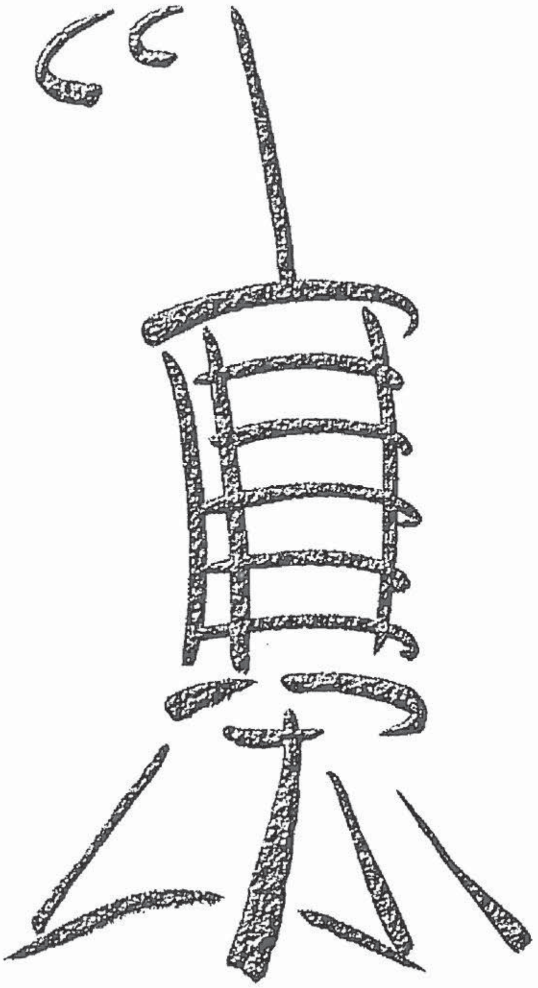

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FHSS TRANSCEIVER OVER WIRELESS INDOOR OPTICAL CHANNELS

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Abstract – *In this paper, experimental results from the operation of a prototype of wireless indoor optical transceiver based on frequency hopping techniques are presented. The use of spread spectrum techniques allows multiple simultaneous access and increases the robustness of the system against multipath-induced distortion and narrowband interference (as could be low frequency optical noise from fluorescence or incandescence lamps). FHSS techniques also allows co-existence with IrDA or emote control emitting devices without interference.*

Keywords – Frequency Hopping, Optical Channel, Diffuse

I. INTRODUCTION

As is well known, nowadays there are two leading technologies for wireless interconnection: Radiofrequency and optical links. Wireless optical communications have been focused on two main areas: line of sight, broadband links achieving high data transmission rates (over hundred of megabits per second) and diffuse and quasi-diffuse links, nondirective, with requirements varying from the few kilobits per second needed for sensor networking to the connectivity of wireless LAN and wireless personal area networks (WPANs). Unless this technology was first proposed 20 years ago it still needs further industrial effort to become a real alternative to RF implementations. The most extended commercial realization is provided from the IrDA (Infrared data Association) which have produced several industrial applications, e.g. the IrDA-based standard for medical device communications (known as HIEEE 1073.3.3 or ISO 11073-30300). Benefits of wireless optical communications can be summarized as follow: they do not require legal procedures for frequency assignment and the cost of the transceivers is usually lower than in radio-frequency (RF). They also assure improved confidentiality of the transmissions (compared with RF communications). On the other hand these systems lack of the presence of several noise and interference sources (thermal noise, incandescence and fluorescent lamps....). Research [1] has shown that the luminous flux produced by fluorescent lighting is not constant on time, but shows large fluctuations and fast variations on time. These components are concentrated on the low frequency region, but removing these components by filtering causes baseline wander in most baseband systems. This channels also suffers severe multipath propagation penalty because of multiple reflections with walls, furniture etc. Most attempts to solve impairments caused by multipath propagation have focused on the use of equalization or angular and imaging diversity [2-3] But FHSS techniques offer a simpler alternative extensively tested on radio channels in order to combat these impairments that not imply major modifications on the optical front-ends.

This paper is organized as follows: in section 2 the special characteristics of the application of FHSS techniques over optical channels are outlined, including their CDMA capabilities (especially important for sensor networks). In section 3, a synchronous wireless network architecture based on a reference signal is also proposed. the measurements produced by operating a prototype of Wireless optical FHSS transceiver are presented in section 4. Finally, some conclusions and future work are proposed.

