AN ENHANCEMENT OF EXISTING RF DATA LINKS USING ADVANCED DIVERSITY TECHNIQUES

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ABSTRACT

The theoretical capacity of communication channel in the presence of additive white Gaussian noise (AWGN) as defined by Shannon's channel capacity theorem has been well understood since 1940s. This theorem bounds the bit error rate (BER) of RF data links achievable for a particular noise level.

The development in digital technology over the last decade has made it possible not just to design devices that operate close to the Shannon's limit, but also to explore techniques, such as best source and best data selectors, for further improvements in performance of RF data links where frequency, spatial or polar diverse reception is possible.

This paper discusses an approach to improving quality of data links using an advanced diversity technique that does not select one source at a time but aligns and combines soft values from each. It shows how the overall bit error rate of RF data link can be improved by combining signals from multiple receivers and/or transmitters. Test results showing practical performance improvements are presented and discussed.

KEYWORDS: PCM/FM, Diversity, Smart Source Selector

1. INTRODUCTION

The increasing sophistication of flight test instrumentation in the recent years has been driving the demand for high quality RF data links. The main modulation schema used for such links for over 30 years has been PCM/FM, primary due to its simplicity and robustness. Consequently most telemetry facilities have invested significant capital in equipment specifically for use with PCM/FM.

One approach to improving performance of RF data links is the use of modern modulation techniques such as such as the ARTM Tier-I and Tier-II schemes. While these methods help to accomplish this goal, it is not without a significant investment in new equipment.

Another approach focuses on enhancement of existing PCM/FM equipment using diversity techniques. This paper elaborates on implementation of these techniques and their practical contribution to the improvement of RF data links.

2. THE KEY PERFORMANCE METRIC

The Bit Error Rate (BER) is commonly used to measure performance of digital communication systems including PCM/FM systems. One of the key implications of the Shannon's channel capacity theorem is the bounding of the best achievable bit error rate for a particular noise level.

For PCM/FM systems this relationship between the best-case bit error rate and the level of noise can be expressed as

$$BER(EbNo) = \frac{1}{2} erfc\left(\sqrt{10^{\frac{EbNo}{10}}}\right)$$

where $EbNo = 10\log\left(\frac{Eb}{No}\right)$ and Eb is the energy per bit and No is the noise power.

Traditionally the above equation has been graphed as shown in Figure 1. The graph illustrates that the theoretical bit error rateBER lowers with increasing Eb/No - i.e. for the same signal power the bit error rates increases with the noise power.

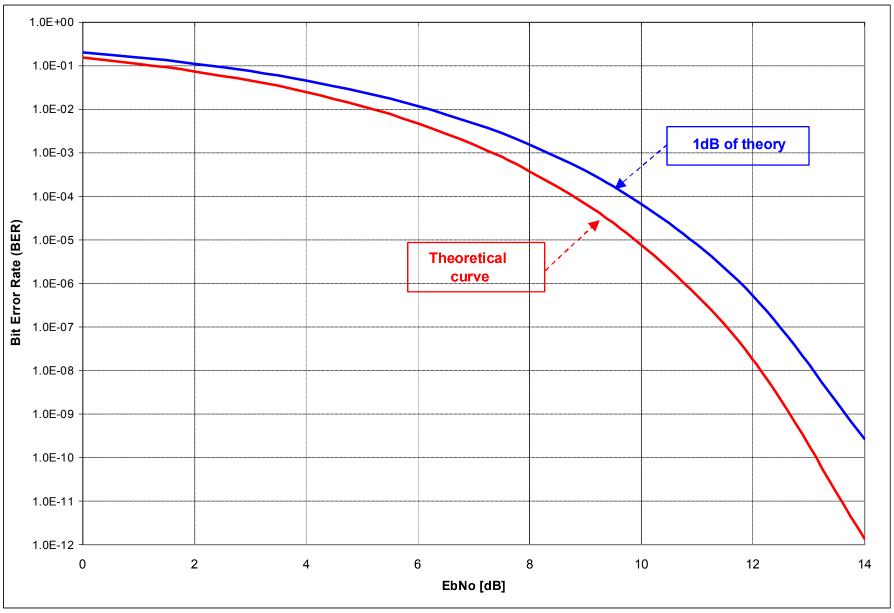

Figure 1- Theory curve and 1dB of theory curve for BER vs. EbNo

The graph also shows the bit error rate for a device with performance of “1db of theory”. The performance of conventional bit synchronizers, the crucial elements of telemetry ground systems, is typically specified as being within 1db of theory. A decade ago this was about the limit of what was technically achievable at acceptable cost.

