

Fast low cost feed-forward burst-mode optical receiver for 622Mb/s.

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ABSTRACT

This paper describes the implementation of and measurements on a fast burst-mode compatible receiver for 622Mb/s NRZ transmission. A prototype receiver with 16dB (optical) dynamic range and -30.7dBm sensitivity is demonstrated. The AC coupled receiver concept is based on a low cost PIN photo diode, a low noise current-current feedback pre-amplifier, a delay-line differentiator, a fast feed-forward gain control (AGC) and a set-reset integrator. The total component cost is about 220 Ecu (10 pieces). The major part of these costs is accounted for the connectorized PIN photo diode (≈ 120 Ecu).

0. INTRODUCTION

In an ATM-PON, received cells at the line termination (LT) in the local exchange, may vary up to 15-20dB in optical power.^{1,2} This is due to the difference in attenuation between the various optical paths of the PON. As a result, the spectrum of this upstream optical signal contains a large varying DC-component. Consequently, the optical receiver at the LT side must have a fast response to optical power variations without loss of sensitivity.

Figure 1 shows an example of a stream of cells received at the LT side transmitted by different subscriber network terminations (NT's).

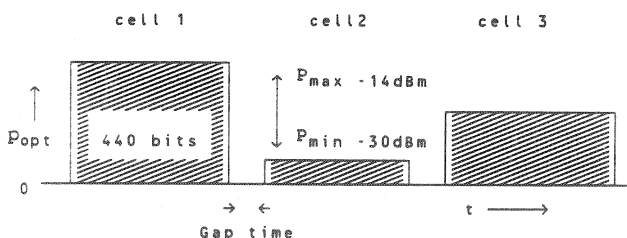


Figure 1. Successive cells in an ATM-PON, as received at the exchange side.

In literature,^{1,2} a DC-1GHz APD receiver with wide dynamic range has been described using a differential amplifier as front end. The reference voltage of the input is set to 0.5 times the amplitude of the received cell using a fast peak detector. In the described implementation however, the peak detector is included in the feedback loop of the amplifier. Reported feedback solutions are associated with wide

gaps and reduced sensitivity. In the case that the delay time in the feedback loop is not neglectable with respect to the receiver bandwidth, the rise time of the peak detector must exceed a critical minimum value to facilitate a stable loop. This basically inhibits the response time to be in the same order as the bit time. The reported cell spacing is between 20-100ns (13-63 bits at 622Mb/s) for a variation in cell power of 10-20dB. Further more an external signal is required to reset the receiver each time a new cell has to be received. Due to the differential amplifier front end, 3dB degradation in sensitivity is expected,^{1,2} from theory, compared to a continuous bit stream receiver.

We propose a novel burst mode optical receiver, in which the feedback control loop for threshold level is replaced by a feed-forward control loop for threshold level or signal gain. In this approach the gap time between the received ATM cells could be less than 2 bits at 622Mb/s (3.2ns).

1. DESIGN CONSIDERATIONS

We will discuss now some design considerations dealing with the problems associated with optical multipoint to point transmission.

As mentioned before, the DC component of a NRZ signal is highly data dependent, and varies within a cell period (DC wandering). In an AC coupled transmission link, DC wandering inhibits the use of a fixed threshold for the reconstruction of the bits from the analog line signal.

To avoid DC wandering, line coding is commonly used. This however, increases the required bandwidth of the transmission link resulting in a loss of receiver sensitivity. A more complex method to eliminate this DC component without an increase in required bandwidth is scrambling.

The non-continuous nature of upstream signals in a PON always results in a large varying DC component in the received signal at the LT side, even if the separate cells would be line coded or scrambled.

1.1. DETECTOR

As indicated by various cost analyses^{5,6}, a very high splitting ratio of the optical tree would not result in a proportionally cheaper system. An optimum is found at a splitting ratio of 8 to 16. This relatively low splitting ratio relaxes the sensitivity requirements and facilitates the use of low cost PIN photo diodes at bit rates as high as 622Mb/s.

