TELEMETRY AND RADIO FREQUENCY IDENTIFICATION

Jouko Heikkinen
Tampere University of Technology, Electronics Laboratory
Finland

ABSTRACT

Comparison of short-range telemetry and radio frequency identification (RFID) systems reveals that they are based on very similar operating principles. Combining the identification and measurement functions into one transponder sensor offers added value for both RFID and telemetry systems. The presence of a memory (e.g. FRAM) in the transponder, required for ID information, can also be utilized for storing measurement results. For passive transponders low power consumption is one of the main objectives. Wireless power transfer for passive transponder sensors together with above aspects concerning a combined telemetry and identification system are discussed.

KEY WORDS

Telemetry, radio frequency identification, FRAM, wireless power transfer

INTRODUCTION

Telemetry systems in general acquire information (e.g. measurement results or control sequence) from one point and transmit this information to another location for processing (display, record or execution) [1]. Telemetry systems can be divided into short-range and long-range applications, where the typical transmission distances are from few millimeters to few meters and from several meters to several kilometers, respectively. In this paper short-range telemetry operating in license-free ISM (Industrial, Scientific and Medical) bands is considered. In radio frequency identification systems the information acquired is the identification code in addition to other possible information stored to the transponder carried by the identification object [2]. The information besides the identification code can be for example the status of the object being assembled in a production line [3]. Identification systems are usually short-range devices having the range of operation from few centimeters to several meters.

Short-range telemetry and RFID systems are very similar in terms of structure and communications. Both can be active or passive (i.e. active, having an own power source for transmission/reception or passive, generating the needed supply power from incident

RF field) and they utilize wireless data transmission methods. First, main features of both systems are discussed, followed by a suggestion of a combined telemetry and RFID system. Wireless power transfer for passive devices is then considered and finally, the objectives of the research are given.

TELEMETRY SYSTEM

A typical structure of a short-range telemetry system is shown in Figure 1 (power supplies have been omitted). It consists of a reader device, usually including computer interface, and a sensor chip. The analog information gathered by a sensor (or sensors) is converted into digital format by an A/D –converter. Logic circuitry then hands this digital data over to a transceiver for modulation and transmission. ASK and FSK are the most used modulation schemes together with AM and FM in the case of analog modulation.

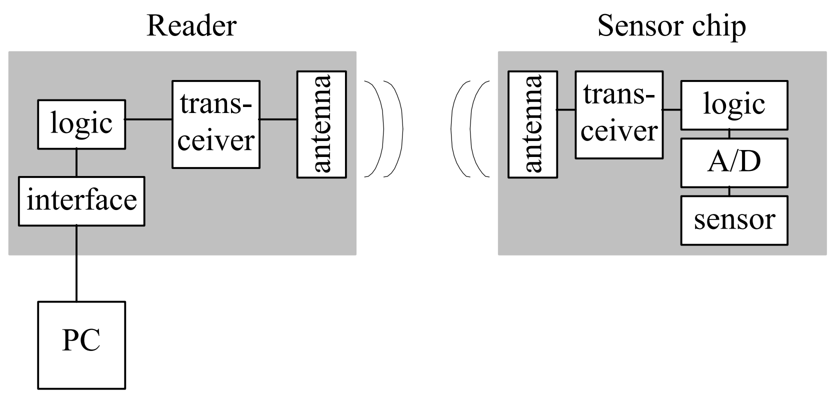

Figure 1. Typical structure of a short-range telemetry system.

Communication between reader and sensor chip can be established in one direction (simplex) or both directions (half-duplex or full-duplex).

Short-range telemetry systems can be roughly divided into two categories according to the coupling between the reader and the sensor chip. In low-frequency systems (operating frequencies up to few MHz) transmission is based on a magnetic field, thus operating range is quite short. Simple loop antennas used both in reader and sensor chip form a loosely coupled air-core transformer establishing the wireless transmission. In high-frequency systems, on the other hand, data is transferred by means of an electromagnetic field. Depending on both operating frequency and performance specifications e.g. loop antennas, dipole, monopole or planar antennas can be used. Transmission distances up to couple meters can be achieved with passive sensor chips compared to about half a meter for low-frequency systems. Distances are considerably longer for active high-frequency systems.

Perhaps the most popular application field for short-range telemetry is implantable medical devices [4],[5],[6]. Transmission power of these devices is limited by health regulations and long reading distance is not a necessity. The upper bound to operating frequency is set by the damping of a human tissue. Other applications for short-range telemetry include animal and structure monitoring where for example temperature and strain forces, respectively, need to be measured [7],[8]. One group of passive telemetry systems utilize SAW (Surface Acoustic Wave) -devices that allow the combination of sensor and transceiver elements in a relatively simple structure [9],[10].

