AVIONICS IR COMMUNICATION LINK WITH SPREAD SPECTRUM ENCODING

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Abstract

This paper describes the design details for a direct sequence spread spectrum communication system over an IR data link for aircraft flying in close formation. The transmitter and the receiver are described in details. Regarding the receiver, particular attention has been given to the very demanding synchronization aspect of the communication system. The experimental results display an important robustness of the link against the AGWN and consistency with the theoretical calculation as concerns the Bit Error Probability.

1 INTRODUCTION

In previous monograph [1] the transmission medium constraints and receiver front ends for an IR communication link for aircraft flying in close formation have been investigated. An experimental voice communication system using simple "Δ" modulation had been built in order to validate the operational concept. The preliminary flight tests had been proved very promising. Among initial features of the system, stealthiness has been imposed as a vital parameter for operational success. Furthermore projects for developing free space optical communication systems for tactical applications are among the immediate goals of the European Defense Agency. In this respect, while the IR data link provides some stealthiness for the communication system, more stealthy modulation systems have to be envisaged in order to obtain a reliable communication system prototype.

The Spread Spectrum appears as the ideal solution for this type of applications. Spread spectrum provides communication stealthiness and robustness in air to air and air to ground radio communication systems [4]. These systems use carrier based transmission. Also spread spectrum has been used as encoding method for base band transmission system specifically on fiber optic avionics data buses [2, 3]. This last type of application appears to be suitable for IR data link as well.

2 THE DS – SPREAD SPECTRUM COMMUNICATION SYSTEM

The basic architecture of the IR communication system is displayed in Figure 1. The improvement circuitry consisting of a direct sequence spread spectrum encoder in the emitter and the spread spectrum decoder in the receiver have been added as improvement to the system (gray modules in Figure 1).

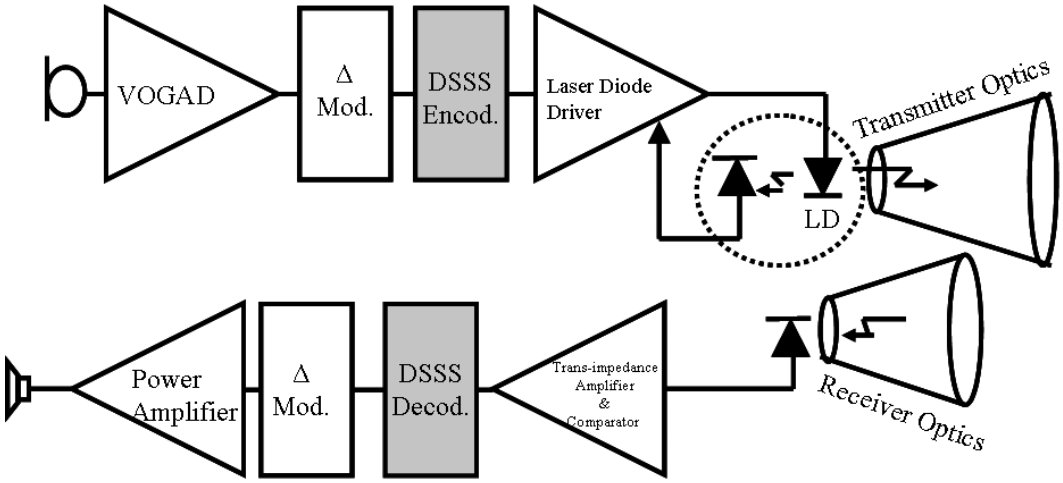

Figure 1 Overall system architecture

2.1 DESCRIPTION OF THE DS – SS EMITTER

The emitter block diagram is presented in Figure 2. It is a typical direct sequence spread spectrum encoding system operating in base band. The message signal (voice) is converted to binary information through a "Δ" modulator running at 32.25kHz. Thus f_m=32.25KHz.

The spreading codes are M – length codes. They are generated by a Pseudo-Noise Random Generator (PNRG) which is constituted by 7 registers leading to an M – code length of 2^n-1=2^7-1=127 bits [4]. The shift register is taped at the 7th and first register in order to deliver maximum length code. The PNRG is running at f_c=4MHz. This leads to a 128 times spreading of the spectrum and therefore to a processing gain $G_P = \frac{f_c}{f_m} = 128$.

