AIRBORNE/SHIPBORNE PSK TELEMETRY DATA LINK

JOHN R. CARLSON
Aydin Computer and Monitor Division
700 Dresher Road
Horsham. PA 19044

ARLEN SCHMIDT
Intera Systems, Ltd.
Calgary, Alberta, Canada

ABSTRACT

This paper describes the design considerations and methodology applied to solve the practical problems posed in the creation of a high bit rate telemetry relay system and specifically the techniques implemented to enhance signal to noise performance under adverse operational conditions.

KEY WORDS:

Telemetry, data link, encoding, decoding, multipath interference.

INTRODUCTION

The system under discussion here was designed to operate as the data link for an airborne synthetic aperture radar imaging system used for support of navigation through ice in Canadian waters. Data are generated by a dual sidelooking X band SAR carried aboard a Canadair Challenger CL-600 Aircraft. The data stream is encoded, scrambled and modulated onto a carrier, then transmitted to Canadian Coast Guard icebreaking ships as a navigational aid. The data are also relayed via satellite to a ground facility, where they are used in the preparation of a daily ice synopsis which is sent out to shipping.

The data link must have line of sight performance, which means a maximum range of 400 KM at high altitudes. A 700 Kbs downlink rate is necessary to ensure adequate real time information suitable for “tactical” navigation through ice. Bit error rate was specified as less than 10e-5 at maximum range, with adequate S/N and fade margins.

Both the aircraft and the ship were assumed to have a combined roll stability of ± 5 degrees.

In this paper we will examine each of the major components of the system designed and built by Aydin's Vector and Computer and Monitor divisions.

SYSTEM DESCRIPTION

The data link (see figure 1) consists of an airborne modulator/transmitter, an airborne antenna, a shipboard antenna, receiver, and demodulation equipment. An essential consideration here is the behavior of the data link in marginal conditions, especially low elevation reception, and fade due to reflection multipath phenomena. All system choices are predicated on the necessity of maintaining the link margin at both 0 degrees and 5 degrees roll. Since each system choice involved tradeoffs in performance, the possibilities had to be evaluated as a series of link budgets to assess their overall value. Each system choice also had to be evaluated on a cost per benefit basis.

The final choices can be summarized as follows:

1) Fixed tuned single bit rate transmission and reception, at 700Kbs;

2) Viterbi ½ rate encoding;

3) Filtered ±90 ° phase modulation;

4) Antennas which provide omnidirectional hemispherical coverage, with excess gain at the horizon to compensate for scattering and multipath losses;

5) Scrambling and differential encoding;

6) Demodulation and bit synchronization equipment optimized for BER performance.

Block diagrams of the airborne transmitter and the shipboard receiver are shown in figures two and three.

Sidelobe regeneration was a major concern during the design phase of this project. It was anticipated that the frequency management authorities might severely bandlimit radiated energy in order to avoid interfering with other services. If QPSK were to be used, a linear power amplifier in the transmitter would be required. A TWT amplifier is thus the logical choice. However, they are costly, power inefficient, and at times unreliable. Paralleled solid state amplifiers are cheaper, but are limiting amplifiers, which would regenerate QPSK sidelobes.

Filtered ±90° phase modulation is a continuous envelope modulation. As such it does not regenerate sidelobes when passed through a limiting amplifier. Other continuous envelope modulation schemes, such as MSK, have a more compact emission spectrum but require more complicated transmission and receiver circuitry, with no significant advantages in BER vs SNR performance. The PM approach was therefore chosen for this project. The transmitter was then designed around four class C solid state amplifiers, paralleled through couplers. These amplifiers use approximately 63 percent of the power input required by a TWTA. They also require much less space and weight allowance on the aircraft. Such a design has the further advantages of a graceful failure mode; the transmitter will still operate (though at a reduced output power) if a stage fails.

The requirement that the system operate in severe fade and multipath environments demanded excellent performance from the antennas. Various forms of tracking antennas and beam switching techniques were considered and rejected, for reasons of cost and complexity. Omnidirectional hemispherical pattern coverage was therefore chosen. The roll stability of both the airborne and seagoing platforms meant that the transmit and receive gains could be arithmetically added to generate a combined radiation pattern as a function of elevation angle and roll angle.

