Phase-Ambiguity Resolution for QPSK Modulation Systems

Part I: A Review

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ABSTRACT

Part I of this report reviews the current phase-ambiguity resolution techniques for Quaternary Phase-Shift-Keyed (QPSK) coherent modulation systems. Here, those known and published methods of resolving phase ambiguity for QPSK with and without Forward-Error-Correcting (FEC) are discussed. The purpose of this part is twofold: (1) to provide the background necessary for a complete understanding of the second part where a new technique will be discussed; (2) to recommend an appropriate technique to the Consultative Committee for Space Data Systems (CCSDS) for consideration in future standards on phase-ambiguity resolution for QPSK coherent modulation systems.

ACKNOWLEDGMENT

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I. INTRODUCTION

The inherent problem associated with coherent Quaternary Phase-Shift-Keyed (QPSK) systems is that of phase-ambiguity at the receiver. This is due to the inability of the carrier recovery circuit to distinguish the reference phase from the other phase (or phases) of the received carrier. For QPSK systems, there are eight possibilities of errors caused by the recovered carrier being at the wrong phase and also caused by phase rotation direction ambiguity (the two channels are reversed) in the transmission medium.

For uncoded systems, the phase-ambiguity problem can be resolved by using the differential encoding-decoding technique. However, this technique causes the decoded output to contain highly correlated errors (errors almost always occurring in pairs, double-error phenomenon). An alternate method of resolving the phase-ambiguity problem in the coherent QPSK systems is to make use of the sync markers already existing in the framed data transmission. For coded systems, the resolution of phase-ambiguity becomes more involved. For example, with the conventional differential coding method implemented inside an FEC encoder and decoder pair, a burst or double-error can occur. On the other hand, the use of the sync markers can result in the reduction of transmission efficiency.

The primary objective of this report is to review in a partly tutorial manner, the currently available phase-ambiguity resolution techniques that are suitable for use with coherent OQPSK systems. The techniques discussed in this report are applicable to both coded and uncoded systems. The secondary objective is to provide proper guidance to the CCSDS regarding this subject.

In summary, Part I is intended to provide the necessary background material for Part II of this report. Part II will emphasize new phase-ambiguity resolution techniques for the coherent QPSK systems.

II. COHERENT QPSK MODULATION SYSTEM

Before going into details of the current available phase-ambiguity resolution techniques, it is essential to describe the basic structure of a coherent QPSK modulation system. Depicted in Figure 1 is a simplified diagram of a coherent QPSK communications link. The modulator accepts the Non-Return-to-Zero (NRZ) input data (D_T), a clock input (c_T), and an RF carrier of frequency f_c. The NRZ input data stream entering the modulator is converted by a serial-to-parallel converter into two separate NRZ data streams I_T (In phase, I-branch) and Q_T (Quadrature phase, Q-branch), with a symbol rate equal to half that of the input data bit rate. Both I_T and D_T data streams are inputted separately to the multipliers. The second input to the

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multiplier in the I- branch is the carrier signal $(\cos(2\pi f_c t))$, and the second input to the Q-branch multiplier is the carrier signal shifted by 90° (i.e. $\sin(2\pi f_c t)$). The outputs of both I and Q multipliers are BPSK signals. The multiplier outputs are then summed to obtain the QPSK signal. At the receiver, the demodulator performs the inverse operation of the modulator and generates the output data stream $D_R \approx D_T$. For a coherent QPSK system, a coherent carrier must be recovered from the received signal and a coherent clock must be reconstructed from the demodulated data waveform.

FIGURE 1. BASIC QPSK SYSTEM REPRESENTATION

BASIC QPSK MODULATOR

BASIC QPSK DEMODULATOR
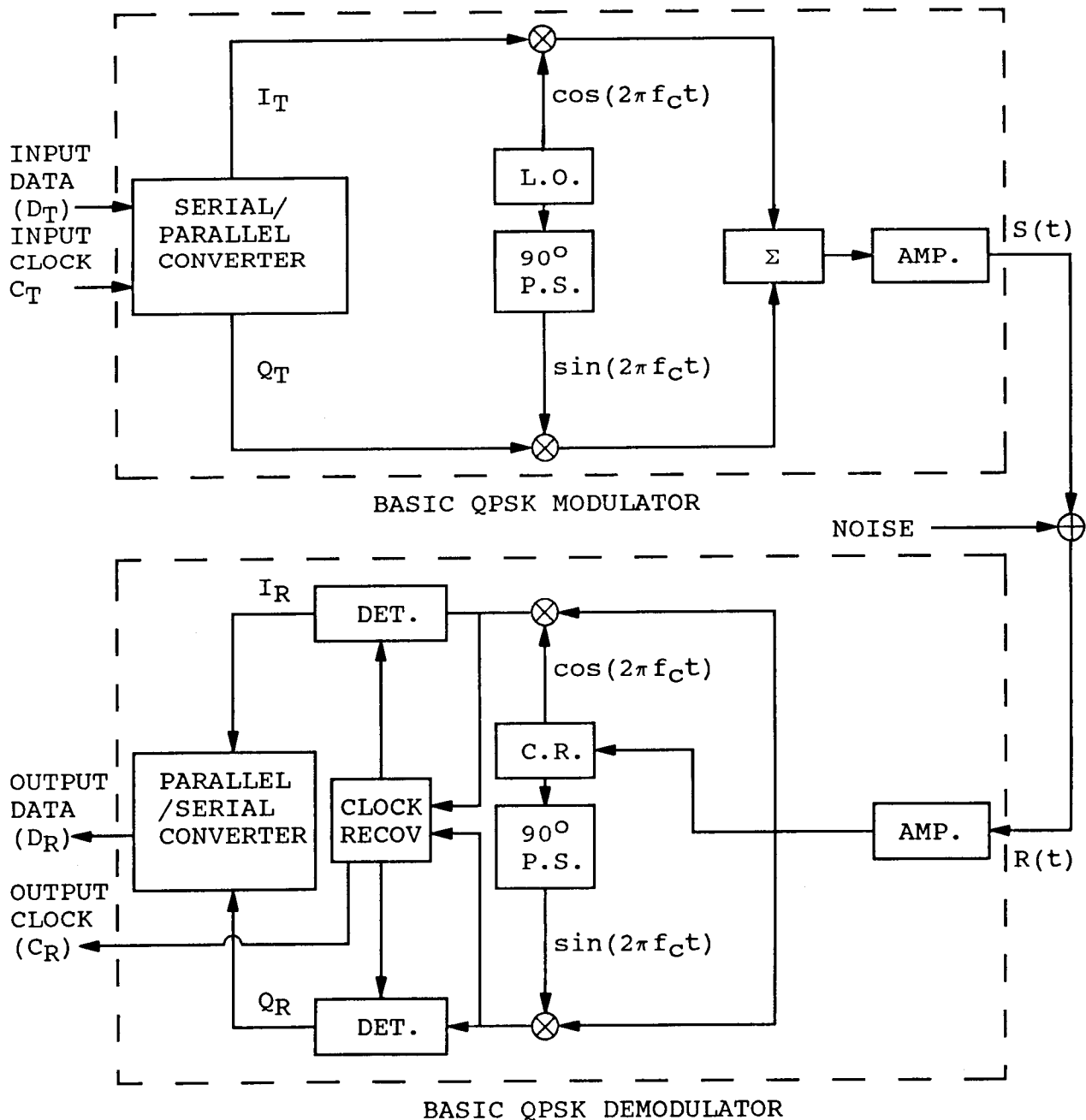
L.O.   : local oscillator
P.S.   : phase shifter
AMP.   : amplifier and filter
C.R.   : carrier recovery unit
DET.   : detector unit
S(t)   : transmitted signal
R(t)   : received signal

The received data stream D_R is not always equal to the transmitted data stream D_T due to the phase-ambiguity in the phase of the recovered carrier. If the carrier recovery (C.R.) circuit locks on the reference phase of the received carrier, then $I_T \simeq I_R$, and $Q_T \simeq Q_R$. This gives $D_T = D_R$. The effect of an incorrectly recovered-carrier phase on the demodulated data is shown in Table 1.

