Design and Implementation of the 155Mbps Adaptive CODEC for Ka-band Satellite Communications

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Abstract – In this paper, we presented the design and implementation of 155Mbps satellite Modem adaptively compensated against the rain attenuation. In order to compensate the rain attenuation over high-speed satellite link, the adaptive coding schemes with variable coding rates and the pragmatic TCM that can be decoded both the QPSK and TC-8PSK using same Viterbi decoder was studied and analyzed. The pragmatic TCM with rate 2/3, selected to the optimal parameters for implementation, was modeled by VHDL in this paper. The key design issues are how to achieve a high data rate and how to integrated into a single ASIC chip various functions such as the different data rates, Scrambler/descrambler, Interleaver, Encoder/decoder, and BPSK/QPSK/8PSK modulator/demodulator. The implemented 155Mbps adaptive MODEM has the simplified interface circuits among the many functional blocks, and parallel processing architecture to achieve the high data rate. This 155Mbps adaptive MODEM was designed and implemented by single ASIC chip with the 0.25 μm CMOS standard cell technology.

I. Introduction

In high-speed information communication networks, the satellite communications play an important role to implement nation-to-nation network, emergency network, back-up network, backbone network, private network. National backbone network like ATM satellite communications require the high reliability(very low bit error rate). But due to rain fading and other channel impairments in satellite channel, especially Ka-band application of error correcting code scheme is necessary. Furthermore, the trend of satellite communication is transformed from narrow-band service to broadband multimedia service. Therefore during poor channel conditions, QPSK with (n,k,m) convolutional code is employed in order to maintain the performance. As channel conditions are improved, higher rate schemes such as TC-8PSK(Trellis Coded 8PSK) are used for satellite communications. In this paper, we implemented the 155Mbps Adaptive Modem for the Broadband Satellite Communications. Adaptive channel coding schemes are defined as European standard[1] which is DVB(Digital Video Broadcasting) specification. The Modem transmission frame is synchronous with the MPEG-2 transport stream(TS). The Modem was implemented BPSK, QPSK and 8PSK modulations, and the concatenation of convolutional and Reed-Solomon codes. For 8PSK, "pragmatic" trellis convolutional code is able to be configured flexibly, allowing the optimization of the system performance for a given satellite transponder bandwidth. Satellite systems can be affected by power limitations, therefore ruggedness against noise and interference has been one of the design objectives of the system. On the other hand, when larger power margins are available, spectrum efficiency can be increased to reduce the cost of the space segment. Therefore our adaptive modem offers many transmission modes(inner coding and modulations), giving different trade-offs between power and spectrum efficiency. All the modes are appropriated for operation in quasi-linear satellite channels. The specifications of the 155Mbps adaptive modem are Table 1. Figure 1 shows a 155Mbps Adaptive Satellite Modem.

Table 1. specifications of adaptive Modem

Items	Specifications
Modulation method	BPSK, QPSK, TC-8PSK, Continuous
Encoding/Decoding	Inner Code : Conv.(1/2,2/3,3/4,5/6, 7/8), TC(R=2/3,5/6,8/9) Interleaver : Conv. Interleaver Outer Code : RS(204,188)
Shaping/Matched filter	SQRC(α=0.25)
Demodulation	Blind Demodulation
Information Rate	155.52Mbps
Scrambling	V.35 scrambler

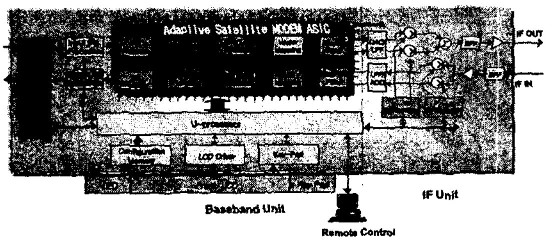


Figure 1. Fundamental Block diagram of the 155Mbps Broadband Adaptive Satellite Modem ASIC

II. Transmitter Structure of the 155Mbps Adaptive Modem

2.1. Randomization for energy dispersal

This modem input stream shall be organized in fixed length packets, following the MPEG-2 TS. The total packet length of the MPEG-2 TS is 188bytes. This includes 1 sync-word byte(i.e.,47HEX). In order to ensure adequate binary transitions, the data of the input MPEG-2 TS shall be randomized. To provide an initialization signal for the descrambler, the MPEG-2 sync byte of the first transport packet in a group of eight packets is bit-wise inverted from 47HEX to B8HEX. This process is referred to as the "Transport Multiplex Adaptation". Figure 2 shows a block diagram of the Scrambler in this modem.

