

# Developments in Wireless Sensor Networks for Structural Health Monitoring

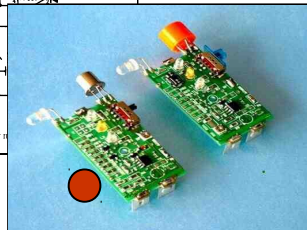
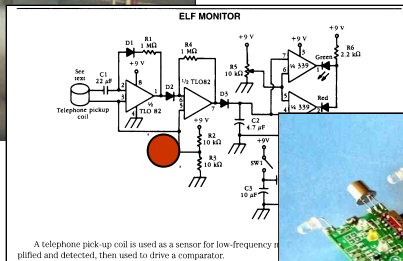
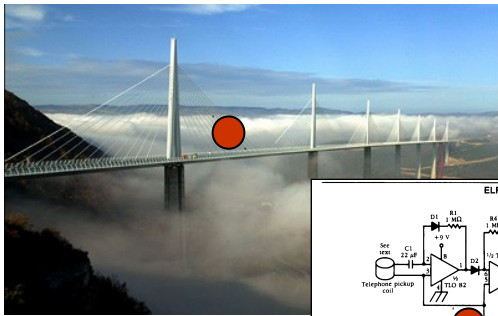
Laboratoire Central des Ponts & Chaussées (LCPC)

French Public Works Laboratory

Division for Metrology and Instrumentation

**Vincent Le Cam**, F. Bourquin, L. Lemarchand

W. Martin, M. Le Pen.



Journées nationales sur la récupération et le stockage d'énergie pour l'alimentation des micro-systèmes autonomes. ESIEE 14-15 oct 2010

# Synopsis :



1. LCPC : French Public Works Laboratory
2. Motivation for Wireless Sensors Networks (WSN) for Structural Health Monitoring
3. Needs translated into electronic constraints (new)
4. Bibliography - Identified Wireless platforms
5. PEGASE : LCPC wireless and Generic Platform
6. An applied and operational WSN acoustic application based on PEGASE
7. Conclusions and roadmap

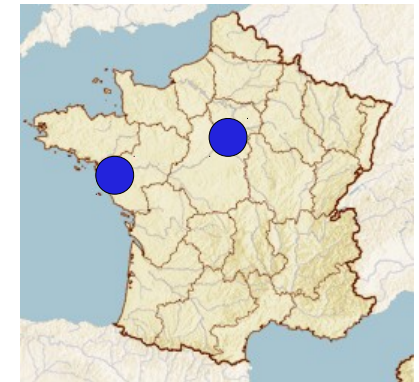




# 1- What LCPC is:

## LCPC : French Public Works Laboratory

- 700 pers. National Lab : researchers, engineers, technicians...
- Mainly located on Nantes and Paris
- Focused on **5 scientific areas** :
  - Traffic security and management
  - Materials for civil engineering constructions
  - Geotechnics and geophysics
  - Structures (bridges, buildings, road)
  - Environment and durability
- Activities are distributed in :
  - **Research and development**
  - Tests and structures validation
  - Assessments and reports
  - Dissemination, valorization, education...



# 1- What LCPC is:

## 1. **LCPC : French Public Works Laboratory**

– LCPC manages some 10<sup>th</sup> exceptional research equipments

- Centrifugal machine
- Cable test bench
- Roadways test bench
- Traffic circuit
- ...



– LCPC teams are involved in

- Local and national projects (ANR)
- International projects (FP7, ESF, NSF)
- Various networks : SHM, NDTCE, ECTP, Cansmart...
- Other joined labs : Navier-ENPC, CEA-LETI, universities...



# 1- What LCPC is:

In **LCPC** especialy **GEII team** (Groupe Électronique et Informatique Industrielle) is fully involved in electronic designs and **wireless systems developments** and application

## Human means (~8 full time pers) :

- 3 engineers
- 1 storekeeper / cabler
- 3 technicians
- Many students (training, alternation) ...

## Competences :

- analog and digital electronic
- microprocessors and embedded computing
- software (c,c++ and object ,Linux, NI/Labview...)
- instrumentation, sensors and conditioning, signal processing,
- networks, **wireless protocols and systems, energy storage and harvesting**

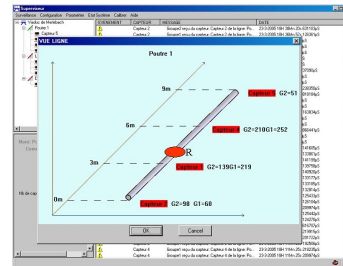
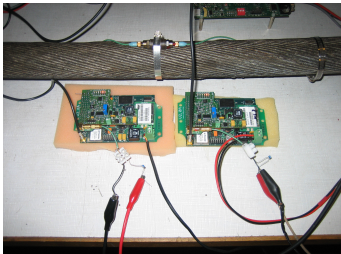


# 1- What LCPC is:

**GEII** team (Groupe Électronique et Informatique Industrielle)

## Applications :

- Products, prototypes, models
- Validation systems...
- Operational instrumentation systems
- Data bases from sensors
- « Help-to-decision » tools
- Sensors and conditioning integrated for SHM or NDT systems





## 2 - Motivation for Wireless Sensors Networks (WSN)

### PART 2 :

Those last 4 years, LCPC GEII team lead active works in [Wireless Sensors Networks](#) applied to LCPC scopes : civil engineerings and specifically [Structural Health Monitoring](#).

For many reasons...





## 2 - Motivation for Wireless Sensors Networks (WSN)

The need for **wireless instrumentation** in civil engineering situations is obvious for (at least) 4 reasons :

**Reason 1:** Structures vulnerability (due to age, vibrations, weather) and complexity :



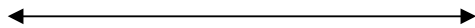
Specifically in Europe, since 2<sup>nd</sup> world war, traffic has considerably increased and structures are often over-exploited.

## 2 - Motivation for Wireless Sensors Networks (WSN)

**Reason 2** : Long structures (i.e. long distances between sensors), difficult to access, requirement of human inspections or **specific and expensive machine**



*gilon*



**Viaduct of Millau : 2.460 Km !**



**« Epsilon » machine**



**Human cable inspection**

## 2 - Motivation for Wireless Sensors Networks (WSN)

**Reason 3** : No choice ! Wireless is sometimes dictated by the situation



- a) Control of an U.AV. for bridges inspection (instead of an « epsilon » machine)
- b) Vehicles to Infrastructure communication for road safety applications
- c) Nomad water level measurements
- d) Etc...

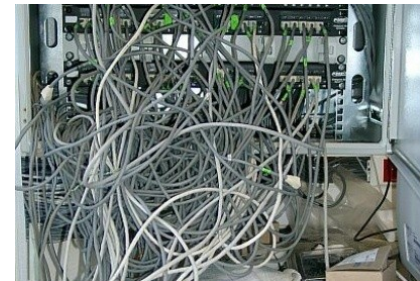
## 2 - Motivation for Wireless Sensors Networks (WSN)

**Reason 4** : Electrical cables between wired sensors are :

- Very **expensive** (48,8 k€ of electrical cables on a total of 297,9 k€ for Aquitaine bridge instrumentation = **16%**)
- Subject to **fatigue**, **corrosion**, E.M. disturbances, tightness of connectors, vandalism...
- Synonym of **limitations** :
  - the number of sensors
  - distances between sensors and/or supervisor due to linear capacity and resistivity effects.

Examples :

- Ethernet            ~80 m (1Mbps)
- RS485              ~1000 m (10Kbps)





## 3 – (Wireless) needs translated into electronic constraints

### PART 3 :

When all previous inputs (wires, cost, security...) have been taken into account, the needs and requirements have to be translated into electronic constraints.

LCPC tried -at its modest level- to identify and to analyse the digital / analog **electronic challenges and the concepts to solve in order to get wireless platforms** that fits SHM needs.

How to ?

A non exhaustive analyse ...





## 3 – (Wireless) needs translated into electronic constraints

At least, following fields have to be investigated :

- **Energy** : power consuming, batteries choices, energy-harvesting and associated charging strategies
- **Sensor time synchronization** : often forgotten in wireless world !
- **Wireless protocols** : *standardization, mass market / lower prices, security, distances*
- **Computing embedded abilities** : *signal processing, remotely configurable systems, smart systems*
- **Sensor dimensions** : *reducing size, ability to be drowned in materials, integration in various environments*



## 3 – (Wireless) needs translated into electronic constraints

**Energy** is a wide subject in wireless sensor world :

**Objective** : an energy-autonomous wireless system that :

- Run 24h a day 365 per/year for typically 3 years
- Mostly under outdoor conditions
- Usually needs some 100 of  $\mu\text{W}$  up to 100 mW



## 3 – (Wireless) needs translated into electronic constraints

**Energy** is a wide subject in wireless sensor world :

- Wireless platform have **to target lower power consumption** while keeping a suitable **level of computing** and **wireless communications range up to some 100<sup>th</sup> m** (typical bridge span)



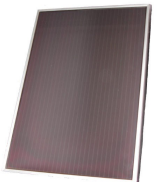
- **Sensor batteries** have to :

- Be **able of slow and fast charging / discharging** phases (sun, wind)
- Not too big (ex. : lead techno.)
- Be **safely managed** (Ex : LiPo techno explosion)



- Energy harvesting **sources impose limitations** :

- Solar cells => outdoor systems only
- Small Wind turbines => outdoor and not determinist
- Vibration based systems => specific sensor location



- **Optimizations harvesting method** have to be implemented (boost)

# 3 – (Wireless) needs translated into electronic constraints

A **wide bibliographical study** has been carried out. 3 main fields have been investigated. Then **choices** have been made (cf. PEGASE part below) :

## 1) Solar cells technologies

- Amorphous
- **Polycrystalline**
- Monocrystalline



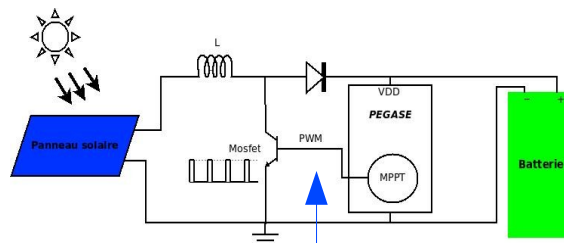
## 2) Battery technologies

- Lead
- **NiMH**
- LiPo



## 3) Optimizations methods

- **Boost**
- Buck Boost
- + an **MPPT** algorithm



## 3 – (Wireless) needs translated into electronic constraints

**Sensor time synchronization** : often forgotten in wireless world

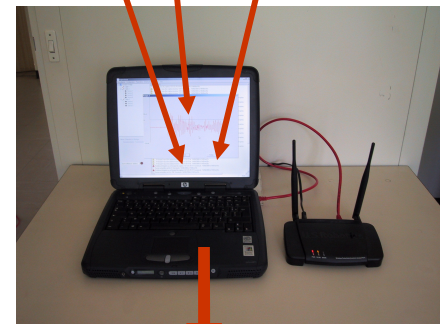
**A good question** : How to get a common time base between sensors that have no physical link between each others ???

