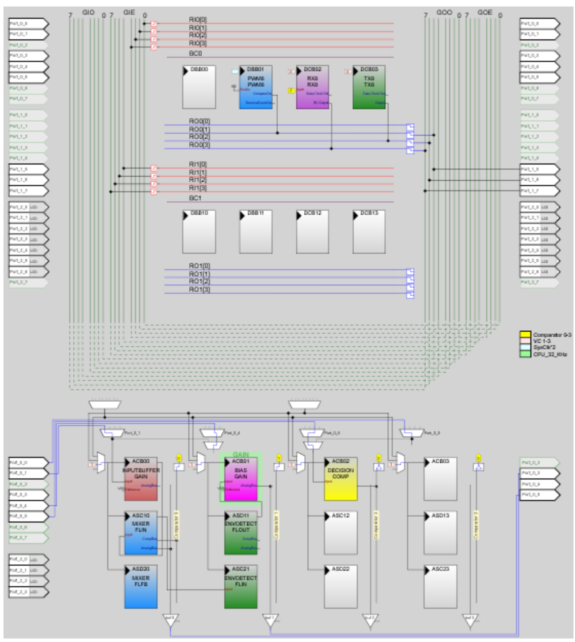

Figure 2 – Chip level design in PSoC Designer

For normal operation the PSoC does not require any external components, apart from the bypass capacitor on the positive voltage supply. The microcontroller contains two internal RC oscillators. With the built-in clock generation circuitry a variety of frequencies can be created for different blocks or for the CPU core. It should be noted that the accuracy of these clocks is ± 2.5 %. This also limits the accuracy for all timing and frequency measurements. For higher accuracy all internally created frequencies can be locked with a built in PLL to an external crystal oscillator. This however increases the physical size of the system and component count. [3]

With PSoC different systems can be implemented without using external active components by using the configurable blocks. Examples range from heart rate measurements [7] to 555 timer IC replacements [8]. PSoCs have also been used in wireless sensor networks [9][10][11] and in a other sensing applications [12]. However, the most typical application for a PSoC is *sensor interfacing*. There are multiple examples [11][13][14][15] on how the actual measurement system is using another microcontroller, but the signal conditioning and/or sampling is implemented with a PSoC. This includes also several medical systems.

The internal configuration of the PSoC can also be changed while the system is running. Dynamic reconfiguration [16] is a process where the PSoC can change the configuration of the blocks within milliseconds. This allows design and implementation of multiple different hardware configurations and rapid switching between these. The configurations are stored in the actual program as all hardware configurations changes are in fact made by altering contents of special configuration registers in the RAM memory.

PSoCs can be programmed using multiple different methods. The most common method is to use In System Serial Programming where the PSoC is programmed using MiniProg hardware adapter [17]. PSoC can also be programmed using another microcontroller [18] or using a simple bootloader [19].

The PSoC chip used in the developed platform is CY8C29466. This contains total of 32 KB of flash memory for the main program and data. The actual memory map is shown in Figure 3. During normal operation the program in the PSoC is stored between memory address 0x0000 and 0x37FF limiting the actual program size to 14 KB. Rest of the memory is reserved for programming the PSoC *without* using any programming adaptors. This uses the PSoC functions that allows both reading and writing of the flash memory by the software currently running in the PSoC [20].

In order to transfer a new program to the PSoC the following method is used. First a PC transfers using a serial data link the new program to the PSoC that stores the data to the flash memory starting at memory address 0x3800. After the new program is received and verified, the PSoC will jump to address 0x7000. This memory location contains routines that will copy the flash memory contents from 0x3700 to 0x0000 overwriting the previously used program. After the copying is complete, the chip is reset. This method allows changing the software, all operational parameters, hardware settings and configuration of the blocks while the system is running even if normal programming adapters cannot be used.