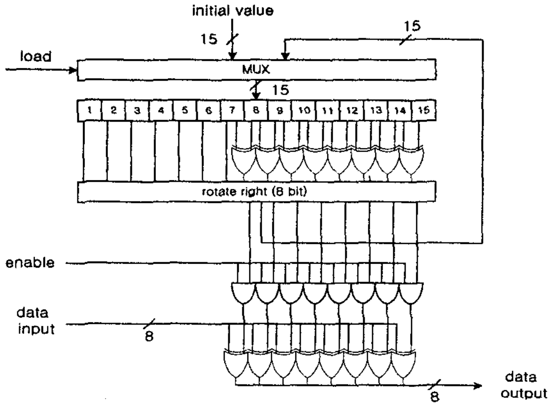


Figure 2. Block diagram of Scrambler

2.2. Outer coding(RS), interleaving and framing

Reed-Solomon RS(204, 188, T=8) shortened code, from the original RS(255,239,T=8) code, shall be applied to each randomized transport packet(188bytes) to generate an error protected packet. Reed-Solomon coding shall also be applied to the packet sync byte, either non-inverted(i.e.47_{HEX})or inverted(i.e.$B8_{HEX}$).
Convolutional interleaving with depth I=12 shall be applied to the error protected packets. This results in an interleaved frame composed of overlapping error protected packets and delimited by inverted or non-inverted MPEG-2 sync bytes(preserving the periodicity of 204 bytes).

2.3 Inner coding(convolutional)

This modem shall allow for a range of punctured convolutional codes, based on a rate 1/2 mother convolutional code with constraint length K=7 corresponding to 64 trellis states. This will allow selection of the most appropriate level of error correction for a given service or data rate. The modem shall allow convolutional coding with code rates of 1/2, 2/3, 3/4, 5/6 and 7/8.

2.4 Inner coding(pragmatic TCM(8PSK))

In this paper, we analyzed the pragmatic coding schemes which is based on realization of rate n/(n+1) trellis coded schemes using a single rate 1/2 encoder/decoder in conjunction with an MPSK signal mapper where M = 2^{n+1}. The term "pragmatic" refers to code implementation employing the widely used, best known rate1/2 convolutional encoder and the corresponding Viterbi decoder. The pragmatic trellis coded modulation shall be produced by the principle scheme shown in figure 3. For 8PSK rate 2/3, inner coding and decoding shall comply with the principle of figure 3. For rate 2/3, bit mapping in the 8PSK constellation shall follow the Ungerboeck's set partition rule. In order to make the 8/9 inner code, rate 2/3 punctured code is applied. If normalization factor $1/\sqrt{2}$ is applied to the I and Q components, the corresponding average energy becomes equal to 1.

III. Receiver Structure of the 155Mbps Adaptive Modem

3.1 Inner decoder

This unit performs first level error protection decoding. It should operate at an input equivalent "hard decision" BER in the order of between 10^{-1} and 10^{-2}(depending on the adopted code rate), and should produce an output BER of about $2*10^{-4}$ or lower. This unit makes use of "soft decision" information. This unit is in a position to try each of the code rates and puncturing configurations until lock is acquired. Furthermore, it is in a position to resolve $\pi / 2$ phase ambiguity.

3.2 Decoding process for rate 2/3(Pragmatic TCM)

As shown in figure 3, the decoder of pragmatic code consists of high-speed Viterbi decoder, sector phase quantizer, and soft decision logic. Sector phase quantizer is used for decoding the uncoded bit c_0 and soft decision logic makes the 3 bit soft decision inputs of the Viterbi decoder, which allows the decoder to accept not only a hard decision but also a relative 3 bits weight indicating the likelihood that received coded bit was a zero or a one. The Viterbi algorithm is well suited to use this information , the use of soft decisions will result in a performance gain of 2 dB over hard decision. In adapting the binary decoder, the use of soft decision is very important. The particular Viterbi decoder used in this system accepts soft decision inputs on a scale of 0 thru 7, with a soft decision 7 indicating the strongest binary 1, and a soft decision 0 indicating the strongest binary 0. With this in mind, the signal vector space is quantized, and a pair of soft decisions (one for each code bit), are assigned to each quantization point. Through simulation, the soft decision assignments of figure 4 were found to yield the best performance among reasonable alternatives.