**Structural Control** implies Sensor distribution all along the structure

**Collected data** (T°C, Vibr., Displ., etc.) often need to be correlated or compared by monitoring algorithms

**A simple conclusion** : Les données mesurées, au niveau du capteur, doivent être correctement datées !

**But** without any synchronization and wired top, each **electronic system time base drift** (i.e. les quartz) quickly.



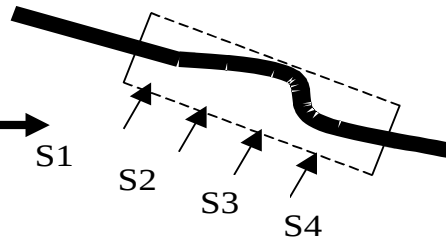
**Alerte !**



## 3 – (Wireless) needs translated into electronic constraints

### Sensor time synchronization and wireless sensors

#### Example 1 : cable-displacement monitoring

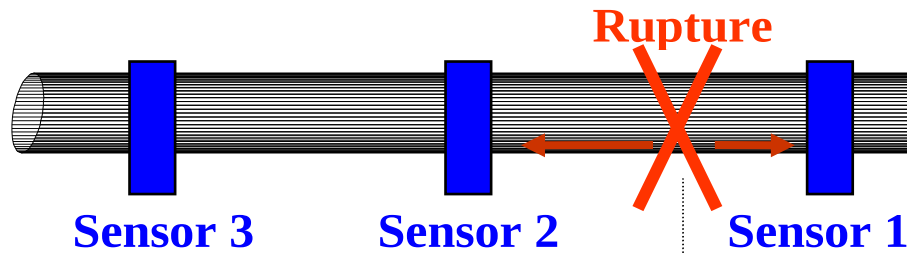


- Vibrations up to  $\sim 30$  Hz
  - Sensor sampling rate at  $\sim 300$  Hz
- $\Rightarrow$  Conclusion: to be compared, each sensor  $\{S_i, S_j\}$  must present a timebase such as  $\| T_i - T_j \| \leq 3 \text{ mS } \forall t$ .

## 3 – (Wireless) needs translated into electronic constraints

### Sensor time synchronization and wireless sensors

#### Example 2 : wire-breaks in cable monitoring



- SHM system based on acoustic wave propagation and detection .  
Typical wave speed ( type « P ») in cable  $\cong 5000$  m/s
- Wished accuracy for rupture localization  $\cong 15$  cm
- => Conclusion: to be compared, each sensor  $\{S_i, S_j\}$  must present a timebase such as  $\| T_i - T_j \| \leq 30 \mu S \forall t$ .

## 3 – (Wireless) needs translated into electronic constraints

### Sensor time synchronization and wireless sensors

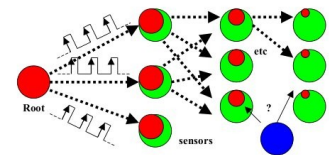
#### SOLUTIONS ???

LCPC lead some studies and wrote articles about synchronization and wireless world :

*Vincent Le Cam, Laurent Lemarchand, Louis-Marie Cottineau. « Synchronization of wireless sensors : review of methodologies. Experience feedback of the very precise GPS solution » in Structural Health Monitoring (SHM), Granada, 2006, July 5,6,7.*

3 main kind of solutions :

- **distributed synchronization** : through the wireless network (ask for energy)
- **post-facto synchronization** : not determinist, low accuracy
- **absoltue-time synchronization** : typically using GPS, used for PEGASE (cf. below)

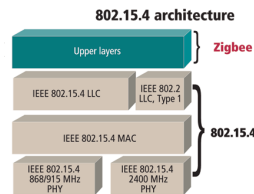


# 3 – (Wireless) needs translated into electronic constraints

## Wireless protocols :

Various standard protocols now exist but have to be evaluated to criteria :

- Power consumption
- Security
- rate
- Reliability
- Easy to integrate
- span range
- Number of nodes
- Scalability
- ...



BlueTooth



Proprietary  
solution ? No !

# 4 – (small) Bibliography - Identified wireless platforms



## **PART 4 :** **Bibliography - Identified Wireless platforms**







## 4 – (small) Bibliography - Identified wireless platforms

A **bibliography** and an active survey allowed to identify that

- some efficient wireless platform solutions exist
- are **very few used and disseminated** - particularly in Civil Engineering- **compared to the need** and literature. Some « intellectual market » have to be convinced
- wireless community is growing, special sessions appears as « wireless monitoring » in (SHM, Structural Control...) workshops, congress.
- Few companies are fully « wireless » oriented. Wireless approach is difficult to define : it's a real job for engineers and just a way of measurement for customers

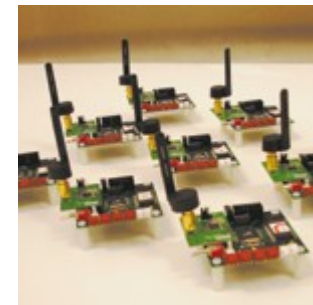
### Operationnal Wireless platforms examples :



Beanair



MicroStrain



Narada - Los Alamos

# 4 – (small) Bibliography - Identified wireless platforms



## Operationnal Wireless platforms examples :



**Newsteo**



**PF développement /  
Zigbee**

2. The sensor boards come with an SMA (shown) or integrated antenna.



**PF Meshnetics Zigbit**



**NI / Labview acq WiFi**

# 5 – PEGASE : LCPC Wireless and Generic Platform



## PART 5 :

**PEGASE** : LCPC Wireless and Generic platform  
And its improvements **about energy**



## 5 – PEGASE : LCPC Wireless and Generic Platform



- **Generic platform** : usable for a wide variety of applications
- **Easily customisable** to specific instrumentation need. No need of electronic nor software expertise. C-Language programming
- **Uses standards** as much as possible : TCP/IP (802.11) for communication, GPS for localization, DSP for signal processing...
- **A synchronized platform** up to some  $\mu\text{S}$
- **Reasonable dimensions** and power consumption
- **A final product** that acts as well as :
  - A ready-to-use platform
  - A pragmatic development board
  - A quick prototyping solution

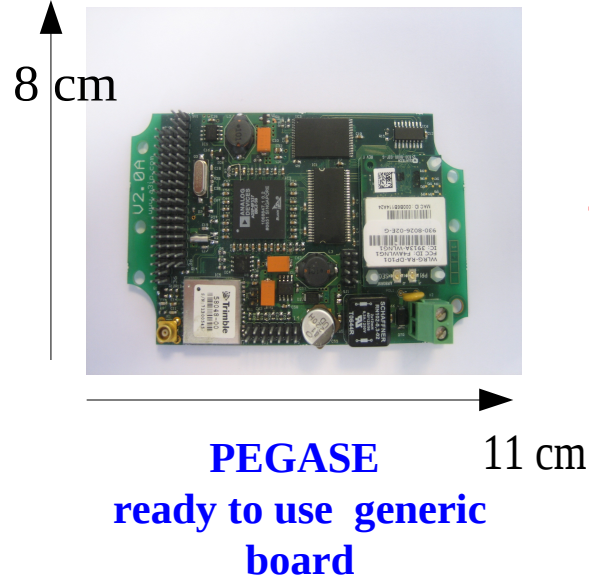




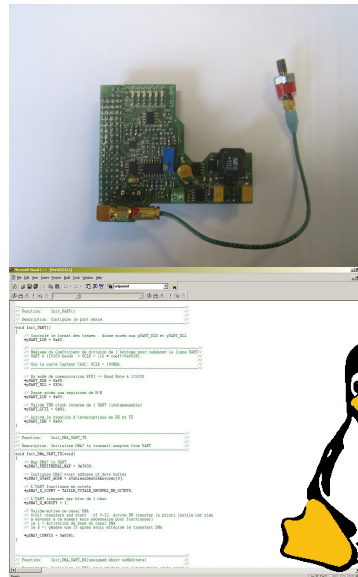
# 5 – PEGASE : LCPC Wireless and Generic Platform

**Result = PEGASE** platform whose genericity resides in:

- **Hardware:** plug and play mother-daughter boards. Many I/O for various purpose
- **Software:** **µClinux as embedded OS** – Standard ANSI-C programming
- **Miscellaneous:** uses a DSP (Blackfin /A.D.), a GPS, WiFi (802.11g) for IP communications

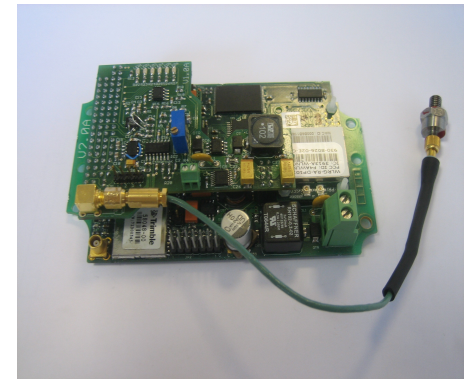


+



A specific & simple daughter board + some C code

=



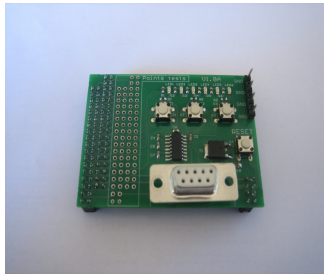
A specific solution for an application



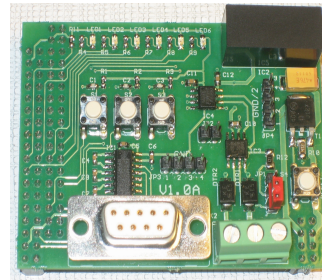


# 5 – PEGASE : LCPC Wireless and Generic Platform

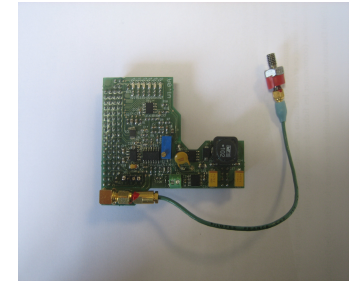
A collection of available daughter boards  
Already designed for specific applications



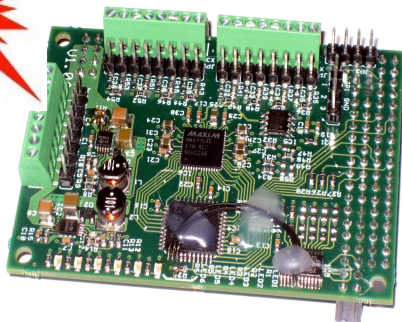
Debug daughter board (d.b.)



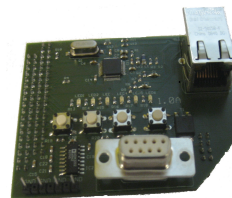
CAN bus d.b.



