# A Test Bed for Wireless Optical LANs

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## ABSTRACT

This paper presents a test bed for wireless optical LANS. This test bed is flexible, supporting multiple implementation choices. The test bed currently covers all physical layer issues, from FEC coders and LED drivers to front-ends, clock recovery circuits, Viterbi decoders, and sectored receivers. These are implemented with multiple technologies, with DSPs and FPGAs for digital functions, and ASICs and discrete electronics for the analogue electronics. Furthermore, the test bed provides a semi-controlled real life test environment, allowing for close comparison between theoretical and practical results.

## 1. INTRODUCTION

Wireless Optical LANs (WOLANs) have gone through large developments in past years, as optical transducer technology (mainly infrared, in this case) has faced a steady price decreased. Due to this emergent wireless LAN technology, and to the promising infrared medium, several efforts have been pursued in the design of wireless networks using infrared communications [1-2]. These require increasingly complex circuits with very flexible characteristics, as more advanced communication techniques are being researched and trailed [2-4]. Unfortunately, these LANs are specially hard to model, both due to its dependence on the physical environment (walls, windows, furniture, etc**...**), and on implementation. In fact, simulation models usually neglect second order effects (e.g. multiple reflections, electronic circuits noise) and implementation issues (such as sensitivity and accuracy; e.g. a given radiation pattern may provide excellent performances, but small variations on this pattern may lead to unacceptable behavior). In consequence, only physical implementation can actually assure the advantages of a proposed communication technique in these environments, and prove it does outperform other proposals in a feasible and reproducible way.

In order to support and evaluate WOLANs developments, we set up an evaluation test bed for optical LANs with low inter-symbol interference. In practice, this corresponds to a limitation on the LAN baud-rate around the 10Mbaud/s. This test bed is fully configurable from 125kbps until this limit, and can incorporate new elements if required. In section 2 we present an overview on current wireless optical LANs characteristics, and highlight some implementation problems to be overcome in high-performance WOLANs. Section 3 presents our test bed implementation, while section 4 mentions some of the conclusions of this work.

## 2. WIRELESS OPTICAL LANS

Our target WOLANs operate under the quasi-diffuse principle (that is, both emitter and receiver have to see ceiling), and are oriented to low-cost optical technology, with LEDs and low cost optical detectors (PIN photodiodes). These networks operate on the infrared (IR) part of the spectrum, and use direct detection methods. Emitted power is strongly limited by portability and eye safety considerations. Only low-cost optical filtering is used, and the network has to handle all channel problems. Cell sizes are on the range of 6m radius, and stations have to detect each other [1-3].

### 2.1 Media characteristics

Within these lines, major channel hindrances in WOLANs result from the low signal amplitudes that have to be used due to cost, health and power consumption constraints. This limitation on emitted power, associated to its large distribution area, implies very low received powers.

For bit rates up to 10Mb/s, the main degrading factor of infrared communication systems is the shot noise due to ambient light, which is highly directive. The optical detectors used in these receivers have high sensitivity to the infrared radiation emanated from the ambient light sources (sunlight and artificial light). Shot noise presents a strong spatial and temporal dependence: it is more intensive under directional lamps and near windows exposed to sunlight, and can vary drastically during a normal day with the position of the sun and with indoor lighting conditions. Note that even in optimally designed receivers, the internal receiver noise can be on the order of magnitude of this light-induced shot noise. For bit-rates larger than 10Mb/s, inter-symbol interference becomes a major problem, still not fully resolved for this type of quasi-diffuse networks.

Furthermore, the non-uniform nature of both the ambient noise and the signal power distribution puts increased demands on the dynamic range of the transceiver circuits, usually hard to comply and frequently calls for sectored receiver strategies [3-5].

All these wireless optical constraints call for new network solutions, namely: (i) networks optimized for the usage of low cost optical components, (ii) development of systems with very flexible characteristics of gain and dynamic range, (iii) advanced communication techniques; (iv) selection of optimal codes and detector structures. All these issues are currently research issues, with some theoretical results already published [2,4-6].

