# Image Cover Sheet

| CLASSIFICATION | SYSTEM NUMBER 148872 |
| --- | --- |
| UNCLASSIFIED | |

**TITLE**

THE FEASIBILITY OF TACTICAL VHF/UHF FACSIMILE ESM

**System Number:**

**Patron Number:**

**Requester:**

**Notes:**

**DSIS Use only:**

**Deliver to:** BA

National Defence / Défense nationale

# THE FEASIBILITY OF TACTICAL VHF/UHF FACSIMILE ESM

by

Andrew Mudry, David Lee and Brad Poulin

**DEFENCE RESEARCH ESTABLISHMENT OTTAWA**
REPORT NO. 1217

Canada

December 1993
Ottawa

National Defence Défense nationale

# THE FEASIBILITY OF TACTICAL VHF/UHF FACSIMILE ESM

by

**Andrew Mudry, David Lee and Brad Poulin**
*Communications Electronic Warfare Section*
*Electronic Warfare Division*

**DEFENCE RESEARCH ESTABLISHMENT OTTAWA**
REPORT N0. 1217

PCN
041LK

December 1993
Ottawa

## ABSTRACT

This report examines the requirements for performing Electronic Warfare Support Measures (ESM) on VHF/UHF facsimile transmissions in the tactical environment. A complete description of the CCITT Group III recommendations is given. These specifications apply to over ninety percent of the facsimile machines currently in use. Both modulation techniques and image encoding formats are discussed thoroughly. A description is then given of the HIGHWIRE system. HIGHWIRE is a communications Electronic Warfare Support Measures System which has been developed in the Electronic Warfare Division at the Defence Research Establishment Ottawa to investigate the feasibility of tactical facsimile ESM. Current capabilities of the system are described, and future work is discussed.

## RESUME

Nous examinons dans le présent rapport le besoin d'exercer des mesures de support électronique sur les signoux des transmissions de télécopies dans les bandes de fréquences VHF et UHF employèes dans des conditions tactiques. Les recommendations concernant CCITT Groupe III sont décrites en détail. Ces caractéristiques techniques s'appliquent à plus de 90% des télécopieurs utilisés présentement. Les techniques de modulation et le format du codage des images sont aussi présentés en détail. Nous procédons ensuite à une description du système HIGHWIRE. HIGHWIRE est un système de communications de mesures de soutien à la guerre électronique, élaboré à la Division de la Guerre électronique du CRDO, pour étudier la faisabilité de MSE tactique de télécopies. Nous décrivons la capacité opérationnelle du système et présentons nos futurs travaux.

# EXECUTIVE SUMMARY

Modern tactical communications systems are becoming increasingly compatible with existing civilian systems. This compatibility allows the military to take advantage of the equipment available commercially and spares the expense of developing costly customized systems. It also increases the interoperability of various communications systems employed by allies involved in multinational operations. Finally, the compatibility allows the military to augment its telecommunications assets with existing commercial equipment and networks during times of conflict. One civilian communication standard that has recently been adopted by the military for tactical communications is that of facsimile. Facsimile, transmitted over VHF or UHF radio links, is now commonly used on the battlefield for the transmission of tactical maps and situation reports. It is therefore a valuable source of intelligence, and is a legitimate target for tactical ESM operations.

This report examines the requirements for performing ESM on VHF/UHF facsimile transmissions in the tactical environment. A detailed description of the most commonly used standard is given. Modulation formats and encoding schemes for the image are discussed in detail, as well as the protocol communications which occur between transmitter and receiver at the beginning of the transmission. A detailed description is then given of HIGHWIRE, which is a prototype system, developed in the Electronic Warfare Division, to demonstrate the feasibility of facsimile ESM. It is assumed that the target facsimile transmission is received on an RF link, and then downconverted to baseband. The baseband information, either live or a recording, is then presented to the facsimile demodulator. The performance of the system is qualitatively described, and limitations in the current performance of the system are discussed. Finally, recommendations for further work are given.