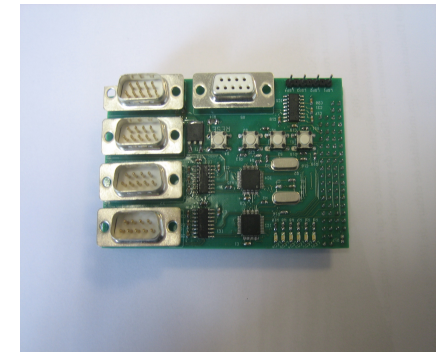
Accelerometer d.b.



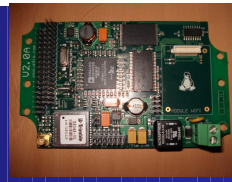
8 analog input +/- 5V / 100 kHz d.b.



Ethernet d.b.

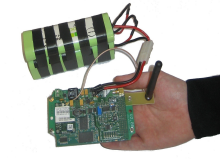
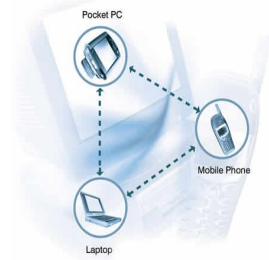
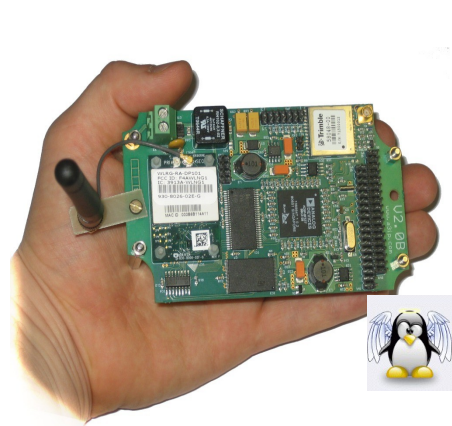


5 RS232 port d.b.



# 5 – PEGASE : LCPC Wireless and Generic Platform

Recent **improvements** added to PEGASE  
with a direct **link to energy**



- 1) **GPS absolute time synchronization / quartz correction**
- 2) Setting GPS *off* while keeping synchronized
- 3) Reusable foundation classes (software bricks)
- 4) **Running H24 using solar cells and an optimized solution : boost + MPPT**





# 5 – PEGASE : LCPC Wireless and Generic Platform

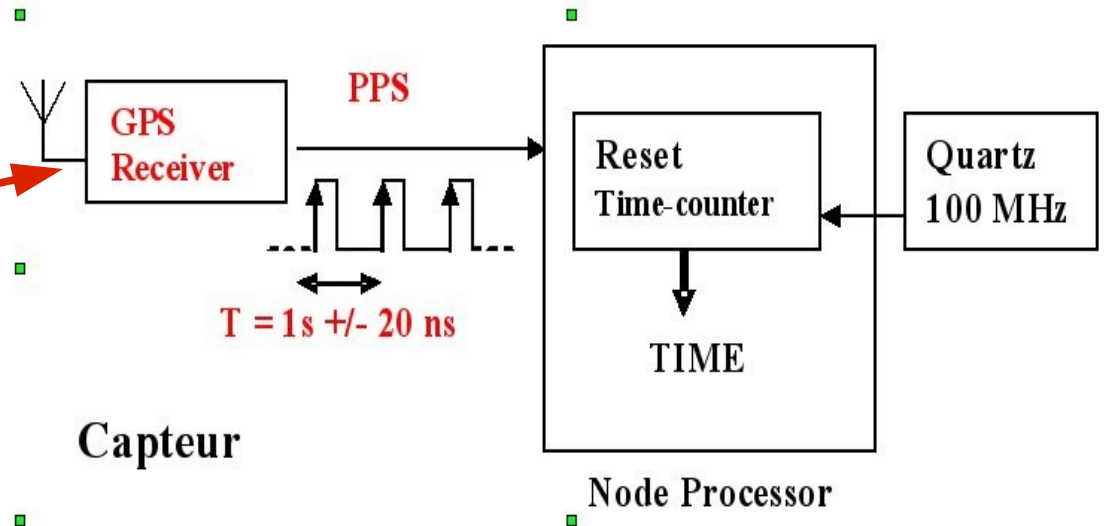
## GPS absolute time synchronization / quartz correction

**Postulate** : No efficient solution exist in WSN to ensure an **accurate** and **determinist** synchronization mechanism between sensors. Nevertheless, in many use-cases, **time-stamping of data, event, edge, routine... is fundamental** to ensure the good SHM algorithm. Ex : control, vibration, wave-propagation... => from mS to  $\mu$ S !

PEGASE implements a solution based on its integrated GPS receiver. Principle :



**To know**: each GPS receiver outputs a synchronized PPS binary signal.  
Period = 1 S +/- 20 nS



Capteur

Node Processor

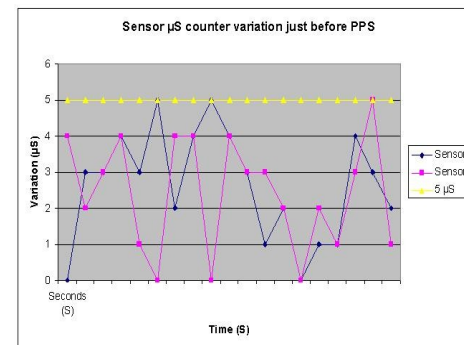
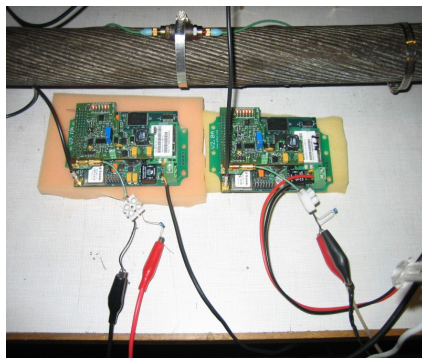


## 5 – PEGASE : LCPC Wireless and Generic Platform

### GPS absolute time synchronization / quartz correction

On each PPS, time counter is reset : each PEGASE is re-synchronized.

Test-bench and verifications have been carried out : comparison in time-stamping of a same event (rising edge)



**First result:** time stamping of a same event by two PEGASE **never exceed 15 μS**.  
That residual difference is not due to PPS but to the natural quartz drift (factory error)

Note that GPS technique also provides an absolute stamping : U.T.C.



# 5 – PEGASE : LCPC Wireless and Generic Platform

## GPS absolute time synchronization / quartz correction

To take into account natural quartz factory error, LCPC has developed its **own real-time driver running in the uClinux** embedded OS (expertise required).

A specific algorithm is applied on each PPS:

1- First delta **d** between theoretical 1000000  $\mu$ S and real *time\_counter* value is computed

$$d = 1000000 - \text{time}_{\text{counter}}$$

2- Then average of 16 last evaluations of d is done

$$d16 = (d16 + d) / 16$$

3- Thus, for each event that has to be time stamped a linear correction is applied to the  $\mu$ S read in *time\_counter* :

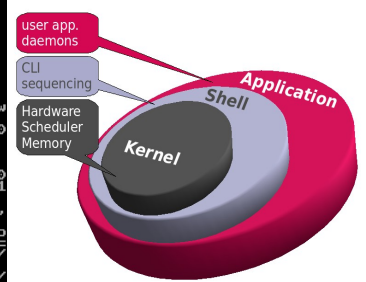
$$\text{Event}_{\mu\text{S}} = \text{time}_{\text{counter}} / (1000000 - d16) \mu\text{S}$$

```

inxmci_start_cmd:390 :: Unknown
in resp type = 0x0
mmchlk0: mmc0:1234 SD256 24780
3KiB
mmchlk0: p1
IP-Config: Complete:
  device=eth0, addr=10.0.0.
.218, mask=255.255.255.0, gw=1
0.0.0.219,
  host=10.0.0.218, domain=,
  nis-domain=(none),
  bootserver=10.0.0.219, ro
otserver=10.0.0.219, rootpath=
Looking up port of RPC 100003/
2 on 10.0.0.219
Looking up port of RPC 100005/
1 on 10.0.0.219
UFS: Mounted root (nfs filesys
tem).
Freeing init memory: 112K

BusyBox v1.01 (2008.04.21-20:5
5+0000) Built-in shell (ash).
Enter 'help' for a list of bui
lt-in commands.

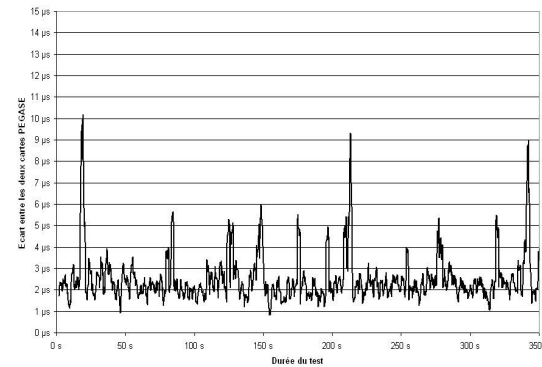
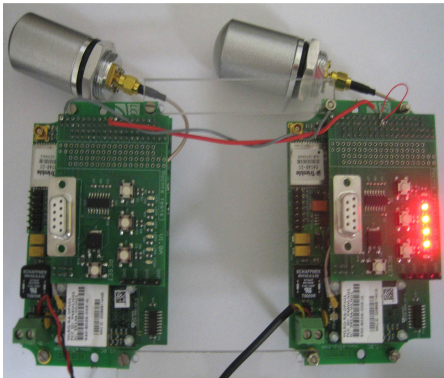
/bin/sh: can't access tty; job
control turned off
#
    
```



## 5 – PEGASE : LCPC Wireless and Generic Platform



### GPS absolute time synchronization / quartz correction



**Final result:** time stamping of a same event by two PEGASE **never 4  $\mu$ S !!! (UTC)** in a determinist manner

PEGASE processus **dynamically takes into account quartz error and temperature effect** as it evaluates and up to dates the quartz drift

The final 4  $\mu$ S (maximum) of error is probably due to the latency of  $\mu$ CLinux to serve the LCPC specific driver interruption.

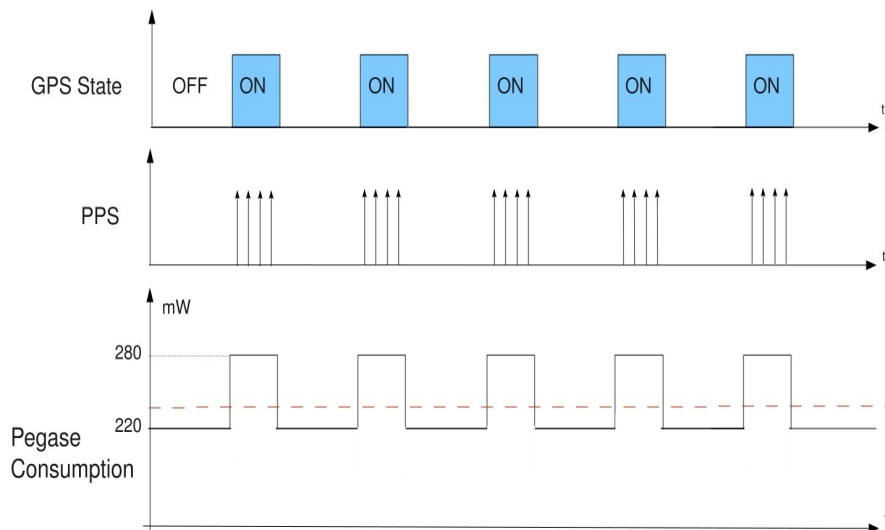


## 5 – PEGASE : LCPC Wireless and Generic Platform

### Setting GPS off while keeping synchronized

**Postulate** : the PPS based synchronization method is robust and very accurate **BUT** the GPS receiver ask  $\sim 30$  mW when set ON. That is a lot in WSN.