II. FREQUENCY HOPPING SYSTEMS. OPTICAL DIFFUSE CHANEL

A. Diffuse Optical Channel characteristics

We have used FHSS with frequency modulation of the data. Photodiode produces a current proportional to the optical power incident upon it. The wireless optical channel can be modelled as a linear, time invariant (at least for a study interval) expressed by (1):

$$y(t) = \int_{\infty}^{\infty} R\cdot x(\tau)\cdot h(t-\tau)\cdot d\tau + n(t) \qquad (1)$$

Where $y(t)$ is the current produced by the photodiode while $x(t)$ is the transmitted IR signal. The relationship between these two magnitudes depends on the active area of the receiver, the photodiode responsivity and the nature of the reflections over all surfaces of the indoor environment. Noise can be considered as independent of $x(t)$ and, since ambient light power is much higher than the transmitted signal power, it can be considered the only source of shot noise at the receiver.

The effect of using SS techniques systems over a wireless optical channel produces the variation of channel impulse response $h(t)$. This new channel response does not

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present multipath components for delays bigger than a *chip* length. In the other hand, SS techniques do not modify the performances of the communication link when is only corrupted by additive white gaussian noise (AWGN). Therefore, the effect of shot noise (present in optical receiver) and thermal noise can not be reduced with using SS methods. We have always considered that emitter and receiver are in a quasi-diffuse configuration (pointing to the same area of the ceiling) in order to reduce the effect or light secundary rebounds over the transmission channel impulse response (figure 1):

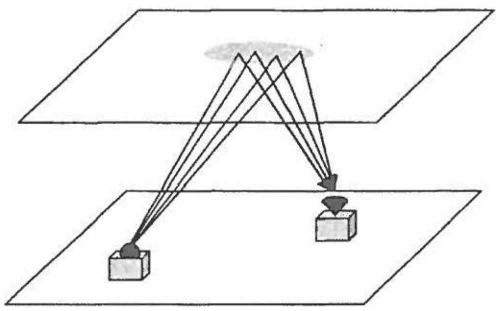

fig. 1. Quasi-diffuse link. We consider a lambertian Emitter radiation diagram and a narrow field-of-view at the receiver

B. Frequency Hopping Systems

We have chosen a fast frequency-hopping (FFHSS) configuration with a carrier mapping as depicted in figure 2 [4]. This mapping is achieved performing an interleaving procedure using the code and the data simbols (Independent Tone Hopping [9]). After the interleaving procedure, the set is MFSK modulated, considering as the set of symbols the coded carriers. The whole process is similar to move a BFSK signal all over the available spectrum as a function of the selected code.

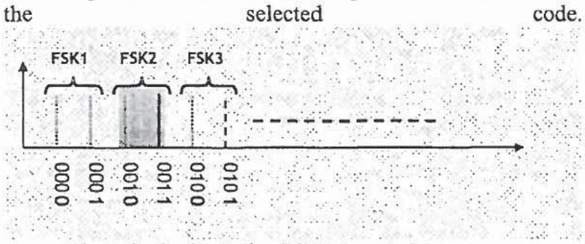

Fig. 2. Carrier distribution. LSB belongs to data sequence .

The structure of the FFHSS signal is shown in figure 3. Redundancy is assured by sending the same datum by different carriers. Using (2) we can calculate the minimum separation for two consecutive carriers [5]:

$$S_x(t)=\frac{T_{Chip}}{N_T}\sum_{m=1}^{N_T}\left\{Sinc^2[(f-f_m)T_{Chip}]+Sinc^2[(f+f_m)T_{Chip}]\right\} \quad (2)$$

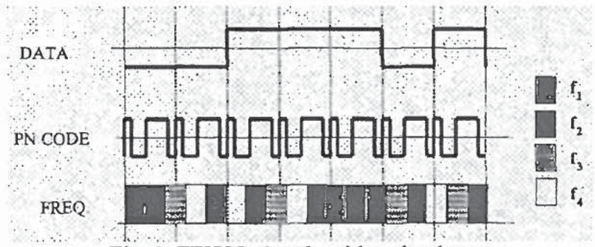

Fig. 3. FFHSS signals with redundancy

The FHSS spectrum can be there considered as a sequence of $Sinc^2(f)$ functions, centred at the carrier frequencies and with a bandwidth (between zero-crossings) of $2/T_{Chip}$, where T_{Chip} is the clock period for the pseudorandom code [6]. This spectrum can be compressed in a similar way that in MSK modulations (figure 4), reducing the carrier separation to $1/T_{Chip}$.