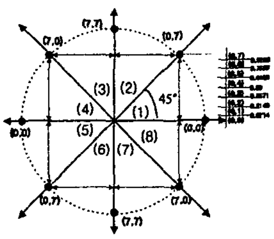


Figure 4. Case of 56 sector, soft decision assignment

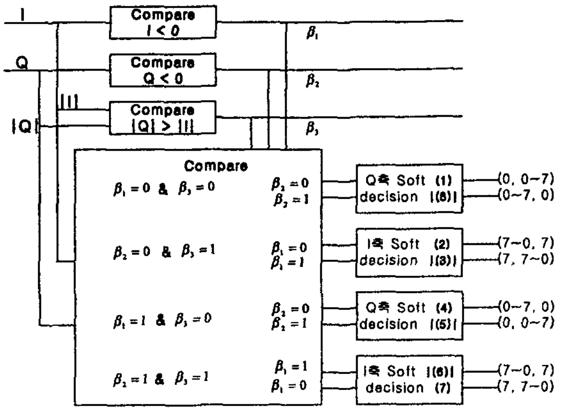


Figure 5. SPQ and Soft decision mapping block

The 56-sector phase quantizer(SPQ) was designed with the assumption that the in-phase and quadrature components of the receiver, noisy signal vectors will be converted to integer numbers, after the length of the received vector has been normalized. The circuit, shown in figure 5, three comparators and two absolute values generate a three bit phase code indicating one of sectors. Each of the three phase bits gives information about the location of the received vector: Ø2 and Ø3 indicate the quadrant, the remaining one bit indicates the location within the quadrant. When |I| < |Q|, Ø1 is one. This is simple logic to generate the soft decisions. Once the convolutional bit has been determined by Viterbi decoding, it remains to determine the outboard bit. This is accomplished by making a threshold decision. Clearly, which threshold should be used depends on the code bits. Maximum likelihood code bits are generated by reencoding the output of the encoder. Due to the structure of the Viterbi algorithm, every Viterbi decoder delays the data by a fixed number of symbol periods. The phase information used by the outboard decision logic must be delayed by banksize and bank number of 3-pointer trace back unit[2] to match up with the reconstructed code sequence[3][4]. First of all, the Viterbi decoder estimates the LSB of each symbol received. Since then, information bits of the LSB is used in the decoding process for bits(for second, third bit) except the LSB by reencoding. The reencoding process is used a same more stable decoding for the rest bits by using the decoded code again. The reencoded bits divide the first set partitioning of the 8PSK constellation and provide the standard subset for deciding the rest bit. The decoding for the rest bits except the LSB bit can be achieved the same process with QPSK demodulation process. In order to achieve the Viterbi decoding for the LSB bits, decoding delay is generated. Therefore, the buffer is necessary. For a transmitted signal point "001" in figure 6, the decoding procedure can be divided into two stages. In the first stage, the decision zones shown in figure 7 are used to decide the least significant bit, which could be either the information bit or the parity bit. Simultaneously, by using the decision zones shown in figure 7(a) and figure 7(b), the first two bits of the subsets B_0 and B_1, are decided separately. The Viterbi decoder then estimates the least significant bit of each symbol. Since the least significant bit of the symbol indicates the subset (B_0 or B_1) in which the signal point locates, the first two bits can be decided in the second stage based on the estimated least significant bit. As shown in figure 7, let's assume that the transmitted signal is $A = 001$. Suppose that the received signal locates at A' At the first stage, the decision maker outputs the first two bits $D_2D_1 = 01/B_0$ and $D_2D_1 = 00/B_1$, and the LSB is made as D_0=0 (type I error occurs here). At the second stage, if the number of errors is less than or equal to 3 within the block, the Viterbi decoder can determine the LSB as D_0=1, which indicates that the signal point locates in subset B1 to make the final decision $D_2D_1D_0$ = 001. However, if there are more than three errors in the block, the Viterbi decoder may not estimate the LSB as D_0=1, and the final decision may be $D_2D_1D_0$ = 010 and the decision error occurs.