RFID SYSTEM

Figure 2 represents a typical structure of a RFID system consisting of a reader unit and a transponder (also called as a “tag”). Memory contains an identification code that is transmitted to the reader when requested. Memory can be read-only or read/write –type and its size can be anything from one bit to several hundred kilobytes. Simplest transponders containing only one bit are used for theft protection while transponders with large read/write -memory can be used to store also the present status of the object (e.g. the contents of a container).

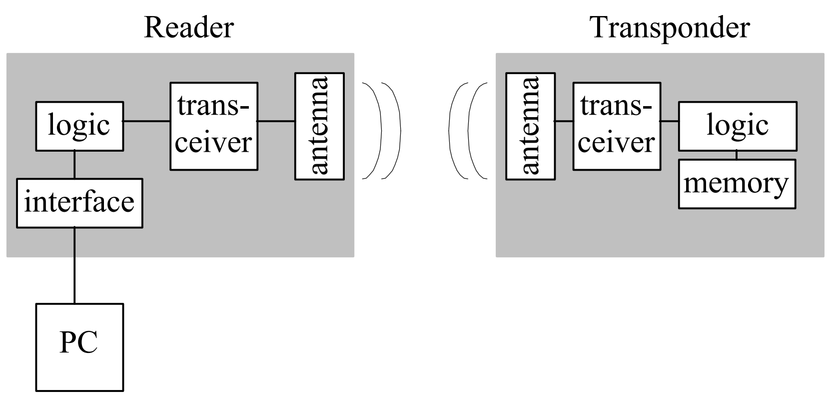

Figure 2. Typical structure of a RFID system.

The properties concerning modulation schemes and the division into low- and high-frequency systems mentioned earlier are valid also for RFID systems. Passive transponders are usually utilized in high-volume applications because of the relatively high cost of active transponders. Passive devices have been realized using different methods:

- The presence of a closed resonance circuit in a one-bit tag can be observed as a change in the reader’s transmission current
- Tag modulates the RF field (sent by the reader) with the identification code and reflects it back to the reader by changing the antenna impedance (so-called modulated backscatter tag)

Tag generates the needed DC supply power from the incident RF field and transmits the identification code with its own transmitter

The first one is simple to realize but contains only on-off –information. The second method is relatively simple but has some problems related to field attenuation and multipath propagation. The third method enables most versatile operation if enough supply power can be generated. Because the size of the tag must almost without exception be minimized, the most popular antenna structure especially at low frequencies is a multi-turn circular loop. At higher frequencies dipole/monopole or planar antennas must be used in order to achieve better data and energy transfer efficiency.

Applications of RFID include theft-protection, passage surveillance and vehicle and animal identification [2],[11].

COMBINED TELEMETRY AND RFID SYSTEM

Combining the telemetry and RFID systems shown in Figure 1 and Figure 2 can be simplified as integrating the memory and necessary additional logic to the sensor chip of the telemetry system. However there are several issues that must be taken into consideration. Most important, especially for passive systems, are those concerning the properties of the non-volatile memory required: compatibility with standard CMOS process, area consumed, access times, endurance, required supply voltage and power consumption. Perhaps the most appealing selection for the reprogrammable data storage is FRAM (Ferroelectric Random Access Memory) because it combines the non-volatile data retention of EEPROM and fast read/write cycle of SRAM.

The operation of FRAM is based on the ferroelectric effect that is the ability of a material to retain an electrical polarization in the absence of an applied electric field. Data is stored in the polarization of such a material in a memory cell that is constructed from transistor(s) and ferroelectric capacitor(s). Because the electric field strength required for polarization (write) is small, low supply voltage (down to 3V) can be used. Short read cycle needed decreases the power consumption. The endurance of 10^{12} read/write cycles is much more than for example EEPROM or Flash EEPROM [12]. Although FRAM does not yet reach the memory density of DRAM and requires a refresh operation every time it is read, it is compatible with standard CMOS process with few additional steps [13]. Some work has already been reported on integration of FRAM into a RFID transponder [14].

One of the future objectives is to integrate measurement properties into a passive RFID transponder structure with an embedded FRAM memory. However, careful consideration of the power transfer between reader and transponder is first required for passive implementation. The efficiency of both power transfer and the storage of the generated supply power in the transponder affect the device performance.