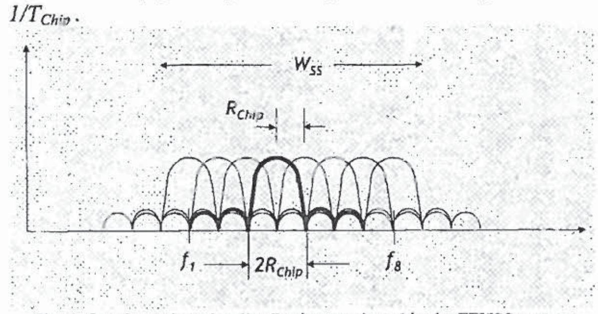

Fig. 4. Overlapped carrier distribution employed in the FFHSS system under study.

C. Bit error rate in FFHSS systems

FFHSS error probability depends on the type of interference and the structure of the receiver. As in this work we have used transmission redundancy (each data bit is transmitted by a set of *i* different carrier frequencies), the receiver accomplish an average of received "1" and "0" data, at each data period, in order to detect the transmitted data, and its robustness allows correct detection even with *(m-1)/2* corrupted frequencies. It is almost similar to the well known majority bit decision [7], but using a filtering operation for average estimation instead of an individual detection for each transmitted carrier. Data discrimination is performed by envelope detection, comparing the signal power in both carriers corresponding to the complementary data [8]. The block diagram of the double branch detector is shown in figure 5.

For these kind of detectors, The BER versus white noise is similar to other conventional modulations. When considering narrowband interference, error probability in a chip transmission can be obtained as a function of the error probability versus white noise and the interfered transmission bandwidth percent. In presence of multitone interference, for FFHSS the probability of an error for each transmmited chip results (3):

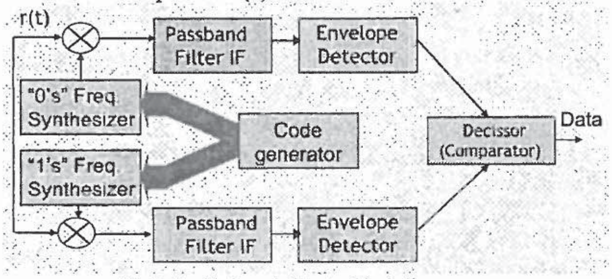

Fig.5. Double branch detector block diagram

$$P_C = \frac{J}{N_t} + 0.34\left(\frac{J}{N_t}\right)^2 + f(\Gamma)\left(\frac{J}{N_t}\right) \quad (3)$$

Where N_T the total number of channels for transmission, J is the number of tones interferences and $f(\Gamma)$ is a function which express the probability for two tones to increase the sum signal (depends on the relative phase between tones). In figure 6, the error probability versus the number of chips per bit (*Cpb*) for a FFHSS system, using 8 frequencies for each data bit, interfered by a tone twice the power of the FFHSS frequencies.

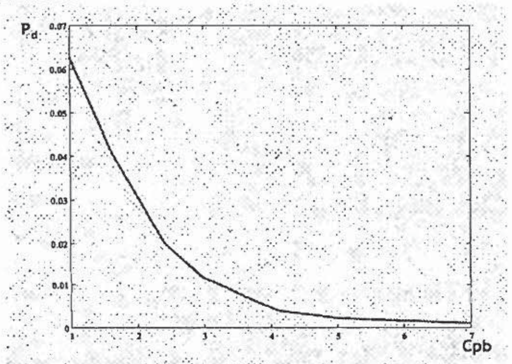

Fig 6. Bit error rate vs. chips per bit (*Cpb*) with an interfering tone

D. Multiuser Interference.(CDMA)

In a multiple-user environment, interferences are produced when two or more transmissions coincide in the same frequency channel. In this way, the bit error rate in a situation of multi user interference (MUI) follows a similar expression for the estimation procedure previously explained. When users are not synchronized there are partial coincidences in the same frequency but not in the whole chip period as in the other case [9-10]. The coincidence percent can be considered as a random variable, so the best way of reducing the error probability in a multi user environment is to reduce the number of coincidences full and partial ones.