1.2. SIGNAL AMPLITUDE CONTROL

To allow for detection of a weak cell within a few bits after the reception of a strong one, amplitude control in the LT receiver must be extremely fast. Three methods are commonly used to handle signal amplitude variations.

■ ADAPTIVE DETECTION THRESHOLD (a)

The reference voltage of a comparator input is set to half the average amplitude of the received cell.^{1,2} Measuring of the cell amplitude is performed with a fast peak detector, using the first bit(s) of a received cell. The reference voltage of the comparator is kept constant during a full cell period.

■ GAIN CONTROL (b)

A (DC coupled) AGC stabilizes the signal amplitude to twice a fixed reference voltage of a comparator, using the first bit(s) of a received cell. The AGC gain is kept constant during a full cell period.

■ LIMITING (c)

The reference voltage of a comparator is set to half the lowest signal level for a given BER.

Methods (a) and (b) have good performance with respect to overshoot, reflection and pulsewidth distortion and BER improvement while receiving strong cells. Both methods however require a reset mechanism to reset the threshold level or gain to a initial value before a new cell will be received.

Limiting (c) is very simple to implement but would introduce pulsewidth distortion in case of a band limited signal. Because the threshold level is near the noise level, the circuitry is sensitive to small reflections. For strong cells, a slight BER improvement by a factor 2 can be expected, since limiting leads to a high signal to noise ratio for ones only.

The adaptation of the threshold level or attenuation in the AGC, affects both zero's and one's and as a result there will be a rapid improvement of the BER for every signal amplitude exceeding the minimum value required for a specified BER. Therefore it is not required to design an AGC with high accuracy while receiving very strong cells.

In the here described receiver, method (b) is used.

1.3. RESET MECHANISMS

For method (a) or (b) the threshold level or gain is derived from the input signal within a settling time of one or few bits. However, the threshold level or gain must be reset to its initial value at the end of each cell to facilitate for the detection of a succeeding cell. Both a cell induces or a bit induced can be used.

CELL INDUCED RESET (EXTERNAL)

In this case the reset must be generated by hardware external to the optical receiver.

A drawback of this method is that the external reset signal must be applied strictly in phase with the time instants of the gaps between the received cells. Loss of synchronization will result in the loss of many cells because the hardware requires a large number of cells to find the beginning.

■ BIT INDUCED RESET (AUTONOMOUS)

As an alternative to the external reset method, resetting of the threshold level or gain can be derived from the input signal on a bit per bit basis. During the receipt of a logical zero (absence of optical signal) the reference level will be reset to the lowest value (gain to its maximum value).

Due to this mechanism, the BER for logical zero's in strong signals equals the BER during zero's in a

weak signal. This holds for both principles (a) and (b) outlined in section 1.2, and makes them equal in BER performance to a limiter (c), however without the disadvantage of pulse width distortion. For research purposes both reset option are implemented.

1.4. CONTROL LOOP

Both the adaptive threshold circuit or AGC can be implemented using a feedback or a feed-forward loop.

■ A feedback loop is accurate, but in general stability requirements prevent the response time of control loop to be as short as the bit time.^{1,2} This was pointed out in the introduction.

■ A feed-forward loop allows the response time to be as fast as one bit time because the delay time in the loop can be fully compensated for by additional signal delay. However, a feed-forward loop is less accurate.

As mentioned in section 1.2, an accurate AGC is not required. As a result, a feed-forward loop design is used in the here proposed burst mode receiver.

1.5. DC SOURCES IN THE NETWORK

Besides a varying DC component caused by optical power variations between cells, there can be a DC component in the network caused by subscriber lasers biased above threshold.

If a the overall receiver concept is DC coupled, the use of fixed threshold levels is inhibited. In general, this problem is solved by switching the lasers off after each transmitted cell. This requires additional electronics at the subscriber side, without resulting in improvement of network performance.

Therefore, the here described burst mode receiver can be AC coupled.

2. IMPLEMENTATION

In figure 2. the basic principle of the proposed burst mode receiver is drawn.