The antenna system had to provide for a 200 nautical mile range with the aircraft at 30,000 feet. The ideal elevation pattern requirements are shown in figure 4. The peak azimuth gain is referenced to +4.5 dBi and 5° platform roll. The azimuth pattern is of course required to be omnidirectional for all elevation angles.
The effects of atmospheric conditions and reflections are most severe at elevation angles below 5°. The dependence of multipath induced fading upon range reflectivity can be seen in the data below:

REFLECTIVITY	REFLECTION NULL DEPTH
0.2	-2 dB
0.4	-4 dB
0.6	-7.5 dB
0.8	-14 dB
1.0	Infinity

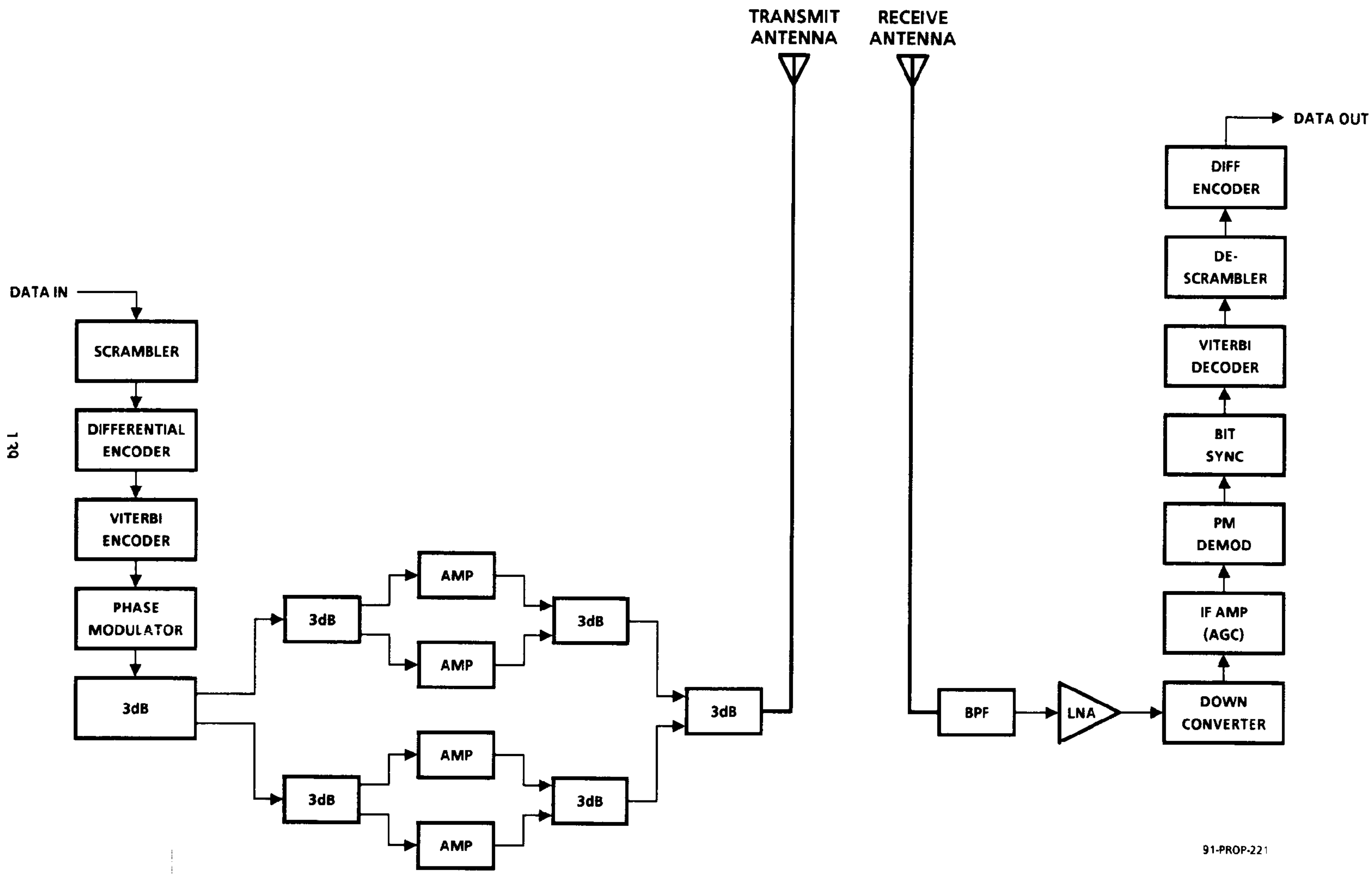

Figure 1. Data Link Block Diagram

TD-A-8395

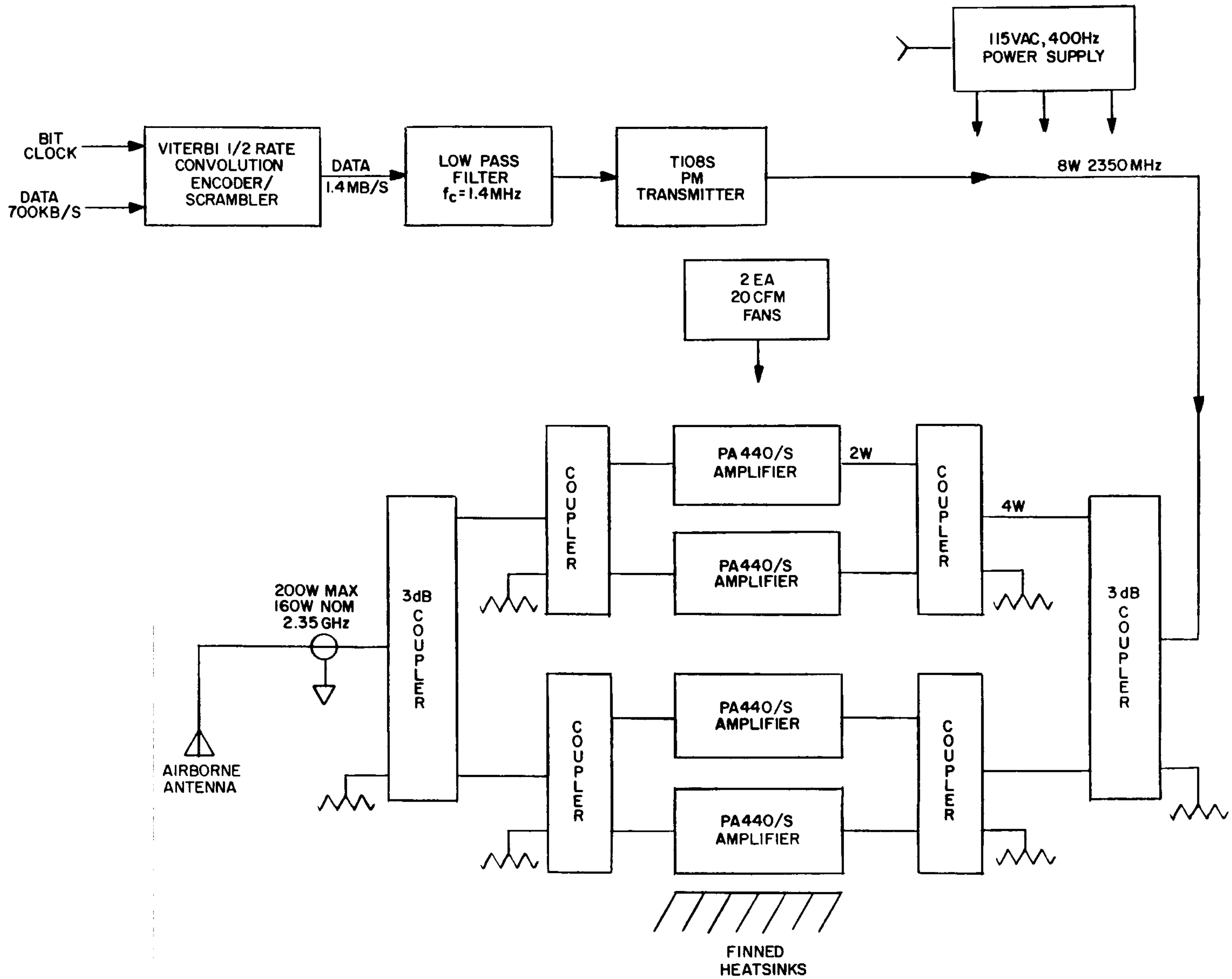

FIGURE 2 AIRBORNE TRANSMITTER

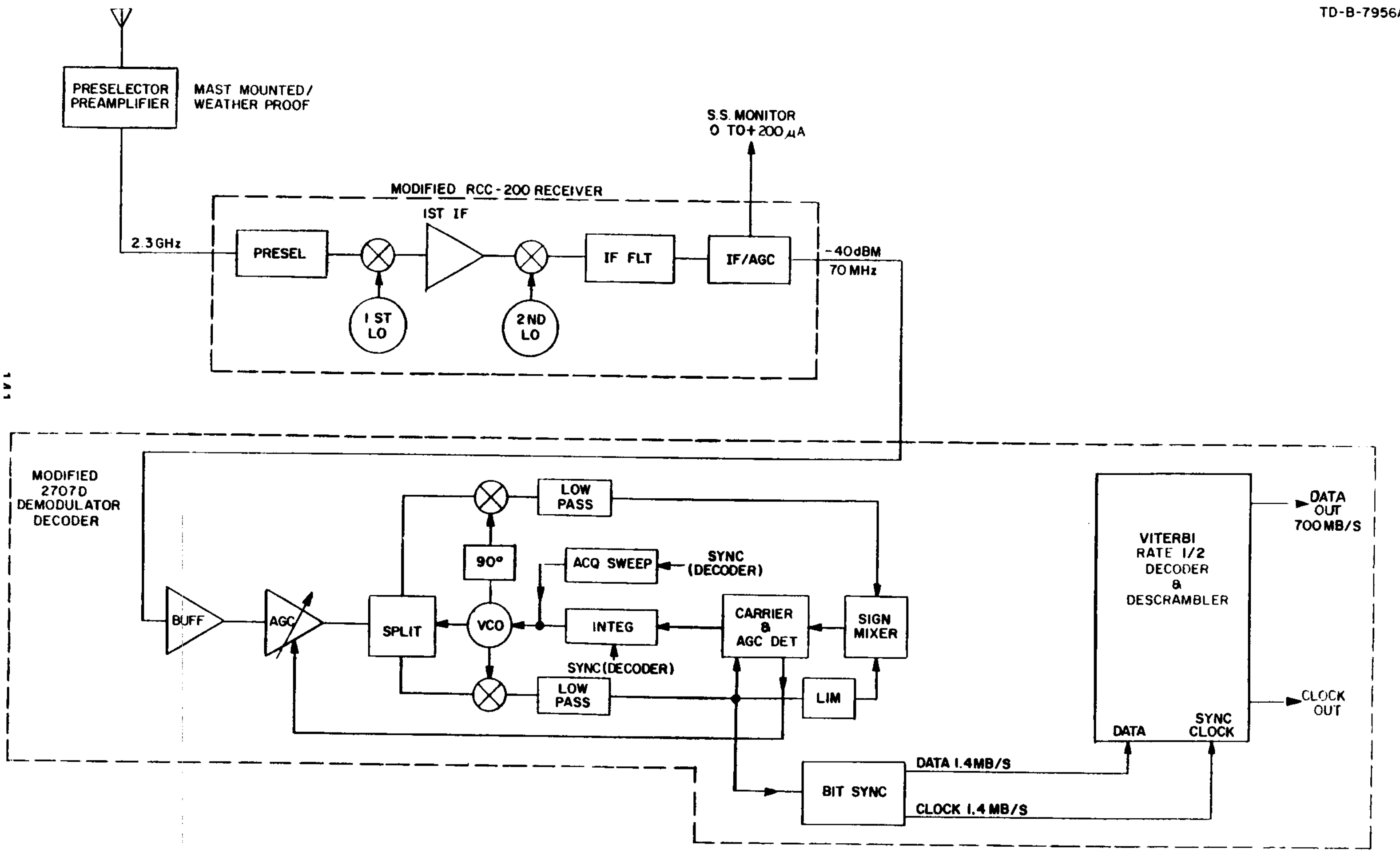