E. Interference due to Multipath

Since transmitted signal reaches receiver from different trajectories we will have replicas of the same signal with different delays (τ_d) and power. From the beginning of each chip until τ_d the delayed signal have a different frequency than received signal and it is eliminated by the FI filter in receiver. For the remaining time of the chip, interference can reinforce or weak the data reception, depending on the random phase misadjusts. This interference can be avoided by taking a T_{Chip} lower than τ_d, or increasing the number of chips per data.

III. SINCRONOUS FFHSS SYSTEMS

A. Synchronization in FFHSS systems

Receiver synchronization, is the most complex stage in Spread Spectrum systems, requiring complex circuits and processes [12]. For non-coherent FHSS systems, the most extended architecture is Traditional Full Time Loop (TFTL). But we have proposed a simplified structure based on a pilot signal. Interferences in multi user environments are due to coincidences of two or more signals in the same frequency channel at the same time. This problem can be solved using a synchronous architecture, which assure that the PN sequences in all users start and end in the same instant. It also allows using the same code in all the users, reducing the probability of using the same channel. Furthermore, specially designed codes can be developed for assuring cero coincidence of frequencies used by two users in the same slot time. In order to obtain the synchronous architecture explained above, it will be necessary a reference signal with information about frequency and phase of code generation (tracking) and information about sequence beginning (acquisition). This reference signal is a square carrier phase, modulated by a square signal whose semi-period has the same duration than the PN sequence length. The carrier frequency is a multiple of the PN clock. This modulation is digitally implemented with a logic programmable device. Figure 7 shows the signals implicated in this process.

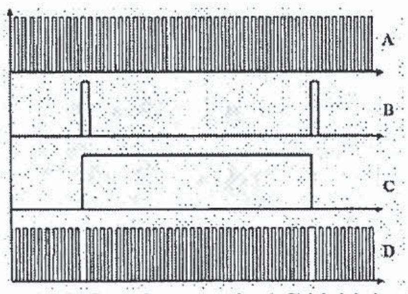

Fig. 7. A) Carrier, B) Start of sequence signal, C) Modulating signal y D) Pilot signal.

Once the digital reference signal has been generated, it is filtered in order to reduce their harmonics power, because they could interfere with the bandwidth occupied by the FFHSS data signal (Figure 9). At the receiver, a carrier detection is accomplished for detecting PN code phase and frequency. To get the beginning of sequence information, a phase demodulator is implemented. Synchronism detector block diagram is presented in figure 8.

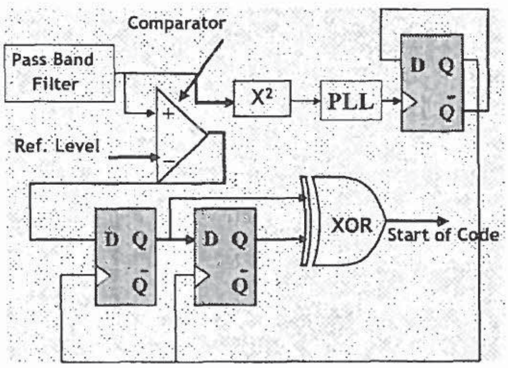

Fig 8. Synchronism recovery block diagram.

B. Prototype design

In this point a system, based on schemes and theories proposed before, is presented. It consist of a synchronous Fast FHSS link for wireless optical communications.

The first module is a transmitter, which generates the FFHSS modulated signal and the pilot signal. The other block is the receiver, which performs the synchronization process and the data detection. Data detection is achieved using a double branch scheme (figure 5) . Every node in the synchronous network implements these two subsystems in its physical layer. The main system characteristics are: 512 Kbps binary rate , 1,536 Mchips/s (3 different carriers for each bit), 32 carrier frequencies, uniformly distributed from 24,384 Mhz to 72 Mhz (1,536 Mhz of separation between two adjacent carrier) and a 9,216 Mhz pilot signal frequency, selected for no interfering in the FHSS signal. Figure 9 shows the spectral power density of received signal (FHSS signal plus pilot signal), where we can see the distance between pilot signal and modulation signal.