WIRELESS POWER TRANSFER

In wireless power transfer a passive system generates its DC supply power from received magnetic or electromagnetic field transmitted by another device. At low frequencies (up to few megahertz) power is usually transferred by magnetic field and inductive loop antennas are used. Because transmitter and receiver are coupled by the mutual inductance between the transmitting and receiving antenna, the maximum transfer distance is usually from few millimeters to about half a meter depending on the inductance, physical size and mutual orientation of the antennas.

Moving towards higher frequencies (UHF/microwave) requires somewhat different approach. Because the energy transfer is carried out with an electromagnetic field the radiation properties of both transmitter and receiver antennas are crucial for efficient transmission to take place. Taking the limitations of the permitted radiation power into consideration the transfer distance and direction are strongly determined by the radiation patterns (define directivity and gain) of these antennas. Greater transfer distance can be achieved with high-gain (high-directivity) antennas at the cost of narrower transfer sector. The determination of antenna parameters is therefore application-dependent. The requirement of small size for portable devices favors the use of planar antenna structures also in wireless power transfer. Therefore operating frequencies high enough are required so that antenna dimensions comparable to the quarter wavelength could be realized efficiently.

The overall efficiency of wireless power transfer is a combination of the receiving antenna efficiency and, most of all, the efficiency of RF-DC –conversion. The rectifying element (usually a microwave schottky detector diode) must be matched to the antenna impedance in order to achieve the maximum RF power transfer and thus maximize the generated DC power. Conversion efficiency is therefore most affected by the quality of the rectifier and passive impedance matching elements.

The lack of available DC bias impedes the use of externally biased Schottky diodes in wireless power transfer. Zero-bias Schottky diodes, on the other hand, are suitable because of their relatively high saturation current. The drawback of this diode type that was originally designed for square law detector applications is the higher loss resistance. In addition to this, because the impedance of the diode changes in accordance with the current drawn by the load of the RF-DC –converter the quality of impedance match (i.e. the amount of power received) also varies. Figure 3 shows the equivalent model of a Schottky diode. Calculated diode resistance R_d and capacitance C_d of the HSMS-2850 Zero-bias Schottky diode when the diode total current I_T changes from 4μA to 53μA (I_T =

$I_s + I_o$, where $I_s = 3\mu A$ is the diode saturation current and I_o is the current drawn by the load) are also represented. R_d and C_d are derived from the equivalent model where L_p and C_p are package parasitics, R_s is the loss resistance, C_j is the junction capacitance and R_j is the junction or "video" resistance [15]. Values are listed in Table 1..