# TABLE OF CONTENTS

## LIST OF FIGURES

# LIST OF TABLES

# 1.0 INTRODUCTION

Modern tactical communications systems are becoming increasingly compatible with existing civilian communications systems. This compatibility allows the military to take advantage of the equipment available commercially and spares the expense of developing costly customized systems. It also increases the interoperability of various communications systems employed by allies involved in multinational operations. Finally, the compatibility allows the military to augment its telecommunications assets with existing commercial equipment and networks during times of conflict [1]. In small and medium intensity engagements, it can reasonably be assumed that many of these commercial networks will remain intact. As an example, commercial terrestrial microwave links located in Saudi Arabia, as well as satellite links, were leased by the U.S. military during operation Desert Storm [1]. Current U.S. Army doctrine calls for an increase in the compatibility of military assets with commercial equipment. It is therefore reasonable to assume that the standards employed in future military communications systems will closely parallel the civilian standards.

One civilian communication standard that has recently been adopted by the military for tactical communications is that of facsimile. Facsimile has been employed by the military in the past, but due to the size of the equipment and the poor reliability, its use as a mode of battlefield communications was very limited. It was used mainly for the transmission of meteorological maps. Today however, the demand by the civilian business community has improved cost, size, and reliability of facsimile transceivers to the point where it is now a viable form of tactical communications. Facsimile is now employed extensively on the battlefield for the transmission of tactical maps, and situation reports. The new Mobile Subscriber Equipment (MSE) which has recently been fielded by the United States Army provides facsimile capability for both fixed and mobile users at echelon corps level and below [1]. The main distinction in the military application of facsimile is that users are generally mobile. At some point between the transmitting and receiving fax, the signal is carried on a wireless radio link.

With the growing use of facsimile for tactical communications seen in Allied countries, it may be assumed that potentially hostile countries are making similar use of facsimile. In these cases, tactical facsimile transmissions could prove to be a valuable source of intelligence, and therefore become legitimate targets for tactical Electronic Warfare Support Measures (ESM) operations.

This report examines the requirements for tactical facsimile ESM. A detailed description of the CCITT Group III Recommendations is given. This is the most commonly used standard. Modulation formats and image encoding schemes are discussed in detail, as well as the protocol communications which occur between transmitter and receiver at the beginning of the transmission. A detailed description is then given of HIGHWIRE, which is a prototype system developed in the Electronic Warfare Division, to demonstrate the feasibility of facsimile ESM. It is assumed that the target facsimile transmission is received on an RF link, and then downconverted to baseband. The baseband information, either live or a recording, is then presented to the facsimile demodulator. The performance of the system is qualitatively described, and limitations in the current performance of the system are discussed. Finally, recommendations for further work are given.

# 2.0 GROUP III FACSIMILE SPECIFICATIONS

## 2.1 Overview

Currently, there are four standards for facsimile transmission which have been adopted by the International Telegraph and Telephone Consultative Committee (CCITT). They are Group I, Group II, Group III, and Group IV. These standards specify parameters such as scanning direction, size of scan line, number of scan lines per millimetre, scanning rate, phasing, synchronization, and modulation techniques. Over 98 percent of the facsimile machines currently in use employ the modulation and encoding techniques outlined in the Group III recommendations [2]. These will be described in detail in this section. Group I and II machines are now obsolete, and are rarely seen. Group IV machines have not yet gained wide acceptance, as they are intended for a four wire ISDN network, and cannot be used on a standard two wire line.

Group III standards eliminate many of the synchronization problems which existed in Group I and Group II machines. All information necessary for the proper reconstruction of the image is transmitted with the image. No external synchronization signals are required. The digital scanning techniques employed in the Group III standards allow a standard vertical scanning resolution of 3.85 lines/mm. An optional higher resolution vertical scanning resolution of 7.7 lines/mm may also be provided [3]. In the horizontal direction, the standard specifies that a horizontal line of width 215 mm shall be quantized into 1728 Picture ELements (PELS). The standard also allows the storage of data between the transmitter and the receiver scanners. This allows the document to be rapidly scanned into memory, and then transmitted at the highest speed possible for the link used. Typically, the document can be scanned into the transmitter in approximately 5 -10 seconds, and can be transmitted in less than a minute. The standard also allows handshaking between the transmitter and receiver for adaptive data rate adjustment prior to transmission, in order to compensate for a noisy channel. The transmitter will send a header to the receiver at the highest data rate it is capable of transmitting. If it fails to receive the proper confirmation from the intended receiver, it will retransmit the header at a progressively lower data rate, until the receiver confirms proper data reception. At that point, the transmitter will send the image. The storage of the image in memory also allows error correction codes to be added to the data before it is sent, allowing for a reduced error rate.