TABLE 1. THE RELATIONSHIPS BETWEEN THE TRANSMITTED AND
RECEIVED DATA

CARRIER PHASE ERROR (DEGREE)	RECEIVED DATA WITHOUT PHASE ROTATION DIRECTION AMBIGUITY (NORMAL SENSE) I_R Q_R		RECEIVED DATA WITH PHASE ROTATION DIRECTION AMBIGUITY (REVERSE SENSE) I_R Q_R	
0	I_T	Q_T	Q_T	I_T
90	$-Q_T$	I_T	I_T	$-Q_T$
180	$-I_T$	$-Q_T$	$-Q_T$	$-I_T$
270	Q_T	$-I_T$	$-I_T$	Q_T

NOTE: The negative sign indicates the complement of the data.

From the above table, it is apparent that for each case (normal or reverse sense) the locked-in phase may be any one of four possible phases. Hence, ambiguity of the fourth degree results. Thus, the resolution of the eight possible relationships between the transmitted and the received phase is a formidable problem in the QPSK system. There are several techniques available for the resolution of this phase-ambiguity. The following sections will discuss these techniques.

III. CLASSIFICATION OF PHASE-AMBIGUITY RESOLUTION TECHNIQUES

The phase-ambiguity resolution techniques can be classified into two categories: (1) differential coding technique, and (2) nondifferential coding technique. For an uncoded QPSK system, the nondifferential coding technique may be described as a "unique-word detection technique." For a coded system, it may be regarded as a "threshold decoder technique," and as a "unique-word detection technique." A simple classification of phase-ambiguity resolution techniques is shown in Figure 2.

