MODERN TELEMETRY

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Preface

Telemetry problematic is based on knowledge of various disciplines like Electronics, Measurement, Control and Communication along with their combination as Computer Networks etc. This fact leads to a need of studying and understanding of these principles before the usage of Telemetry on selected problem solving. Spending time is however many times returned in form of obtained data or knowledge which telemetry system can provide.

Usage of telemetry can be found in many areas from military through biomedical to real medical applications. Modern way to create a wireless sensors remotely connected to central system with artificial intelligence provide many new, sometimes unusual ways to get a knowledge about remote objects behaviour.

This book is intended to present some new up to date accesses to telemetry problems solving by use of new sensors conceptions, new wireless transfer or communication techniques, data collection or processing techniques as well as several real use case scenarios describing model examples.

The book is split to several sections containing one or more chapters. The text starts with a first section "Sensors" (contain 4 chapters) describing new sensor architectures, communication strategies between them as well as description of same modern ways to develop sensors.

Second section "Telemetry Data Mining" introduces problems related to telemetry, satellite, autonomy, etc. This section contains one very well structured chapter.

Telemetry Use Cases focused on the theme of biomedical, medical, animal as well as military, are considered in following four sections containing the rest 16 chapters. These chapters deals with many real cases of telemetry issues which can be used as a cookbooks for Your own telemetry related problems.

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Part 1

Sensors

1

Optical Fiber Sensors

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1. Introduction

Telemetry is a technology that allows remote measurement and monitoring of data. It normally refers to one-way direction of information, that is, from the sensor to the interrogation system or data logger system. Telemetry could be defined as a sub-class of telecom, a more complex way of exchanging information such as Internet, telephone calls or video transmission.

Telecommand, the counterpart of telemetry, occurs when the remote systems require remote instructions and data to operate, which means that the information goes on the other direction.

Telemetry finds applications in aerospace, automotive, consumer, engineering, industrial manufacturing, medical, military, electric power industry etc.

Although the term telemetry commonly refers to wireless data transfer mechanisms (e.g. using radio or infrared systems), it also encompasses data transferred over other media, such as a telephone or computer network, optical link or other wired communications.

In the applications mentioned above and particularly in the electric power industry, we find normally protocols that can be either bidirectional or mono directional, such as Fieldbus, RS-485, Ethernet, 4-20 mA, 0-10 V, all working in a twisted-pair basis. These protocols, although being among us for many decades, have disadvantages, particularly when applied to the electric power industry. One of these disadvantages is that data transmitted through electric wires normally need electric energy at the sensor end, or in other words, the transducer needs to be powered in order to measure and transmit data. However, it occurs that sometimes providing electric energy at the sensor location is difficult for it could be far away from any appropriated power supply. This happens in long high voltage transmission lines or along pipe-lines or in deep ocean, for instance. The other problem with these protocols is that they electrically connect the sensor location with the interrogation location. The main consequence of this is that short circuits due to malfunctioning or atmospheric discharges can easily be transferred to the operation room and furthermore putting the substation personnel and equipment at risk.

With the invention of the practical optical fiber in the 70´s the world watched a boom in the telecommunication technology. In the 80´s, with the popularity of optical fiber technology, scientists started to develop a new class of sensors and transducers: the optical fiber sensors. They came offering many advantages over the other technologies and soon started to be applied in telemetry with very good return in costs, maintenance and efficiency.

In conclusion, when it comes to telemetry, optical fibers perform telemetric measurements at distances much longer than conventional telemetry protocols and media. Additionally, due to its virtually infinite capacity to multiplex, one can mix different kinds of signals in one single fiber therefore saving many kilometers of copper wires, which is also welcome by the maintenance personnel.
In this article we will concentrate on applications of telemetry over optical fiber and on optical fiber sensors which encompass telemetry and sensor in one single media.