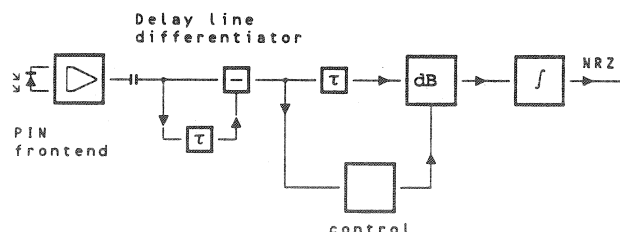


figure 2. Basic diagram of feed forward burst mode receiver.

2.1. FRONT-END

To have maximum profit of the low noise front end, the signal is amplified to a level far above the noise floor of the signal processing circuitry. Consequently the front end must have a wide dynamic range. In principle this can be fulfilled by a conventional transimpedance amplifier. However this is not a noise optimized solution. Therefore, a 2nd order capacitive current-current feedback amplifier equipped with a low cost PIN photo diode (1.3pF) is used. Based on the principles outlined in ref³ this has resulted in a low noise front end ($\approx 2\text{pA}/\sqrt{\text{Hz}}$), with respect to the relative high capacitance of the used PIN diode [10], and in a front end with wide dynamic range (20dB_{opt}).

As a consequence of the use of a differentiator (see section 2.2) the front end may be AC coupled under the condition that the time constants of the (de)coupling capacitors are much larger than the bit time. This can easily be fulfilled.

2.2. DELAY-LINE DIFFERENTIATOR

A delay line "differentiator" based on the subtraction of the original and delayed signal removes slow signal variations (DC wandering) before gain control or signal processing is performed.

The major advantage compared with an RC differentiator is that the output voltage is independent of the fall and rise times of the bits.

This type of differentiator introduces a small penalty in SNR, compared to ideal threshold detection. The signal u_s and noise u_n from the front end is split up in two paths, causing two mutually delayed signals with an amplitude of $(0.5u_s + 0.5u_n)$. The noise in both paths is uncorrelated due to this delay and adds in the subtractor on a power basis. The noise amplitude

at the output equals $\sqrt{2 \cdot (u_n/2)^2} = 0.707u_n$, which results in a penalty of $10 \cdot \log(0.5/0.707) = -1.5\text{dB}$.

2.3. AGC.

The AGC circuit is implemented by a voltage variable attenuator (VVA) in a feed-forward loop. The attenuator control signal is derived from the differentiated input signal by a fast peak detector. A part of the differentiated signal is fed via an emitter follower, to a Schottky diode and a small capacitor (10-20pF). The capacitor will be charged to the peak value of the positive pulse. The charge of the capacitor is converted by a MOS-FET into a current (0-20mA) proportional to the input level. This current controls the attenuator. Charging the capacitor takes less than 2ns and the storage time is more than 200ms. To reset the attenuator in its initial state, the capacitor is discharged within 2ns by a shunt transistor.

2.4. SET-RESET INTEGRATOR

The (differentiated) output signal of the attenuator is fed to a set-reset integrator to restore the original NRZ data. The set-reset integrator consists of two comparators, one with a positive threshold and one with a negative threshold. The output of the comparators controls a set-reset flip-flop. A positive pulse forces the flip flop to the "1" state, a negative pulse to the "0" state.

Figure 3 shows the prototype of the burst mode receiver build with SMD components on a eurocard (100x160mm). The optical front which is separated at the moment will be integrated on the same board in the next version of the PCB.

The overall component costs including IC's and PCB is about 220 Ecu for 10 pieces. The major part of these costs is accounted for the connectorized PIN photo diode (≈ 120 Ecu).