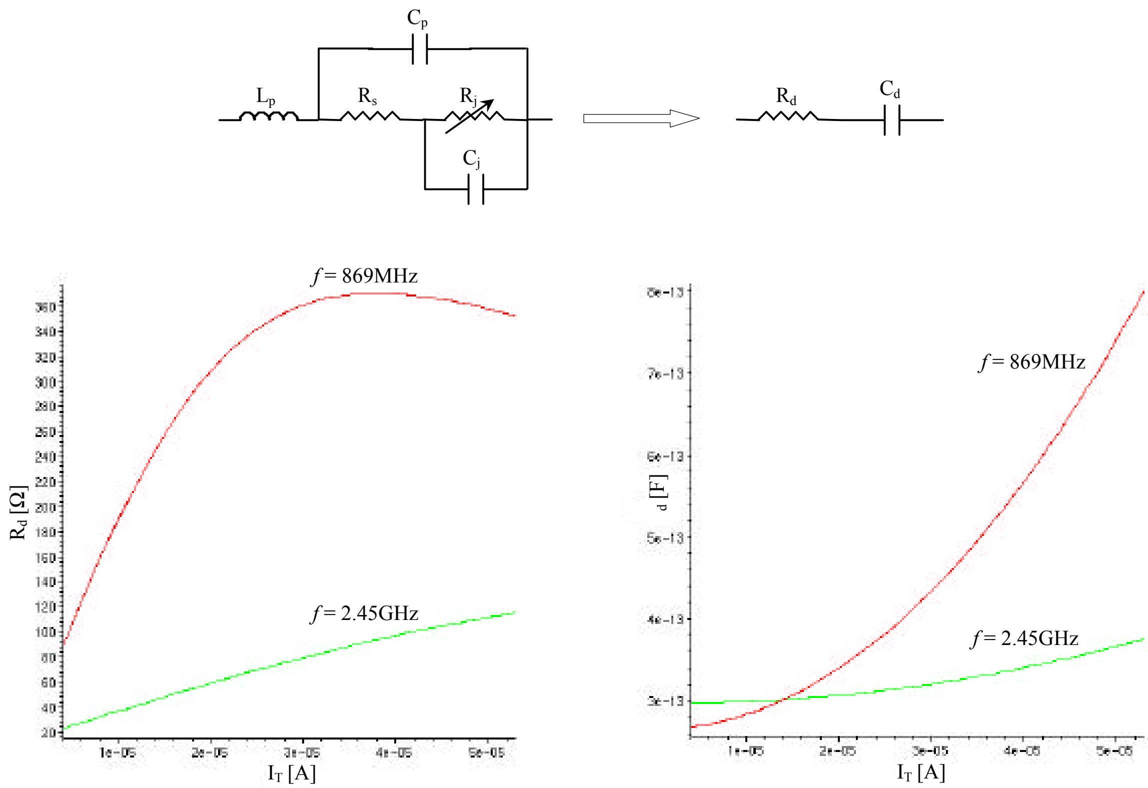

Figure 3. Equivalent model of a Schottky diode (upper circuits). Calculated diode resistance R_d and capacitance C_d as the function of the diode total current I_T at 869MHz and 2.45GHz (lower graphs).

As Figure 3 indicates, the change in diode impedance at fixed frequency is due to the change of junction resistance. The situation for impedance matching gets worse as the diode current is increased or the operating frequency is decreased. This stresses the importance of the quality of the matching components.

Figure 4 shows an example of a diode matching circuit at 2.45GHz, where the effect of the matching inductor's Q-value on the diode voltage has been simulated by SPICE. The amplitude of the AC source voltage in antenna circuit corresponds to received RF power of 0dBm. Diode parameters for I_T=25µA can be obtained from the graphs in Figure 3.