The Group III facsimile transmission is divided into the five distinct phases shown in Figure 2.1 [4]. Phase A consists of the establishment of a communications link between the transmitter and receiver. On a normal telephone link this is done when the originating station dials up the intended receiver. Once the dial tone is detected, the calling unit sends the dialled information to the central switching office. The switching office then routes the call between the originator and the intended receiver, and sends a RING signal to the intended receiver. When the intended receiver acknowledges the RING signal, the link is completed. For tactical communications systems the process is similar, except that at some point the two way conversation between the originator and the receiver is carried on either a full, or half duplex radio link. To aid in the automatic connection of facsimile machines during Phase A, the called facsimile always sends a called station identification (CED) signal upon answering. This consists of a 2100 Hz tone, of duration 2.4 to 4.0 seconds. The purpose of the CED signal is to identify the called station as a non-speech terminal. Phase B of the transmission is the pre-message procedure. During this phase, the transmitter and receiver identify and select mutually compatible parameters for the transmission of the fax image, which follows in Phase C. Phase C also consists of an in-message procedure, composed of message synchronization, error detection and correction, and line supervision. Phase D of the transmission is the post-message procedure, during which multipage, confirmation, and end-of-message signalling takes place. Phase E is the call release, where the communications link between transmitter and receiver is broken, and the links are returned to the control of the switching station for reallocation.

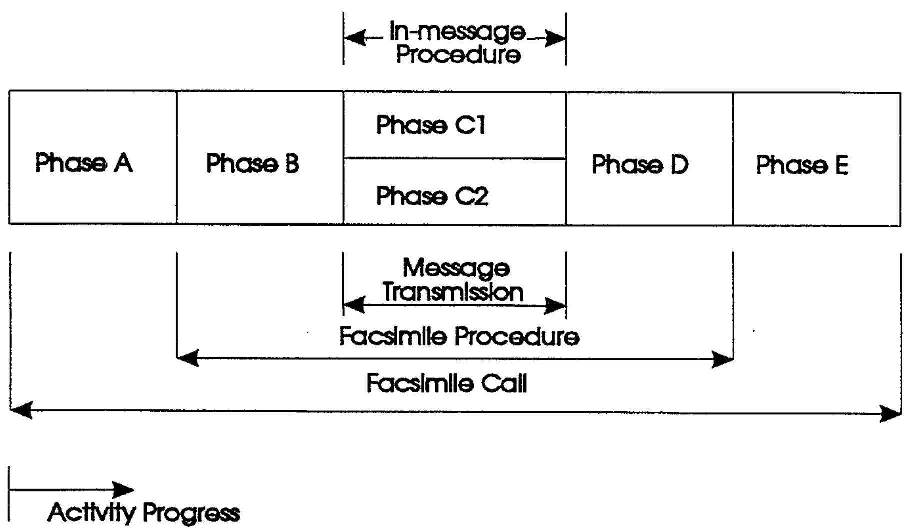



**Figure 2.1: Group III Facsimile Sequence**

Figure 2.2 shows the call procedure for the case where the transmitting facsimile machine is the call originator. This is the most common situation. Those signals which are not contained in brackets are required signals. These are essential for the proper transmission and reception of the facsimile. Failure to receive a required signal after an appropriate period of time, generally results in termination of the call by either the transmitter or the receiver. As indicated, the Group III standards also allow for the transmission of various optional signals. The signals indicated in Figure 2.2, are each transmitted in a group of one or more frames of bits. The exact structure of these frames will be discussed in Section 2.2. In cases where a group of bits contains one or more optional frames along with the required frame, the required frame will be the last group of bits transmitted.