FIGURE 3 SHIP BOARD RECEIVER

The reflectivity of the ice flow is dependent on surface roughness; at grazing angles it is expected to be .6 or greater. A link margin of at least 8 dB (over the CNR required for a BER of 10 °) near the horizon is therefore necessary. That in turn requires an omnidirectional antenna gain at the horizon of at least +4.5 dB. Circular polarization of the transmitted signal offers a statistical advantage over linear polarization, as quadrature polarized components are unlikely to fall into a null at the same time.

Based upon these considerations a bifilar helical antenna was chosen for both the transmit and the receive antennas. The airborne antenna was reduced in size and enclosed in a radome for aerodynamic reasons. The combined transmit/receive pattern of these antennas is shown in figure 4.

MODULATION, ENCODING AND SCRAMBLING

Carrier generation and modulation is accomplished by modulating the output of a crystal modulated with a ±5 ° phase deviation, then multiplied 18 times to achieve the requisite carrier controlled oscillator with a linear analog phase modulator. In this case the oscillator signal is modulated with a ±5 ° phase deviation, then multiplied 18 times to achieve the requisite carrier frequency with ±90 ° phase modulation. The advantage of this method is that the carrier level is constant and no AM component is present. Thus a limiting (i.e. solid state) amplifier can be used in the transmitter without sidelobe regeneration. The premodulation filter cutoff frequency is chosen to optimize the tradeoff between emission bandwidth and bit error rate.
In addition to reducing the signal bandwidth, prefiltering a PM signal has the undesired effect of introducing a carrier component. The magnitude of the carrier component varies directly with the amount of filtering used. The presence of the carrier degrades both carrier acquisition and the bit error rate performance. The size of the carrier component can be reduced by increasing the deviation beyond ±90 °.

The final transmission modulation parameters were as follows:

Premodulation filter:	five pole, linear phase, 2.1 MHZ cutoff frequency.
Deviation:	set for carrier null with 1.4 MB/s 2047 PRN pattern. This is approximately ±96 ° peak phase deviation.
Carrier Null:	20 dB minimum over temperature, which is equivalent to 96 ° ±6 ° peak phase deviation.