Today the all-digital state-of-the-art bit synchronizers are able to achieve performance that is virtually aligned with the theory. One approach to improving the performance of ground systems beyond the theory is to employ some form of transmit and/or receive diversity.

3. DIVERSITY AND SMART SOURCE SELECTOR

Diversity is a method of improving link quality by transmitting or receiving two or more versions of a signal and combining/selecting the best signal(s) adaptively so that the resultant bit error rate is lower than for any one version of the signal in isolation.

There are a variety of schemes for separating the diversity signals including spatial, frequency and polarization diversity. Some FTI programs use frequency diversity where data is transmitted on two carrier frequencies. Some receivers on the ground are placed apart or at different altitudes, this is called spatial diversity. Some receivers support polar diversity. The purpose of the ground system is then to recover the transmitted signal using the two (or more) diversity signals.

A number of techniques for recovering transmitted data have been developed. *Best Source Selectors (BSS)* switch to the stream with the best signal to noise ratio while *Best Data Selectors (BDS)* switch to the stream with the fewer data (syncword) errors. In both of these cases care must be taken on switching such that downstream decoders remain in lock. Best data selectors require decryptors on each channel if encryption is used. *Correlated Source Selectors (CSS)* time align different streams then vote on a bit by bit bases - possibly using error metrics to weight the voting of each channel.

Smart Source Selectors (SSS) is the term given to devices that do not simply switch or vote but rather use the best of both worlds. The critical function of all selectors is to decide whether the received bit represents a logical “0” or logical “*1*”. The way in which this decision is made does not just differentiate a selector from others, but also predetermine the selector’s potential performance.

The technique used by Smart Source Selectors is performed at the soft-symbol stage, allowing for any of the diversities described earlier. A Smart Source Selector first selects those channels with the signal levels above a certain level and with Eb/No within a predefined margin of a channel with the best Eb/No. The selected data streams are then time aligned. Smart Source Selectors reconstruct transmitted data by combining bits from aligned streams using soft-bits produced by each channel’s bit synchronizer. The block diagram of a dual-channel Smart Source Selector is shown in Figure 2.

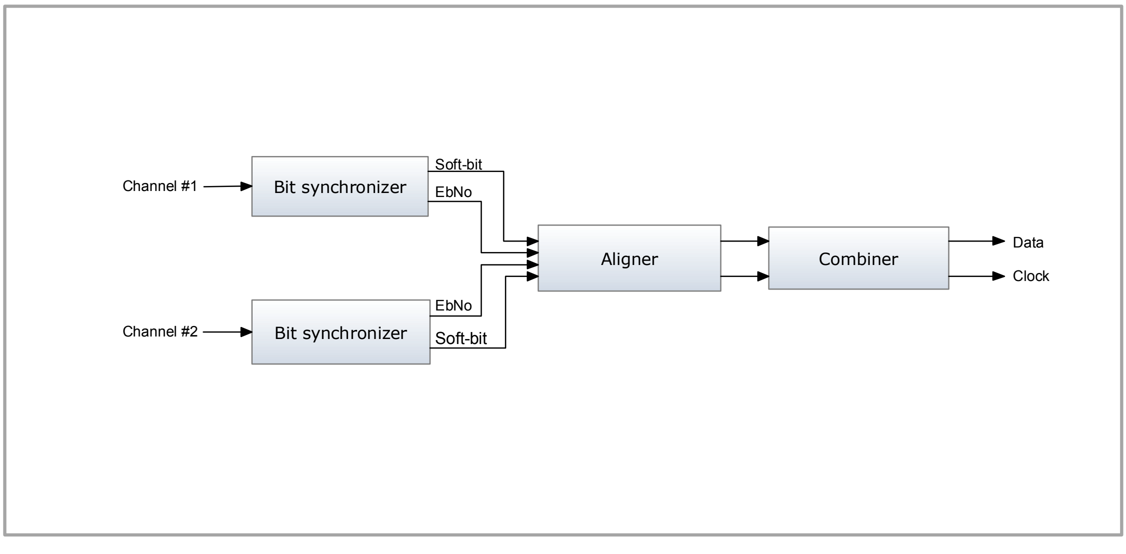

Figure 2 - Block diagram of a dual channel Smart Source Selector

The technique for combining bits from selected channels uses calculated Euclidean distances between a point representing received bit and the points representing an ideal "*0*" and ideal "*1*". The decision on the logical value of received bit is made by comparison of the two distances.