FIGURE 2. A LIST OF PHASE-AMBIGUITY RESOLUTION TECHNIQUES

```
                          ┌──────────────┐
                          │ QPSK SYSTEM  │
                          └──────┬───────┘
               ┌─────────────────┴─────────────────┐
      ┌────────────────┐                   ┌────────────────┐
      │ UNCODED QPSK   │                   │  CODED QPSK    │
      │    SYSTEM      │                   │    SYSTEM      │
      └───────┬────────┘                   └───────┬────────┘
         ┌────┴─────┐                         ┌─────┴─────┐
 ┌─────────────┐ ┌─────────────┐      ┌─────────────┐ ┌─────────────┐
 │ DIFFERENTIAL│ │ UNIQUE WORD │      │ DIFFERENTIAL│ │ NONDIFFER-  │
 │   CODING    │ │  DETECTION  │      │   CODING    │ │   ENTIAL    │
 │  TECHNIQUE  │ │  TECHNIQUE  │      │  TECHNIQUE  │ │   CODING    │
 └──────┬──────┘ └─────────────┘      └──────┬──────┘ │  TECHNIQUE  │
                                             │        └──────┬──────┘
     ┌─────┴─────┐                        ┌─────┴─────┐
 ┌─────────────┐ ┌─────────────┐      ┌─────────────┐ ┌─────────────┐
 │ DIFFERENTIAL│ │ DIFFERENTIAL│      │  THRESHOLD  │ │ UNIQUE WORD │
 │  INSIDE FEC │ │ OUTSIDE FEC │      │   DECODER   │ │  DETECTION  │
 │    CODEC    │ │    CODEC    │      │  TECHNIQUE  │ │  TECHNIQUE  │
 └─────────────┘ └─────────────┘      └─────────────┘ └─────────────┘
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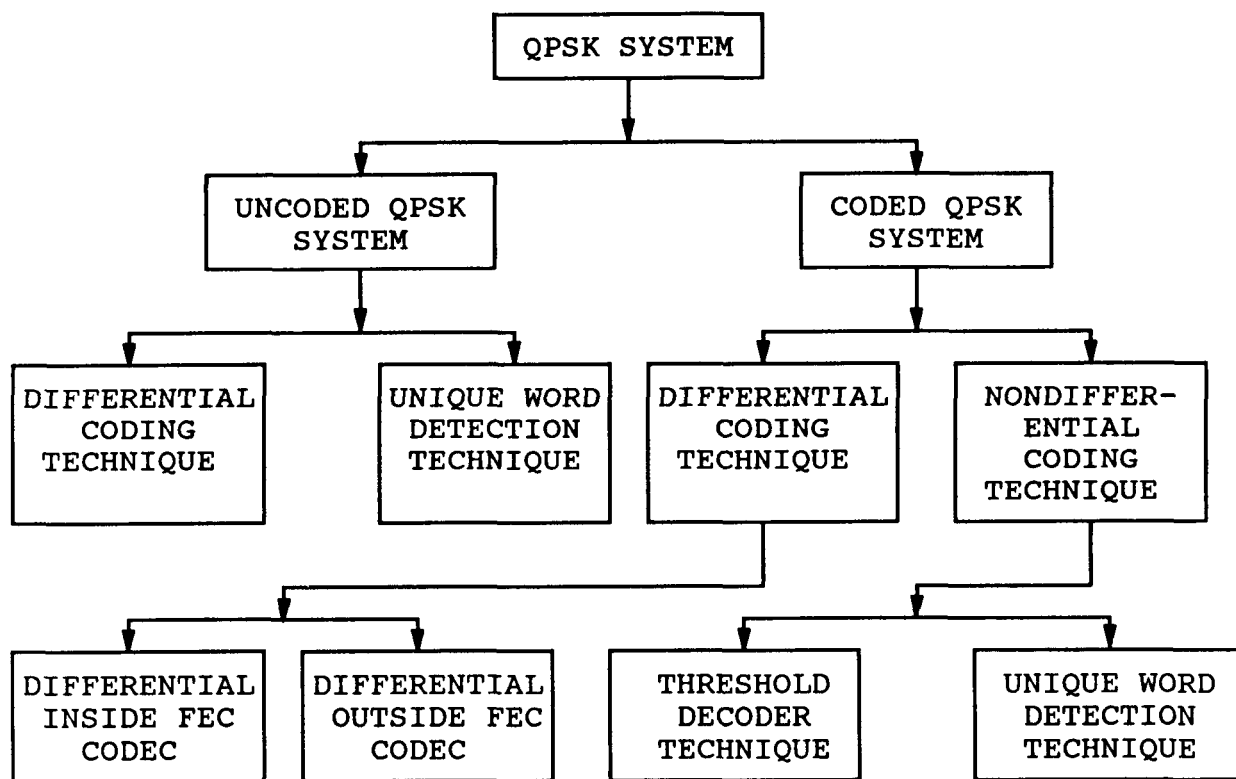
LEGEND:

FEC   :   forward-error-correcting
CODEC: encoder and decoder pair

IV. PHASE-AMBIGUITY RESOLUTION TECHNIQUES FOR UNCODED QPSK SYSTEMS

IV.1. DIFFERENTIAL CODING TECHNIQUE

This technique is well known in literature [Refs 1, 2, 3, 4, 7]. The differential encoder-decoder can be inserted into the CODEC. The receiver resolves the phase ambiguities based on the difference between the detected symbol phases. Since the

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difference is independent of the locked-in phase, the four-phase ambiguity associated with each case (normal or reverse sense) disappears. A simple QPSK system with the differential encoder and decoder is illustrated in Figure 3.

FIGURE 3. QPSK SYSTEM WITH DIFFERENTIAL ENCODER-DECODER

QPSK MODULATOR

QPSK DEMODULATOR
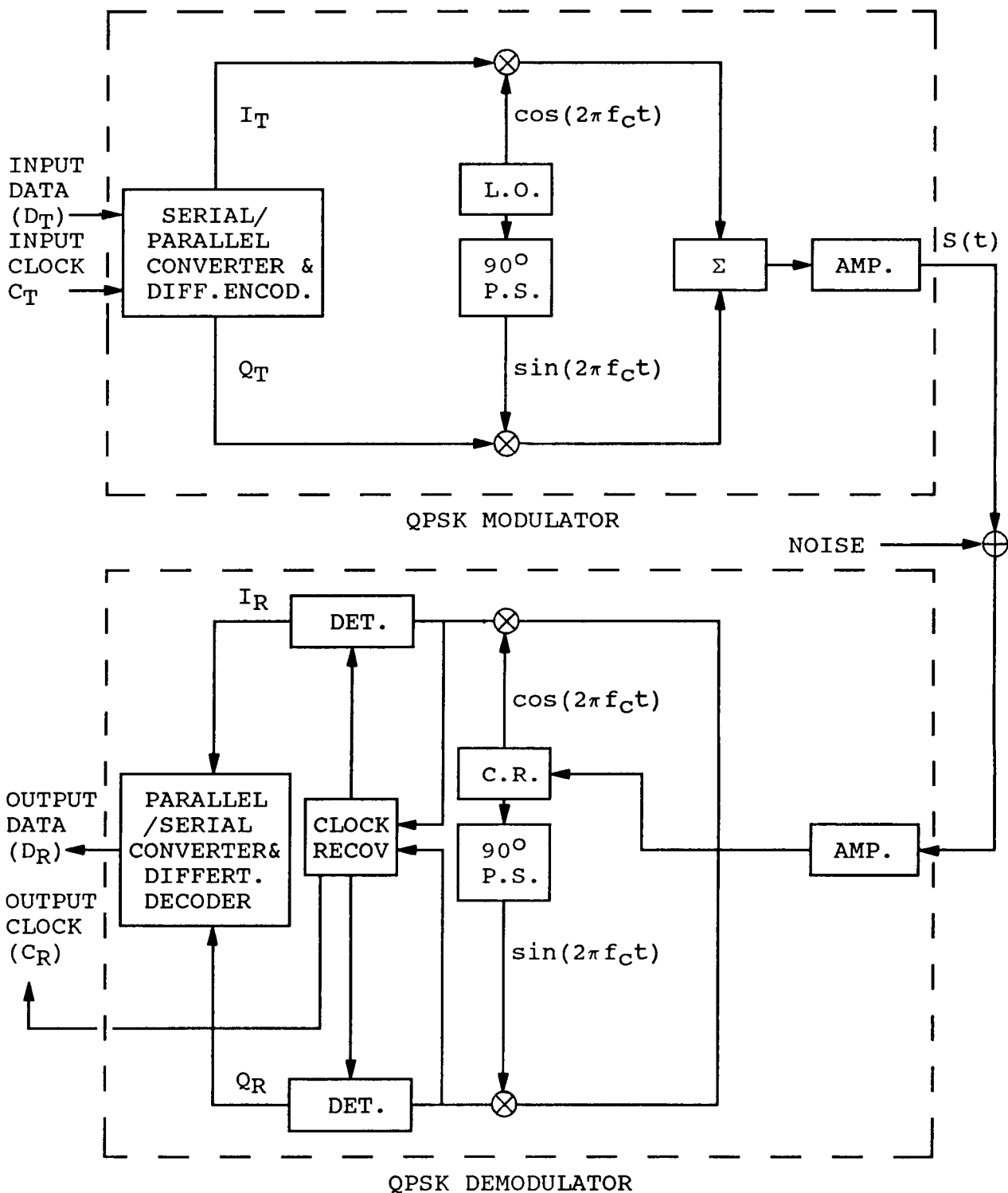
ADVANTAGE: This technique is very simple to implement and can be performed in the modem independently on any data acquisition equipment [Refs 3, 6].

DISADVANTAGE: Due to the burst error (one erroneously detected phase will cause two consecutive false symbols) associated with this technique, the detection performance of the transmitted sync markers can be degraded seriously [Ref. 6].

IV. 2. UNIQUE-WORD DETECTION TECHNIQUE

This technique was developed by Wolejsza and Cacciamani [Refs 5, 8]. It utilizes the two unique words (sync words) which are separately modulated onto the two quadrature channels at the transmitter. Since there are eight possible combinations of the two possible cases (as shown in Table 1), each combination uniquely defines the phase ambiguity. Thus, each error appearing in the two data channels of the QPSK demodulator is uniquely defined by a particular phase error. The technique proposed here is to simply correct the errors at the outputs of the channels by using the two unique words. The correction is done by monitoring and detecting the true or complement of the two unique words. For example, if the two unique words are detected in their complements, then the received data should be inverted. It should be noted here that this technique does not identify the phase error of the recovered coherent carrier which caused the errors, but corrects the errors caused by the phase errors. A generalized block diagram of the modulator and demodulator with phase-ambiguity correction using unique-word detection is shown in Figures 4 and 5, respectively.

Figure 4 shows that the unique words A_u and B_u (the length of each unique word is N) are inserted into the quadrature channels before the carrier modulation. At the receiver, as shown in Figure 5, the basic QPSK demodulator is modified with the unique-words detector. The block diagram of a generalized unique-words detector is shown in Figure 6. This detector is comprised of invertors, gating means (these are used to shift the shift-registers), shift registers, correlators, and a decoding matrix. The operation of this generalized unique-words detector is carefully explained in References 5 and 8.

Figures 5 and 6 illustrate a generalized form of logic for performing the correction of errors caused by phase errors. However, a preferred form of correction logic is shown in Figures 7 and 8. It is seen, from Figure 7, that the data in the I and Q channels are combined prior to detecting the unique words A_u, B_u and their complements $-A_u$, $-Bu$. As shown in Figure 8, this connection enables the elimination of two correlators in the unique-word detector. The detail of the decoding matrix is described in Reference 8.