### 2.2 Challenges for wireless optical testing

In the current stage of WOLAN research, a testing environment has to fulfil quite diverse objectives: i) to provide experimental results able to be confronted against theoretical models; ii) to provide a controllable and flexible environment, where several network techniques can be evaluated; iii) to present well defined system interfaces, for easy upgrading and maintenance. Additionally, such a test system should not be overly expensive and present unnecessarily long implementation periods.

Some of these requirements are hard to comply. For once, WOLAN performance is often dependent on multiple environmental and optical parameters. Thus, confronting theoretical and measured results requires a clear control on these parameters; however, this control must not be overly restrictive, under the penalty of the tests being poor evaluators of system performance on real conditions: in real situations, the WOLAN environment is always changing slightly (people and furniture movements). As a different aspect of the problem, WOLAN electronic requirements are hard to achieve, in analogue terms: the combined requirements on low noise levels, large area photodiodes, and large dynamic range are complex to accomplish, specially when these values may be required to vary (in order to test different WOLANs) [3]. The flexibility aspect has special implications precisely on this analogue design; and even if digital processing is able to be easily changeable –sometimes this comes associated at a steep price.

## 3. TESTBED

### 3.1 Global System

Our aim was to create a flexible testing environment for WOLANs, in order to field test multiple advanced techniques for WOLANs. Our test bed is composed of several components developed with a layered structure to comply with the requirements discussed above. These components can be classified in five different parts: i) the test environment, covering the room and ambient lighting; ii) the emitter electronics; iii) the optical transducers at the emitter and receiver; iv) the receiver analogue electronics, covering the front-end(s), combination units, and the clock recovery system; v) the receiver digital electronics, covering decoding, error processing and recovery.

The test bed is fully configurable, per block (although some combinations may lead to inoperative wireless LANs…), and is generally prepared for handling packet testing. However our interests are centred in Bit Error Rate (BER) evaluations, and we have used our measurement system only with continuous bit rates: measurements have been made only with BER measurement equipment (due to the easy availability of such equipment). This means that we are mostly concerned with physical layer issues, and specific problems related with cell startup, neighbour identification, resource reservation, collision detection, etc… have not been covered in our implementation. Nevertheless our test bed does provide for the future incorporation of these issues.

Digital electronics are mostly implemented over programmable devices, both FPGAs and DSPs. This strategy provides maximum flexibility and performance with minimal reconfiguration effort at a reasonable cost. On the other part, analogue electronic circuits have been implemented both with discrete electronics and ASICs (such as those reported in [7-8], e.g.)