This process can be mathematically described using the following formula:

a received bit is "***1***" if $\sqrt{\sum_{i=1}^{n}\left(p_i - A\right)^2} > \sqrt{\sum_{i=1}^{n}\left(p_i + A\right)^2}$ otherwise it is "***0***"

where

- ***p*** is the soft-bit value of received bit
- ***A*** is the value of the ideal "1"
- ***-A*** is the value of the ideal "0"
- ***n*** is the number of channels being combined

This decision process can be applied to any number of channels. For a single channel system it simply means that the received bit represented by a point ***p***, on a line is "1" if the measured value is closer to the ideal "1" than the ideal "0" - see Figure 3 (a).

For a two-channel system the received bit is represented by a point **[p_1, p_2]** on a plane, with its coordinates being the soft-bit values from each of two channels. The received bit is considered a logical "1" if its Euclidean distance from the ideal "1" [*A*, *A*] is smaller than the distance from the ideal "0" [-*A*, -*A*] - see Figure 3 (b).

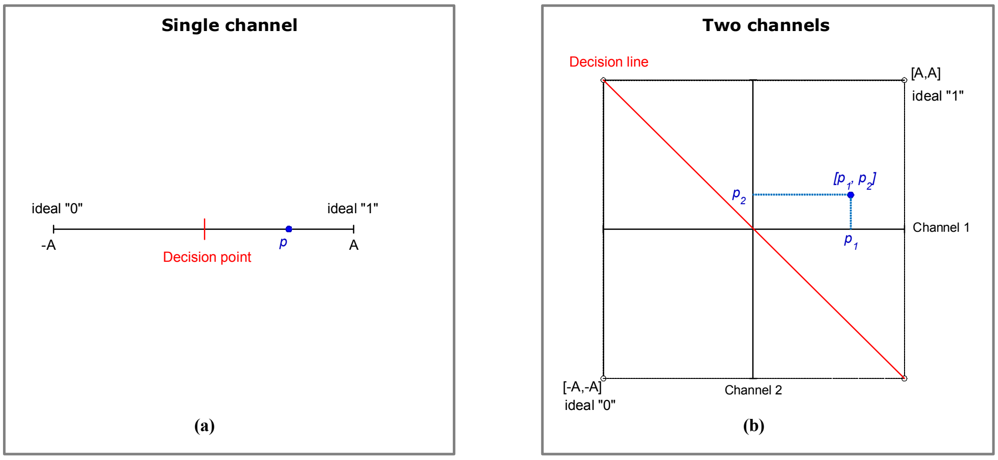

Figure 3 - Decision between "0" and "1" with (a) single channel bit synchronizer and (b)dual channel Smart Source Selector

Using the above model it is possible to determine an improvement achievable with Smart Source Selectors.

In order to make a wrong decision with a single channel system when an ideal "1" is received, a noise with amplitude of -***A*** needs to be added to the amplitude of the received bit. With a two channels Smart Source Selector the amplitude of noise required to corrupt an ideal "1" is -***A**√2***.

Therefore, it is expected that the performance of a two-channel Smart Source Selector can match a performance of a single channel system while operating in an environment with $(\sqrt{2})^2$ times higher noise power. This equals to EbNo improvement of 3dB for a two-channel Smart Source Selector.

An improvement of 6dB can be achieved with four-channels and 9dB with eight-channels. This is a superior strategy over Best Source Selectors and Best Data Selectors as they output a resultant BER that is equal only to the best of combined channels, but not better.

4. TEST RESULTS AND ANALYSIS

4.1. Laboratory Test

In order to test the effectiveness of smart source selection in laboratory conditions, a Bit Error Rate Tester (BERT) was used to produce two identical pseudo random bit sequences of 4Mbps with NRZ-L coding. A continuous variable delay of up to 100 bits per second was added to the first stream in respect to the second stream. Both streams were corrupted by white noise using two independent additive white Gaussian noise generators with programmable Eb/No.

The two streams were then used as inputs to a two-channel Smart Source Selector with an aligner length of 128 bits. The configuration of Smart Source Selector laboratory test system is shown in Figure 4.