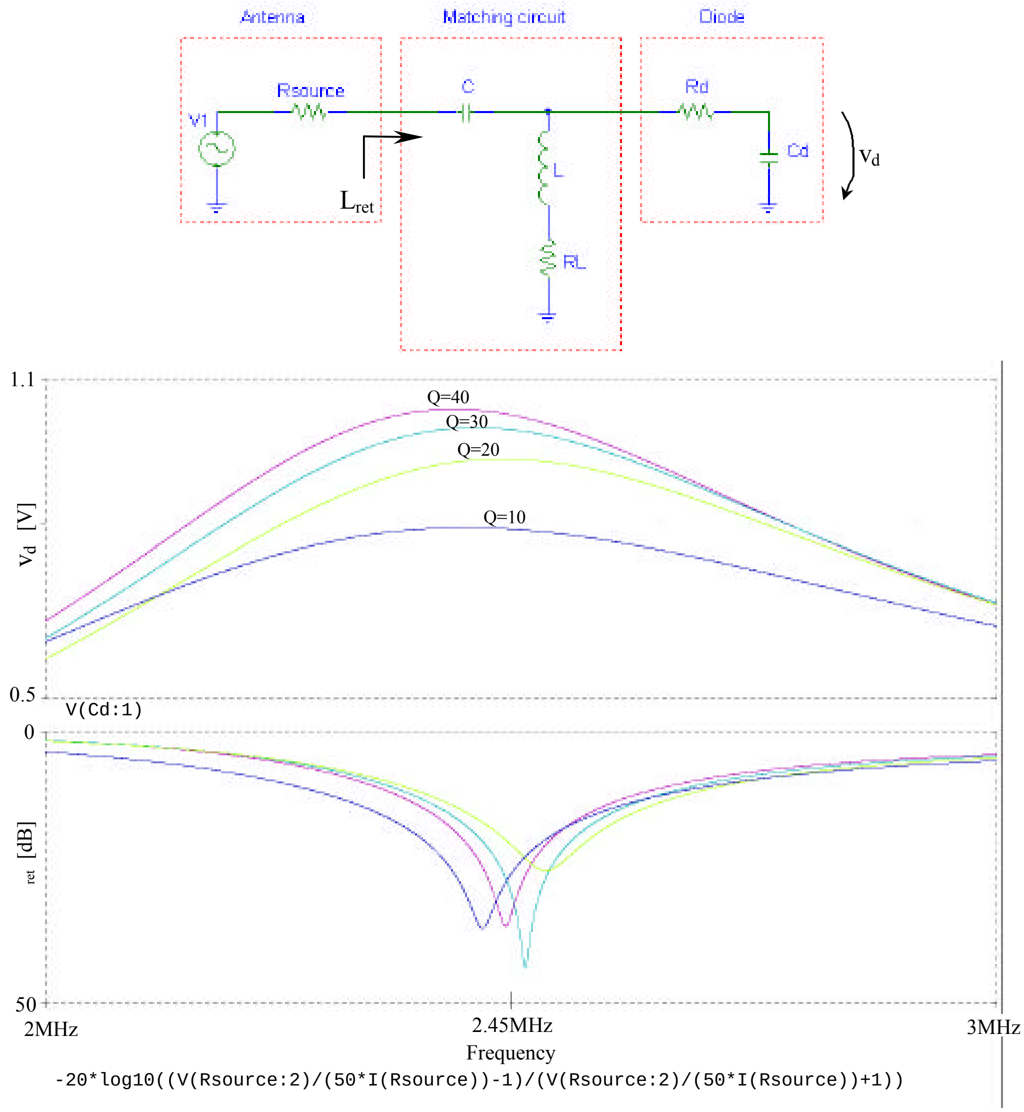

Figure 4. Simulation schematics for diode impedance matching circuit (upper picture). Diode voltage v_d and return loss of the matching circuit L_{ret} as the function of frequency for different Q-values of the matching inductor L (lower graphs).

The impedance matching circuit is formed of the series capacitor C and the shunt inductor L. The values of these components together with the inductance loss resistance RL are represented in Table 1. The antenna is modeled as a voltage source having a 50Ω characteristic impedance. In real world, however the impedance of the antenna is seldom pure resistive and equal to 50Ω but includes some capacitive or inductive reactance. This can be utilized in impedance matching by canceling some of the diode reactance with the antenna reactance.

Table 1. Diode equivalent model parameters and simulation parameters at 2.45GHz.

Diode equivalent model parameters for HSMS-2850				
L_p [nH]	**C_p [pF]**	**R_s [Ω]**	**C_j [pF]**	**R_j [Ω]**
2	0.08	25	0.18	$0.026/I_T$

Simulation parameters for R_d = 68.6Ω and C_d = 0.31pF			
Q	**C [pF]**	**L [nH]**	**RL [Ω]**
10	0.5	6.0	9.0
20	0.4	6.4	5.0
30	0.4	6.5	3.3
40	0.4	6.6	2.5

The effect of the Q-value is not usually a serious problem in discrete component designs because Q-values over 50 are obtainable for chip inductors. The problem is emphasized in integrated circuit designs on silicon where the typical Q-value for inductors is less than 10. The capacitor losses have been omitted in the example but must be taken into account in IC design, although their influence on performance is smaller (Q-values of over 100 are obtainable). The quality of integrated passive components can be improved by using high-resistive substrates, such as SOI (Silicon on Insulator), glass or glass ceramics [16],[17],[18].

The objective of the wireless power transfer research in progress is to maximize the transfer efficiency for short-range passive RFID and telemetry. As the size of devices decrease, the realization of the objective requires study and combination of antennas and integrated passive components for RF-DC –conversion/short-term storage of generated DC-power. The emphasis of the antenna study will be on planar antenna structures, such as slot and microstrip antennas. Integrated capacitor, planar coil and transformer implementations on high-resistive substrates are also required in order to minimize RF-DC -conversion losses. The importance of these issues is further stressed by the fact that usually the amount of available power in the converter end is already limited by emission restrictions.

CONCLUSION

The basic structure of short-range telemetry and RFID systems was shown and the combination of these systems was considered. The composite system enables for example

Identification of the measurement target
- with a reader monitoring several targets new measurement results can be compared to the previous ones saved to the reader database

The gain of additional information from the identification target
- reader monitors the target continuously or
- sensor chip saves measurement results to the memory, from where they can be read when the chip is identified

For passive systems the total power consumption must be minimized in order to enable the operation by wireless power transfer. In the case of memory this requirement can be achieved by using Ferroelectric RAM. The focus of the wireless power transfer research is in the efficiency optimization through the combination of antenna and integrated passive component design.

REFERENCES

[1] Carden, Frank, Telemetry systems design, Artec House, Norwood, MA, 1995, 256 p.

[2] Worthman Ernest, “RFID - The Technology and Applications Behind Auto ID,” RF Design, July 1997, pp. 44-47.

[3] Ueda K., Kurita K., “Data carrier application to factory automation,” Fuji Electric Review, Japan, Vol. 36, Iss. 2, 1990, pp. 100-104.