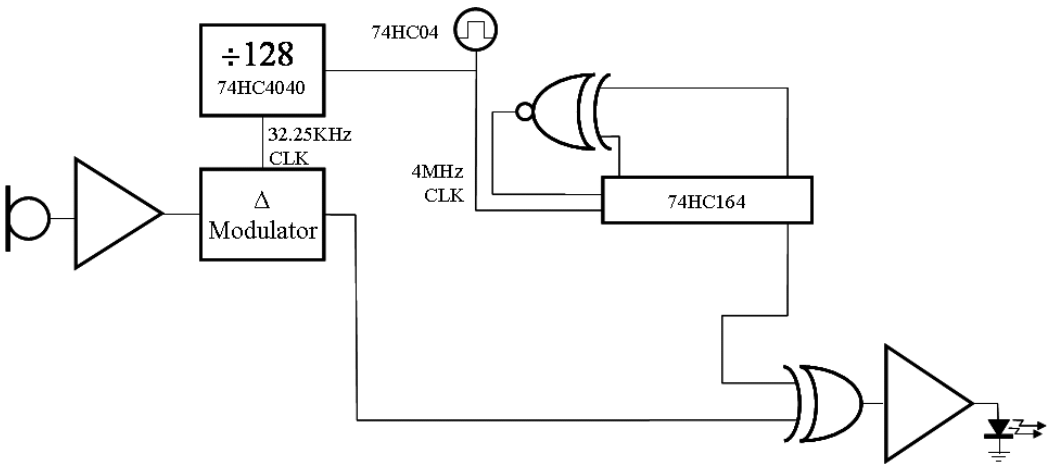

Figure 2 Emitter Block Diagram

The all – zero state is not allowable as the PNRG would lock – up, since EXORing two logic "0" will result in another "0" at the input. To avoid the all zero lock – up problem, the feed back EXOR has been substituted by an EXNOR gate.

The clock signal is generated by a series of not gates and a 4MHz crystal. The same clock signal is divided by 128 through a counter in order to drive the "Δ" modulator.

The message signal is encoded (BPSK) by the PNRG signal in the EXOR and transmitted through IR laser diode array.

2.2 DESCRIPTION OF THE DS – SS RECEIVER

The detailed receiver bloc diagram is displayed in Figure 3. The received DS – SS signal is superimposed by noise and interference. After being amplified by a transimpedance amplifier it is processed in the base band correlator.

The base band correlator consists from a video amplifier which delivers the signal in 0^0 and 180^0 phases. These phase inverted signals are switched to the "Δ" modulator, as a function of the value of the incoming code bit (0 or 1). In this way the

incoming signal is biphase shift keyed one more time by the pseudonoise random code, and therefore the decoding is achieved.

The dispreading of the incoming signal depends to the accurate synchronization (within one chip duration) of the receiver's PNRG with the generator of the emitter. After initial acquisition, the spread spectrum receiver must maintain synchronization by tracking changes in the transmitter's pseudonoise spreading code clock. The tracking synchronization is achieved by a delay lock tracking loop – DLL [4 – 6]. For this purpose two separate correlators are used which are driven by two local code reference signals – identical except that one is delayed in time and the second is in advance. The input signal supplies the three correlators. The main (on time) correlator correlates the incoming signal with the locally generated pseudonoise spreading code which is assumed to be synchronized (on time) with the code that has spread the message. If so, the message is decoded.

The late and early correlators drive a comparator which output controls the frequency of an 8MHz Voltage Controlled Crystal Oscillator VXCO. The frequency is divided by 2 to run the receiver's PNRG. The original frequency of 8MHz runs a serial to parallel shift register which is supplied by the pseudonoise code. This last component delivers the early, on time and late sequences with half chip difference ($\tau_c/2$) from three consecutive registers. The on time code supplies the main correlator, while the late and the early codes supply the corresponding correlators of the DLL.