2. Optical fiber sensors

Optical fiber sensors (OFS) came just after the invention of the optical fiber in the 70's. At the beginning of this era, optical devices such as laser, photodetectors and the optical fibers were very expensive, adequate only to the already saturated telephone network in which companies would pay any price to transmit more information and more telephone calls. With the great diffusion of the optical fiber technology in the 80´and on, optoelectronic devices became less expensive, what favored their use in OFS.
OFS can be applied in many branches of the industry but we will concentrate here their applications through our experience in the electric power industry.
In this area, the operators need to measure and monitor some important physical parameters that include:

- Strain (µϵ)
- Vibration of structures and machines
- Electric current (from A to kA)
- Voltage (from mV to MV)
- Impedancy (µΩ)
- Leakage current of insulators (µA to mA)
- Temperature
- Pressure
- Gas concentration
- Distance between stationary and rotating or moving parts

Some of these parameters, depending on where they are located, are very difficult or even impossible to be conventionally monitored because of a well-known paradigm of the electrical power industry: An electric sensor cannot be close enough to a high potential in order to break the electric rigidity of the air, which is about 1 kV/cm. This would cause a short circuit when the current would flow from high voltage to ground potential by the sensor's connecting wires. The best option to avoid this catastrophic effect is the OFS, because the fiber is made of dielectric materials and therefore it is possible to be placed very close or even touch a high potential conductor and they do not necessary need electrical power at the sensor location.
OFS can be built using several physical principles and materials. They have specific characteristics that are well exploited when applied to the electric power industry and in this case OFS offer a large number of advantages over conventional sensors. The most important are:

- High immunity to EMI
- Electrical insulation
- Absence of metallic parts
- Local electrical power not required
- Lightweight and compactness

- Easy maintenance
- Chemically inert even against corrosion
- Work over long distances
- Several sensors can be multiplexed on the same fiber

The high immunity to electromagnetic interference (EMI) is a strong requirement for sensing in electromagnetic contaminated environments, e.g. RF-field and high electric and magnetic fields present in power lines.

The insulation is another special requirement, because as these sensors are inherently electrically insulated (dielectric) and do not require external power, this means that there is no electric path from the power line to ground, which means high personnel security. Therefore the optical fiber sensors can work at high electrical potentials and in potentially explosive environments.

Optical fibers can be used as sensors by modifying a fiber so that the measurand interferes on the guided light and modulate light parameters such as intensity, phase, polarization, wavelength, or transit time of light over the fiber. Sensors that vary the intensity of light are the simplest, since only a simple source and detector are required.

We can divide OFS in three basic categories: intrinsic, extrinsic and evanescent field based.

Extrinsic fiber optic sensors use an optical fiber, normally multi-mode, to transmit modulated light from either a non-fiber optical sensor or an electronic sensor connected to an optical transmitter. In this case the optical fiber is used only to transmit light to and from the sensor. This kind of sensor sometimes is called hybrid sensor for it enclosures different technologies such as optics and electronics.

In intrinsic sensors the light does not leave the fiber and the light modulation takes place inside the fiber. This kind of sensor presents the major benefit to have the ability to reach otherwise inaccessible places and without the need of electrical energy at the sensing location.

The third category is the evanescent field based sensor. Due to the total internal reflection phenomenon that occurs in the core-cladding interface of the fiber, the light propagating in the fiber has two components - an oscillatory field in the core and an exponentially decaying field in the cladding. The latter field, referred to as the evanescent field, is the key to sensing and is based on the modulation of the light amplitude in the core of the fiber by the optical properties of the surrounding medium.

When developing an OFS we can use the fiber for: a) conducting light; b) to be the sensor itself; and c) for both applications, that is, sensing and conducting light to and from the sensing area.

An optical fiber is a thin, flexible, transparent glassy filament that acts as a waveguide, or "light pipe", to transmit light from the light source to the photodetector located at the two ends of the fiber. They are mainly used for telecom and sensing but find many uses in the industry, research sciences, medicine, entertainment etc.

By the 70's all telephone cables and microwave links in the planet were already saturated. The solution came when Charles Kao and George Hockham of the British company Standard Telephones and Cables (STC) promoted the idea that the attenuation in the existing optical fibers could be reduced below 20 decibels per kilometer (dB/km), making fibers a practical communication medium. They proposed that the attenuation in fibers available at the time was caused by impurities that could be removed by chemical processes. They correctly and systematically theorized the light-loss properties for optical fiber, and pointed out the right material to use for such fibers — silica glass with high purity. This discovery earned Kao the Nobel Prize in Physics in 2009.