Figure 1 represents the general model for the electronics of

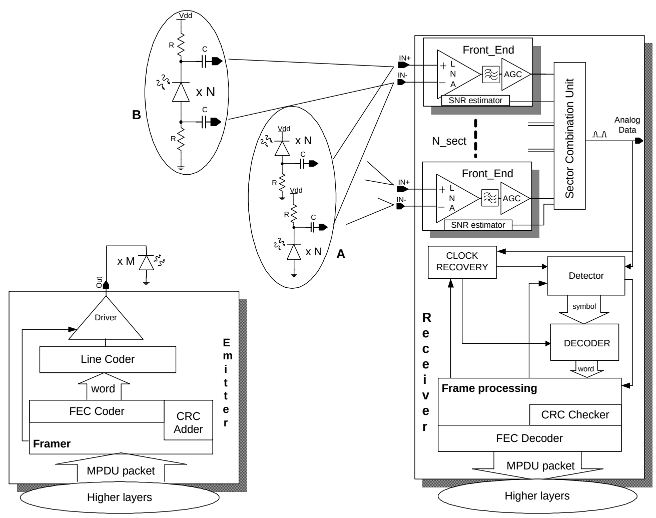


**Fig. 1** Overall Test Bed Electronics

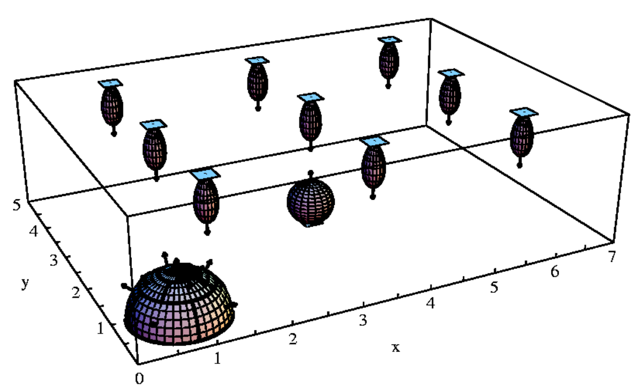


**Fig. 2** General WOLAN Optical Model

our communication system, where the multiple blocks are identified. The test bed allows multiple implementation choices for most blocks, although in our typical usage all framing processing is turned off.

This electronics system model is adequate for the general network optical model (Fig. 2) we considered, with multiple localized noise sources in the ceiling and on the walls, and where both emitter and receiver were placed 0,9m above the floor (typical table height) oriented upwards. The optical components of the measurement setup (both emitter and receiver) may presented anisotropies (i.e different radiation diagrams for different directions). This incorporates sectored systems (as represented by the *N_sect* sectors at the receiver in Fig. 1) properties.

### 3.2 The Environment

We selected two typical environments for indoor WOLANs. Our target room layouts are shown in figure 3; the first room is representative of an office layout, and the second is representative of a laboratory. Test room 1 with dimensions 7.0m × 4.5m × 3.1m was illuminated by 9 incandescent spot lamps. Test room 1 also has three large windows, usually in the shadow. Test room 2 of dimensions 6.0m × 4.5m × 3.1m was illuminated by 4 fluorescent units. Each fluorescent unit contained two 36W tubular lamps and had a flat prismatic lens. Both rooms contained typical furniture, as in fact they are real working rooms at our premises.

These physical environments had to be properly characterized for performance measurements, and for providing reference data for theoretical WOLAN analysis. In order to achieve this, we measure the optical noise distributions inside the rooms (without furniture, to obtain completely controlled results), and these results were fitted to non-linear expressions, based on Lambertian functions [2-9]. Figure 4 exemplifies the results achieved inside test room 1, presenting both noise distributions: i) Fig. 4a presents the measured data and ii) Fig. 4b the estimated modelled noise based on the fitted results.

It is apparent that the model provides a very close match with measured data, and can thus be used in network performance simulation previous to actual test bed measurements. This provides simulation results that can be easily confronted with measured data in the test bed.

### 3.3 Emitter

The emitter electronics present a very small analogue unit (a fast LED driver, custom designed) used generally in all tests. The digital electronics are implemented in a Xilinx device (a XC4013): most implemented blocks are written in VHDL, although some are still in schematic format. Currently, amongst others, we have several line coders (Manchester, NRZ, RZ, PPM-n, with n smaller than 6), several FEC coders (repetition coding and convolutional coding) and several other control strategies (e.g. line rate reduction, interface with external buses). The convolutional coder is fully programmable both in terms of code rate and in terms of generation polynomials, with eight outputs maximum. The test bed supports different combinations, but requires the manual assembly of the proper blocks and consequent device programming. Some frame tools are also included (e.g. CRC generator) but they are not currently in use.

### 3.4 Optical Transducers

The optical emitter is fixed in this test bed. It is the result of simulation optimization of the radiation pattern of a generic emitter, using the package described in [9]. Thus the optical emitter is composed by two types of LED's with the following characteristics: A) $P_t = 12mW@50mA$ and $hpbw = 15°$; B) $P_t = 15mW@50mA$ and $hpbw = 50°$. The LED's were separated in two arrays with the following distribution and orientation (Fig. 5):