As can be seen from Figure 2.2, the first two sequences of information are provided by the called machine. It must first identify itself as a non-voice terminal using the CED tone. This is followed by a Digital Identification Signal (DIS), in which the called facsimile identifies its transmission and reception capabilities to the call originator. In addition to the DIS, two optional signals may be transmitted at this time. The Non Standard Facilities (NSF) frame is used to allow facsimile manufacturers to specify additional transmission features which are not covered in the Group III standards. These features are specific to the machine and are generally recognized only by another machine of the same type or manufacturer. A second optional frame which may be transmitted at this time is the Called Subscriber Information (CSI) signal. This group of bits is used to indicate the international telephone number of the called machine.

Upon reception of the DIS frame, the calling facsimile analyses the capabilities of the receiver and selects a transmission mode compatible with the receiver capabilities. The transmitter then responds with a Digital Command Signal (DCS) in which it specifies the modulation and data rate that will be used for the transmission of the image information. Any optional parameters used by the transmitter are indicated in a Non Standard facilities Setup (NSS) signal, which is sent in response to a NSF frame. Another optional signal which may be sent by the transmitter to the receiver at this time is the Transmitting Subscriber Information (TSI) signal. The TSI is used by the transmitter to identify its telephone number. Upon reception of the DCS signals, the receiver configures itself for the reception of a training sequence from the transmitter. This training sequence will be sent in the modulation format specified in the DCS, and allows the receiver modem to train and phase itself for proper reception. Its exact structure will be detailed in Section 2.3. Following the training sequence, the transmitter then sends a series of zeros in the same modulation format. This allows the receiver to assess the suitability of the channel for the chosen modulation and data rate. If the zeros are received with an acceptable bit error rate, the receiver will respond with a ConFirmation to Receive (CFR) signal. If the receiver determines that the bit error rate is unacceptable, it will respond with a Failure To Train (FTT) signal. The transmitter will then select a lower data rate and issue another DCS, followed by another training sequence.

| Calling Transmitter Procedure | | Called Receiver Procedure |
|---|---|---|
| | **Phase A** | |
| | ← | 1. Transmit CED |
| | **Phase B** | |
| 3. Detect DIS | ← | 2. Transmit DIS, (NSF), (CSI) |
| 4. Transmit DCS, (TSI), (NSS) | → | 5. Detect DCS |
| | | 6. Select Mode |
| 7. Transmit Phasing/Training Sequence | → | 8. Phasing/Training |
| 10. Detect CFR | ← | 9. Transmit CFR |
| | **Phase C** | |
| 11. Transmit Image | → | 12. Receive Image |
| | **Phase D** | |
| 13. At end of page send one of the following: EOM, EOP, MPS, PRI-EOM, PRI-EOP, PRI-MPS,PPS-NULL, PPS-MPS, PPS-EOM, PPS-EOP, PPS-PRI-EOM, PPS-PRI-EOP, or PPS-PRI-MPS | → | 14. Detect one of the following: EOM, EOP, MPS, PRI-EOM, PRI-EOP, PRI-MPS,PPS-NULL, PPS-MPS, PPS-EOM, PPS-EOP, PPS-PRI-EOM, PPS-PRI-EOP, or PPS-PRI-MPS |
| 16. Receive MCF or RTP. If Document Transmission Is Complete, Proceed To Phase E, Otherwise Go Back To Phase B, or C | ← | 15. Transmit MCF or RTP |
| | **Phase E** | |
| 17. Transmit DCN | → | 18. Receive DCN |
| 19. Disconnect | | 19. Disconnect |

