A SPECIFIC COMMUNICATION STUDY FOR WIDE IRRIGATION SYSTEMS WITH INTEGRATED POWER TRANSMISSION

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Abstract- *Water volumes for agriculture copes with the water scarcity (drought), which is a big problem for this sector. Agrarian Exploitations are introducing new Irrigation Systems with high technologies to prevent this problem, especially in the Mediterranean Region. An Irrigation System consists of several elements: aquifers, water pumps, a hydraulic network (pipes) and a great number of electro-valves, which are far from the central post (in the order of km). To control the whole system is necessary to operate remotely every electro-valve; which requires simultaneously control information (to open/close these electro-valves) and power. The only way to operate with the lowest cost, is using a single wire for both, control and power. In this paper is shown a specific communication study for wide Irrigation Systems with Integrated Power Transmission, to carry out data communications over 2 x 1.5 mm section wires and distances no longer than 10 km, under very restrictive current consumption requirements, using OOK (On-Off Keying) modulation and a suitable filter design, both for transmission and reception.*

1 Introduction

Protection, management and improvement of the earth's aquatic environment are of increasing importance for the conservation and development of social and economic structures. Water has become an economic good.

Typically, conditions of water scarcity (drought) in the Mediterranean Region has made analyse and look for solutions in the agrarian exploitations, by introducing new Irrigation Systems (IS). In the *Institut de Robotica Research Centre* and with public support[1] has been developed a new IS, adapted to this region and based on a hierarchical computer architecture.

This IS meets next requirements: to optimise water resources, to provide water distribution and irrigation scheduling, to manage great number of users and finally to control a large number of devices, such sensors, water pumps, electrovalves ...Also this IS has next properties: scalability, flexibility and reliability. Some photos[2] are provided as example of this IS: at the top is shown the dripping infrastructure and at the bottom is shown typical irrigation pipes access and electrovalves. It should be noticed that all electrovalves are connected to the same single wire.

The scope of this paper has been to develop over this kind of Irrigation Exploitations, a reliable data communication system with Integrated Power Transmission, what means that we use the same power line (single wire[3]) to supply and to control every device. This requires to overcome problems related with the current consumption, data transmission and its modulation, attenuation of the communication signal, filter design and operation of a reliable control protocol.

Related papers to Integrated Power Transmission can be found in next references. In [1] is

[1]This system has been economically supported by Impiva and Generalitat Valenciana. IMPIVA through PRIFEM and SERSIM projects. Generalitat Valenciana through SIDCEP projects.

[2]These photos have been taken in the Village of Sagunto (Valencia), where the Institut de Robotica proves its irrigation system, called PRIFEM.

[3]The wire is 2 x 1.5 mm section, lays undergroung and is no longer than 10 km. It should be pointed out, that the power supply is determined to 24 AC volts-50 Hz for safety and legal reasons.

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Figure 1: *Photografies of a irrigation system. Top: the dripping infrastructure. Bottom: the irrigation pipes and electro-valves*

shown a CAN (Controlled Area Network) implementation, using recessive and dominant bits, but using direct supply and short distances (indoor applications), not for large distances. In [2] presents a complete analysis and different cases about attenuation communication signals over power distribution, for short distances and without any current consumption limitation. About power line modems and domotic applications, next references are relevant [3] and [4], nevertheless for the IS requirements, they have excessive current consumption. Also a commercial product, with similar features to the IS presented in this paper, should be found in [5].

This paper is structured in the next sections. In section 2 is described the hierarchy of the whole IS. The control protocol that it is used, is described in section 3. In section 4 is described the power line features and its physical characteristics. It determines the hardware specifications and requirements, explained in section 5, to fulfil with the whole communication demands, studying and analysing adequate filters. Finally, in section 6 we summarise the conclusions and future work.

2 Irrigation system requirements

Fist of all, we are going to describe the whole IS, which can be seen further explained in references [6] and [7]. The three levels of hierarchy have been defined and introduced in order to develop three different functions. Table 1 summarises the functionality of these levels and shows their acronyms that here after are going to be used in this paper. In figure 2 is shown a complete overview of an IS.