**Idea** : as far as quartz drift is very well estimated ( $d_{16}$ ) and stable in time, then it is possible to turn OFF the GPS receiver and then to makes *time\_counter* based on a new period equals to  $1000000 - d_{16}$   $\mu$ S (that represent the "real second").



#### Results :

Only the uncertainty on launching a new timer synch. to SCLK has consequences

When GPS is ON during 60s and then OFF during 600s the drift of the sensor is about  $270 \mu$ S

Under development

**Most of the time GPS can be set OFF and then 30 mW of GPS power consumption become 3mW (average)**





## 5 – PEGASE : LCPC Wireless and Generic Platform

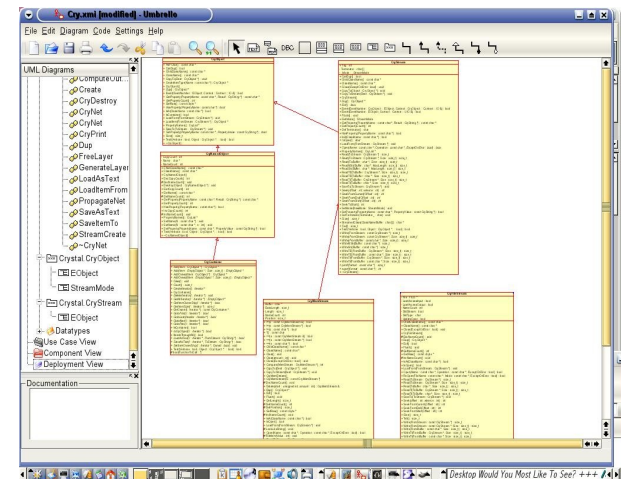
### Reusable foundation classes (software bricks)

To ensure simplicity, quick developments and reusability of source code, PEGASE also provides a **collection of ready to use classes** (written in C-object or C++) :

#### UFC UcLinux Foundation Classes 😊

Thus, for a specific application, user can implements available objects. Each classe encapsulates the management of a physical port, a service, some function...

- CPortSPI
- CPortRS232
- CTcpIpClient
- CTcpIpServer
- CPortFlag
- CGPS
- CAbsoluteTime
- CSignalProcessing
- CTimer
- CNetworkManager
- CLeds
- ...





## 5 – PEGASE : LCPC Wireless and Generic Platform

### Running on a solution using solar cells

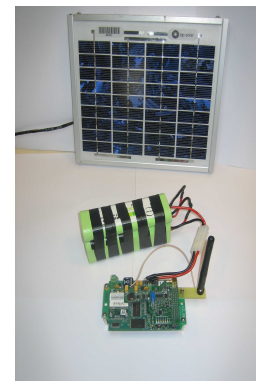
PEGASE **energy assessment = 260 mW** ( 12V x 22 mA) with CPU = 250 Mhz, WiFi OFF & GPS OFF (most of the time).

This is a lot ? Remember that an OS is embedded and high level functions are integrated

**Objective** : making PEGASE to run H24, indefinitely, using solar cells and a battery.  
Solar cells must fit reasonable dimensions : less than an A4 paper dimension



How to ?





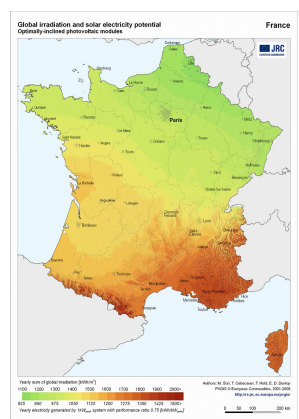
# 5 – PEGASE : LCPC Wireless and Generic Platform

Running on a solution using solar cells

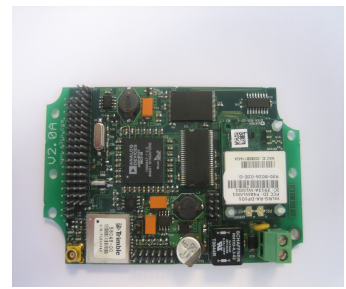
Theoretical approach / dimensioning the solution :

- Official database servers allows to predict the shining possible hope (per localization / per m<sup>2</sup> / per month). Example ISPRA JRC database
- The effectiveness of a solar cell is well know (~16 % for polycrystalline)
- Wished power consumption is an known input by WSN designer (260 mW for PEGASE)

=> So the minimal theoretical dimension needed for solar cell can be predicted



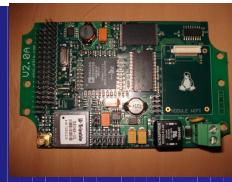
Mois	H(70)	Hopt	lopt
Jan	1740	1680	63
Feb	2670	2670	57
Mar	3840	4100	47
Apr	4010	4670	32
May	3910	4910	18
Jun	4020	5250	13
Jul	4230	5450	17
Aug	4350	5240	27
Sep	4350	4770	43
Oct	3380	3430	55
Nov	2520	2390	64
Dec	1560	1460	66
Year	3880	3880	36



Dimensions = 269 x 251 mm  
 Pmax = 4.5 Watt  
 Vmax = 16.5 Volts



Hopt : Irradiation on optimally inclined (36°) plane (Wh/m<sup>2</sup>)  
 H(70) : Irradiation on plane at angle : 70deg. (Wh/m<sup>2</sup>)  
 lopt : Optimal inclination (deg.)

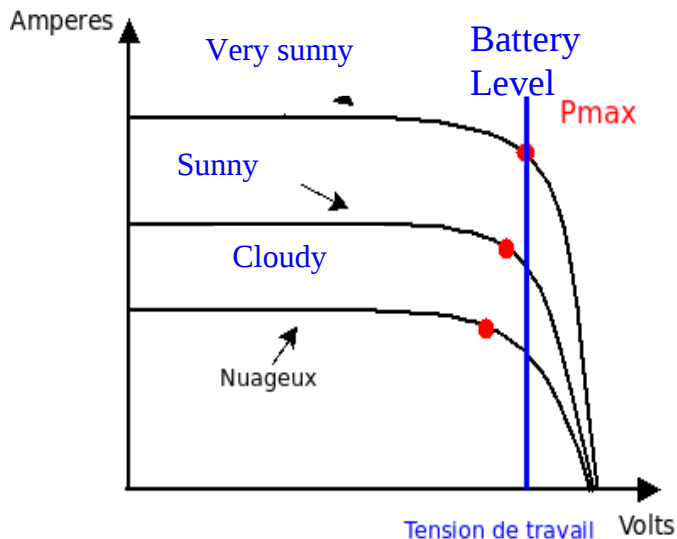


## 5 – PEGASE : LCPC Wireless and Generic Platform

### Running on a solution using solar cells

The challenge of running on solar cells => getting the maximum power than possible !

Most of the time, solar solutions miss the available energy available under the battery level !



Even if solar cell voltage is lower than battery voltage, why not getting that lost energy ???

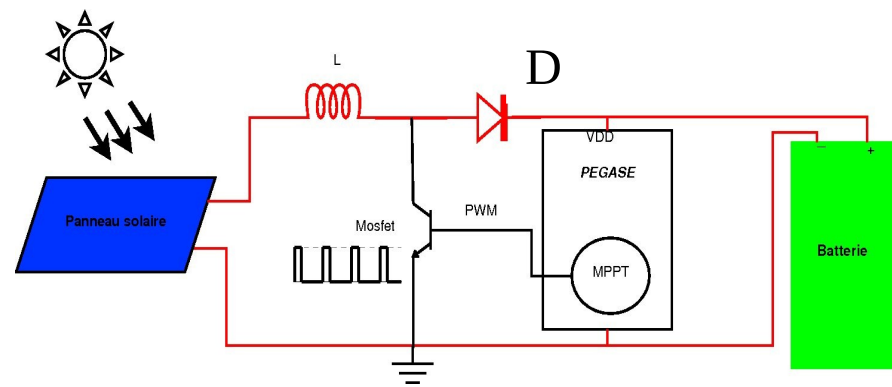
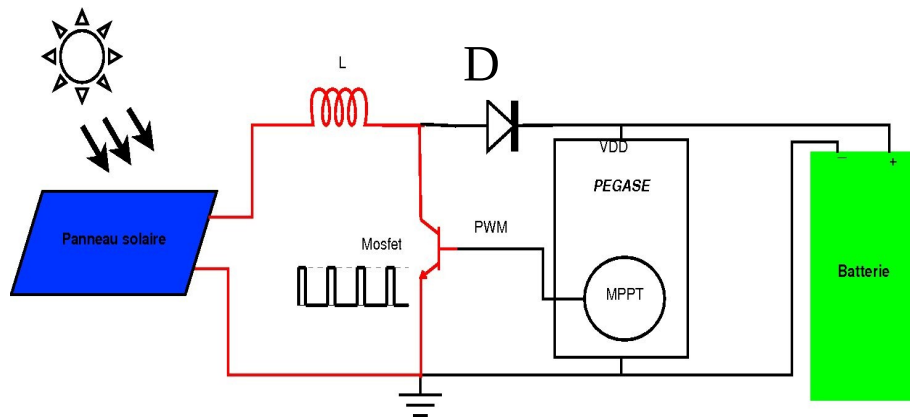
**Solution :** increasing (boosting) solar cell voltage as much as possible over battery voltage threshold



# 5 – PEGASE : LCPC Wireless and Generic Platform

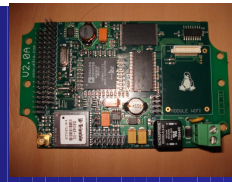
Running on a solution using solar cells

Principle of a **boost circuit** to increase solar cell voltage



- Continuously adding a  $L \cdot di/dt$  voltage to solar cell via mosfet transistor transitions
- Charge and discharge of the self  $L$  increase apparent voltage
- Then diode  $D$  threshold is most of the time exceeded
- Then solar cell current makes PEGASE running and battery charging