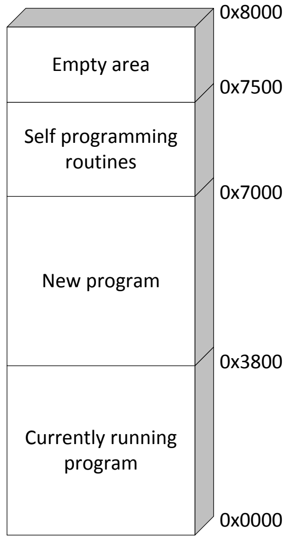

Figure 3 – Memory map of the PSoC in the developed platform

IV. Inductive Power Transfer

Inductive power transfer (IPT) sends energy from the transmitter to the receiver through inductive coupling. Change in the current flow of the transmitting coil creates a changing magnetic field which induces a voltage on the receiving coil. Efficiency of this type of power transfer depends on multiple factors including the relative size of the coils, coil distance and coil displacement. [21][22]

Simplified schematic of IPT using parallel resonance on transmitting and receiving sides is shown in Figure 4. High frequency AC is fed to the transmitter coil L1. Having capacitor C1 parallel to L1 creates a resonant LC, or a tank circuit. When this LC circuit is fed with AC having the same frequency as the LC circuit resonant frequency this increases the transmitter efficiency significantly. The high frequency AC on the transmitting coil L1 creates an alternating magnetic field which induces a voltage on the receiving coil L2. Capacitor C2 in parallel to coil L2 will bring the receiving circuit into resonance increasing the receiver efficiency. It should be noted that there are multiple other configurations to achieve inductive power transfer. [23]

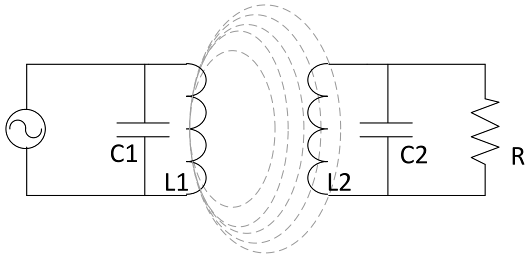

Figure 4 – Simplified schematic of inductive power transfer

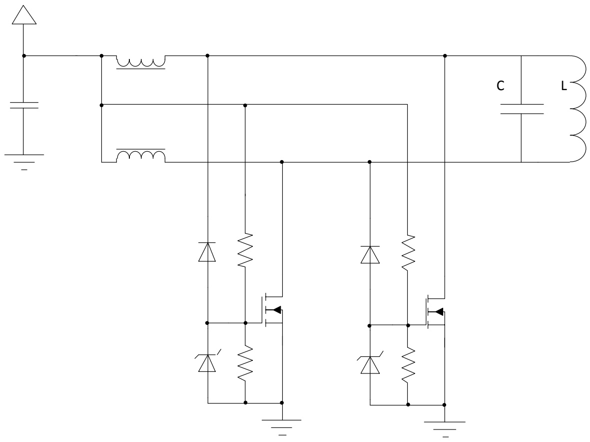

Figure 5 – Simplified schematic of inductive power transmitter

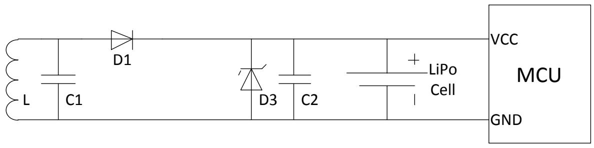

Figure 6 – Simplified schematic of the power subsystem of developed platform

The developed power transmitter is built around a push-pull inverter network. Simplified schematic is shown in Figure 5. Essentially the configuration of the network is two parallel boost converters operating with 180° phase difference. The transmitter coil L and capacitor C form a parallel LC circuit. This is fed with AC having the frequency set as the resonant frequency of the LC circuit. As a result large currents circulating in the LC circuit induce an alternating magnetic field. This kind of an approach has been used on multiple different inductive power transmitters. [24][25]

Operation at the exact resonant frequency of the LC circuit can be achieved by using for example a Royer oscillator [26]. The Royer oscillator is typically used to drive a transformer which has an additional feedback winding. The feedback is used to drive the switching transistors. The operation of the developed transmitter is not exactly a Royer oscillator, but has some similarities. The switching FETs are driven through pull-up resistors and have a negative feedback from the LC circuit. This forces the oscillator to operate always on the resonant frequency of the LC circuit. It has been shown that this kind of an approach on inductive power transfer can provide high efficiencies (up to 30 %) for relatively long distances (20 cm) [27].

The schematic of the receiving side of the IPT is shown in Figure 6. Receiving coil L and capacitor C1 form a parallel resonant circuit that is tuned to the approximate frequency the transmitter greatly increasing the efficiency. D1 performs half-wave rectifying, Zener diode D3 limits the voltage to 4.1 V and C2 reduces high frequency voltage ripple. Energy is stored directly into a Lithium Polymer cell. The PSoC microcontroller used has a wide operating voltage range and can operate directly from a single cell battery without additional voltage regulators.