**Figure 2.2: Facsimile Procedure For Calling Transmitter and Called Receiver**

Image transmission begins when the calling unit receives the CFR signal. The transmittrer sends an additional training sequence, followed by the image information. The image encoding is discussed in Section 2.4. At the end of a page of image transmission, the transmitter sends one of the following signals: End Of Message (EOM), MultiPage Signal (MPS), or End Of Procedures (EOP). In the case of an EOM or an MPS signal, the transmitter returns to the beginning of stage B or C and transmits a subsequent page of information. The training and phasing signal is always retransmitted at the start of a new page. The EOP signal indicates that the complete document has been transmitted. In the case of a manual transmitter, operator intervention may be requested following the transmission of the image page. In this case, the transmitter will send one of the following PRocedure Interrupt signals: PRI-EOM, PRI-MPS, or PRI-EOP. The exact meaning of these signals is discussed in Section 2.2. If an optional error correction mode is employed, during transmission, the end of the transmitted page is signified by one of the following Partial Page Signals: PPS-EOM, PPS-MPS, PPS-EOP, PPS-NULL, PPS-PRI-EOM, PPS-PRI-MPS, or PPS-PRI-EOP. This is the T.4 error correction mode, and is discussed in Section 2.5.

After receiving one of the above end-of-page signals, the receiver will generally respond with either a Message ConFirmation (MCF) signal or a ReTrain Positive (RTP) signal, assuming that the page was received with an acceptable number of errors. Upon receiving an MCF signal, the transmitter sends a training/phasing sequence, followed by the next page of information. Upon receiving an RTP signal, the transmitter will return to Phase B and will issue another DCS command, followed by a training/phasing sequence, and the next page of information. If the original page of information was received with an unacceptable number of errors, the receiver will issue a Retrain Negative (RTN) signal upon receiving an end of page command from the transmitter. The transmitter will then send a DCS and training signal, and will then retransmit the previous page of information. If the receiver continually responds with RTN, the transmitter may lower the data rate of the image transmission, and advise the receiver of this via a DCS signal. The training and image transmission will then take place at the lower data rate. This optional feature is known as fallback. It should be noted that neither the RTP nor RTN signals are applicable to the T.4 error correction mode of transmission.

Following the reception of an MCF signal, the transmitter will send a DisCoNnect (DCN) signal. After this, both transmitter and receiver disconnect, and the call is completed.

A similar sequence of handshaking occurs when the call originator wishes to receive a facsimile. This situation is illustrated in Figure 2.3. As in the previous case, the first two sequences of information are provided by the called unit, in this case the transmitter. Upon reception of the DIS, the calling receiver transmits a Digital Transmit Command (DTC) signal, in which it identifies its capabilities to the called transmitter. This command is analogous to the DIS signal provided by the transmitter at the origin of the call. At this time, two optional signals may also be sent. The CallInG subscriber identification (CIG) is used by the calling receiver to identify its international telephone number to the transmitter. Any non-standard capabilities of the calling receiver are identified in a Non Standard facility Command (NSC) signal. These two optional signals are analogous to the CID and NSF signals respectively. The rest of the handshaking between the facsimile transmitter and facsimile receiver is identical to the previous case.

| Calling Receiver Procedure | | Called Transmitter Procedure |
|---|---|---|
| | **Phase A** | |
| | ← | 1. Transmit CED |
| | **Phase B** | |
| 3. Detect DIS | ← | 2. Transmit DIS, (NSF), (CID) |
| 4. Transmit DTC, (CIG), (NSC) | → | 5. Detect DTC |
| 7. Detect DCS | ← | 6. Transmit DCS |
| 8. Select Mode | | |
| 10. Training/Phasing | ← | 9. Transmit Phasing/Training Sequence |
| 11. Transmit CFR | → | 12. Detect CFR |
| | **Phase C** | |
| 14. Receive Image | ← | 13. Transmit Image |
| | **Phase D** | |
| 16. Receive one of the following: EOM, EOP, MPS, PRI-EOM, PRI-EOP, PRI-MPS, PPS-NULL, PPS-MPS, PPS-EOM, PPS-EOP, PPS-PRI-EOM, PPS-PRI-EOP, or PPS-PRI-MPS | ← | 15. At end of page, send one of the following: EOM, EOP, MPS, PRI-EOM, PRI-EOP, PRI-MPS,PPS-NULL, PPS-MPS, PPS-EOM, PPS-EOP, PPS-PRI-EOM, PPS-PRI-EOP, or PPS-PRI-MPS |
| 17. Transmit MCF or RTP | → | 18. Receive MCF or RTP. If Document Transmission Is Complete, Proceed To Phase E, Otherwise Go Back To Phase B, or C |
| | **Phase E** | |
| 20. Receive DCN | ← | 19. Transmit DCN |
| 21. Disconnect | | 21. Disconnect |