FIGURE 4. QPSK-MODULATOR WITH UNIQUE WORDS MODULATION

CODE WORD
A_u

INPUT
DATA
(D_T)
INPUT

CLOCK
C_T

SERIAL/
PARALLEL
CONVERTER

I_T

$\cos(2\pi f_c t)$

L.O.

90°
P.S.

Q_T

$\sin(2\pi f_c t)$

CODE WORD
B_u

Σ

AMP.

$S(t)$

FIGURE 5. GENERALIZED BLOCK DIAGRAM OF QPSK-DEMODULATOR
WITH PHASE-AMBIGUITY CORRECTION USING UNIQUE-
WORDS DETECTION TECHNIQUE

CHANNEL IDENTIFICATION

$R(t)$

BASIC QPSK-
DEMODULATOR
(SEE FIGURE 1
FOR DETAIL
DESCRIPTION)

I_R

Q_R

UNIQUE WORDS
DETECTOR

I

Q

PARALLEL/
SERIAL
CONVERTER

DATA
OUTPUT

$D_R = D_T$

CLOCK
OUTPUT
(C_R)

C_R

CR

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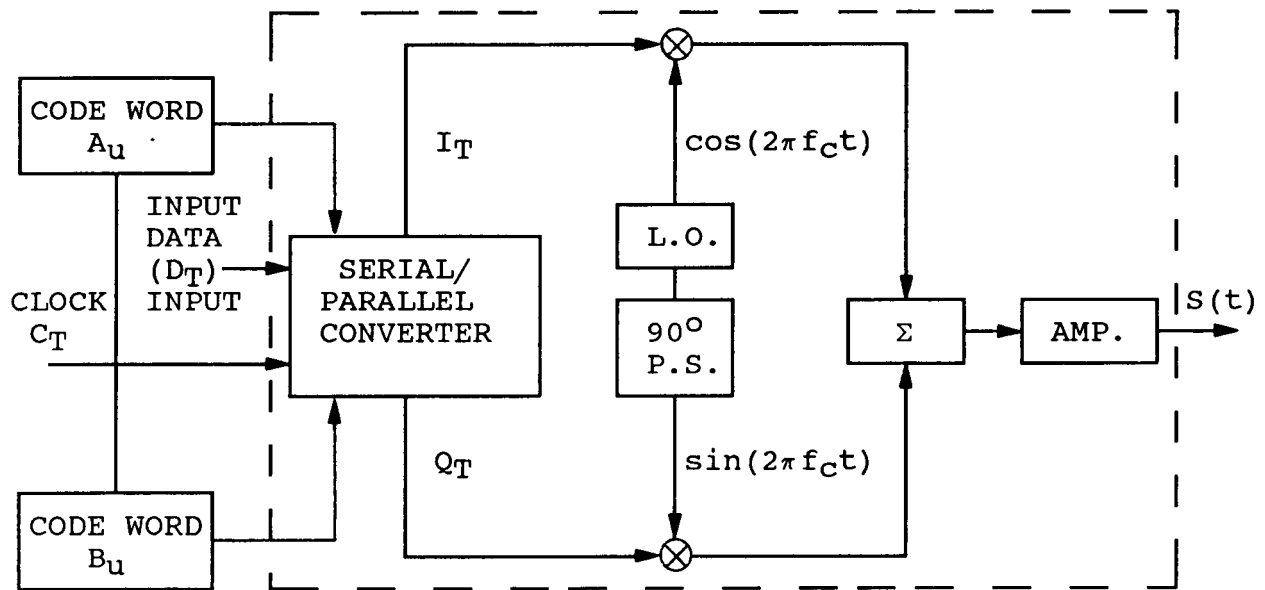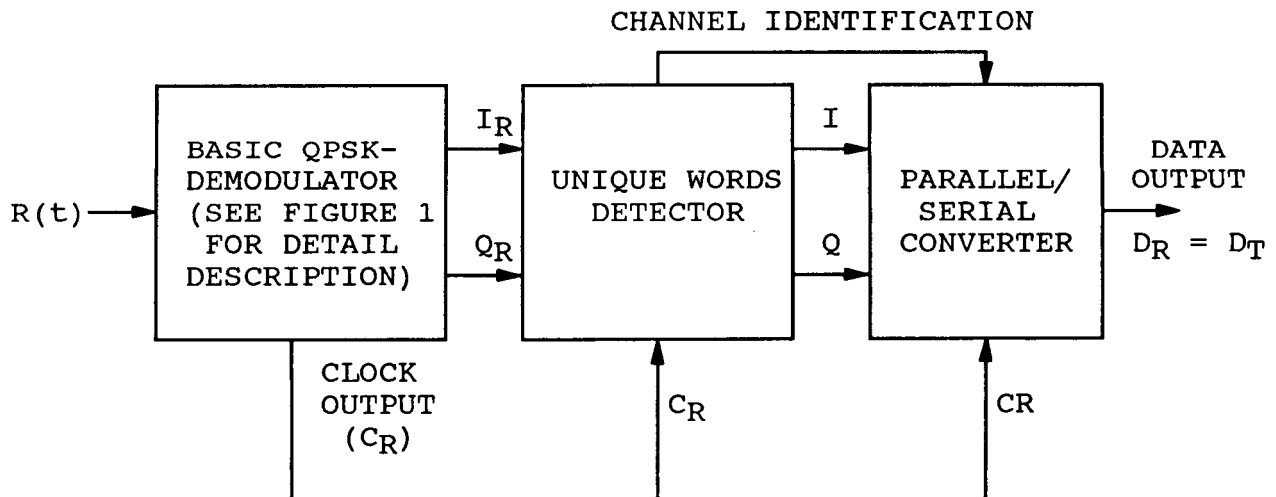FIGURE 6. GENERALIZED BLOCK DIAGRAM OF THE UNIQUE-WORD DETECTOR
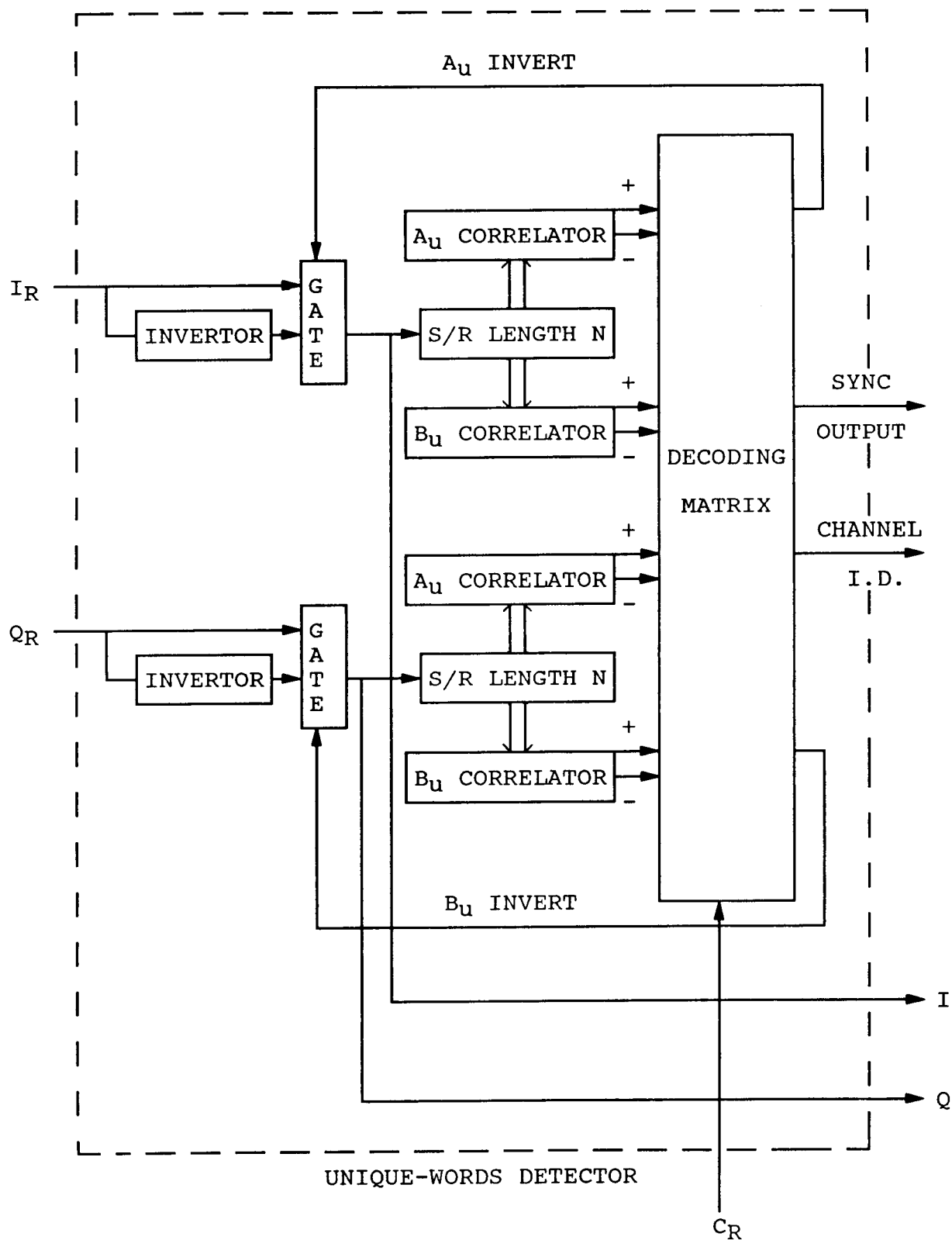
FIGURE 7. PREFERRED BLOCK DIAGRAM OF QPSK-DEMODULATOR
WITH PHASE-AMBIGUITY CORRECTION USING UNIQUE-
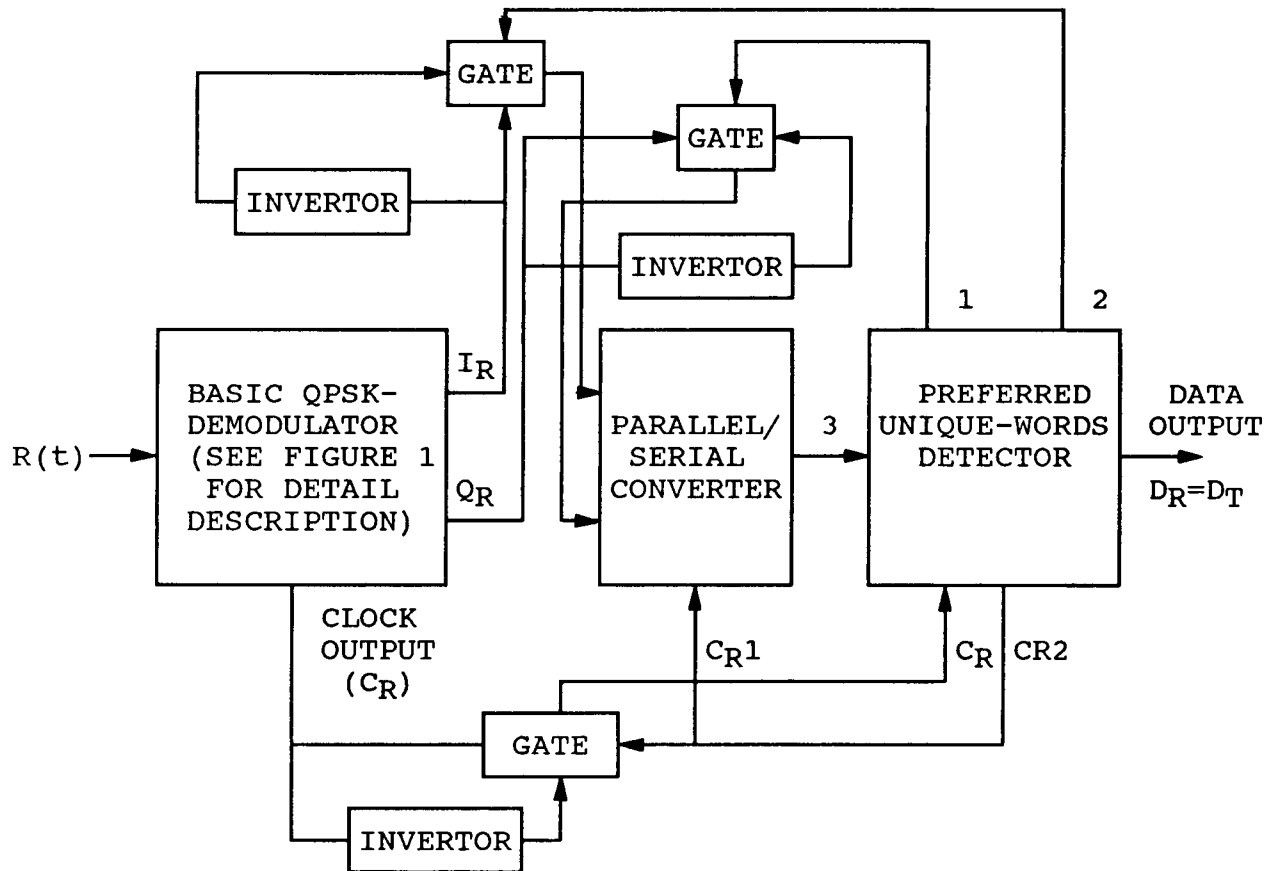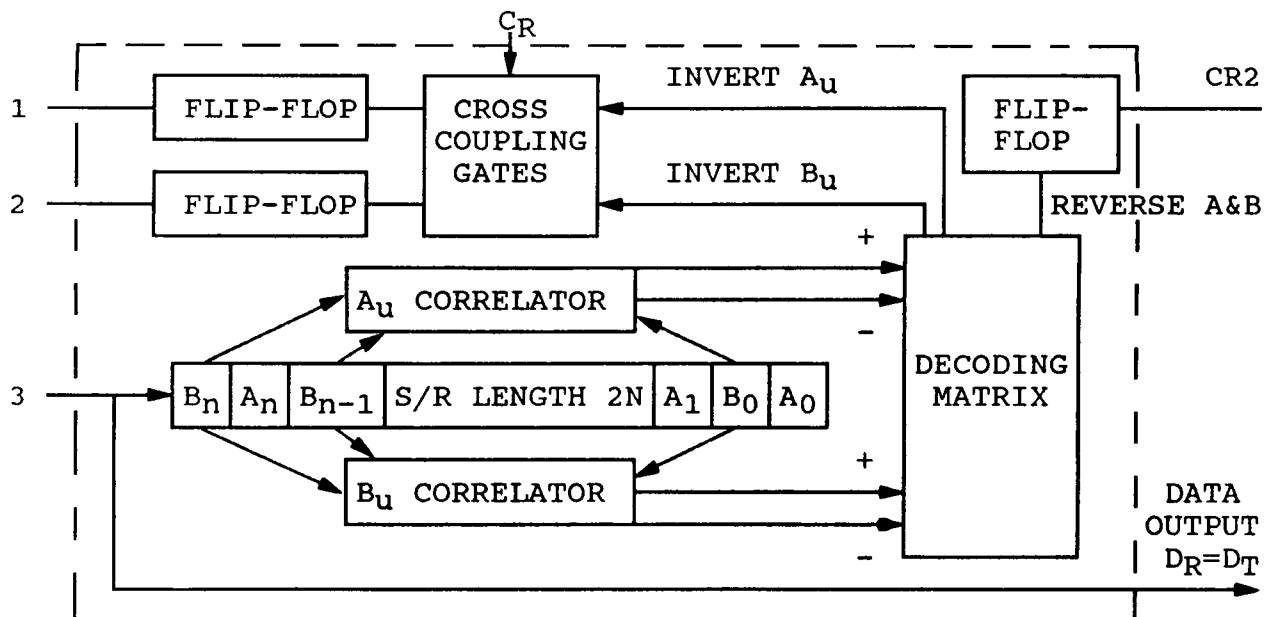WORD DETECTION TECHNIQUE

FIGURE 8. PREFERRED BLOCK DIAGRAM FOR UNIQUE-WORD DETECTOR

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ADVANTAGE: The sync markers already existing in the framed data transmission can be used as the unique words for resolving the phase ambiguity. The unique-word detection technique also has the advantage of not excluding the use of FEC techniques [Ref.6].

DISADVANTAGE: This technique is more complex than the differential encoding-decoding technique. This technique also requires a careful selection of a suitable pattern for the unique words in order to achieve a low probability of false detection. This technique also has the deficiency of increasing the number of non-information bits in the total data stream, thereby increasing the bandwidth necessary to transmit a given amount of information.

V. PHASE-AMBIGUITY RESOLUTION TECHNIQUES FOR CODED QPSK SYSTEMS

V.1. DIFFERENTIAL CODING TECHNIQUES

As shown in Figure 2, this technique can be classified into two categories: (1) phase-ambiguity resolution by differential coding inside FEC codec; and (2) phase-ambiguity resolution by differential coding outside FEC codec.   In this subsection we briefly describe these two techniques.

V.1.1. DIFFERENTIAL CODING INSIDE AN FEC CODEC

A generalized block diagram for phase-ambiguity resolution by using the differential coding internal to error-control coding is shown in Figure 9. This scheme has a major drawback which is serious degradation in the bit error rate due to the burst error. It is well known, for the differential coding scheme, that one erroneously detected phase will cause two consecutive false symbols (a burst error) even if the next phase is received correctly. This burst error can cause serious degradation to the decoder [Refs 6, 9, 10].   A bit error rate degradation of 3 dB can occur [Ref. 6].

The adverse effect of the differential coding inside the FEC codec can be eliminated by using the symbol interleaving method [Ref. 10].   The even and odd symbols are encoded independently so that the burst error is changed to random error, thus avoiding unnecessary degradation. The block diagram for this preferred scheme is illustrated in Figure 10.

ADVANTAGE: (a) WITHOUT SYMBOL INTERLEAVING: The use of the differential coding inside the FEC codec without using symbol interleaving does not require synchronization time to eliminate the phase ambiguity for the error decoder.   (This technique can be used in either burst mode signal or a continuous mode signal); (b) WITH SYMBOL INTERLEAVING: This technique does not degrade the capability of FEC codes with simplified hardware [Ref. 10].

DISADVANTAGE: (a) WITHOUT SYMBOL INTERLEAVING: Serious bit error rate degradation due to burst error can occur; (b) WITH SYMBOL INTERLEAVING: Since two buffer memories are alternately required to read the bits corresponding to a symbol, the operation of this technique depends on the reading ability of the buffer memories.

FIGURE 9. GENERALIZED BLOCK DIAGRAM FOR PHASE-AMBIGUITY RESOLUTION USING DIFFERENTIAL CODING INSIDE AN FEC CODEC

TRANSMITTER

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           ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐
           |  ┌──────────┐  ┌──────────────┐  ┌──────────┐  |
INPUT ───▶ |  │   FEC    │  │ DIFFERENTIAL │  │   QPSK   │  | ───▶ S(t)
DATA       |  │ ENCODER  │─▶│   ENCODING   │─▶│ MODULATOR│  |
           |  └──────────┘  └──────────────┘  └──────────┘  |
           └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘
```