The crucial attenuation limit of 20 dB/km was first achieved in 1970 by researchers at the American glass maker Corning Glass Works, now Corning Incorporated. They demonstrated a fiber with 17 dB/km attenuation by doping silica glass with titanium. A few years later they produced a fiber with only 4 dB/km attenuation using germanium dioxide as the core dopant. Such low attenuation allowed optical fiber to be used in telecom from the 80's until today when the telecom fiber presents an attenuation of only0.25 dB/km.
Although polymeric optical fibers (POF) are around us much longer than silica fibers, only in the last decade they start to attract attention for LANs and small industrial networks and their use for sensors has just emerged few years ago. Figure 2.1 shows the different diameters as comparing POFs with silica fibers.

Fig. 2.1. Relative comparison of diameters in different kinds of fibers. SI-POF=step-index polymeric optical fiber; PCS=plastic cladding silica fiber; MM Silica=multimode silica fiber; SM silica=single mode silica fiber; PF-GI-POF=perflorinated graded-index POF. The light color represents the cladding and dark color the core.

The first report of poly-metil-meta-acrylate (PMMA) POF dates from 1968 when Du Pont presented a POF with an attenuation of 500 dB/km. From then on several laboratories are keeping trying to decrease the attenuation in order to apply POF in telecom. Figure 2.2 shows the results of those efforts.

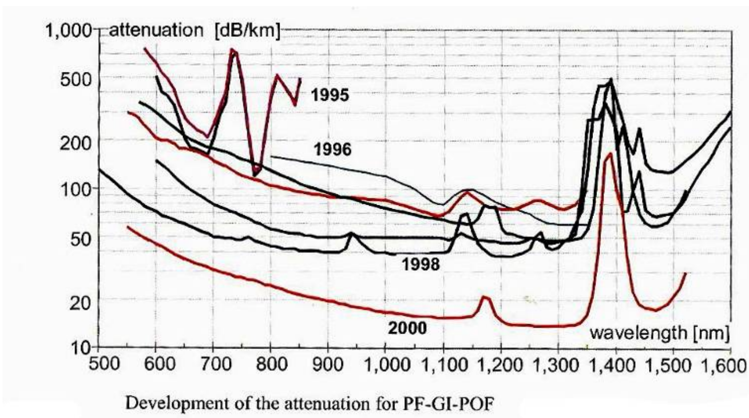

Fig. 2.2. History of the attenuation improvement of PF-GI-POF.

Comparing POF and silica fibers by the attenuation, silica fibers are much better. However, when constructing a fiber sensor using POF instead of silica, we have some additional advantages:

- Maintenance costs
- More resistance to strain
- Cheaper peripherical components
- Easy handling
- No need of special skill for splicing and connectorization

Due to their larger diameter, it is simpler to work with open optics and easy handling. POFs are cheaper than their counterpart as well as the peripheral components and devices, such as connectors, LEDs and photodetectors. They also present more resistance to strain (larger modulus of elasticity) which means more reliable networks. Finally, many interfaces can be built in laboratory what makes the maintenance cost much lower than when dealing with silica fibers.

Of course POFs have disadvantages too. POF only transmits visible and near infrared light, so we cannot use the available technology of telecommunications such as 1300 nm and 1500 nm telecom windows. Additionally, POF has a very high attenuation in the visible spectrum (see Fig. 2.3).

The other issue is the temperature because plastic materials cannot withstand high temperatures as much as glasses. POFs can operate only up to 70 to 85°C. However, some specials POFs have been developed mainly for harsh environment such as in car networks. In these applications POFs have to withstand temperatures as much as 150°C. Table 1 shows some examples.