Level	*Acronym*	*Description*
1^{st}	UC	Central Unit
2^{nd}	UDA	Autonomous Distributed Unit
3^{rd}	URA	Activation Remote Unit

Table 1: *Main elements in an automated irrigation system: description and level hierarchy*

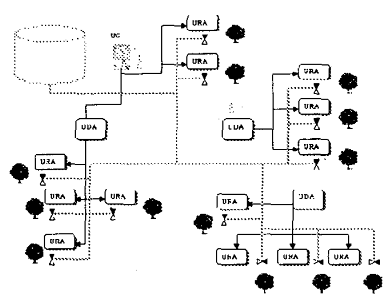

Figure 2: *Overview of a typical irrigation system, with UC (Central Unit), UDA (Autonomous Distributed Unit) and URA (Activation Remote Unit)*

The UC runs an expert system and schedules irrigations. The UDA performs the Irrigation and it is based on a Philips 82652 (Intel MCS51 Family) with I2C bus and a Real Time Clock. Finally the URA, which has latch electrovalves directly connected, runs the open/close commands on them.

The URA is based on a PIC microcontroller and integrates the Power Line Communications. Due to current restrictions, a maximum of 64 URA devices can be connected to a single power line.

The elements or devices of this hierarchy can communicate one each other at different hierarchy level, but can not communicate within the same hierarchy level. The different topologies that can be built, are shown in figure 3. To communicate first and second levels (between UC and UDA) several technologies are used : radio links, modems, RS-485 links, RS-422 links... depending on its requirements. Communication with third level (URA devices), is the purpose of this paper and it is full explained.

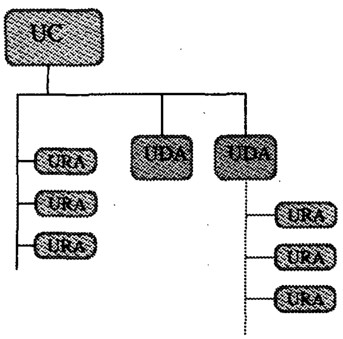

Figure 3: *Hierarchical computer architecture with UC (Central Unit), UDA (Autonomous Distributed Unit) and URA (Activation Remote Unit)*

The URA devices are connected to a single wire, which is used both for data transmission and for power supply. We are going to give a brief description of the behaviour of the URA device, just to bear in mind its operation, because the communications at this level are very close to the implementation.

The URA device is based on a PIC16C73A microcontroller, because it has embedded several useful things: Analog to Digital (A/D) input, watchdog mechanism and very low current consumption in stand-by mode. For further information see [8]. The operation of the URA devices is to open and close the latch electro- valves that are connected to it. An URA example, can be seen at the bottom of figure 1, where the URA device is just the white box next to the electro-valve, which is on the pipe.

The latch electro-valves consist of a solenoid and a hydraulic-mechanical device. It works as follow: when a single current pulse crosses the solenoid (generated with a discharge circuit in the URA device) of at least 400 mA during 20 ms [4], it activates/deactivates the latch mechanism and forces in the hydraulic-mechanical device two possible states, openned or closed. It has a very low current consumption.

The URA device requires a proper power management just to supply and to charge its capacitors in order to produce the requested discharge when the URA device receives the open/close command.

3 The control protocol with integrated power transmission: a master and slave protocol

The basic commands required to the URA device, as explained in section 2, are related to the open and close operations of the electro-valves, as well as, other specific commands for monitoring. This kind of information exchanged with the URA devices, and taking into account the low performance of URA device by comparison with UC and UDA, it fits with a Master/Slave protocol.

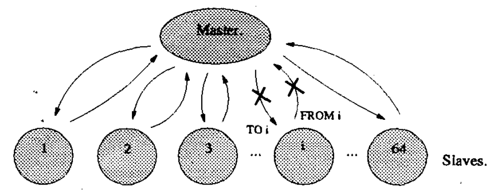

Figure 4: *Master and Slave Protocol*

The Master/Slave protocol can be seen in figure 4. The master and the slaves are based on the URA design. The master directly connects to a superior hierarchy level and it is embbebded to it. By means of this protocol, the master unit controls every slave and commands its behaviour. On the other hand, the slaves are always waiting for any communication, to be woken up. If any slave is requested, then it answers, otherwise it will still remain quite. In this way, the line is free collision and the master can run a pooling procedure, to check every single URA device.

Yet, several communication errors can appear from Master to Slave, from Slave to Master or both, as can be seen in figure 4). Then, the Master

[4]This information is according to manufacturer's specifications

unit must perform a recovering process by retrying during an estimated time. If the Slave has been long time without any update, just when Slave's Time Out had expired, for safety reasons the URA device keeps its state. So, this permanent state will be monitored at a superior level of the hierarchy.