One challenge in the developed system is the small size of the receiving device. Typically mismatch in coil sizes causes low efficiency [22]. Parameters of the coils used in IPT are show on Table 1. When measuring the efficiency the receiving coil was placed inside the transmitting coil to simulate charging small measurement device. Measurements show that the transmitter uses 2.9 W of power while the receiver produces 60 mW. This gives total efficiency including all losses of approximately 2 %. When considering the relative sizes of the coils we can say that the system is nearly optimal.

Table 1 – Properties of the coils used in IPT

	TX coil	RX coil
Wire gauge	8 mm	0.2 mm
Turns	3	50
Diameter	9 cm	1.4 cm
Surface area	63.6 cm²	1.5 cm²

Early prototypes of the IPT transmitter and the developed platform with wireless charging are shown in Figure 7 and Figure 8, respectively. Note that the platform in Figure 8 has all passive components located underneath the PSoC microcontroller. The Lithium Polymer battery used has 70 mAh of capacity.

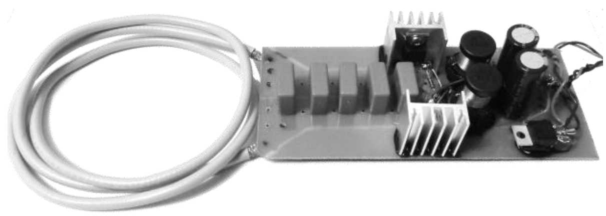

Figure 7 – An early prototype of inductive power transmitter

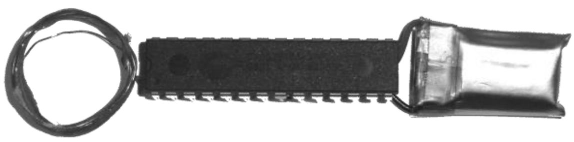

Figure 8 – An early prototype of the developed platform

V. WIRELESS DATA TRANSFER

Inductive power transfer allows multiple different methods for short-distance data transfer from the transmitter to the receiver. The most common methods are frequency shift keying (FSK) [28], amplitude shift keying (ASK) [29]. Other more exotic modulation methods are usually not used.

In FSK the transmitter is changing the frequency it operates on. In the simplest FSK method one frequency corresponds to bit 1 and another frequency to bit 0. This modulation method has the benefit of constantly transmitting power to the receiving device as the transmitter operates all the time regardless of the symbol being sent. The challenge is in creating the demodulation circuit. Also, if either the transmitter or the receiver have an LC circuit with very high Q factor, which equals to low bandwidth, the power transfer efficiency drops significantly. In ASK the transmitter changes the transmitted power. The simplest form of ASK is OOK where the transmitter is either on or off depending on the symbol currently being sent. The benefit of this is the simplicity of the receiving circuit.

For uplink, from the receiver to the IPT transmitter, the data transmission methods are slightly different. The device can feed through a capacitive coupling either ASK or FSK modulated signal to the coil used for receiving the power. The transmission could be picked up with the primary transmit coil or with an additional coil used only for data reception. The other option is that the device modulates the amount of power it is drawing from the IPT transmitter [30]. This so called load modulation or absorption modulation requires an accurate measurement of the consumed current on the IPT transmitter.

Wireless data transfer on the developed platform

The wireless data transfer serves two different purposes in the developed platform. First, in order upload new software and to modify the hardware configuration a reliable link to the platform must be provided. Second, to retrieve any sensory reading an uplink is required for the platform to a base station. The reliability of these links can be provided either by the link itself or by higher layer protocols. The reliability for the software reprogramming is achieved by verifying transmitted data.

The developed platform can be equipped with two different data transfer systems. The primary – when hardware simplicity is required – is using the same inductive coupling that is used for the inductive power transfer. This is relatively low-speed channel with data rates up to 2400 bps, and distances up to 5 cm. The secondary data transfer system is based on commercially available nRF24L01+ [31] 2.4 GHz radio modem that provides data rates up to 2 Mbps and operates for relatively long distances. Distances of over 100 m with 250 kbps data rates have been tested. However, this adds more complexity to the platform and requires approximately 2 cm² surface area.