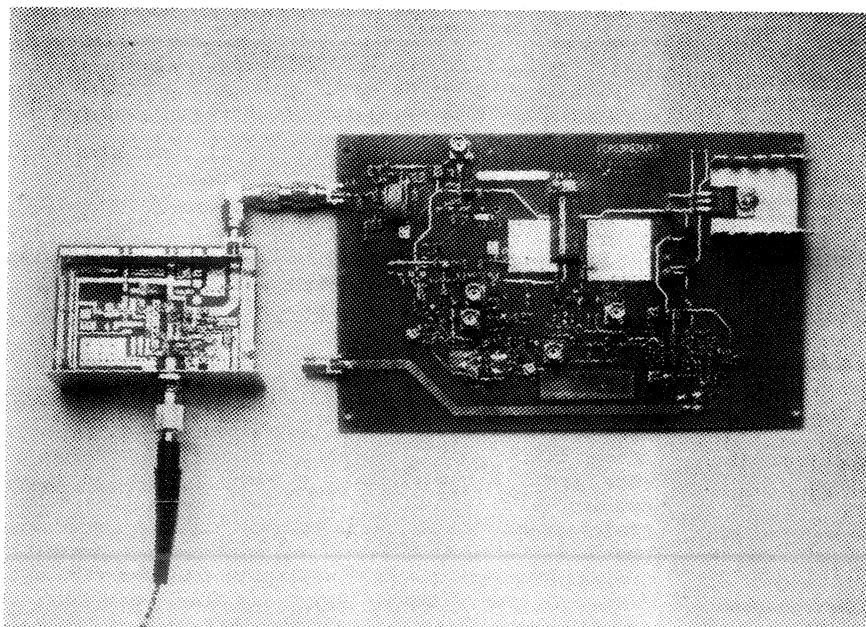
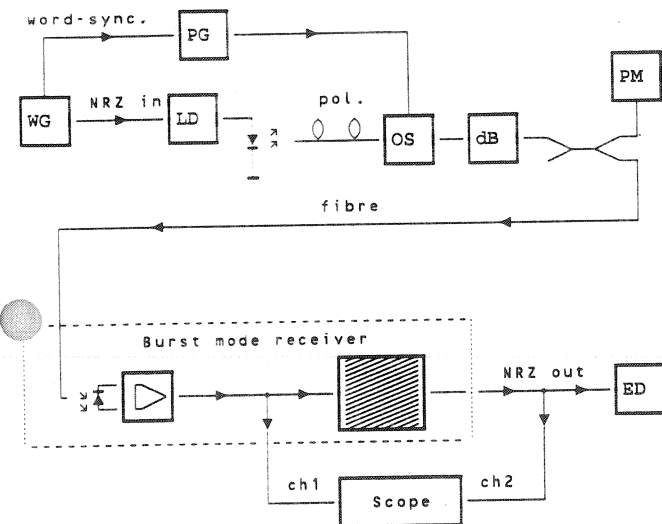


Figure 3. Prototype of the burst mode receiver.

3. MEASUREMENTS

In the measurement setup (fig. 4), ATM cells were simulated by a continuous bit stream of 16bit words (0010010101010111). An optical switch controlled by the word-sync signal of a word-generator alternated the optical power of successive words. The on/off ratio of the switch was controlled by the driver signal level.

The first 2 zero's of the 16 bit words simulated the gap in which the optical attenuation is changed. Due to these zero's, which must have a fixed position, measurements could not be performed with a random pattern. The other 14 bits were set arbitrarily. Simulation of a gap of one bit was not possible because the rise time of the optical switch was 2ns which exceeds the bit time of 1.6ns at 622Mb/s.



WG.....Word generator, Anritsu MP1604A.
PG.....Puls generator, HP 8082A.
LD.....Laser driver.
OS.....Optical switch, Cristal Technology SW313P.
Pol....Polarisation adjustment (for optical switch).
dB.....Optical attenuator, Anritsu MN95B.
PM.....Optical power meter, Anritsu ML910B.
Scope..Digitizing oscilloscope, HP54100D.
ED.....Error detector, Anritsu MP1605B.

Figure 4. Measurement setup

3.1. MEASUREMENTS IN CONTINUOUS MODE

When the reset signal of the receiver was switched off, the receiver acted as a normal continuous bit stream receiver with AGC, comparable with a normal point-point receiver, so a standard BER set with random pattern can be used.

The sensitivity in that case was measured using a fixed word (0010010101010111) as well as a (2^7-1) random pattern. The measured sensitivities for a BER of 10^{-9} are given in table 1.

Table 1.