RECEIVER

```
           ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐
           |  ┌──────────┐  ┌──────────────┐  ┌──────────┐  |  OUTPUT
R(t) ───▶  |  │   QPSK   │  │ DIFFERENTIAL │  │   FEC    │  | ───▶ DATA
           |  │DEMODULATOR│─▶│   DECODING   │─▶│ DECODER  │  |
           |  └──────────┘  └──────────────┘  └──────────┘  |
           └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘
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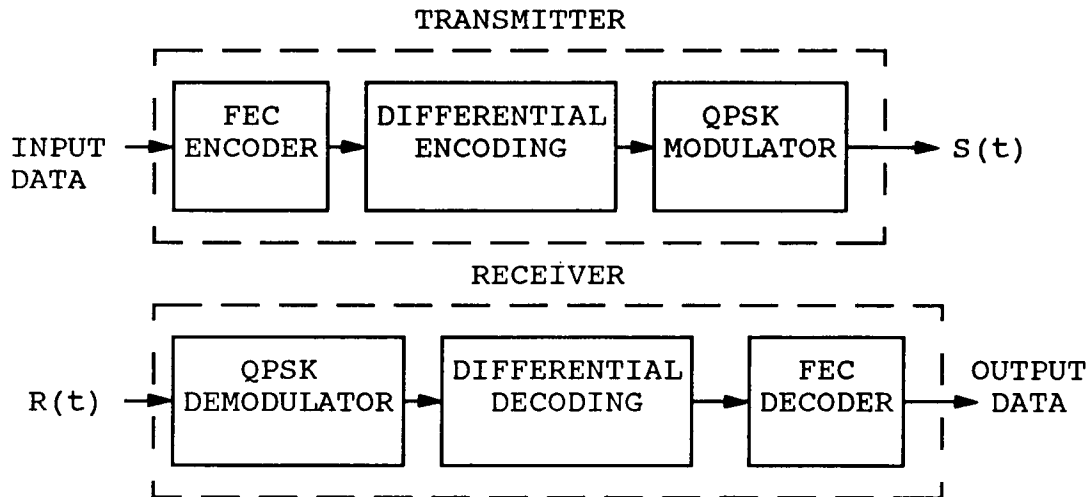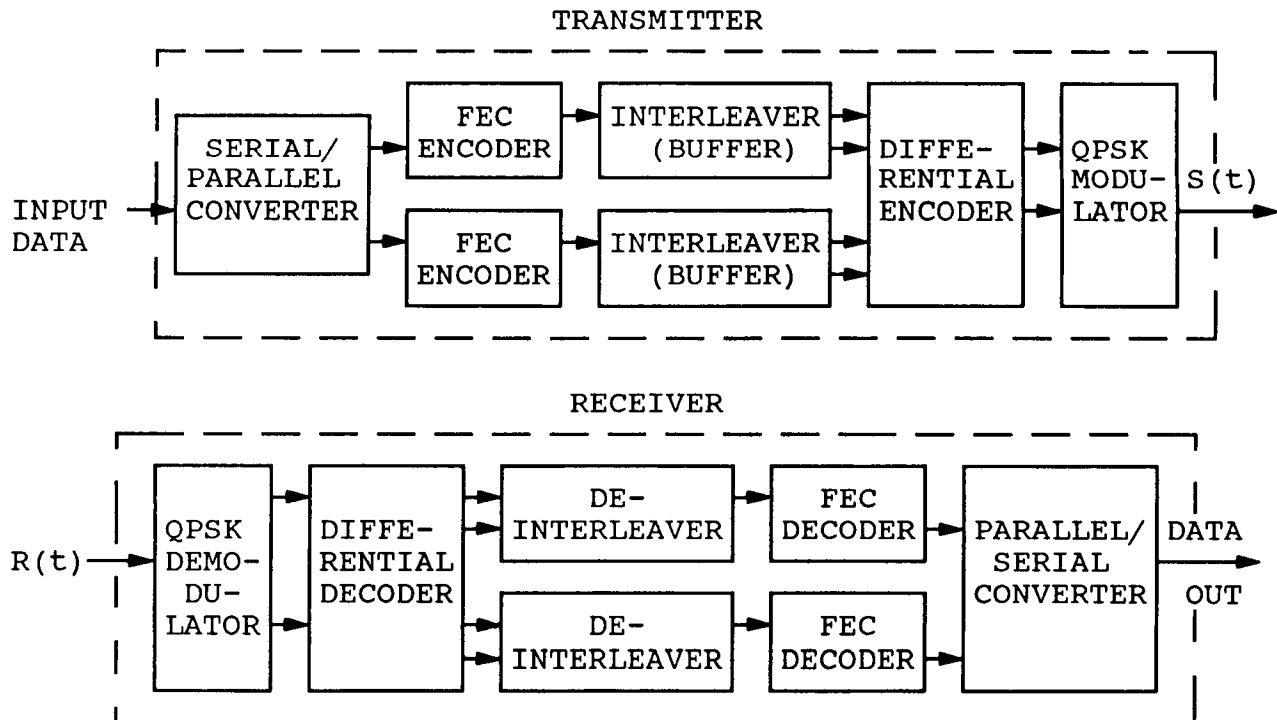
FIGURE 10. A BLOCK DIAGRAM FOR PHASE-AMBIGUITY RESOLUTION USING DIFFERENTIAL CODING INSIDE AN FEC CODEC WITH SYMBOL INTERLEAVER (A PREFERRED TECHNIQUE)

TRANSMITTER

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        ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐
        |              ┌─────────┐  ┌────────────┐                  |
        |              │   FEC   │  │ INTERLEAVER │                 |
        |   ┌────────┐ │ ENCODER │─▶│  (BUFFER)   │─▶┌────────┐ ┌────────┐|
        |   │SERIAL/ │─│└─────────┘  └────────────┘  │DIFFE-  │ │ QPSK   │|
INPUT ─▶|   │PARALLEL│ │                             │RENTIAL │─▶│MODU-   │| S(t) ─▶
DATA    |   │CONVERTER│ │┌─────────┐  ┌────────────┐  │ENCODER │ │LATOR   │|
        |   └────────┘ │└│   FEC   │  │ INTERLEAVER │─▶└────────┘ └────────┘|
        |              │ ENCODER │─▶│  (BUFFER)   │                |
        |              └─────────┘  └────────────┘                |
        └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘
```