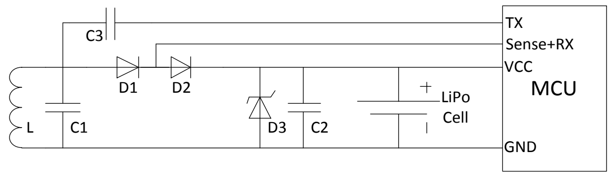

Figure 9 – Simplified schematic of the power subsystem capable to inductive data transfer

The primary data transfer system using the inductive coupling uses essentially on-off keying (OOK) for downlink and frequency-shift-keying (FSK) for uplink. Simplified schematic of the platform is shown in Figure 9. On data downlink the IPT transmitter is simply switched on or off depending on the symbol currently being sent. At the device it is relatively trivial to sense the existence of an external field. The PSoC used is programmed to have an envelope detector feeding the signal to a comparator. The uplink is implemented by feeding an FSK signal through capacitive coupling to the LC circuit. On the base station the FSK signal is received by an additional coil used only for data reception. The FSK demodulation [32] uses also PSoC.

Using the described approach communication distances of up to 15 cm for download (from the IPT transmitter to the device) have been achieved. Reliable distance for uplink is 8 cm. Data rates were tested and found error-free up to 10 kbps, but 2400 bps was selected for extra tolerance for interference. These results are within the original design goals. In case longer transmission ranges are desired, a separate 2.4 GHz radio module can be used as described earlier. Also, increasing the communication distances is possible by modifying the coils and changing parameters of amplifiers used by the receivers.

VI. CASE: ELECTRONIC FISHING LURE

Typical fishing lures are attracting fish by size, color and the movement of the lure in water. Some lures produce flashing light by mirroring sun light to different directions. In the market there are also electronic fishing lures that have been around for decades. In most cases these are simple devices having only a LED light or a vibration motor powered by a small battery. There is also more sophisticated electronic lures [33] that contains in addition to the LED and the vibration motor a microcontroller that can be programmed with a sequence that mimics living creatures.

Creating a new kind of electronic fishing lure using the developed sensor and actuator platform could bring additional benefits to fishing. The platform is designed to be completely sealed. It can be wirelessly charged and the programming – including the hardware configuration – can be changed. This allows creating an electronic lure where all parameters can be tuned in real environment.

The first generation electronic lure using the developed platform is encased in a fishing lure shown in Figure 10. The lure is originally made for fishers to paint the lure by hand to achieve desired look. As the lure is hollow and contains nearly 10 cm long cavity it is perfect test bed for the developed platform. When the electronics is secured in the lure there is approximately 4 cm^3 of empty space for future modifications.

The operation of the first generation electronic lure is relatively simple. When the lure is placed in water it will automatically start to emit light and vibration to attract fish. The light and vibration sequences are pseudo random. When removed from the water the lure enters in a low-power sleep mode. The lure contains a 140 mAh Lithium Polymer battery which can power the lure for 4-5 hours. Charging the battery takes 10 hours from empty to full using earlier described IPT transmitter.

The sensor used to detect when the lure is placed in water is a dielectric sensor. Schematic of this is shown in Figure 11. Two 2 x 60 mm copper strips are placed inside the lure. To detect whether the lure is under water the capacitance of the sensor is measured. Water having relative permittivity almost two orders of magnitude higher than air causes increase of capacitance. To minimize the complexity of the external measurement circuitry a very simple method is used. Digital output is first switched to high state. After a fixed delay the analog input is sampled. After the sampling is complete, the digital output is switched back to low state. The sampled voltage depends on the capacitance between the copper electrodes. This kind of an approach works to detect major changes surrounding material, but is highly inaccurate.

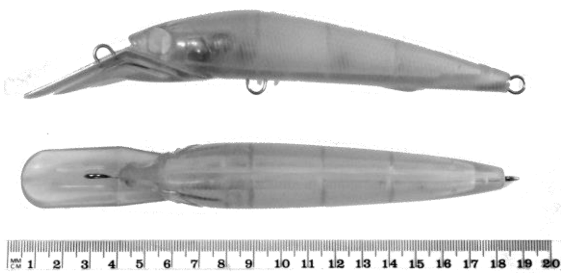

Figure 10 – Fishing lure, top and side view. Scale in cm

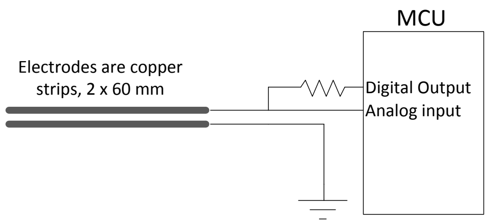

Figure 11 – Schematic of the dielectric sensor

The developed lure operates as expected. However, it should be noted that real life performance cannot be evaluated as it has not yet been tested in real fishing situations. Field evaluation during the fishing season of 2015 will give the final results whether this project should continue or not. During the lure implementation process the benefit of the re-configurability became clear. Setting up the water sensor requires that the sensor is in fact inside the lure before it can be tested. Tuning the parameters and making slight alterations on the hardware would not have been possible without the re-configurability of the platform.