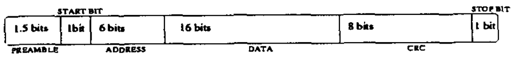

Figure 5: *Data Frame Description. Fields: preamble, start bit, address, data, CRC and stop bit*

The data frame that is used in the protocol consist of: preamble (1.5 bits), start bit (1 bit), address (6 bit), data (16 bit), CRC (8 bit) and a stop bit (1 bit), as can be seen in figure 5. Further information about timing and baud rates is given later in section 5, because is very closed to the design and implementation. Next are described the main features of the power lines.

4 Power line characteristics and usage of digital modulation: On-Off keying (OOK)

Long power lines are used in wide IS, no longer than 10 km and with 24 AC volts-50 Hz, where the URA devices are connected.

The topology of these systems is virtually unpredictable and at large, any previous assumption can not be done. Nevertheless, the communication system has to meet the worst characteristics of these installations.

An empirical study done of the frequency response of these power lines, meets with the results that can be drawn by simulation and with reference [2]. In figure 6 can be seen the frequency response of these lines, with next wire specifications: 1.3 Ω/km and 125 nF/km[5]. It is observed that above 10 kHz frequency, signals are partially filtered. The cut-off frequency directly depends on the wire length, the wire specifications, the topology and so, which determines a trade-off for the frequency of the carrier signal at 5 kHz. At large, this frequency is quite good for this and the wire can not filter it. This has been checked empirically. If it works above 5 kHz, the communication signal is drastically attenuated by the wire. On the other hand, it could expected a better response under the 5 kHz frequency, nevertheless a difficult filter design is needed to avoid the harmonics from 50 Hz of power supply.

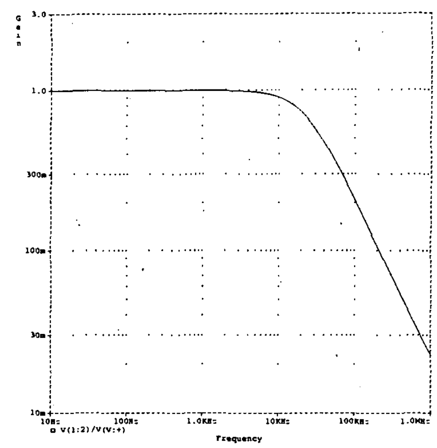

Figure 6: *10 km Power line frequency response: gain vs. frequency*

Another discussion must be argued related to the kind of modulation. Three kind of modulations should be used, changing amplitude, frequency and phase. Amplitude modulation is discarded because of amplitude variations are related to current variations (the Ohm's Law), then if every device has different impedance line (different distance to the Master), it makes impossible the usage of such modulation. Phase modulation should be possible, but the reception system is a bit difficult (see reference [1]). Finally, the suitable one is frequency modulation, because it is easy to implement using a digital output (a single pin) of microcontroller and it is independent of the distance to the Master, within a specific boundaries explained in section 5.

A binary FSK (Frequency shift Keying) modulation has been implemented using two levels, 0 or 1 states with frequency values 0 (or none transmission) and 5Khz (or carrier transmission) respectively. In this way, by turning the carrier on and off, we implement an On-Off keying (OOK) modulation. Then, only when a 1 is being transmitted is just when current consumption is required. This is very interesting from the point of view of low power consumption. In figure 7 can be seen an ex-

[5]See reference from Pirelli N05 VV-F PVN, http://www.ar.pirelli.com/cables/tech/indexa.htm

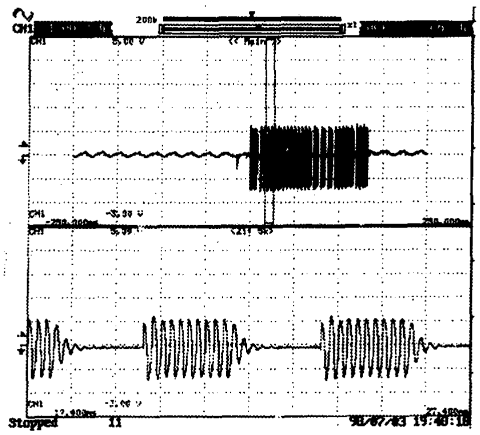

Figure 7: *On-Off modulation for transmission and reception*

ample of OOK modulation using an oscilloscope. On the top of the figure 7 has been captured a transmission frame and using the cursors of oscilloscope has been zoomed a single piece of this frame on the bottom of the figure, where easily can be distinguished these two states: none transmission and 5 kHz signal transmission.

Next section, it is explained the outstanding performance of these communications with integrated power transmission and how it can be implemented using a proper filter design.