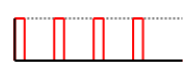
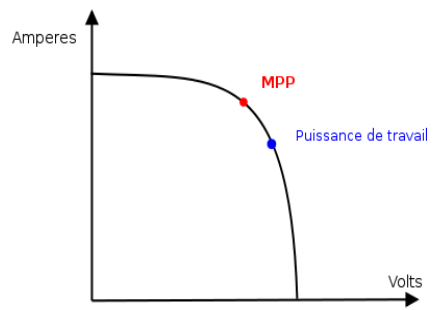
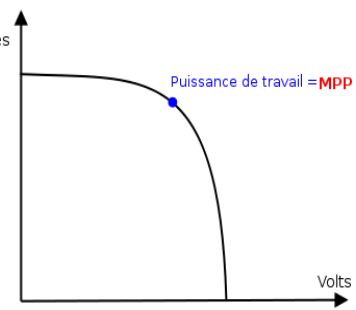
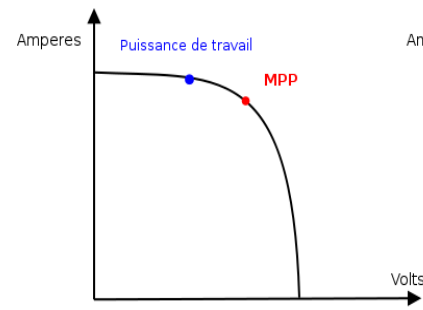
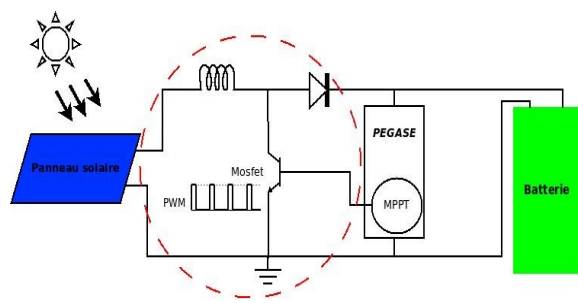


# 5 – PEGASE : LCPC Wireless and Generic Platform

## Running on a solution using solar cells

Improving the boost circuit with a MPPT algorithm : Maximum Power Point Tracking

- The boost circuit doesn't guarantee that the Maximum Power Point is always reached
- The best consists in implementing a control algorithm that is always searching the maximum available power by making variation of the transistor open/close phases
- This can be achieved by a PWM (Pulse Width Modulation) on Mosfet transistor while reading continously Voltage and Current that ouput from boost circuit.



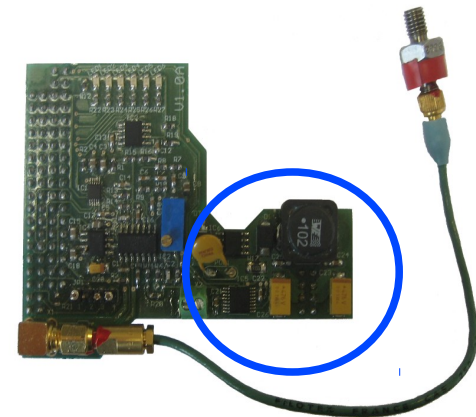
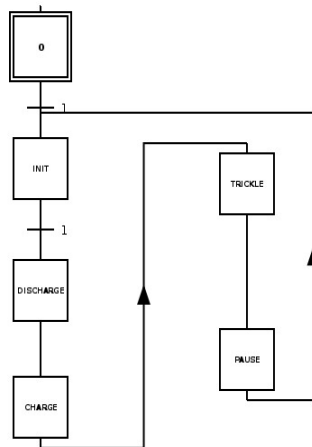
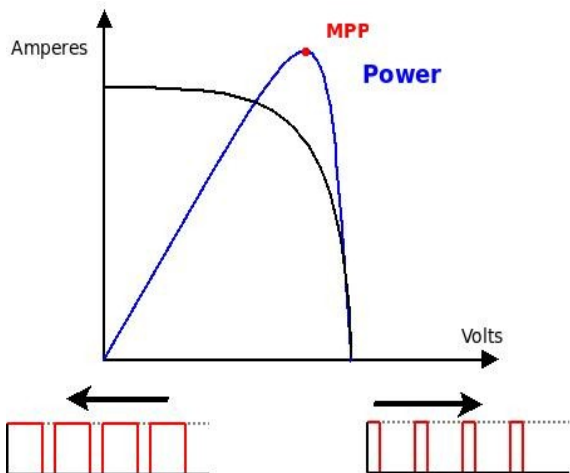
# 5 – PEGASE : LCPC Wireless and Generic Platform



## Running on a solution using solar cells

Such a solution has been implemented. The solution is then double :

- **Hardware** : a specific **PEGASE daughter board** integrates : **boost circuit** + reading voltage/current operation via an I2C component
- **Software** : a simple **real-time algorithm** (under IT) that perform a Pulse Width Modulation (PWM) at 80 kHz that always modify width to in/de-crease boost voltage **to get the MPPT**

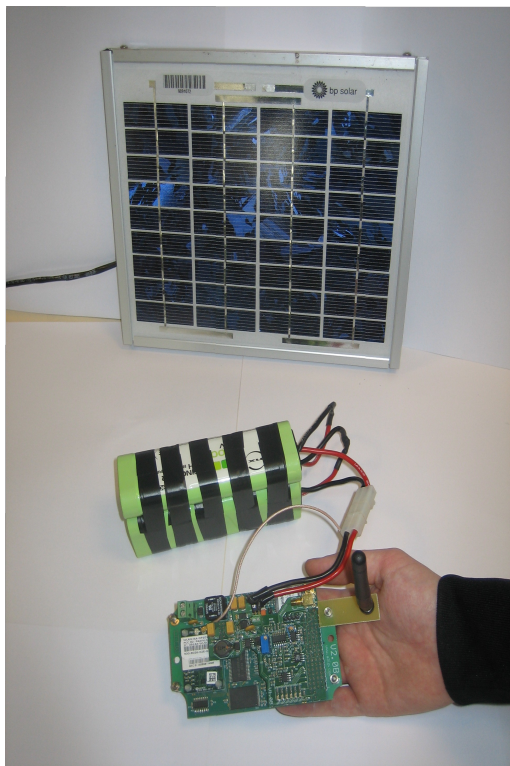




# 5 – PEGASE : LCPC Wireless and Generic Platform

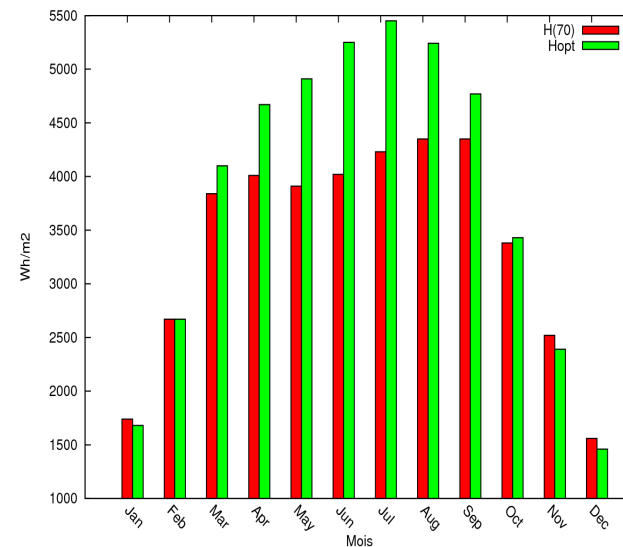
## Running on a solution using solar cells

Such a solution has been implemented, tested, qualified during 1 year:



Mois	H(70)	Hopt	Iopt
Jan	1740	1680	63
Feb	2670	2670	57
Mar	3840	4100	47
Apr	4010	4670	32
May	3910	4910	18
Jun	4020	5250	13
Jul	4230	5450	17
Aug	4350	5240	27
Sep	4350	4770	43
Oct	3380	3430	55
Nov	2520	2390	64
Dec	1560	1460	66
Year	3880	3880	36

Hopt : Irradiation on optimally inclined (36°) plane (Wh/m<sup>2</sup>)  
H(70) : Irradiation on plane at angle : 70deg. (Wh/m<sup>2</sup>)  
Iopt : Optimal inclination (deg.)

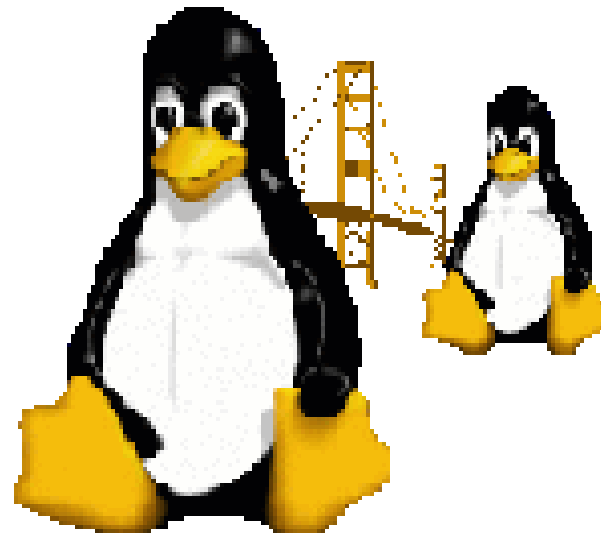


**PEGASE WORKS**  
**24/24h 365d/year !!!**

# 6 – Acoustic application based on PEGASE :

**PART 6 :**

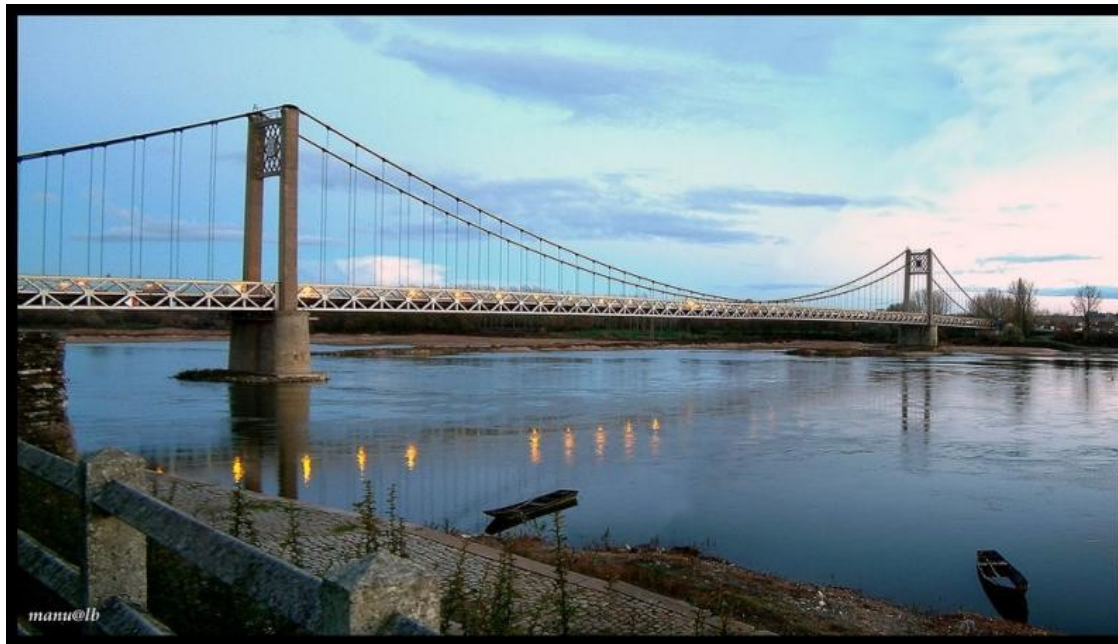
An **acoustic application** based on PEGASE