It has to be noted that during a cold start initial acquisition is required. For this purpose the VCXO operates at a slightly higher frequency than 8MHz, and in such way it works as a sliding correlator in the very beginning of the operation. Once initial acquisition is achieved, the DLL force the VCXO down to 8MHz or even lower.

3 TEST AND EXPERIMENTAL RESULTS

The experimental setup is displayed in Figure 4. Transmitter and receiver are placed front to front on the optical table. The message is simulated using a PNRG inserted in the place of the "Δ" modulator. The message simulator is running under the same clock which drives the "Δ" modulator as well. To optical signal intensity is controlled in two ways: (a) The intensity control system embedded in the emitter circuit and (b) a variable optical attenuator on the IR laser beam. This last provides accurate, reliable and measurable optical attenuation.

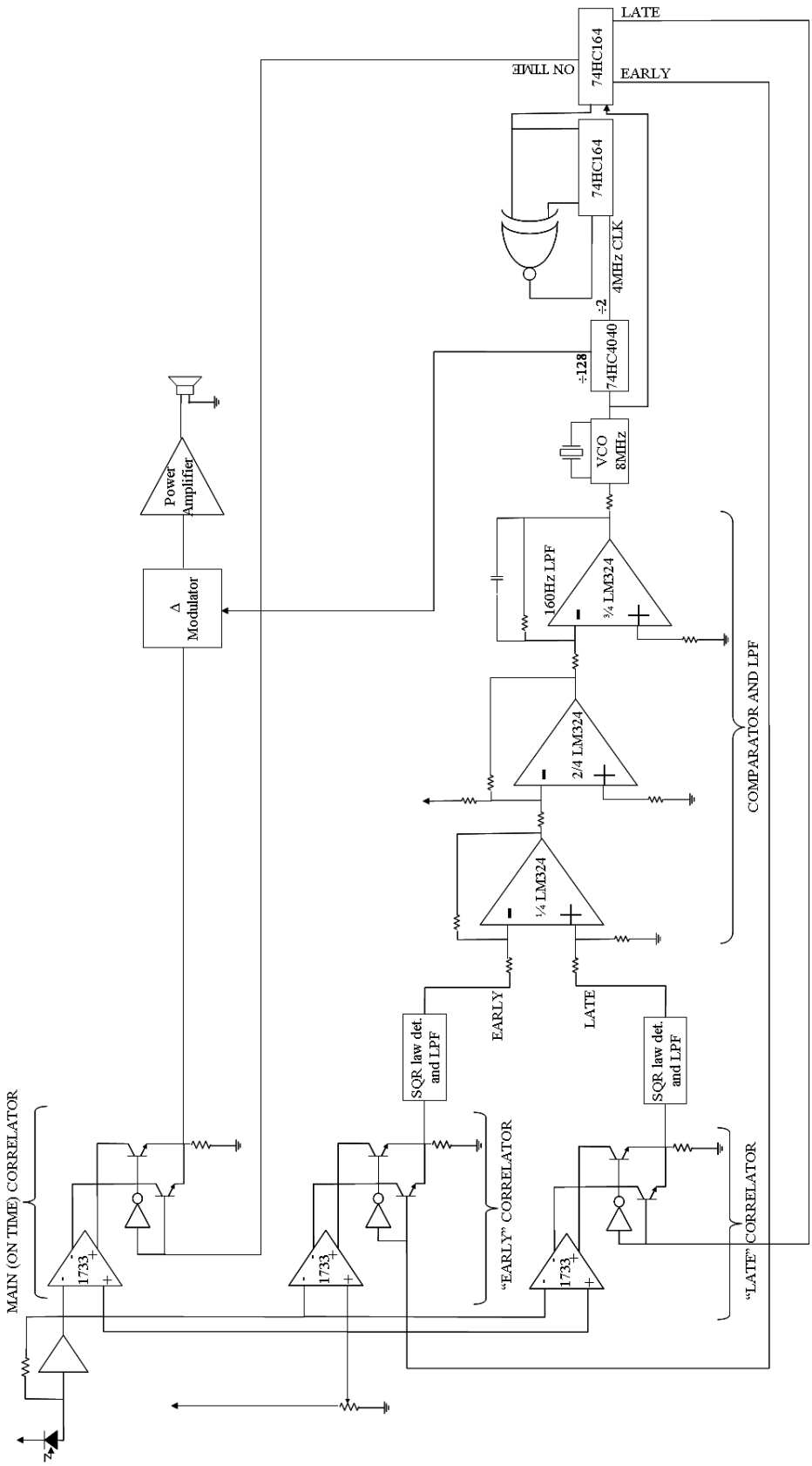

Figure 3 Receiver block diagram

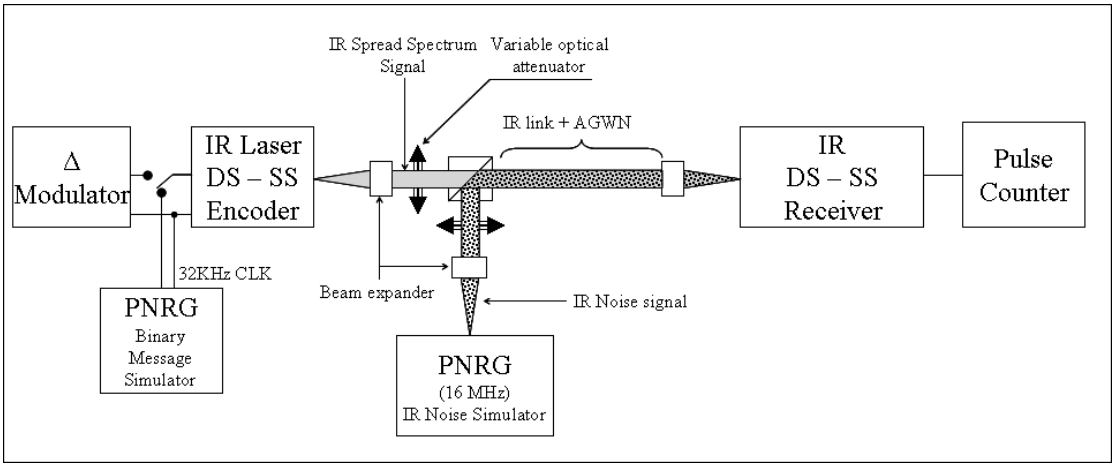

Figure 4 IR Spread Spectrum link simulation setup

The Noise simulator is a PNRG running with an independent clock of 16MHz. The PNRG drives a high power LED. The noise beam is collimated and added to the message beam using a prism, this way achieving a message beam with additive white noise. The intensity of the noise beam is controlled by a variable optical attenuator as well. This setup has been proved to be reliable for the testing of the communication system in the laboratory with repeatable results.

The decoded signal (before the "Δ" modulator) is tested with a bit counter and the Bit Error Rate – BER is measured for different values of SNR. The experimental results display consistency with the calculated BER graph (Figure 5). The difference of 1dB is attributed to the circuit imperfections and particularly to those of the optical components. The eye pattern (Figure 6) consolidated the measurement results.

4 COMMENTARY DISCUSSION – WORK FORWARD

The system which has been developed provides a laboratory prototype for a secure and robust IR communication link for aircraft. The experimental results display parallelism with the theoretical calculations. It has to be noted, however, that in the optical laboratory ideal environmental conditions exist in terms of circuitry, temperature etc… For this particular reason a supplementary 5 – 6dB degradation of the system has to be envisaged in real operational environment. This is expected to provide an adequate safety margin. Furthermore the system has to be tested in various

environmental conditions, and specifically for large temperature variations, in order to validate the system synchronization and the beam's optical qualities.