IV. SIMULATIONS AND RESULTS

A. System evaluation.

In order to verify the link performance, we have simulated it in presence of the most important interferences present in the diffuse optical channel separately. Link performances is characterized by the bit error rate. Block diagrams used to simulate the systems are similar to those in the prototype design. Furthermore, several similar transmitters has been added to simulate a multi user environment. Channel number of each transmitter and chip rate are easily configurable. All simulations have taken into account the reference signal added at receiver input and assuming involved delays, due to this synchronism detection. Furthermore, for the system evaluation, impulses responses of quasi-diffuse optical channel have been employed. As seen before, these impulse responses come from links between a transmitter and a receiver placed in different positions inside a square room, as can be seen in figure 11.

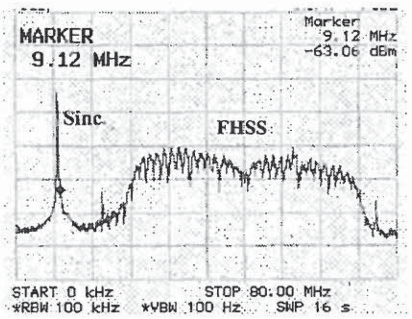

Fig 9: SPD of pilot signal and FHSS signal

Prototype is based on programmable logic devices for reference signal and PN codes generations and Direct Digital Synthesizers (DDS) for FFHSS modulation. Figure 10 shows the prototype used for measurements.

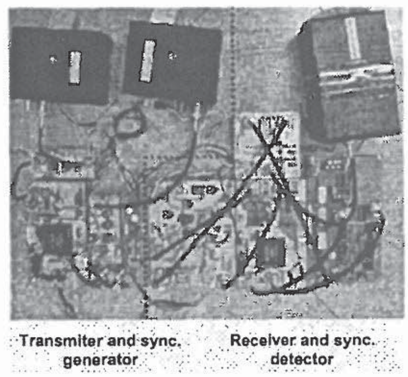

Fig 10: Hardware prototype implemented. Emmiter, receiver and reference signal generator and detector.

Results obtained using the hardware prototype is also presented in the presence of artificial lighting.

B. Results

First of all, the system was evaluated in presence of a interferer tone using different numbers of chip per bit rate. This system employs 128 carrier frequencies (64 for each data). The results are compared with those obtained in a DSSS link with *PG*=50. Figure 12 shows the obtained BER.

As it can be seen, increasing the system redundancy, the BER is reduced as seen before. Moreover, FFHSS system response in presence of a interfere tone is better than those obtained using direct sequence systems. In order to test the synchronous architecture in a multi-user environment (CDMA), we have simulated the FFHSS link in two different cases: several users sharing the same channel employing different MLS codes belonging to the same family or several users sharing the same channel employing the same MLS code delayed a integer number of clock periods. Figure 13 shows the BER versus the number of user sharing the channel for various chip rate. Synchronous system response is better for the same chip rate than in a asynchronous environment. These results are due to the low autocorrelation property of the MLS codes (with few coincidences between the symbols generated by PN

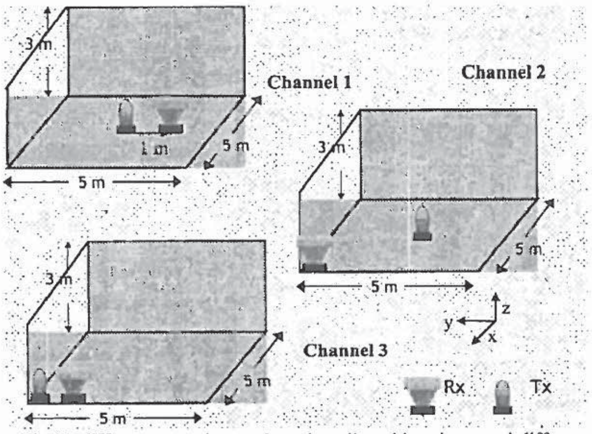

Fig 11. different transmitter and receiver dispositions in a quasi-diffuse environment.

sequences belonging to the same family). In multipath propagation case, simulations have been performed using the impulse responses from configurations at fig. 11, a MUI environment. and white Gaussian noise. Synchronous and asynchronous systems has been compared in Figure 14. Optical emitters are implemented by two LED's using a wavelength of 890 nm pointing to a reflective surface. Optical receiver is a APD C5351-03 Hamamatsu module. This link was evaluated in presence of a fluorescent lamp to verify the system performance in presence of a tone interference. The eye diagram obtained at the double branch envelope detector is presented in figure 15.