**Figure 2.3: Facsimile Procedure For Calling Receiver and Called Transmitter**

## 2.2 V.21 Modulation and HDLC Coding

Most of the signalling which takes place during Phases B and D of the procedure occurs using the V.21 modulation. This is a simple Frequency Shift Keyed (FSK) modulation with mark and space frequencies of 1650 Hz, and 1850 Hz respectively. A standard data rate of 300 bits per second (bps) is used, but an optional data rate of 2400 bps is also specified. The initial signalling between facsimile units is always done at a rate of 300 bps The only non-V.21 signalling occurring during these phases is a modem training/phasing sequence which takes place during Phase B, and is used to train the receiver modem. This training sequence is sent using V.29, or V.27ter modulation, and will be discussed in Section 2.3. .

As mentioned in the previous section, the data is arranged and transmitted in a group of one or more frames of bits. These frames are structured according to the CCITT High Level Data Link Control (HDLC) standard. The exact HDLC frame format is shown in Figure 2.4, which illustrates an example of an HDLC sequence sent by a called receiver at the beginning of Phase B of the procedure. Each frame contains the information to be transmitted, as well as an error detection capability. A unique **flag** sequence, located at the beginning and end of each frame is used as a delimiter. When more than one frame is sent sequentially, the closing flag of the first frame may be used as the opening flag of the next frame. The flag sequence is the bit pattern **01111110**. This pattern is unique and can never appear within the transmitted frame, only at the beginning or the end. Of course, this pattern could conceivably appear within the data to be transmitted. In order to ensure that it is not transmitted within the HDLC frame, a bit stuffing procedure known as zero insertion is used. With the exception of the delimiting flags, the transmitter will insert a **0** after each occurrence of five consecutive **1**'s. At the receive side, the receiver monitors the incoming bit stream for a sequence of five consecutive ones. If detected, and the next bit is a **0**, that **0** is ignored. If the five **1**'s are followed by a **1** and a **0**, a flag is recognized. If the receiver detects a pattern of seven consecutive **1**'s, it is assumed that the transmitting station has sent an abort signal.

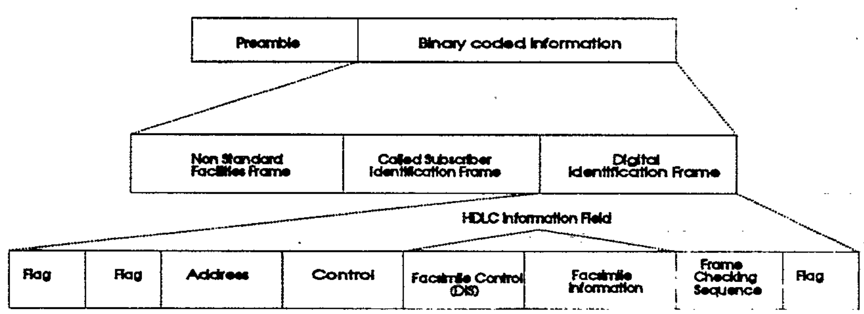



**Figure 2.4: Sequence Of HDLC Frames Sent By Called Facsimile At Beginning Of Phase B**

HDLC frames are generally sent in a group, with each frame in the group consisting of one of the handshaking signals discussed in the previous section. Each sequence of frames begins with a series of flags of approximately one second duration. This initial sequence of flags is referred to as the **preamble**, and is used by the receiver to acquire initial synchronization. The preamble is then followed by the individual HDLC frames. Each HDLC frame begins with another flag sequence, followed by an eight bit **address field**. This field is constant on the general switched telephone network, and is composed of a group of eight ones (**1111 1111**). The address field is always followed by the **control field** which is of the form **1100 X000**, where a value of X=0, indicates that another HDLC frame will follow the completion of the current one. A value of X=1, indicates that the current HDLC frame is the last one in the sequence.