RECEIVER

```
        ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐
        |  ┌──────┐ ┌────────┐  ┌──────────┐  ┌────────┐              |
        |  │ QPSK │ │DIFFE-  │─▶│   DE-    │─▶│  FEC   │─▶┌──────────┐ | DATA
R(t) ─▶ |  │DEMO- │─│RENTIAL │  │INTERLEAVER│  │DECODER │ │PARALLEL/ │ | ───▶
        |  │DU-   │ │DECODER │  └──────────┘  └────────┘  │ SERIAL   │ | OUT
        |  │LATOR │ │        │─▶┌──────────┐─▶┌────────┐─▶│CONVERTER │ |
        |  └──────┘ └────────┘  │   DE-    │  │  FEC   │  └──────────┘ |
        |                       │INTERLEAVER│  │DECODER │               |
        |                       └──────────┘  └────────┘               |
        └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘
```

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V.1.2. DIFFERENTIAL CODING OUTSIDE AN FEC CODEC

Since differential coding is used outside an FEC codec, the unnecessary bit error rate degradation due to burst error can be avoided. This is because the error correcting decoder does not encounter the double-error phenomenon, and only the bit error rate of the error-correcting decoder output is doubled. Note that this decoder output bit error rate is an improved bit error rate due to error correcting action. Doubling the decoder output error rate results in a smaller bit signal-to-noise ratio loss than doubling the input error rate because the curve of bit error rate versus bit signal-to-noise ratio is steeper for the decoder output [Ref. 10]. A generalized block diagram for the differential coding external to error-control coding is depicted in Figure 11.

FIGURE 11. GENERALIZED BLOCK DIAGRAM FOR PHASE-AMBIGUITY RESOLUTION USING DIFFERENTIAL CODING OUTSIDE AN FEC CODEC
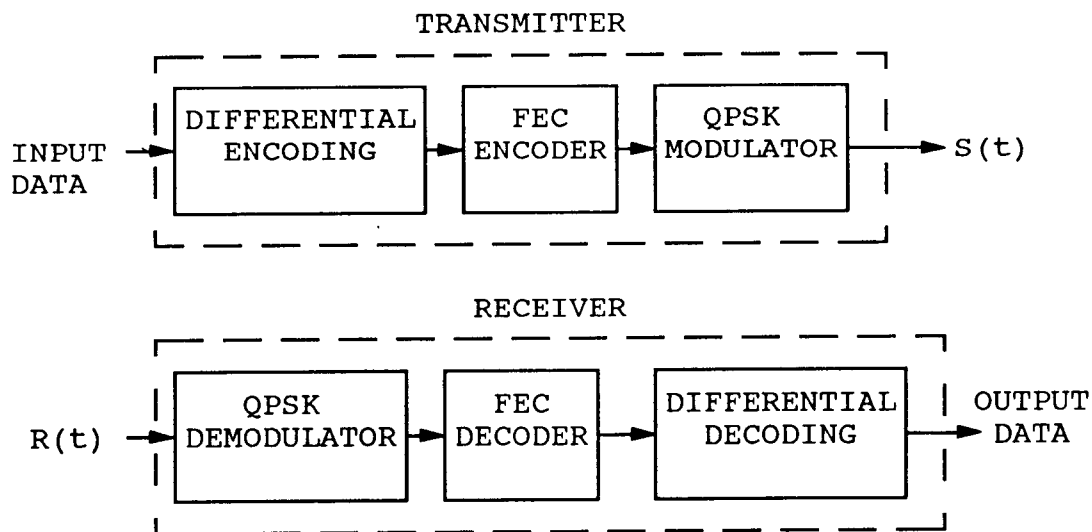
It is important to note here that the phase-ambiguity resolution by using differential coding external to error-control coding is to be used together with the synchronizer circuit of the FEC decoder.