## 6 – Acoustic application based on PEGASE



First application based on PEGASE :  
CASC system : **cable health monitoring**



manu@lb



# 6 – Acoustic application based on PEGASE



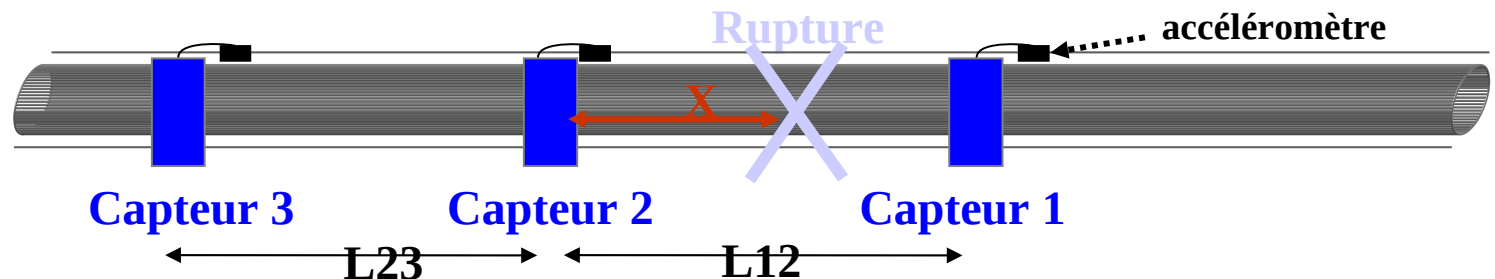
**Objective :** detect and localize wire-breaks in cables

**Principle :** a wire break occurs => two acoustic wave are generated in both direction from X.

A distribution of sensors all along cable, able to detect that acoustic wave Une using an accelerometer and a threshold comparison

Each sensor that make wave-detection transmits wave-shape and time of detection to a remote Supervisor close to the bridge

Supervisor knows each relative sensor location and then is able to compute wave speed and to determine X as point of rupture



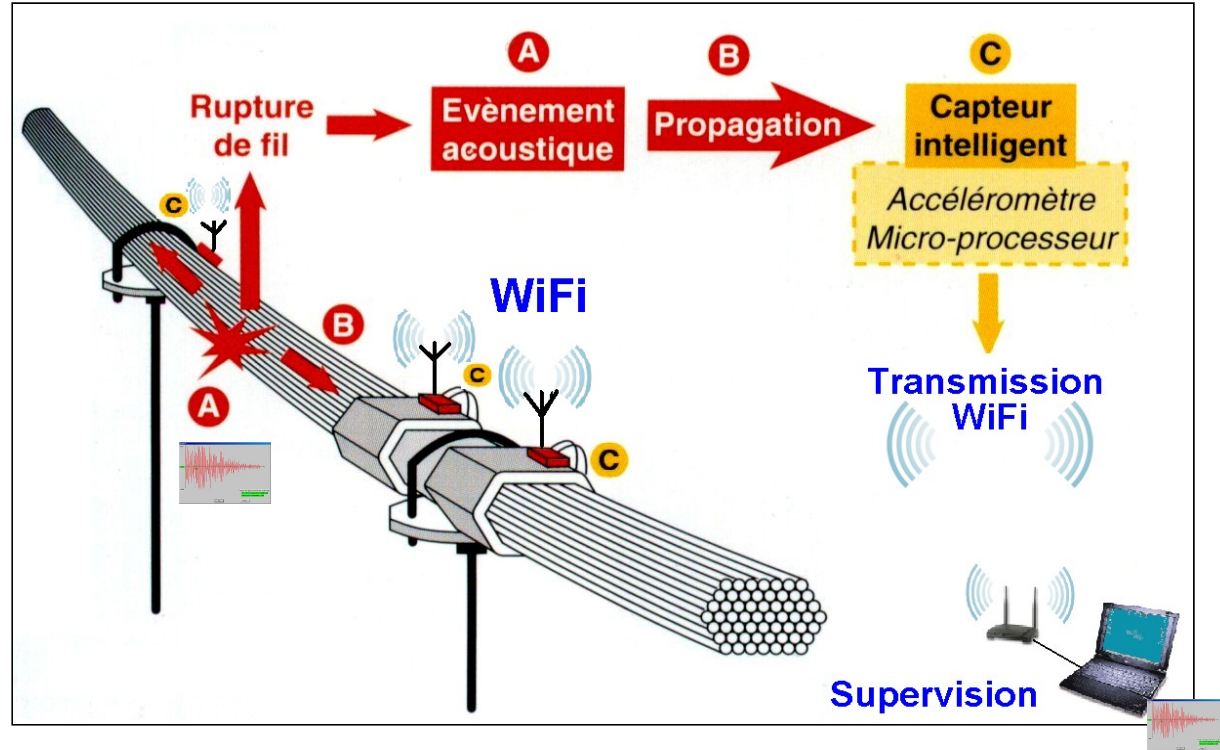
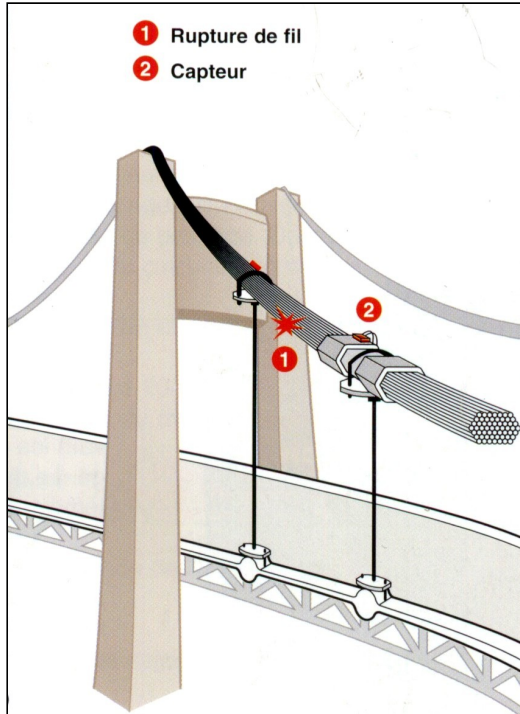
$$x = \frac{1}{2} * (L12 - v * \Delta t12) \text{ avec } v = L23/\Delta t23.$$

Speed  $v \approx 5000$  m/s



# 6 – Acoustic application based on PEGASE

## Development / principle :



Detection by tracking the wave by a distribution of sensors. Each accelerometer is directly fixed to the cable.

# 6 – Acoustic application based on PEGASE :



A **first generation** of such a system has already been deployed on several bridges in France (Aquitaine, Tancarville, Iseron, Foix, Merlebach, Ancenis,...). Actually som bridges are under such a monitoring (~ 300 sensors)

QUASAR  
CONCEPT



Contrôle en temps réel  
de la sécurité  
des ponts suspendus

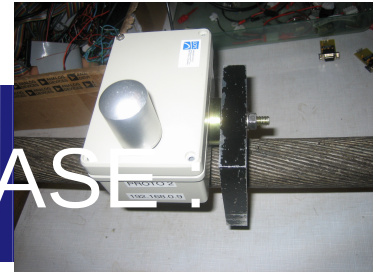


Tancarville



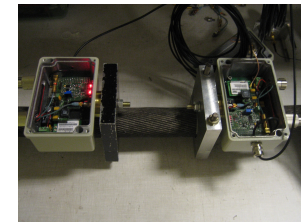
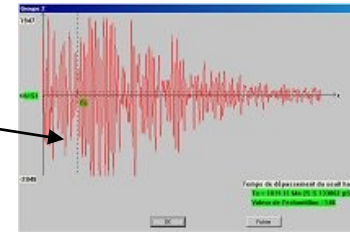
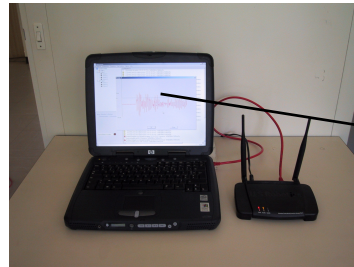
Iseron

# 6 – Acoustic application based on PEGASE



**Objective = a second generation with new goals**

- To record the full shape of acoustic waves to improve phenomena knowledge and accuracy
- To develop a wireless version (less expensive) at least for communication (not for energy)
- To simplify the management of hundreds of sensors by modern protocols and software

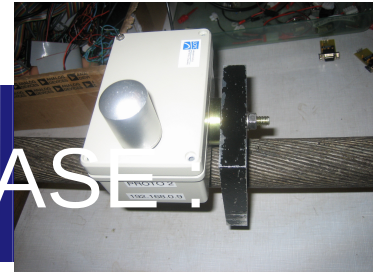


**First generation**

**New generation**



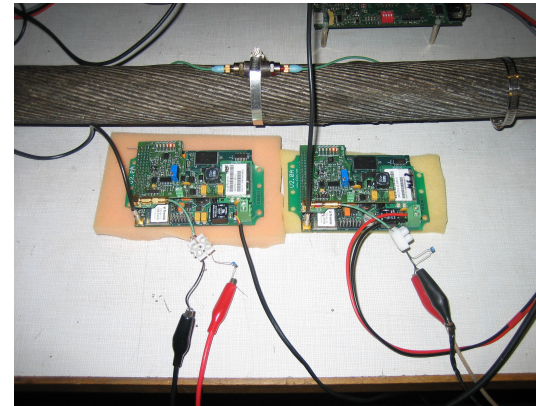
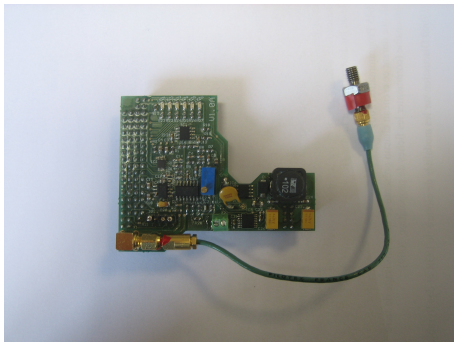
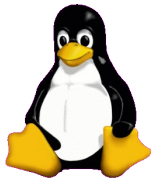
# 6 – Acoustic application based on PEGASE



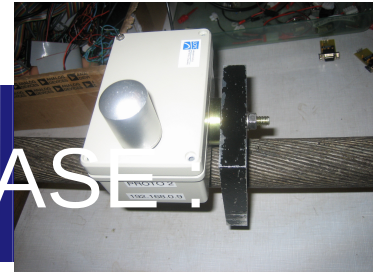
## Sensor design...