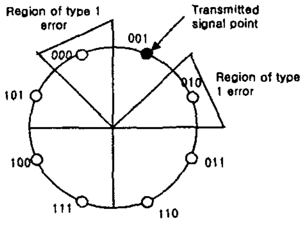
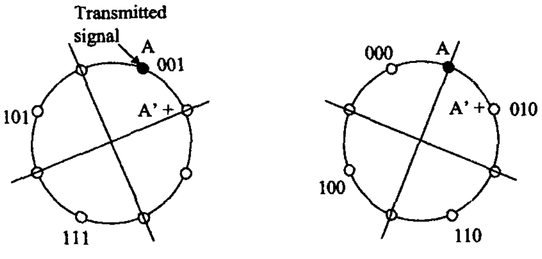


Figure 6. Decision zones and regions of type 1 error



(a) Subset B_1 (b) Subset B_0

Figure 7. Decision zone

3.3 Outer decoder

This unit provides second level error protection. It is in a position to provide BER of about 10^{-10} to 10^{-11}, Quasi error free) in the presence of input error bursts at a BER of about $7*10^{-4}$ or better with infinite byte interleaving. In the modem interleaving depth is I=12

IV. Simulation Results

In this section, we analyzed the performance of the pragmatic code according to number of sector and coding rate in additive white gaussian noise channel.

The BER performance of rate 2/3 for the sector phase numbers is shown in figure 8. At a bit error rate of 10^{-5} (log scale is -5), the pragmatic code with parallel transition achieves 2.5 dB coding gain over uncoded QPSK and only 0.5 dB is sacrificed than ungerboeck TCM. Also, we know that 24 sector phase is optimal at a bit error rate of a 10^{-5}.

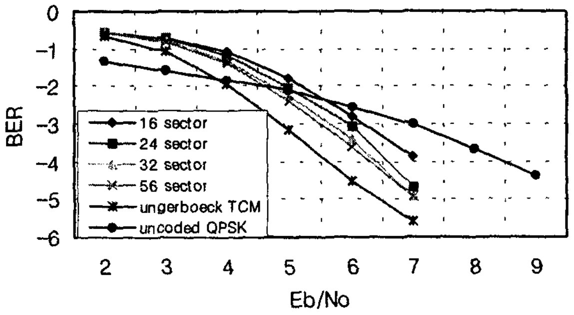
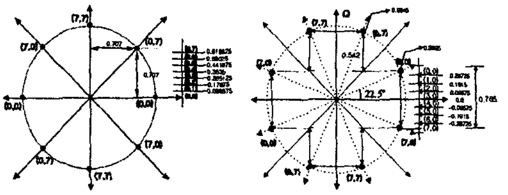


Figure 8. BER performance as sector phase numbers

Figure 9 shows the soft decision distance according to 8PSK constellation initiated at 0° and 22.5°. In the case of initiating at 0°(Figure 9(a)), the soft decision distance of 0.707 is the same at all the quadratures, but initiating at 22.5°(Fig. 9(b)), soft decision distance of Q -channel is 0.765 and I-channel is 0.542.



(a) 8PSK constellation initiated at 0°

(b) 8PSK constellation initiated at 22.5°

Figure 9. Softdecision assignment of 8PSK constellation initiated at 0° and 22.5°

Coding gain P of the two different mapping point is easily calculated as bellows and this calculated coding gain is 0.8dB. According to computer simulation, figure 10 shows that constellation of figure 9(a) achieves 0.78 dB coding gain over constellation of figure 9(b) at the 10^{-3} BER.

$$P = \frac{1}{2}\left(10\log_{10}\left(\frac{0.707^2}{0.765^2}\right) + 10\log_{10}\left(\frac{0.707^2}{0.542^2}\right)\right) \cong 0.8$$

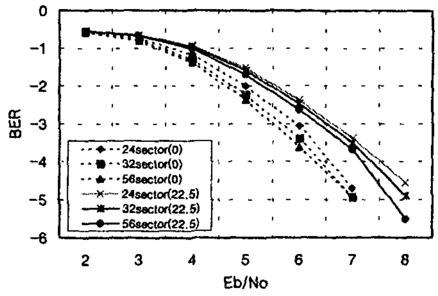


Figure 10. BER performance of 8PSK constellation of 0° and 22.5°

V. Conclusion

Today's satellite communication is required the high-speed data rate and the interactive broadband multimedia services. To satisfy this requirements, the above frequency band including Ka-band is necessary. But the rain fade is one of key factors to decrease the satellite channel quality if Ka-band is used. To overcome this factor in Ka-band satellite communication, we designed and implemented 155Mbps adaptive MODEM. This MODEM use QPSK with (n,k,m) convolutional code in order to maintain the required quality during poor channel conditions, and TC-8PSK during good channel conditions. This 155Mbps adaptive MODEM was designed and implemented by single ASIC chip with the 0.25 μm CMOS standard cell technology. In addition this MODEM can provide the several network interface both ATM network and MPEG-2 TS. Therefore this MODEM implemented single ASIC chip will be utilized to provide the Ka-band broadband satellite communication services with low cost, low power and small size.

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