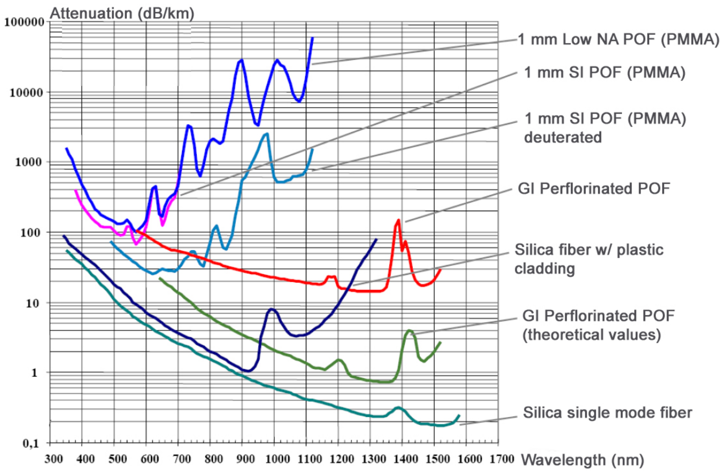

Fig. 2.3. Optical attenuation of silica fibers and POFs.

The attenuation of silica fibers is negligible for sensing distances (around 1 km), but when using a POF for transmitting light, the first thing to have in mind is the high attenuation the POF impinges to the light.

3. Case studies

This section will present real applications of OFS and telemetry in the electrical power industry. The techniques presented here have been tested in the field mainly in high voltage transmission lines, in substation equipments and in hydroelectric generators, all in a connected-to-the-grid basis.

3.1 Application of POF and ruby for temperature measurement in an electric power substation

3.1.1 Introduction

Temperature is a very important parameter for the electric power industry because insulators, copper conductors, iron core of transformers, insulating oil and every equipment are very sensitive to the temperature which has to be kept under strict control during all times. Nevertheless, when dealing with high voltage, sometimes one cannot use conventional electric sensors particularly when working near high voltage areas. This case reports the development of a temperature sensor system using the fluorescence technique.

The fluorescence effect can be used as an indicator and generate a signal proportional to a specific parameter need to be monitored. In the same way, fluorescent materials can be used as sensors. It is well known that the fluorescence decay time of some crystals is proportional to the temperature. Therefore, one way to build a temperature sensor is by the measurement of the time constant of the exponential decay that produces a linear relationship with the temperature.

Optical fibre sensors offer a large number of advantages over conventional sensors such as high immunity to electromagnetic interference, electrical isolation and the absence of metallic parts, a strong requirement for sensing in electromagnetic contaminated environments, e.g. RF/microwave. The sensor probes are inherently electrically insulated system and external power is not required for their operation, they can work at high electrical potentials and in potentially explosive environments. It can be made as lightweight, compact, disposable of low cost and is highly chemically inert even against corrosion.

The fluorescence based sensors offer the advantage of a near-zero background, because the wavelength of the emitted light is always larger than that of the excitation light, which makes then in principle much more sensitive and error immune than those that change only the absorption when the temperature varies [Asada and Yuki, 1994, Grattan and Zhang, 1995]. Previously, experiments with commercial polystyrene fluorescent fibres as temperature sensor were done [Ribeiro et al., 2003]. Although it features some advantages as compatibility with standards POFs, a weak fluorescence signal with time-decay < 100 ns was measured, thus requiring a much complex electronics. Furthermore, the polystyrene can withstand only up to ~70^{o}C thus limiting its usefulness for the electrical energy industry. Ruby has been used for fluorescence thermometry because it is of low cost, easily available, POF compatible, requires low cost source (blue or green ultra-bright LEDs), Si-based photodetection and simple electronics. Additionally it presents strong intensity and long lifetime of fluorescence signal. The fluorescence peaking at 694 nm wavelength features a long-decay time of 2-4 ms. Persegol and co-workers [Persegol et al., 1999] described a POF-based temperature sensor in the range –20^{o}C to +120^{o}C with an accuracy of ± 2^{o}C for early detection of faults in medium-voltage (36 kV) substations. They used heavily-doped ruby powder packaged at the POF end as fluorescent material pumped with a green LED. Two POF-probe were used, one for pumping the ruby and the other for bringing the fluorescence back to the photodetector.

In this case study we describe the temperature sensor prototype development based on the ruby crystal and a one-probe-POF for “low” and “high” temperatures. Low cost passive and active components as couplers, connectors, adapters, LEDs etc were used. Ruby crystals are