Each sensor is a smart system based on PEGASE that :

- Accelerometer conditioning, threshold comparison of acoustic wave on a specific PEGASE daughter board
- When threshold is exceeded (wire break) : an 8 ms frame of signal is recorded (at 250 kHz) including a pre-trigger period
- Ensure an absolute time -synchronization up to some  $\mu\text{S}$  thanks to PPS technique
- Wireless TCP/IP / WIFI transmission of data, updates, keepalive...



# 6 – Acoustic application based on PEGASE



## SUPERVISOR

**Supervisor** = high level software written in oriented objet language (Visual C++) :

- globale view of the system (sensor status, events...)
- Records and shows waves from signal
- Interfaces to remotely parameterize each sensor : localization, threshold, sampling frequency, TCP/IP config. ...
- Real time routine for rupture detection
- Sends alarm by SMS/GSM to operators



50



# 6 – Acoustic application based on PEGASE



## Supervisor

**Superviseur**  
Surveillance Configuration Paramètre Evénements Etat Système Calibrer Aide

ÉVÉNEMENT	CAPTEUR	MESSAGE	DATE	GPS
i	Capteur 3	Le capteur: Capteur 3 de la ligne: Câble chambre ancrage av...	16-11-2006 13h 59Mn 58s 0uS	NON
i	Capteur 2	Le capteur: Capteur 2 de la ligne: Câble chambre ancrage av...	16-11-2006 13h 59Mn 43s 0uS	NON
i	Capteur 1	Le capteur: Capteur 1 de la ligne: Câble chambre ancrage av...	16-11-2006 13h 59Mn 33s 0uS	NON
i		La ligne: Câble chambre ancrage aval ouest a été ajoutée à l'...	16-11-2006 13h 59Mn 19s 0uS	NON
i		La ligne: Câble n°32 amont a été modifiée.	16-11-2006 13h 58Mn 50s 0uS	NON
i	Capteur 4	Le capteur: Capteur 4 de la ligne: Ligne 1 a été ajouté.	16-11-2006 13h 58Mn 36s 0uS	NON
i	Capteur 3	Le capteur: Capteur 3 de la ligne: Ligne 1 a été ajouté.	16-11-2006 13h 58Mn 21s 0uS	NON
i	Capteur 2	Le capteur: Capteur 2 de la ligne: Ligne 1 a été ajouté.	16-11-2006 13h 58Mn 4s 0uS	NON
i		L'ouvrage: Viaduc Ancenis a été modifié.	16-11-2006 13h 57Mn 50s 0uS	NON
i	Capteur 1	Le capteur: Capteur 1 de la ligne: Ligne 1 ne s'est pas conne...	20-10-2006 16h 9Mn 44s 0uS	NON

**Représentation graphique de la ligne: Câble n°32 amont**

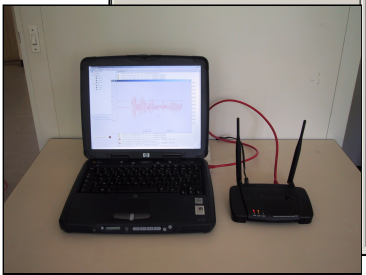
**Vue de la ligne:**  
**Câble n°32 amont**

0.00 m    10.00 m    20.00 m    30.00 m

Capteur 1    Capteur 2    Capteur 3    Capteur 4

Fermer    Fichier     Voir toutes les ruptures de la Ligne :

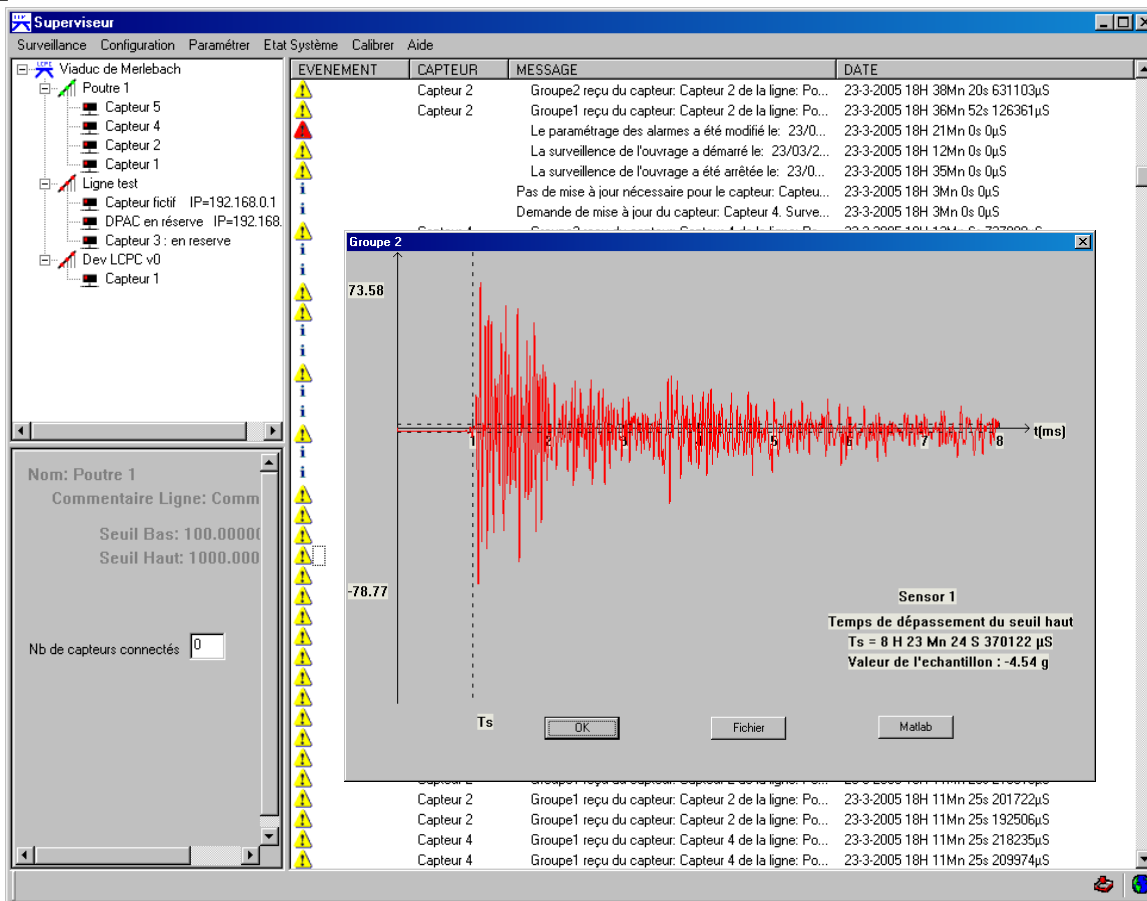
Global view and management of deployed sensors



# 6 – Acoustic application based on PEGASE



## Supervisor



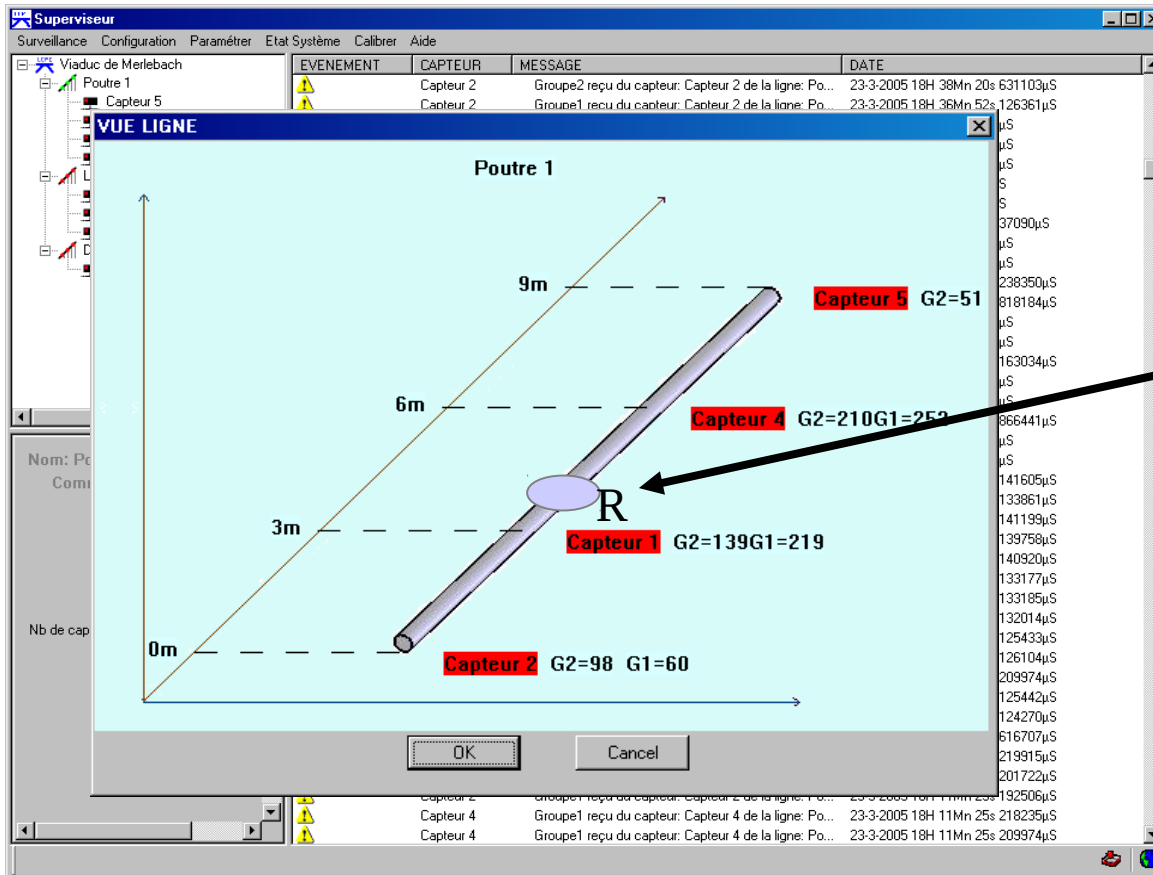
View of acoustic waves  
from sensors

Transfers to Matlab,  
DLL,...possible

# 6 – Acoustic application based on PEGASE



## Supervisor...



Real time algorithm and automatic detection of ruptures.