Future modifications include creating a hand-held terminal that could easily be used to change the light and vibration profiles using the wireless data link. This way a fisherman could use the most optimal settings for current conditions. Including an acceleration sensor could give some statistics that could be downloaded from the lure afterwards. The statistics could include for example number of throws or information on miniature movements caused by interested fish giving the lure a small nudge, but not actually biting. Also, some fishermen could appreciate a function where when towing the lure it would automatically descent to a pre-programmed depth using small pressure sensors and miniaturized servo motors.

CONCLUSIONS

PSoC microcontrollers provide interesting possibilities for systems requiring hardware alterations and modifications after installation. This is significant for applications where the system is un-accessible and operational for extended periods of time or where the exact parameters are unknown before installation. The possibility of changing the hardware setup also speeds up the design process. With an inductive power transfer small systems can be easily powered and charged.

The developed platform works as expected. The fishing lure acts a demonstration system showing that the PSoC is suitable for this kind of system, the inductive power transfer performs as expected and that the hardware configuration can be changed even after the system is sealed. If needed, the platform can be installed in less than 2 cm^3 space.

There are still multiple other application areas where the platform should be evaluated further. Some of these might also be commercially viable. The challenges on using the platform in other applications are related to the data transfer using the inductive power link. Miniaturized devices with very small coils have very limited usable communication distances. This area should be researched further.

REFERENCES

[1] "Gartner Says the Internet of Things Installed Base Will Grow to 26 Billion Units By 2020." [Online]. Available: http://www.gartner.com/newsroom/id/2636073. [Accessed: 18-Sep-2014].

[2] P. Hämäläinen, M. Kuorilehto, T. Alho, M. Hännikäinen, and T. Hämäläinen, "Security in wireless sensor networks: Considerations and experiments,"