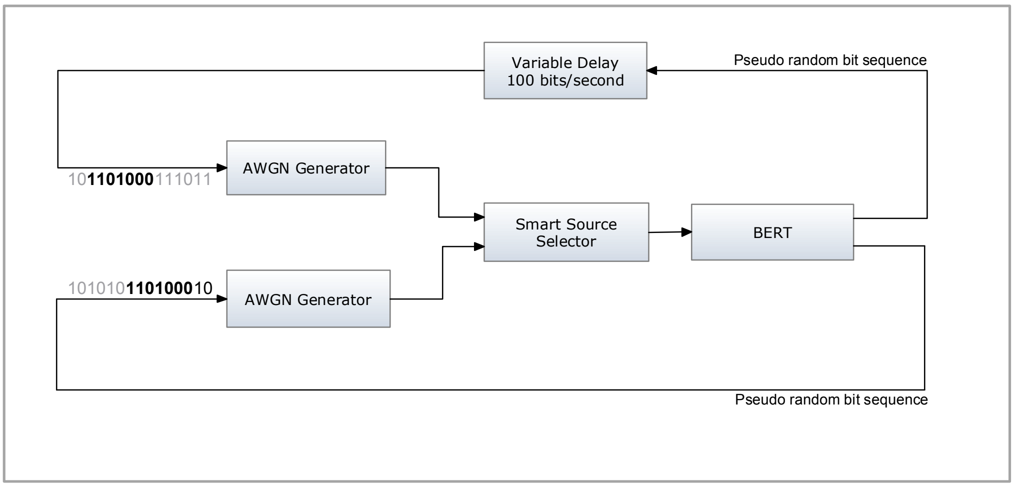

Figure 4 - Configuration of Smart Source Selector laboratory test

During the test, bit error rate was measured for Eb/No in the range from 0dB to 10dB. The resultant bit error rate together with a curve for a single channel and the theoretical curve is shown in Figure 5.

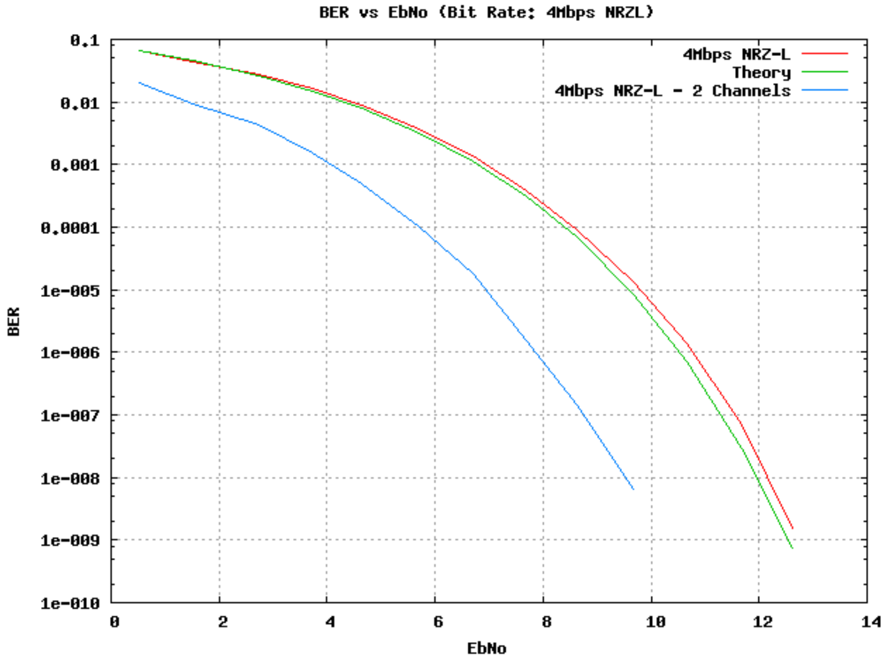

Figure 5 - BER vs. EbNo of dual channel Smart Source Selector for NRZ-L of 4Mbps

The test results demonstrate that the resultant bit error rate of a two-channel Smart Source Selector is as expected - approximately 3dB better than of either channel on its own. The essential precondition for achieving the maximum theoretical improvement of 3dB was the independence of two AWGN sources. In the real-life applications this condition can best be met using one or combination of multiple diversity schemas.

4.2. Real-life Benchmarking

A benchmarking test of the smart source selector against a traditional flight-test ground system was carried out at an ACRA Control's customer site. In this test, the dual-channel Smart Source Selector was run alongside a highly tuned four-channel cascaded diversity system.

The existing system utilized spatial and polarization diversity. Using three diversity combiners it processed streams from two antennas each producing both left-hand and right-hand circular polarization signals. The tested Smart Source Selector was fed with left-hand circular polarization signal from each antenna. A bit error rate tester was used for generating a pseudo random binary sequence for the test and for measuring the bit error rate. The configuration of Smart Source Selector benchmarking test is shown in Figure 6.