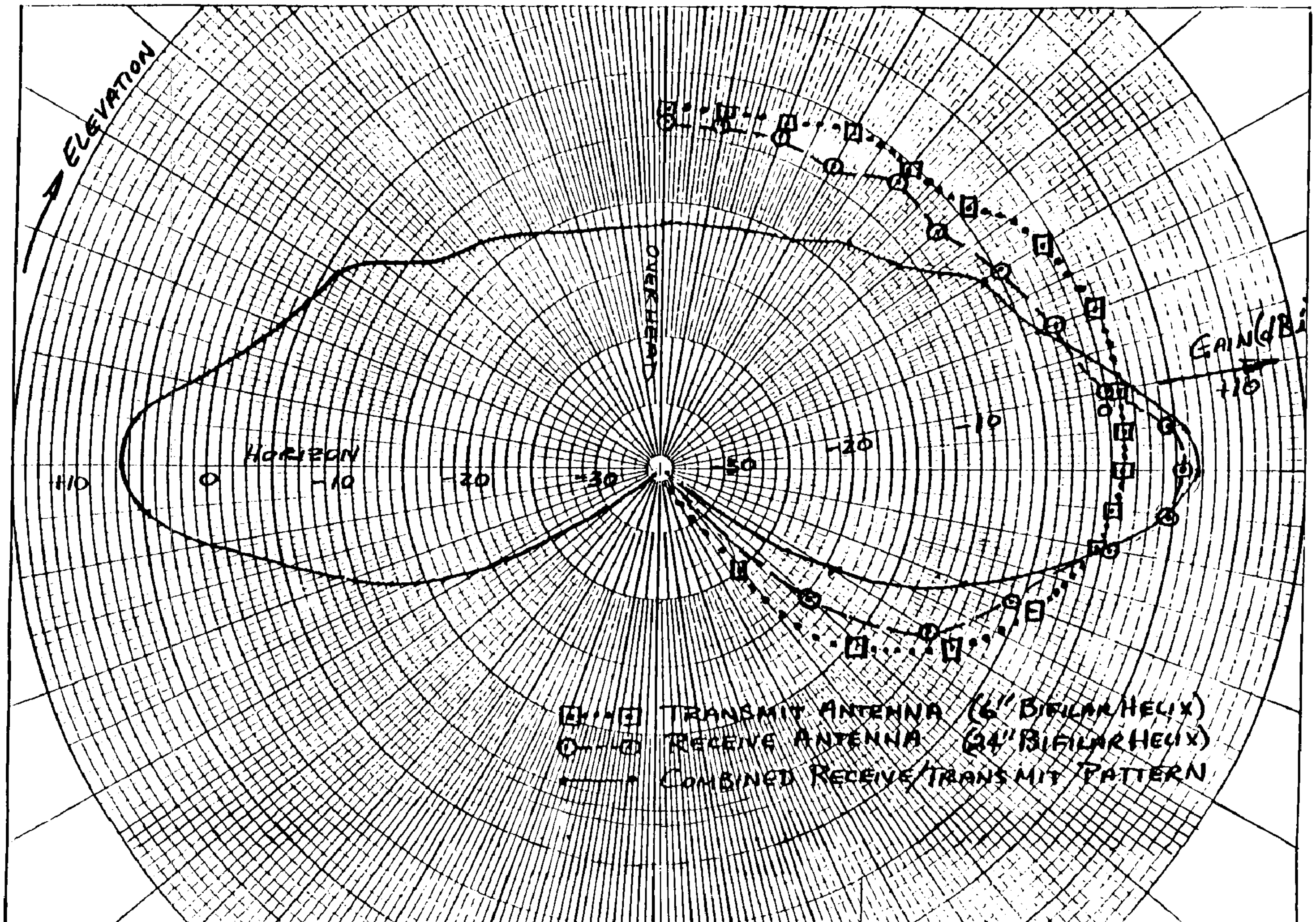

FIGURE 4 : ANTENNA PATTERNS, BIFILAR HELIX

The receiver and demodulator filters were chosen as a compromise between performance and selectivity. The receiver was designed to reject an identically modulated carrier 6 MHZ away from the desired carrier. The receiver/demodulator filter characteristics are as follows:

IF Bandpass Filter: four pole Butterworth, 4.2 MHZ 3dB bandwidth

Demodulator Lowpass filters: 4 pole Bessel, 1.4 MHZ 3dB bandwidth.

The desired carrier to noise ratio, with equal levels of desired and undesired signal power at the receiver inputs, was calculated to be 30.7 dB. Worst case interference occurs with the aircraft overhead at 30,000 feet. Worst case desired signal occurs at the horizon with 200 nautical mile slant range, and -5 ° of aircraft and ship roll. From the antenna performance described above, the relative received carrier levels are:

	DESIRED	INTERFERENCE	DELTA
Air plus ship antenna gain	+5 dBi	-16.5 dBi	DESIRED
Path loss	-151 dB	-119 dB	+32 db
Interference level above desired			+ 10.5 dB
CNR for equal interference and desired carrier:			30.7 dB
Worst case CNR (due to interference):			20.2 dB

Based on a required BER of 10 °, a CNR of 7.7 dB is necessary. The link therefore has a worst case fade margin at the horizon of 20.2 dB - 7.7 dB = 12.5 dB. It will be seen that this is almost identical to the overall link margin.

To assure data transitions required for bit synchronization and avoid creation of high power spectral lines, a CCITT V.35 scrambler was used.