V. CONCLUSIONS

In this work, we have tested the use of FFHSS techniques in a multi user optical network environment. An alternative to traditional synchronization schemes have been also developed. This synchronization method allows users to employ the same codes with different delays, or deterministic codes, avoiding carrier coincidences between them. Furthermore, the synchronization scheme is easier to implement and adjust than traditional ones. A BER improvement has been demonstrated using the synchronous architecture versus a conventional one.

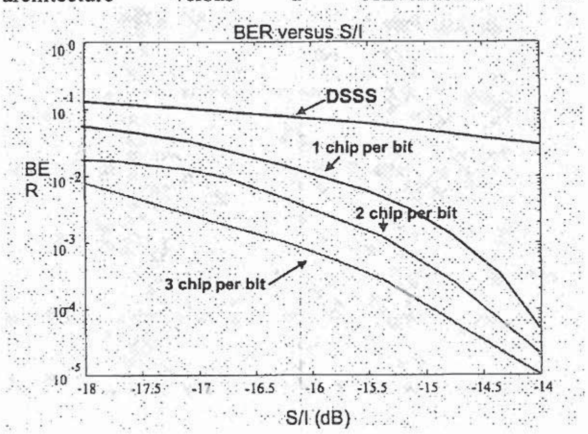

Fig. 12. *BER* versus *S/I* in presence of an interfering tone. 128 carrier frequencies used.

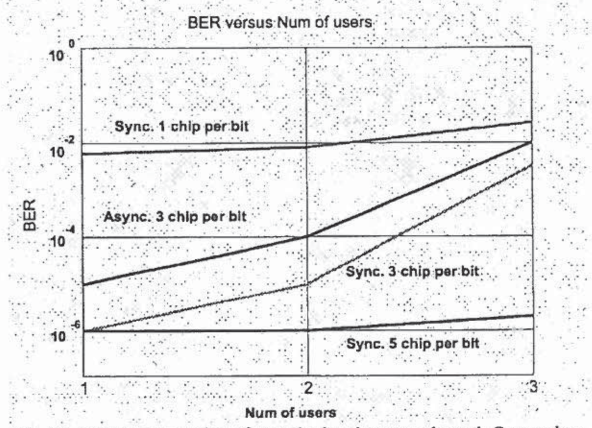

Fig. 13. *BER* versus number of user sharing the same channel. Comparison between synchronous and asynchronous systems

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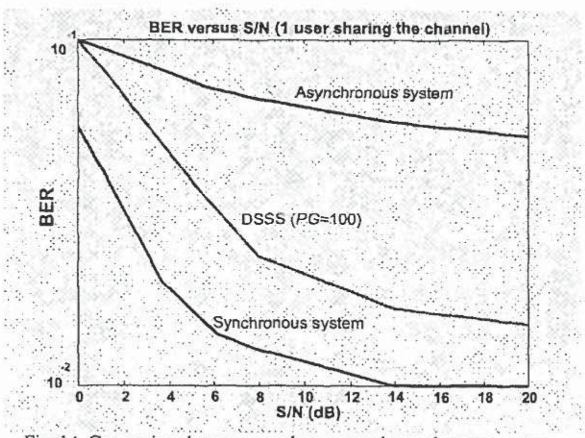

Fig. 14. Comparison between synchronous and asynchronous systems, (channel 1, in presence of an interfering user)

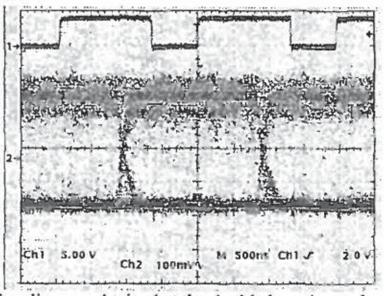

Fig. 15. Eye diagram obtained at the double branch envelope detector output.

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