Embed. Comput. Syst. Archit. Model. Simul., pp. 167–177, 2006.
[3] Cypress Semiconductor Corporation, “PSoC® Programmable System-on-Chip Technical Reference Manual (TRM).” 2011.
[4] “CY8C29x66 - PSoC Mixed Signal Array Data Sheet.” Cypress Semiconductor, 2004.
[5] “Cypress PSoC Programmable System-on-Chip Brochure.” Cypress Semiconductor, 2010.
[6] G. Reynolds, “Cypress Application Note AN47310 - PSoC 1 Power Savings Using Sleep Mode.” Cypress Semiconductor, 2011.
[7] S. Matviyenko, “Cypress Application Note AN2284 - Low-Cost EKG Pulsometer.” Cypress Semiconductor, 2006.
[8] D. Van Ess, “Cypress Application Note AN2286 - Simulating a 555 Timer with PSoC.” Cypress Semiconductor, 2005.
[9] R. Mohiddin, M. Kumar, S. K. Palakurty, S. Bothra, P. Phaneendra, M. B. Srinivas, N. Pidugu, K. Mahalingam, P. Kane, and others, “Building a sensor network with PSoC,” in *Sensing Technology (ICST), 2011 Fifth International Conference on*, 2011, pp. 353–357.
[10] D. Arvind and K. J. Wong, “Speckled computing: Disruptive technology for networked information appliances,” in *IEEE International Symposium on Consumer Electronics*, 2004, pp. 219–223.
[11] F. Hu, Y. Xiao, and Q. Hao, “Congestion-aware, loss-resilient bio-monitoring sensor networking for mobile health applications,” *Sel. Areas Commun. IEEE J. On*, vol. 27, no. 4, pp. 450–465, 2009.
[12] De Marziani, C., Alcoleas, R., Colombo, F., Costa, N., Pujana, F., Colombo, A., Aparicio, J., Alvarez, F.J., Jimenez, A., Urena, J., and Hernandez, A., “A low cost reconfigurable sensor network for coastal monitoring,” presented at the OCEANS, 2011, Spain.
[13] Fei Hu, S. Lakdawala, Qi Hao, and Meikang Qiu, “Low-Power, Intelligent Sensor Hardware Interface for Medical Data Preprocessing,” *IEEE Trans. Inf. Technol. Biomed.*, vol. 13, pp. 656–663, Jul. 2009.
[14] B. Quach, M. Balakrishnan, D. Benhaddou, and X. Yuan, “Implementation of integrated wireless health monitoring network,” in *Proceedings of the 1st ACM international workshop on Medical-grade wireless networks*, 2009, pp. 63–68.
[15] N. X. Fernando, D. N. Macklin, M. Y. Hsu, and J. W. Judy, “An embedded wireless neural stimulation and recording system,” in *Neural Engineering, 2007. CNE’07. 3rd International IEEE/EMBS Conference on*, 2007, pp. 333–336.
[16] B. Kropf, “Cypress Application Note AN2104 - PSoC 1 - Dynamic Reconfiguration with PSoC Designer.” Cypress Semiconductor, 2007.
[17] M. Hastings and V. S. Kannan, “Cypress Application Note AN2014 - Basics of PSoC 1 Programming.” Cypress Semiconductor, 2007.
[18] N. Kamran, “Cypress Application Note AN44168 - PSoC 1 Device Programming using External Microcontroller (HSSP).” Cypress Semiconductor, 2008.
[19] A. Smetana, “Cypress Application Note AN2100 - Bootloader: PSoC.” Cypress Semiconductor, 2005.
[20] K. Praveen, “Cypress Application Note AN2015 - PSoC 1 - Getting Started with Flash & E2PROM.” Cypress Semiconductor, 2007.
[21] G. A. Covic and J. T. Boys, “Inductive Power Transfer,” *Proc. IEEE*, vol. 101, no. 6, pp. 1276–1289, Jun. 2013.
[22] E. Waffenschmidt and T. Staring, “Limitation of inductive power transfer for consumer applications,” in *Power Electronics and Applications, 2009. EPE’09. 13th European Conference on*, 2009, pp. 1–10.
[23] O. H. Stielau and G. A. Covic, “Design of loosely coupled inductive power transfer systems,” in *Power System Technology, 2000. Proceedings. PowerCon 2000. International Conference on*, 2000, vol. 1, pp. 85–90.
[24] J. T. Boys, G. A. Covic, and A. W. Green, “Stability and control of inductively coupled power transfer systems,” *IEE Proc. - Electr. Power Appl.*, vol. 147, no. 1, p. 37, 2000.
[25] C. Tang, X. Dai, Z. Wang, Y. Sun, and A. P. Hu, “Frequency bifurcation phenomenon study of a soft switched push-pull contactless power transfer system,” in *Industrial Electronics and Applications (ICIEA), 2011 6th IEEE Conference on*, 2011, pp. 1981–1986.
[26] B. R. L and R. G. H, “Electrical inverter circuits,” helmikuu-1957.
[27] A. Costanzo, M. Dionigi, F. Mastri, and M. Mongiardo, “Rigorous modeling of mid-range wireless power transfer systems based on royer oscillators,” 2013, pp. 69–72.
[28] S. Shabou, N. Rekik, M. Ghorbel, A. B. Hamida, and M. Samet, “Conception of an emitter for transcutaneous power and high-speed data transmission,” in *Microelectronics, 2004. ICM 2004 Proceedings. The 16th International Conference on*, 2004, pp. 655–659.
[29] M. Dong, C. Zhang, Z. Wang, and D. Li, “A neuro-stimulus chip with telemetry unit for cochlear implant,” in *Biomedical Circuits and Systems, 2004 IEEE International Workshop on*, 2004, pp. S1–3.
[30] P. A. Neukomm and H. Kündig, “Passive wireless actuator control and sensor signal transmission,” *Sens. Actuators Phys.*, vol. 21, no. 1–3, pp. 258–262, Feb. 1990.
[31] “nRF24L01+ Single Chip 2.4GHz Transceiver Product Specification.” Nordic Semiconductor ASA, 2008.
[32] D. Seguine, “Cypress Application Note AN2336 - Simplified FSK Detection.” Cypress Semiconductor, 2006.
[33] C. B. Hughes and E. D. Hughes, *Electronic programmable fishing lure*. US patent, 2004.