The V.35 scrambler consists of a modulo 2 adder, a 20 stage shift register and an adverse state detector. The incoming data is added to the third and twentieth stages of the shift register. The result is a 1,049,575 pseudorandom pattern for a flat data input. The adverse data detector limits high frequency components by sensing and avoiding short repetitive sequences. To avoid having to resynchronize the Viterbi decoder due to a fade-induced carrier cycle slip, the scrambled data is then differentially encoded using temporary memory and an exclusive OR gate. By comparing each incoming bit with the previous bit, a logical one is produced when the bits are different, and a logical zero when they are the same. A convolutional encoder, paired with a Viterbi decoder is also employed. The differentially encoded data then goes to the convolutional encoder, which computes check bits or parity as a function of up to seven data bits, which corresponds to a constraint length of K = 7. Each bit into the encoder produces two output bits, which creates an input to output data rate of ½. The output data streams are multiplexed into one data stream, in which the G1 bit coincides with the first half of the clock, and the G2 bit coincides with the second half. Propagation delay errors in the encoder are corrected by putting the encoder output through a deglitcher.

The model 2713 integrated receiver was developed to perform the functions of down conversion, demodulation, bit synchronization, Viterbi decoding, differential decoding and descrambling. Special attention was given to selection of the carrier and clock recovery phase lock loop bandwidth. The bandwidths were chosen to assure that the loops were slow enough to flywheel through the expected duration of a fade, yet fast enough so that carrier synchronization, bit synchronization and node synchronization are typically acquired within 2 seconds at an Eb/No of 7.7 dB, and within 10 seconds as worst case. The worst case figure is based on the maximum time to sweep the 500 KHz bandwidth and acquire phase lock. The loss budget allocated for the 2713 is shown below, for a BER of 10^{-5}.

THEORETICAL Eb/No	9.6 dB
DIFFERENTIAL DECODING LOSS	+0.1 dB
DESCRAMBLING LOSS	+0.2 dB
BIT SYNC LOSS	+ 2.0 dB
CONVOLUTION DECODE GAIN	-5.5 dB
REQUIRED Eb/No	6.4 dB

PERFORMANCE

The system link performance at the horizon is shown below. It should be noted that the performance is given for both 0 ° and -5 ° roll angles from the horizon.

ROLL ANGLE FROM THE HORIZON	0°	5°
TRANSMITTER POWER OUTPUT	+52 dBm	+52 dBm
TRANSMIT CABLE LOSS	-0.5 dB	-0.5 dB
COMBINED Rx/Tx ANTENNA GAIN	+6.5 dBi	+4.5 dBi
POLARIZATION LOSS	0.0 dB	0.0 dB
PROPAGATION LOSS (200 nmi)	-151 dB	-151 dB
RECEIVED CARRIER LEVEL	-93 dBm	-95 dBm
PRESELECTOR LOSS	-0.2 dB	-0.2 dB
PREAMPLIFIER GAIN	40 dB	40 dB
CABLE LOSS	15.5 dB	15.5 dB
RECEIVER NOISE FIGURE	12 dB	12 dB
SYSTEM NOISE FIGURE	1.3dB	1.3 dB
ANTENNA TEMPERATURE	100 K	100 K
EQUIV.SYSTEM NOISE FIGURE	-1.6 dB	-1.6 db
NOISE INPUT POWER (BW = BR)	-114.1 dBm	-114.1 dBm
RECEIVED Eb/No	21.1 dB	19.1 d B
Eb/No REQUIRED FOR BER 10E-5	6.4 dB	6.4 dB
LINK MARGIN WITHOUT FADE (AT 200 nmi RANGE)	14.7 dB	12.7 dB
LINK MARGIN WITH FADE OF 8 dB (200 nmi RANGE)	6.7 dB	4.7 dB
LINK MARGIN WITH FADE OF 8 dB (400 nmi RANGE)	0.7 dB-	1.3 dB

CONCLUSION

The system has been installed in aircraft and ships of the Canadian Coast Guard as a part of a high reliability SAR based airborne reconnaissance system to provide navigational support to shipping. The use of convolutional and differential encoding, scrambling, and judicious antenna choices establish a highly reliable data link at small grazing angles over ice at ranges well in excess of 200 nautical miles.

REFERENCES

1. Mercer, J. Bryan. “A New Airborne SAR for Ice Reconnaissance Operations”, Proceedings of the IGARSS '89 Symposium, Vancouver, B.C. July 1989.

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