- 15 LED's, type A, oriented at 58° with the vertical

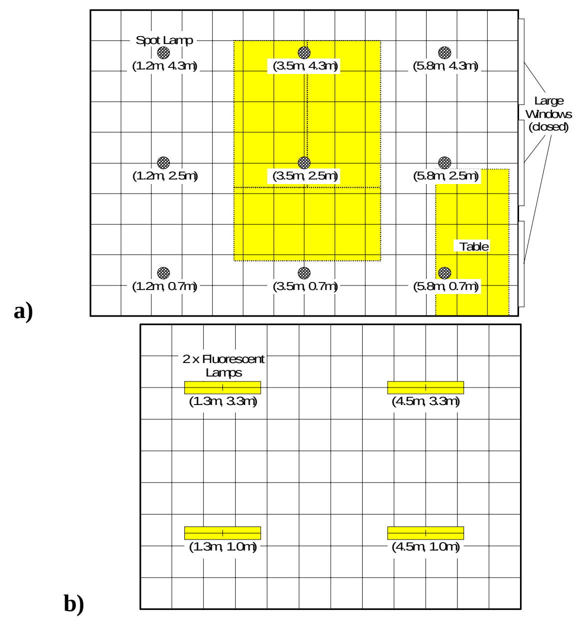


**Fig. 3** General layout. (a) Test room 1. (b) Test room 2.

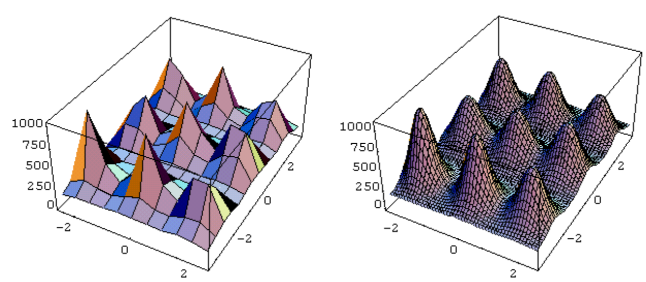

**Fig. 4** Optical noise distribution inside Test Room 1; left: measured data; right: fitted model.

and uniformly distributed on the azimuth plane;

- 1 LED, type B, oriented vertically.

The optical receiver is implemented with several types of PIN photodiodes, depending on the specific receiver being tested. Both non-sectored and sectored receivers are supported in our test bed: a (large) "fly-eye" structure has been mounted to support sectored receivers. These photodiodes presented junction capacitances between 10pF and 80pF.

## 3.5 Analog Devices

The test bed implements three different types of analogue (or analogue-digital) devices: i) front-ends; ii) clock recovery circuits; iii) code detectors.

A typical non-sectored IR front-end is depicted in Fig. 6 with the required differential path to prevent EMI. We have implemented several different front-ends, based in multiple circuits (e.g. bipolar transistors, CMOS, integrated devices, ASICs), with and without AGC, and with multiple gain*bandwidth characteristics [3]. These blocks can be easily interchanged, and some can be adapted and controlled (e.g. gain) with minimal changes.

We have also implemented sectored receivers [4-5]**.** These receivers are composed by multiple front-ends, associated to a combination unit that resorts to the SNR of each sector to produce an output signal. A sectored receiver structure is illustrated in figure 7. Three main approaches were implemented: *maximal-ratio* (where the output signal is achieved by a weighted combination of all front-end, and the weights are dependent on the SNR of each front-end), Equal Gain (the weights of this combination are equal in all front-ends) and Best Sector (where the output signal is the one with the best SNR associated). Once more, this selection has to be programmed in switches. The SNR evaluation presents major design problems by itself, due to the large dynamic range required to work in these wireless optical environments.

All these receivers have been carefully characterized, and their electrical performances (bandwidth, gain, noise, etc..) are known, providing data for simulation models.

The clock recovery circuits implemented were based both on ASICs and traditional integrated circuits. Two different phase detectors are used, a Hogge phase detector and an EXOR. This is one of the most critical units, and has to be carefully adjusted for each test bed configuration. Optionally, the test bed provides for bypass possibilities, allowing receiver synchronization directly on the emitter clock.

Symbol detection has been implemented both with traditional threshold detection (both with and without level shifting) and with MAP approaches (only for PPM-based line codes) [3]. However, due to usual environmental electrical noise levels, MAP detection is not usually used in the test bed.