For systems using nontransparent codes that do not have phase rotation direction ambiguity, there is no need for differential encoding because the synchronizer itself can resolve the phase ambiguity [Ref. 10]. This topic will be discussed in a subsequent section. For systems that have both phase rotation direction ambiguity (reverse sense) and recovered carrier phase ambiguity (normal sense), the differential coding is always required regardless of the type of codes used (transparent or nontransparent). A detailed description of these schemes is presented in Reference 10.

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ADVANTAGE: This technique eliminates the unnecessary bit error rate degradation due to double-error phenomenon.

DISADVANTAGE: The resolution performance depends on the synchronizer circuit of the FEC decoder. This technique is not suitable for application to burst mode operation due to a relatively long time for resolving the phase ambiguity.

V.2 NONDIFFERENTIAL CODING TECHNIQUES

In this subsection we will describe two nondifferential coding techniques: (1) threshold decoder technique; and (2) unique-word detection technique.
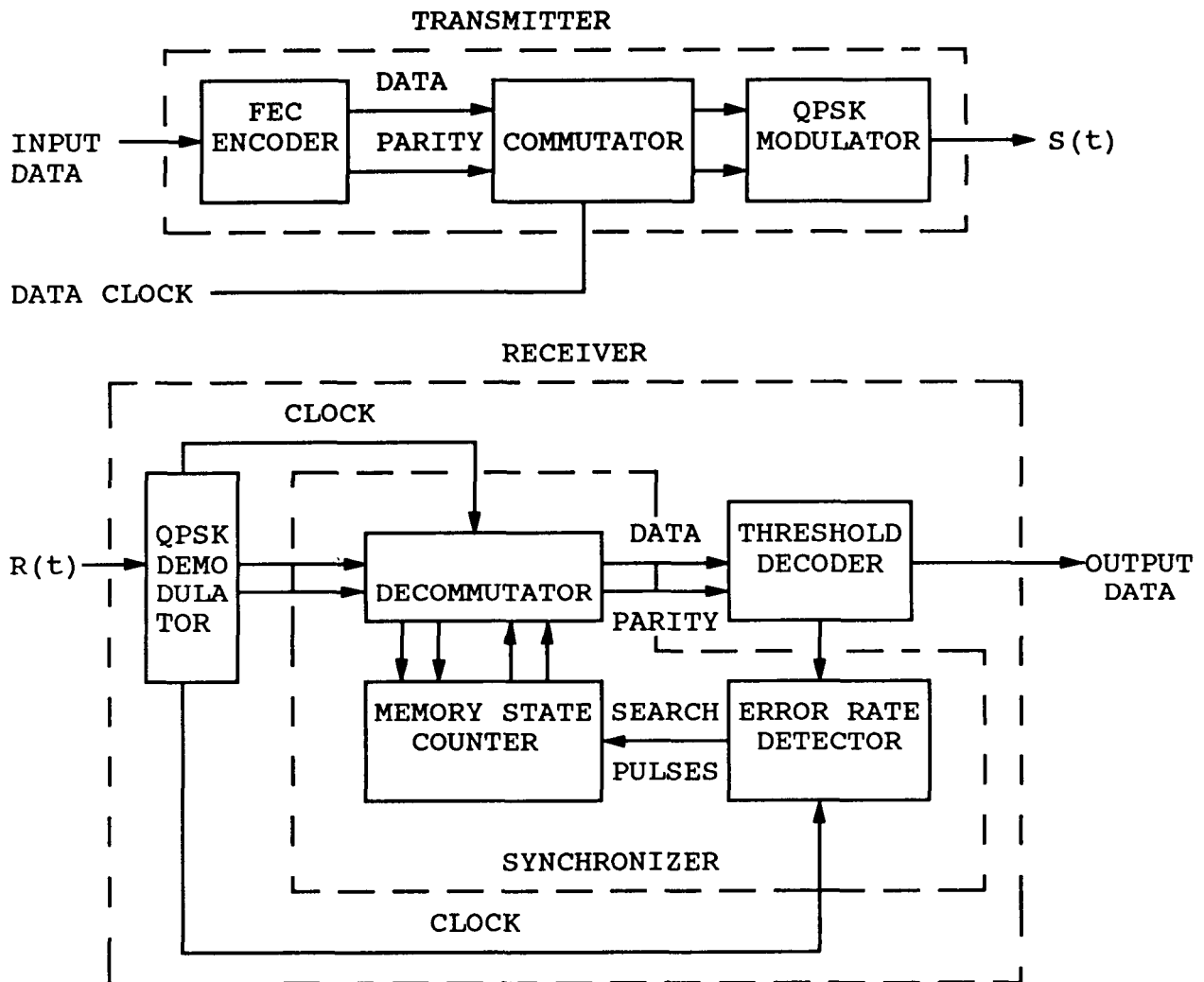
V.2.1. THRESHOLD DECODER TECHNIQUE

This technique was invented in 1972 by Dohne and Cacciamani [Ref. 11]. It makes use of the synchronizer circuit that is inserted between the output of the QPSK demodulator and the input of a threshold decoder of the type which can correct a predetermined number of bit errors in a coded stream. This particular synchronizer performs both phase-ambiguity resolution and node synchronization without using the unique code words. This synchronizer includes a memory counter which has all possible combinations of errors caused by the phase ambiguity. This memory counter is controlled by correction pulses which are generated in the synchronizer by an error rate detector. When the number of correction bits during a frame exceeds the number which would normally occur if the system was operating correctly without phase ambiguity and without incorrect node synchronization, the synchronizer assumes that there is a problem caused either by phase ambiguity or node synchronization. Each time this occurs, the error rate decoder generates the correction pulses. The correction pulses are used to advance the memory counter through its states. It will eventually reach the state which makes all needed corrections since all possible combinations of errors are stored in the memory counter. When all errors are corrected, there will no longer be errors in the bit stream applied to the threshold decoder, the search pulses will then no longer be generated, and the memory counter will remain in the state which provides all needed corrections. Figure 12 shows a generalized block diagram of a QPSK system using the threshold decoder technique for resolving the phase ambiguity.

ADVANTAGE: Improves communications efficiency, i.e., requires less bandwidth to transmit a given amount of information.

DISADVANTAGE: Since the synchronizer has to search for the correct state out of all possible combinations of errors caused either by the phase ambiguity or node synchronization, this technique may require a relatively long time for phase-ambiguity resolution.

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FIGURE 12. GENERALIZED BLOCK DIAGRAM FOR PHASE-AMBIGUITY RESOLUTION USING THRESHOLD DECODER TECHNIQUE

TRANSMITTER

```
        ┌── ── ── ── ── ── ── ── ── ── ── ──┐
        │        ┌─────────┐  DATA   ┌───────────┐        ┌───────────┐  │
        │        │   FEC   │────────▶│           │───────▶│   QPSK    │  │
INPUT ──┼───────▶│ ENCODER │ PARITY  │ COMMUTATOR│        │ MODULATOR │──┼──▶ S(t)
DATA    │        │         │────────▶│           │───────▶│           │  │
        │        └─────────┘         └───────────┘        └───────────┘  │
        └── ── ── ── ── ──┬── ── ── ── ── ── ── ── ── ── ── ──┘
                          │
DATA CLOCK ───────────────┘
```

RECEIVER

```
┌── ── ── ── ── ── ── ── ── ── ── ── ── ── ── ── ── ──┐
│        CLOCK                                         │
│     ┌──────┐  ┌── ── ── ── ── ──┐                    │
│     │ QPSK │  │   ┌──────────────┐  DATA  ┌──────────┐  │
R(t)──┼─│ DEMO │──┼──▶│              │───────▶│ THRESHOLD│──┼──▶OUTPUT
│     │ DULA │  │   │ DECOMMUTATOR │        │ DECODER  │  │    DATA
│     │ TOR  │──┼──▶│              │ PARITY └──────────┘  │
│     └──────┘  │   └──────────────┘                    │
│               │    ▼  ▼   ▲  ▲         ┌── ── ── ──┐ │
│               │  ┌──────────────┐ SEARCH │ERROR RATE│ │ │
│               │  │MEMORY STATE  │◀───────│ DETECTOR │ │ │
│               │  │  COUNTER     │ PULSES └──────────┘ │ │
│               │  └──────────────┘                   │ │
│               │         SYNCHRONIZER                 │ │
│               └── ── ── ── ── ── ── ── ── ── ── ──┘ │
│          CLOCK                                       │
└── ── ── ── ── ── ── ── ── ── ── ── ── ── ── ── ── ──┘
```

Note that the purpose of the commutator-decommutator is to prevent the case of inverted data and true parity (or vice versa) inputted to the threshold decoder.   For detailed discussion see Reference 11.