SMS alarm sends automatically

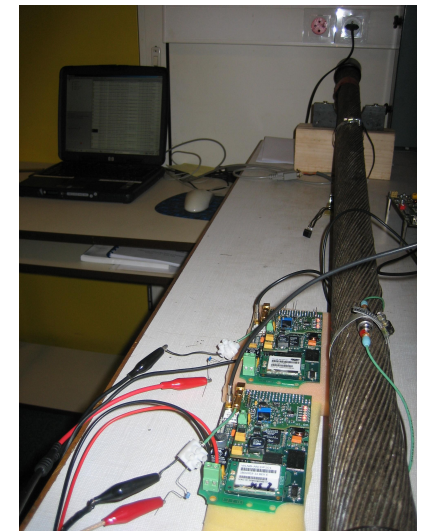
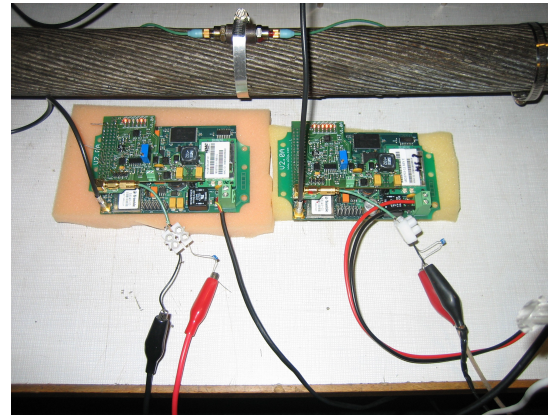


# 6 – Acoustic application based on PEGASE



## Validation and tests:

- Continuous sampling at 250 kHz on 12 bits
- Absolute time-stamping up to some  $\mu\text{S}$  thanks to PPS/ GPS tech.
- Real-time monitoring. LCPC wrote its own «Linux driver to manage SPI-DMA » !





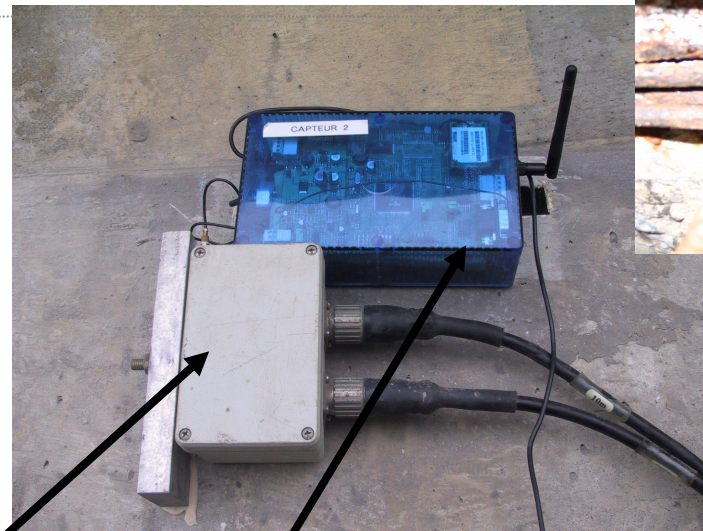
# 6 – Acoustic application based on PEGASE



## Validation test at Merlebach viaduc (57)



First tests on a pre-stressed beam pushed to rupture. **Real wire-breaks** !

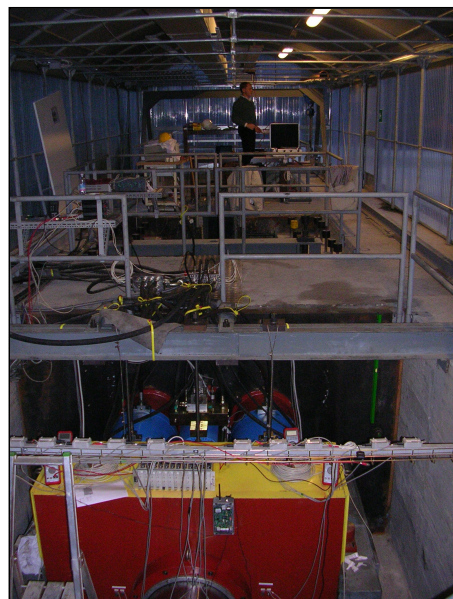


First and second generation of the acoustic system under competition

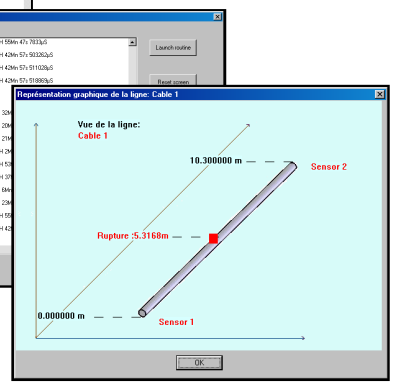
# 6 – Acoustic application based on PEGASE



## Validation test at JRC of ISPRA - Italy



STATION	SENSORS	REPERES	DATE	GPS
Cable 1	Sensor 1	WPE BR160 between sensor 1 and sensor 2	14.11.2007 09:42h 51:51232,5	—
	Sensor 2	WPE BR160 between sensor 1 and sensor 2	13.11.2007 09:42h 51:51232,5	—
Cable 2	Sensor 1	WPE BR160 between sensor 1 and sensor 2	13.11.2007 09:42h 51:51232,5	—
	Sensor 2	WPE BR160 between sensor 1 and sensor 2	13.11.2007 09:42h 51:51232,5	—
	Sensor 1	WPE BR160 between sensor 1 and sensor 2	13.11.2007 09:42h 51:51232,5	—
	Sensor 2	WPE BR160 between sensor 1 and sensor 2	13.11.2007 09:42h 51:51232,5	—
	Sensor 1	WPE BR160 between sensor 1 and sensor 2	13.11.2007 09:42h 51:51232,5	—
	Sensor 2	WPE BR160 between sensor 1 and sensor 2	13.11.2007 09:42h 51:51232,5	—
	Sensor 1	WPE BR160 between sensor 1 and sensor 2	13.11.2007 09:42h 51:51232,5	—
	Sensor 2	WPE BR160 between sensor 1 and sensor 2	13.11.2007 09:42h 51:51232,5	—
	Sensor 1	WPE BR160 between sensor 1 and sensor 2	13.11.2007 09:42h 51:51232,5	—
	Sensor 2	WPE BR160 between sensor 1 and sensor 2	13.11.2007 09:42h 51:51232,5	—

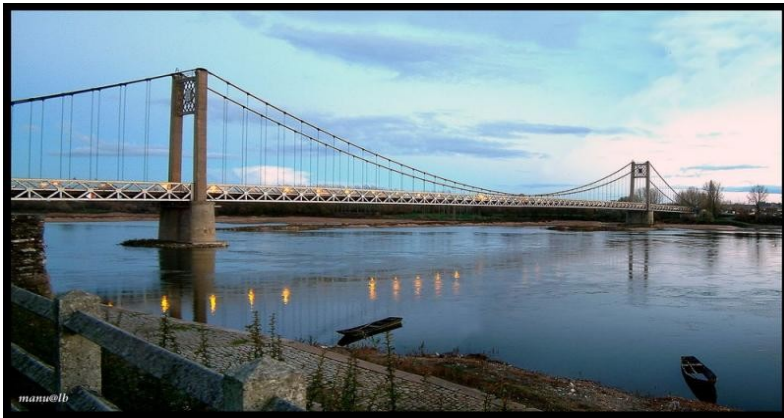




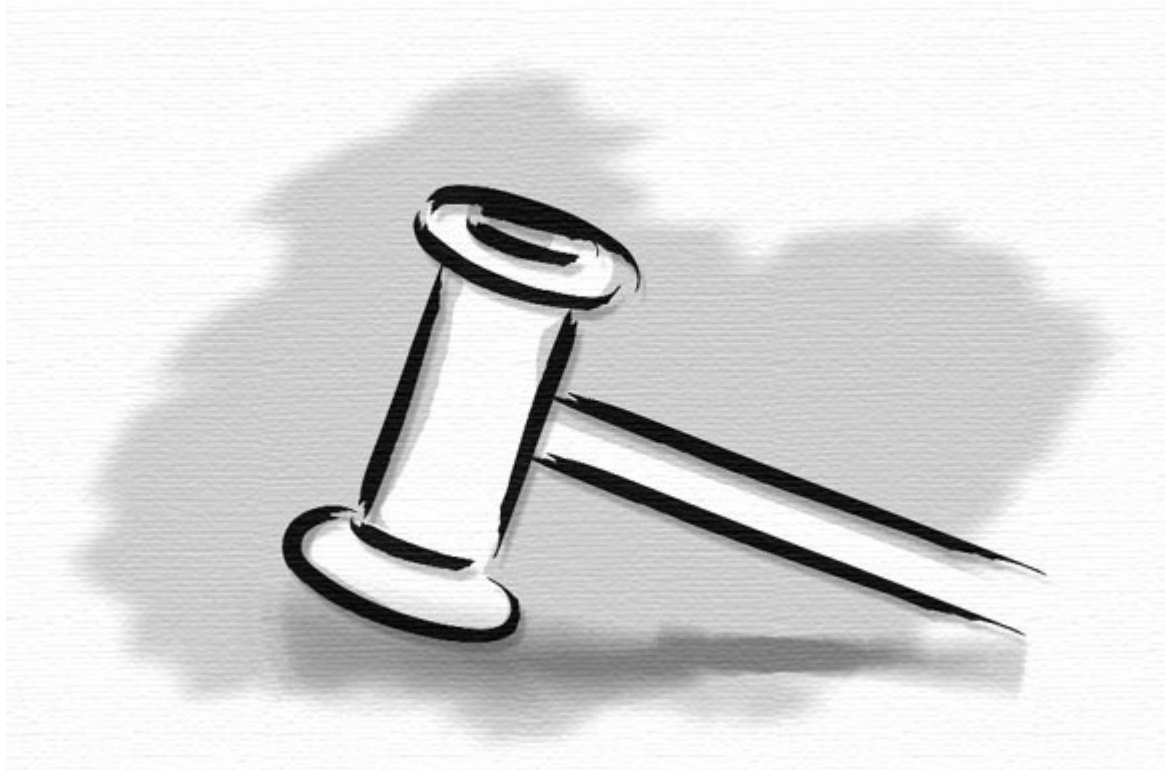
# 6 – Acoustic application based on PEGASE.



## Final validation on Ancenis bridge



# Conclusion and roadmap



# Conclusion and roadmap

Compare to traditional wired instrumentation, wireless systems are **promised to future growing dissemination** especially in Civil Engineerings (cost reasons)

The development of **PEGASE** generic platform lead to a global view of the key points to perform. Even if it has some limitations (power consumption), that board is actually **under a third-party partner** (www.A3IP.com company) **and is sold in hundreds of specimens.**

**Implementation of std technology paves the ground of wide dissemination** and support : TCP/IP/WiFi, GPS / PPS synch., DSP processing, C-under Linux programming, etc

Some **concepts have to be perform** : MPPT algorithm, BOOST circuit, battery charging management (NiMH charge limit), GPS and processor sleeping...etc.

At LCPC, a lot of work in WSN has been done since 4 years but a lot reminds to do especially in: energy harvesting and power management, other protocols (802.15.4, 6 LoPan...)

**We are open to any contribution / collaboration**59

# Conclusion and roadmap



THANK YOU !  
QUESTION ?