## 3.6 Digital Processing

Digital processing units cover several aspects of the communication, from generic functions on digital communication systems to adaptive data rate support [2]. These adaptive rate systems are represented in Fig. 8. Data adaptation can be done through different techniques, such as repetition coding, convolutional coding and adaptive filtering (this last technique requires some changes on the analogue front-ends) [3]. Thus several functions are digitally implemented: symbol decoding (for block codes, as PPM-n),

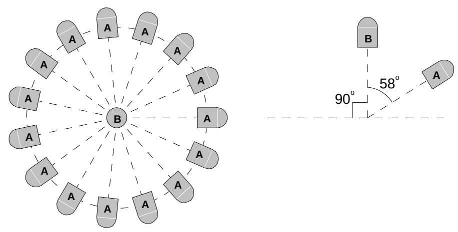


**Fig. 5** – IR LED's horizontal distribution (left) and vertical orientation (right).

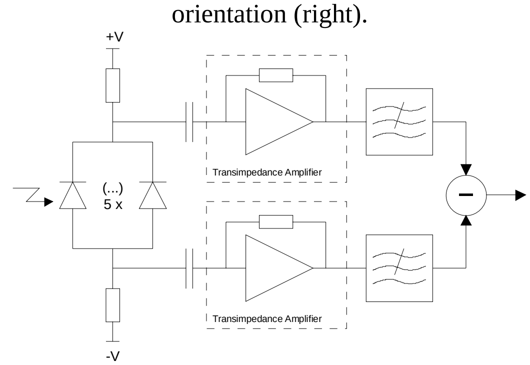


**Fig. 6** - Block model of IR front-end.

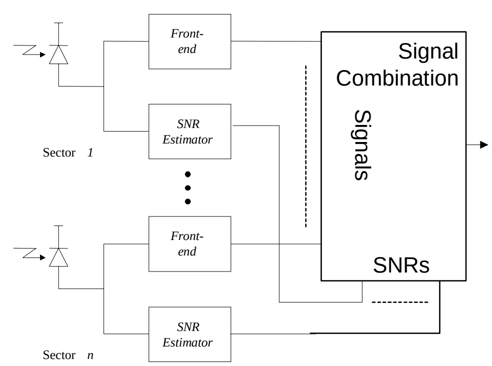


**Fig. 7** - Block model sectored receiver.

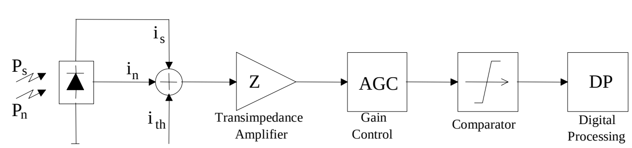


**Fig. 8** - Block diagram of an adaptive data rate receiver

error processing, based on Viterbi decoders and repetition coding and global receiver control.

These blocks are implemented in an FPGA (Xilinx 4013), with some more complex processing (Viterbi decoding) being performed in an associated TMS320C6203GLS DSP. Actually the test bed supports two such DSPs operating in parallel, for frame processing, but this facility cannot be used for continuous BER measurements. As a result, our Viterbi decoder implementation is limited to bit-rates up to 4 Mb/s, which can be doubled for tests with frames.

Some other digital control functions for frame testing are implemented (such as CRC checking and header interpretation, which could dynamically change – in terms of coding e.g. - the digital configuration of the test bed on the receiver) but are not currently in use.

## 4. CONCLUSIONS

This paper presents the most complete test environment for direct detection WOLANs ever reported. This environment is flexible and allows for easy reconfiguration and upgrading of most of its elements. As a result it allows for the test of WOLANs with quite different characteristics, with minimal reconfiguration on system electronics. Naturally, proper selection (and configuration) of implementation blocks has to be performed to test a WOLAN with given characteristics. The test bed has been carefully characterized both in terms of environment and in terms of the electrical characteristics of some of its blocks, providing reference data for network analysis and simulation. As a result, measured data can be confronted with simulated values, and discrepancies used for increased understanding of the network behaviour.

This test bed is currently on use for evaluating multiple aspects of WOLANs. As an example, this test bed has already been used to question the practical usage of some modulation methods popular for WOLANs (e.g. PPM-4), due to their implementation complexity (and associated noise) and achievable performances in real systems. Another practical result from this test bed is the measured low performance improvement achievable with MAP decoding in typical systems.

### Acknowledgements

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