V.2.2. UNIQUE-WORD DETECTION TECHNIQUE

This technique has been described in Section IV.2, and can be modified for use with the coded QPSK system.   At the transmitter, the unique words are applied after the data has been encoded.   While at the receiver, the unique words are detected before the FEC decoder.   This implementation will allow the system to correct the errors caused by the phase ambiguity as described in Section IV.2.   A generalized block diagram of the coded QPSK system with phase-ambiguity correction using unique-word detection is shown in Figure 13.

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FIGURE 13. GENERALIZED BLOCK DIAGRAM OF THE CODED QPSK SYSTEM WITH PHASE-AMBIGUITY CORRECTION USING UNIQUE-WORD DETECTION TECHNIQUE
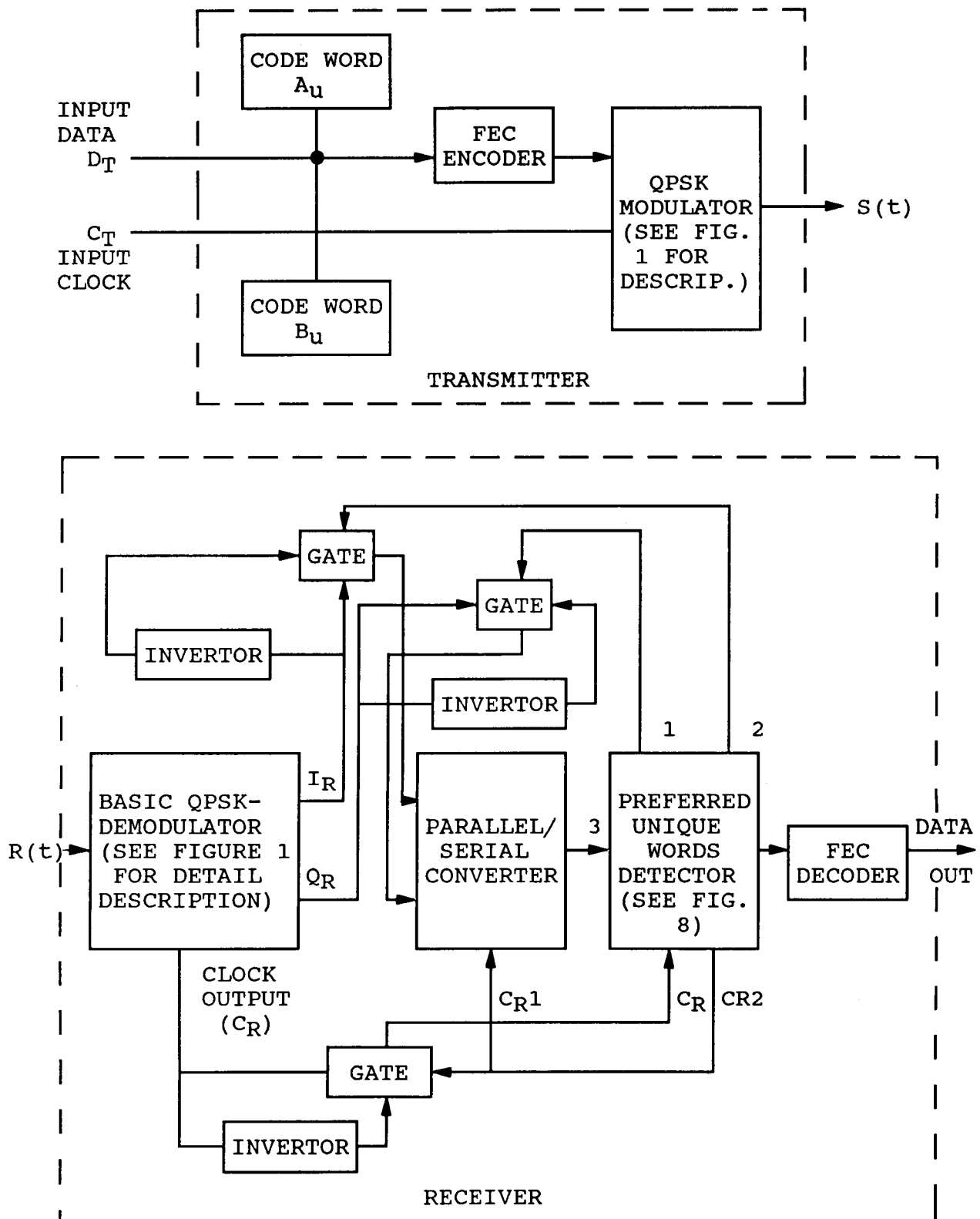
VI. CONCLUSIONS AND RECOMMENDATIONS

The current available techniques of resolving phase ambiguity in a QPSK (coded or uncoded) system have been reviewed in this report. For an uncoded QPSK system, the first method resolves the phase ambiguity by using the differential encoding technique. This technique is simple to implement, but there is a major drawback regarding the performance degradation of the transmitted sync markers. In order to avoid this unnecessary performance degradation, the unique-word detection technique has been proposed as a second method for uncoded-QPSK phase-ambiguity resolution. This technique utilizes the "already existed sync markers" to correct the errors caused by the phase ambiguity. However, this technique is much more complex than the first technique. Its resolution performance depends heavily on the data acquisition equipments and the pattern of the sync markers. The complexity of the system is greatly reduced if it is designed properly (see Section IV.2).

For a coded QPSK system, we classified the phase-ambiguity resolution techniques into two categories: (a) differential coding technique; and (b) nondifferential coding technique. There are two techniques associated with the differential coding technique: (1) differential coding inside an FEC codec; and (2) differential outside an FEC codec. The first method does not require synchronization time to resolve the phase ambiguity, although the output bit error rate is worse compared to the case without differential coding. However, this bit error rate degradation can be minimized by using the symbol interleaving-deinterleaving technique (see Section V.1.1). The second technique (differential encoding outside an FEC codec) does not encounter the bit error rate degradation phenomenon, but it does require considerably more time to resolve the phase ambiguity than the first technique.

The nondifferential coding techniques for use with the coded QPSK system described in this report are: (1) threshold decoder technique; and (2) unique-word detection technique. The threshold decoder technique resolves the phase ambiguity by a particular synchronizer circuit with the aid of the threshold decoder (see Section V.2.1). This technique does not require unique words or sync markers to correct the errors caused by the phase ambiguity. Thus, it improves the communication efficiency, i.e. higher bit rates can be sent through a given channel. A disadvantage of this method is that it requires a relatively long time to resolve the phase ambiguity. In the second method of phase-ambiguity resolution for a coded QPSK system (since the unique-word detection technique is used), the resolution performance has the same features as compared to the uncoded case.

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Based on the above investigation, the following conclusions can be reached:

1. The differential coding technique is to be used only when there are some means of breaking the occurrence of pairs of errors which are associated with this technique. This technique is suitable for burst mode signals.

2. The unique-word detection technique is attractive only when the system is properly designed.

3. The threshold decoder technique is recommended only when the systems are operating in limited-bandwidth channels.

When bandwidth limitations are imposed by regulatory agencies, the issue of radiated spectral density becomes even more important. The QPSK modulation described in this report may not be the best choice (Offset QPSK is best for this case, Ref. 12). Therefore, the associated phase-ambiguity resolution techniques may require some modifications for optimum performance as well as hardware requirements. Part II of this report will discuss a new method to resolve the phase-ambiguity for the Offset QPSK modulation systems.

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15. Supplementary Notes

16. Abstract

Part I of this report reviews the current phase-ambiguity resolution techniques for QPSK coherent modulation systems. Here, those known and published methods of resolving phase ambiguity for QPSK with and without Forward-Error-Correcting (FEC) are discussed. The purposes of this report are twofold: (1) to provide the background necessary for a complete understanding of the second part where a new technique will be discussed; (2) to recommend an appropriate technique to the Consultative Committee for Space Data Systems (CCSDS) for consideration in future standards on phase-ambiguity resolution for QPSK coherent modulation systems.

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