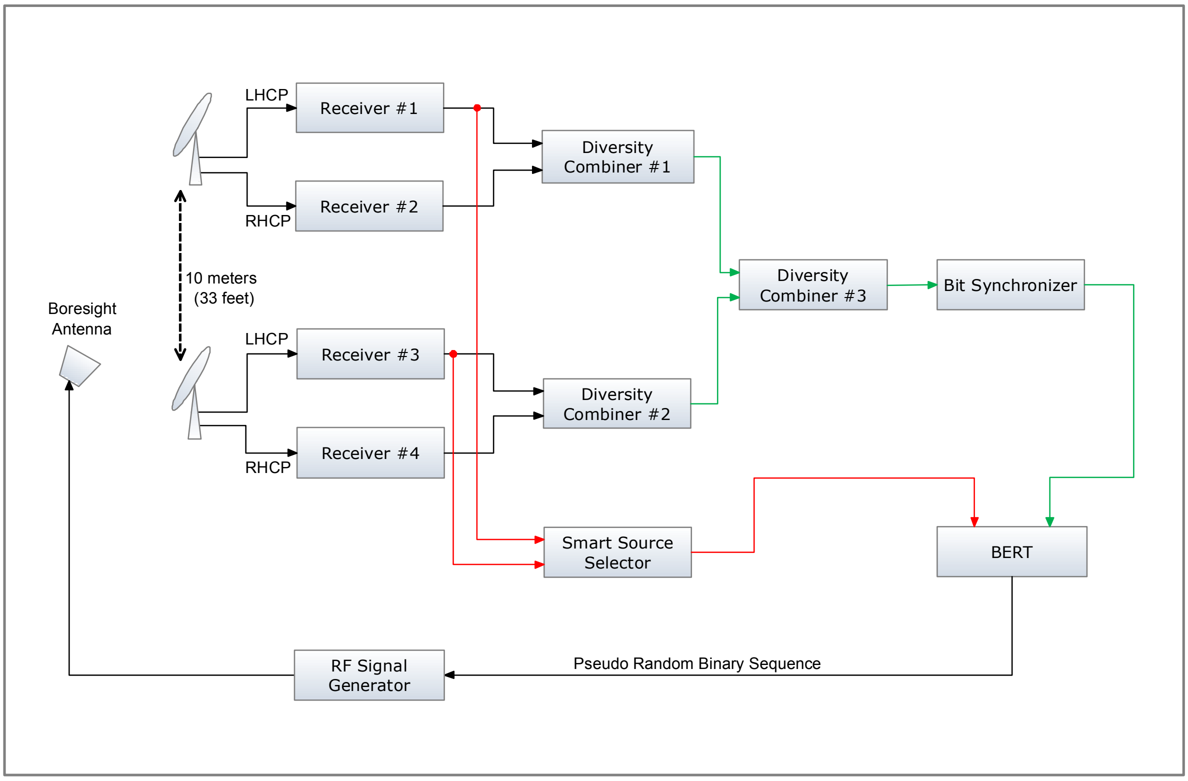

Figure 6 – System configuration of Smart Source Selector benchmarking test

In total three benchmarking tests were run and bit error rates achieved at ambient threshold levels using both the existing diversity combiners and the Smart Source Selector over a period of 1 minute were recorded. The measured bit error rates are shown in Table 1.

Test	Date	BER with Diversity Combiners	BER with Smart Source Selector
1	25 Jan 2010	2.68E-08	1.10E-08
2	4 Feb 2010 (AM)	No errors	3.70E-09
3	4 Feb 2010 (PM)	3.22E-09	1.30E-09

Table 1 - Bit Error Rates for Smart Source Selector benchmarking test

The benchmarking tests results demonstrate that bit error rates achieved using both systems were comparable. In the context of complexity and cost of each system, these results show that the Smart Source Selector is a cost effective plug-in replacement for a complex traditional telemetry ground systems. It is also reasonable to expect that significantly lower BERs can be achieved using a four-channel Smart Source Selector fully utilizing both spatial and polarization diversity.

5. CONCLUSION

With modern digital techniques, today’s bit synchronizers achieve bit errors rates very close to theory. Other techniques must be explored in order to further improve the performance of RF data links.

This paper focused on an enhancement of existing ground systems using advanced diversity technique called smart source selection. It has been shown that Smart Source Selectors offer a superior diversity strategy over traditional Best Source Selectors and Best Data Selectors.

The presented test results quantified performance improvements achievable using dual-channel Smart Source Selector. The results of benchmarking against a real-life ground system suggested that a Smart Source Selector is a cost-effective replacement for complex conventional diversity systems.

6. REFERENCES

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