5 URA design and implementation

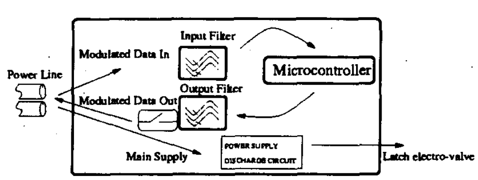

Figure 8: *Top schematic design for the URA devices*

In figure 8 is shown the URA scheme, which it is based on three different parts: communication filters, modulation/demodulation procedure and power management. Next is given an explanation of each one:

1. The communication filters have been considered in two parts to better fit both transmission (output filter) and reception (input filter) requirements, as will be deeply seen in next subsections. Notice in figure 8 that the output filter connects to the power line through a miniature solid-state relay (often used in telecommunication circuits), as will be explained in subsection 5.2.

2. About the modulation and demodulation process, it is managed a 5 kHz signal (carrier signal) to implement OOK modulation. Nevertheless, just to keep bit synchronisation, is needed Manchester coding to avoid long periods without carrier in the Off keying state. The Manchester coding associates a high to low transition with a 1 bit logic and low to high transition with a 0 bit logic. So a bit duration has always two halves: one with and other without 5 kHz signal or vice versa. Then, to decide if 0 or 1 is being transmitted, the microcontroller operates in such a way that it counts the number of transitions when a 5 kHz signal is detected. In this case, the number of transitions is determined to 10 periods, which means 2 ms per half bit, or 4 ms per bit, or a binary baud rate of 250 bps. If we take into account the frame description of section 3, a single transmission takes 33.5 bits x 4 ms = 144 ms, in both ways it means 288 ms (aproximattely) and in a pooling process with 64 URA devices, it takes 18.4 s (aproximattely), quickly enough for IS requirements.

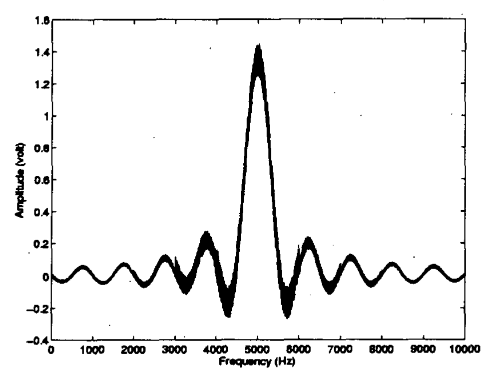

Figure 9: *On-Off Modulated signal: frequency domain*

In the end, in figure 9 can be seen how the modulation chosen meets the wire constraints respect the cut-off frequency, with the major part of energy around 5 kHz, which prevents us from being attenuated by the wire.

3. The power management should prevent the removal of the power supply from the line (by the Ohm's Law, mainly at the start up when capacitors are discharged) and it is based on a proper filtering circuit for 50 Hz signal or power supply. Although constant power supply is needed to charge the capacitors as have been explained in section 2, this charging procedure is slow and it determines the interval time between two consecutive open/close commands.

5.1 Reception filter (input filter)

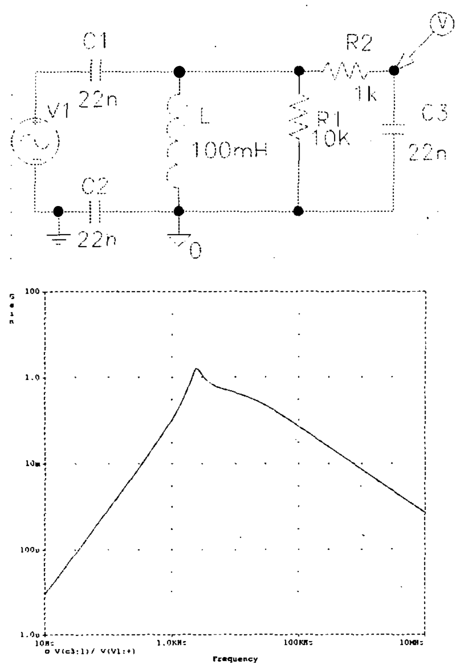

Figure 10: *Top: reception filter for URA device. Bottom: frequency response of the reception filter*

In the reception filter it is intended to get a simple band-pass filter easy to implement, using a cascade of a low-pass filter and a high-pass filter. The former is just to avoid frequencies above 20 kHz (cut-off frequency) and the latter to avoid 50 Hz and its harmonics.