BER= 10^{-9} $\lambda=1300\text{nm}$	622Mb/s	
	word	(2^7-1) pattern
Sensitivity $P_{\min}$ [dBm] _{opt}	-31.5	-30.7
Saturation $P_{\max}$ [dBm] _{opt}	-13.6	-14.6

■ Note that this sensitivity includes the penalty introduced by the analog signal processing.

■ The difference in sensitivity for a fixed word which had many transitions and a random pattern which could have longer successive one's or zero's is caused by a small difference between HF response and LF response (below 6MHz) of the optical front end.

■ The maximum optical power is mainly limited by the amplifier stages after the front end. The maximum optical power at the front could be as large as -10dBm.

■ Above -18dBm the delay time through the receiver decreases about 0.3ns at -14dBm, resulting in a small additional phase shift of a received bit stream or cell with large amplitude.

This effect is caused by the limited control range of the AGC. Above the control range the threshold timing becomes amplitude dependent caused by the rise and fall times of the band limited signal (0.75·622MHz).

3.2. MEASUREMENTS IN BURST MODE

To measure the sensitivity in burst mode, ATM cells were simulated by a continuous bit stream of 16 bit words with alternate optical power, using the successive words described in section 3. For alternating optical power levels of -30dBm and -17dBm for successive words, the measured BER was observed to be better than 10^{-9} .

For power levels exceeding -17dBm, the amplitude induced delay variations (section 3.1) in the receiver, caused synchronization problems in the used error detector. Therefore, the real dynamic range will be significantly better than 13 dB (optical).

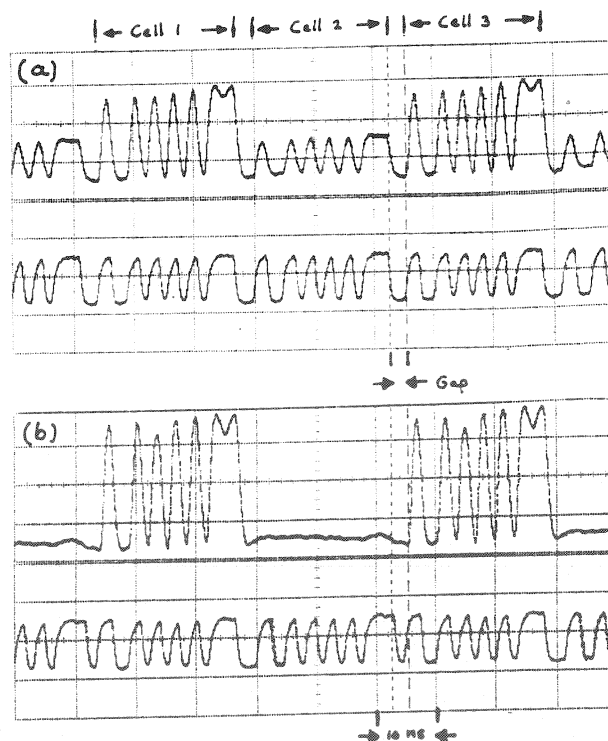


figure 5. Oscilloscope diagrams for a difference in optical power of 3dB (a) and 16dB (b) between two simulated cells (14 bits long with a gap of 2 bits) at a bit rate of 622Mb/s

Figure 5 demonstrates the reconstruction of the NRZ signal for optical power variations of 3 dB and for 16 dB. The upper trace is the measured output signal of the front end and the lower trace is the restored NRZ output signal.

The plot in figure 5b demonstrates a successful signal reconstruction under large optical power variation, which indicates that the dynamic range of the burst-mode receiver exceeds 16 dB (optical).

4. CONCLUSIONS

A low cost burst mode receiver, with PIN photodiode, very fast response time and wide dynamic range is proposed.

The feed-forward principle has resulted in an extremely fast response on bursty signals, which facilitates efficient ATM systems with cell gaps less than 2 bits at 622Mb/s.

To the authors knowledge, this is the fastest burst mode receiver (<2ns) with wide dynamic range (>16dB), reported in literature.

The proposed method is verified experimentally, both with bit as well as with cell induced reset mechanism for the gain.

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