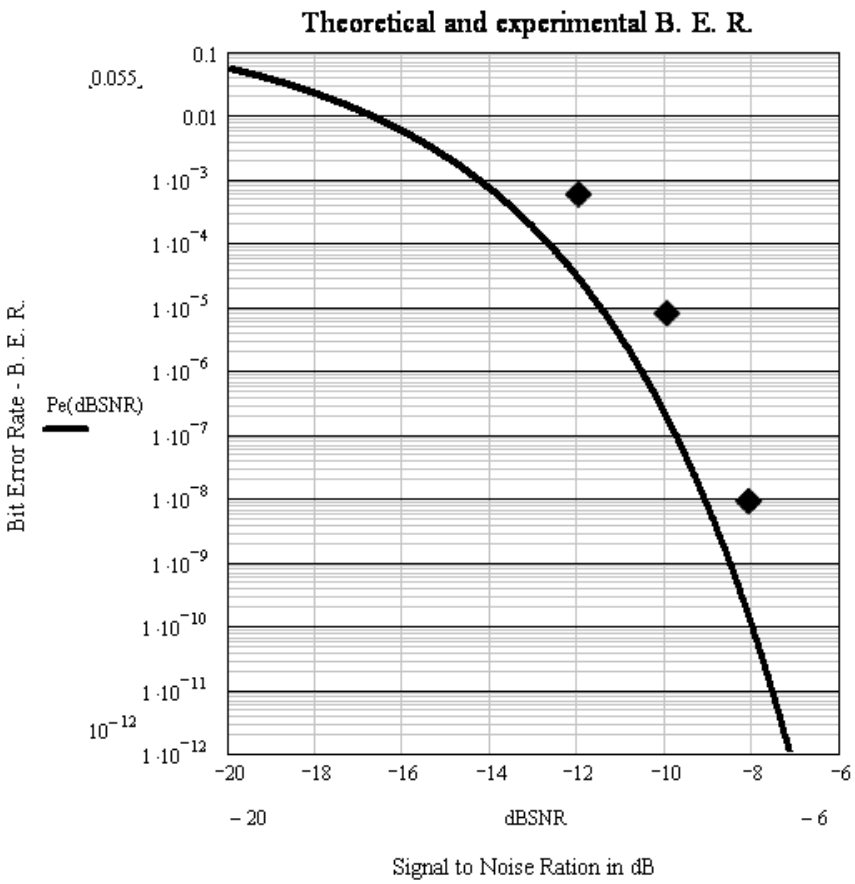

Figure 5 Theoretical and experimental Error Probabilities of the DS - Spread Spectrum IR link for a processing gain of 128 (21dB)

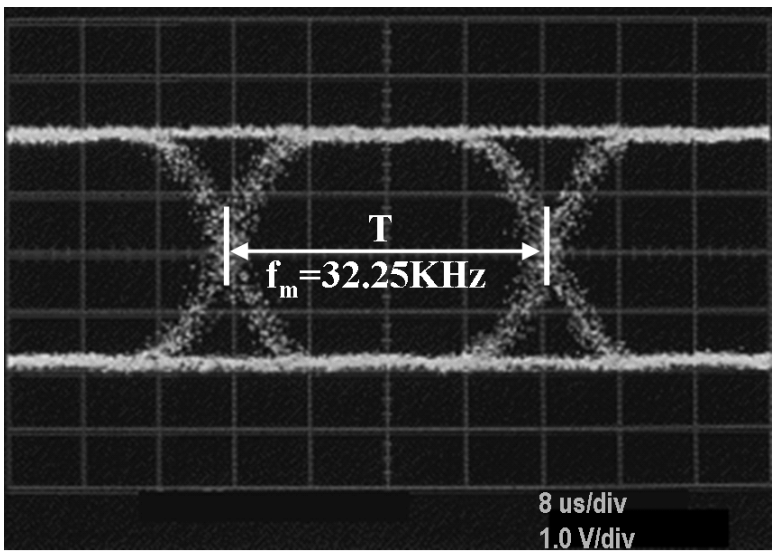

Figure 6 Eye pattern at the input of the Δ modulator

As future improvement of the communication system three coming steps can be envisaged:

a. Insertion of encryption codes which will provide increased security and code division multiplexing capability additionally to the broadcast emission mode,

b. CW carrier modulation of the laser beam diversifying the communication system from the base band which is originally designed,

c. More robust synchronization system to enhance the initial acquisition process. This will allow much more longer m – codes and improvement of the sliding correlator's performance,

It is estimated that the system's performance as full scale operational system can meet that requirements which are necessary for data transmission, additionally to the voice communication feature.

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