In addition because the attenuation of the communication signal is very sensitive and a critical point, the reception filter must meet next requirements: high input impedance and low output impedance from the line point of view. Mainly, the input impedance is more restrictive and it has been set up to 3 $k\Omega$ for 5 kHz and 300 $k\Omega$ for 50 Hz. So, if at least 2 URA devices are connected, the lowest impedance that the 5 kHz signal will see is 1.5 $k\Omega$. Then, using this values and with the filter design of figure 10, where $V_1 = V_{in}$ and $V = V_{out}$, the transfer function is:

$$\text{Gain} = \frac{V_{out}}{V_{in}} = \frac{\frac{1}{C_3 s}}{R_2 + \frac{1}{C_3 s}} \frac{\frac{R_1 L s}{R_1 + L s}}{\frac{1}{C_1 s} + \frac{R_1 L s}{R_1 + L s}}$$

with a trade-off for next values: L=100 mH y $C_1 = C_2 = C_3 = 22$ nF, $R_1 = 10k\ \Omega$ and $R_2 = 1k\ \Omega$. The frequency response of this filter is shown at the bottom of figure 10, where is seen a resonant behaviour just on 5 kHz.

5.2 Transmission Filter (Output filter)

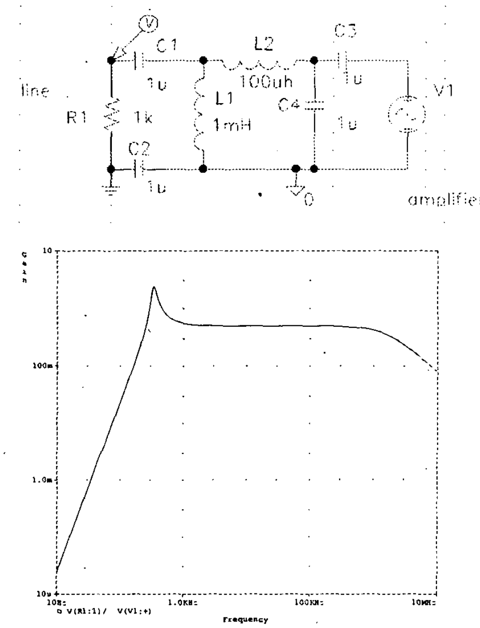

Figure 11: *Top: transmission filter for URA device. Bottom: frequency response of the transmission filter*

In the transmission filter also it is intended to get a simple band-pass filter with the same cut-off frequency requirements, but now the filter impedances are with low output impedance to the power line for 5 kHz signal and high impedance for 50 Hz signal from the power line to the URA device. The scheme for this filter and its frequency response is shown in figure 11. In this case has been chosen next values: output impedance of 30 Ω for 5 kHz and 2.2 $k\Omega$ for 50 Hz. Next equation shows the transfer response, where $V_1 = V_{in}$ and $V = V_{out}$ regarded to figure 11:

$$\text{Gain} = \frac{V_{out}}{V_{in}} = \frac{L_1 s \frac{1}{C_4 s} \frac{1}{C_3 s}}{(\frac{1}{C_1 s} + L_1 s)(L_2 + \frac{1}{C_4 s})}$$

with values $C_1 = C_2 = C_3 = C_4 = 1\mu F$, $L_1 = 1mH$ y $L_2 = 100\mu H$. Also, as in the reception filter, in figure 11 is seen a resonant behaviour just on 5 kHz.

Obviously, 30 Ω for 5 kHz is a low output impedance, which means that if a simultaneous transmission and reception is produced, then the carrier will be removed. Therefore, this filter should be isolated from power line while it is not in operation and only to connect it when required by means fo a miniature solid-state relay, as can be seen in figure 8. It forces a half-duplex operation, which is not a restriction for this IS, because as in section 4 a simple Master/Slave protocol meets the IS requirements.

6 Conclusions and future work

This paper shows new trends and emerging technologies for IS. Strategies for irrigation scheduling under water scarcity make to take profit of the state of art on communications technologies. So, it has been described a whole hierarchical computer system, based on a cheap and reliable communications mechanism to manage the URA devices, with Integrated Power Transmission. It should be noticed that these power lines are long indeed, but no more than 10 km, which is a strong constraint in current consumption requirements. In addition from the bus topology point of view, the IS enjoys of scalability possibilities, which means that can be dimensioned as much wider as it is required.

Furthermore, power transmission needs a proper power management and filter design. The filter design, both for transmission and reception, has to adapt the wire impedance and its frequency response. Also, has been shown several trade-off related to power consumption and modulation. All this, have concluded in a communication system using OOK modulation and Manchester coding, with none transmission for 0 logic and 5 kHz carrier for 1 logic.

Future work is intended to improve the proposed system, by introducing potential A/D measures and managing analogue sensors under low current consumption.

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