[4] Hamici, Z.; Itti, R.; Champier, J., ”A high-efficiency power and data transmission system for biomedical implanted electronic devices,” Measurement Science & Technology, UK, Vol. 7, Iss. 2, February 1996, pp. 192-201.

[5] Huang, Q., Oberle, M., ”A 0.5-mW passive telemetry IC for biomedical applications,” IEEE Journal of Solid-State Circuits, Vol. 33, Iss. 7, July 1998, pp. 937-946.

[6] McCreesh, Z., Evans, N.E., Scalon, W.G., “Vaginal Tamperature Sensing Using UHF Radio Telemetry,” Medical Engineering & Physics, UK, Vol. 18, No. 2, 1996, pp. 110-114.

[7] Puers, R., ” Linking sensors with telemetry: impact on the system design,” Sensors and Actuators A [Physical], Switzerland, Vol. 52, Iss. 1-3, March-April 1996, pp. 169-174.

[8] Neuzil, P., Krenek, O., Serry, F. M., Maclay, G. J., “Measurement and Wireless Transmission of Embedded Capacitive Microsensor's Output Using SigmaDelta Conversion and Radio Frequency Identification (RFID) Technology,” Proceedings of

Smart Structures and Materials 1997: Industrial and Commercial Applications of Smart Structures Technologies, pp. 178-185, San Diego, CA, 4-6 March, 1997.

[9] Buff, W., Rusko, M., Vandahl, T., Goroll, M., Moller, F., “A Differential Measurement SAW Device for Passive Remote Sensoring,” Proceedings of the 1996 IEEE Ultrasonics Symposium, Vol. 1, pp. 343-346, San Antonio, TX, 3-6 November, 1996.

[10] Sachs, T., Grossmann, R., Michel, J., Schrufer, E., “Remote Sensing Using Quartz Sensors**,”** Proceedings of the SPIE - The International Society for Optical Engineering, SPIE Vol. 2718, pp. 47-58, San Diego, CA, 26-28 February, 1996.

[11] Sharpe Claude Andrew, “Wireless Automatic Vehicle Identification,” Applied Microwave & Wireless, fall 1995, pp. 39-58.

[12] Philofsky, E., “FRAM-The Ultimate Memory,” Proceedings of the Sixth Biennial IEEE International Nonvolatile Memory Technology Conference, pp. 99-104, Albuquerque, NM, 24-26 June, 1996.

[13] Sumi, T., Judai Y., Hirano, K., Ito, T., Mikawa, T., Masato, T., Azuma, M., Hayashi, S., Uemoto, Y., Arita, K., Nasu, T., Nagano, Y., Inoue, A., Matsuda, A., Fuji, E., Shimada, Y., Otsuki, T., “Ferroelectric Nonvolatile Memory Technology and Its Applications,” Japanese Journal of Applied Physics. Part 1, Japan, Vol. 35, No. 2B, February 1996, pp. 1516-1520.

[14] Inoue, A., Shimaria, Y., Nakane, G., Moriwaki, N., Chaya, S., Nakakuma, T., Matsuura, T., Sumi, T., Otsuki, T., “Ferroelectric Memory Embedded In a RFID Transponder With 2.4 V Operation and 10 Year Retention at 70ºC,” Proceedings of the 16th International Conference on Consumer Electronics, ICCE, pp. 290-291, Rosemont, IL, 11-13 June, 1997.

[15] “Designing the Virtual Battery,” HP Application Note 1088, Hewlett Packard, November, 1997.

[16] Eggert, D., Huebler, P., Huerrich, A., Kueck, H., Budde, W., Vorwerk, M., "A SOI-RF-CMOS technology on high resistivity SIMOX substrates for microwave applications to 5 GHz," IEEE Transactions on Electron Devices, Vol. 44, Iss. 11, November 1997, pp. 1981-1989.

[17] Dekker, R., Baltus, P., van Deurzen, M., Einden, W v.d., Maas, H., Wagemans, A., "An ultra low-power RF bipolar technology on glass," Proceedings of the International Electron Devices Meeting 1997, pp. 921-923, 7-10 December, 1997.

[18] Tagami, K., Kubo, T., Makihara, C., Tanahashi, S., Emura, H., Tanaka, J., Sueyoshi, T., Kunimatsu, Y., Sigliano, R., Nelson, C., "Glass ceramics functional substrate development," Proceedings of the International Conference on Multichip Modules, pp. 363-370, 2-4 April, 1997.