The first byte of data that follows the address and control fields is called the **facsimile control field**. In this field the handshaking signals discussed in the previous section are sent. The pattern sent for each possible handshaking signal is illustrated in Tables 2.1 - 2.5.

In Tables 2.1 - 2.5, the **X** appearing as the first bit of the facsimile control field will be defined as follows:

- X is set to 1 by the station which receives a valid DIS signal;

- X is set to 0 by the station which receives a valid and appropriate response to a DIS signal;

- X will then remain unchanged until the station again enters the beginning of phase B.

As can be seen from Tables 2.1 - 2.5, many of the facsimile control fields are followed by an additional field of bits. This is the **facsimile information field**. It is used to augment the signal sent in the facsimile control field. In the case of a DIS, DTC, or DCS signal sent in the facsimile control field, the facsimile information field which follows contains either 24, 32, or 40 bits. These bits are used to describe the capabilities of either the transmitting or receiving machine. Basic capabilities may be described using 24 bits, but extended capabilities require 32 or 40 bits. A **1** in bit 24 indicates that the 8 bits which follow are to be taken as a continuation of the facsimile information field. A **1** in bit 32 has identical meaning. The meaning of the bits composing the facsimile information field for DIS, DTC, and DCS signals is shown in Table 2.6. A **1** in any of the bit positions indicates that the machine has the designated option.

**Table 2.1: Facsimile Control Field Data For Signals Sent At Beginning Of Phase B**

| SIGNAL | BIT PATTERN | DESCRIPTION |
|---|---|---|
| **Signals Sent From Called Station To Calling Station At Beginning Of Phase B** | | |
| Digital Identification Signal (DIS) | 0000 0001 | Identify capabilities of called station. Always followed by a 24, 32, or 40 bit facsimile information field. |
| Called Subscriber Information (CSI) | 0000 0010 | Identify telephone number of called unit. Always followed by a 160 bit facsimile information field |
| Non Standard Facilities (NSF) | 0000 0100 | Identify optional capabilities of called unit. Always followed by a manufacturer dependent facsimile information field |
| **Signals Sent From Calling Receiver To Called Transmitter At Beginning Of Phase B** | | |
| Digital Transmit Command (DTC) | 1000 0001 | Identify capabilities of calling receiver. Always followed by a 24, 32, or 40 bit facsimile information field |
| Calling Subscriber Identification (CIG) | 1000 0010 | Identify telephone number of calling receiver. Always followed by a 160 bit facsimile information field |
| Non Standard Facilities Command (NSC) | 1000 0100 | Response to NSF signal. Identify optional capabilities of calling receiver. Always followed by a manufacturer dependent facsimile information field. |
| **Signals Sent From Transmitter To Receiver At Beginning Of Phase B** | | |
| Digital Command Signal (DCS) | X100 0001 | Response to DIS or DTC signal. Always followed by a 24, 32, or 40 bit facsimile information field. |
| Transmitting Subscriber Identification (TSI) | X100 0010 | Identify telephone number of transmitter. Always followed by a 160 bit facsimile information field. |
| Non Standard Facilities Set Up (NSS) | X100 0100 | Response to NSF or NSC signal. Always followed by a manufacturer dependent facsimile information field. |

**Table 2.2: Facsimile Control Field Data For Signals Sent At End Of Phase B**

| SIGNAL | BIT PATTERN | DESCRIPTION |
|---|---|---|
| **Signals Sent From Receiver To Transmitter At End Of Phase B** | | |
| Confirmation To Receive (CFR) | X010 0001 | Confirms that pre-message procedure, including training, has been completed, and the message transfer may commence. |
| Failure To Train (FTT) | X010 0010 | Rejects training/phasing sequence sent during phase B, and requests retraining. |

Facsimile control fields which contain CSI, CIG, or TSI signals are always followed by a 160 bit facsimile information field which identifies the telephone number of the sending unit. The full international telephone number is coded as 20 digits. Each digit is coded according to the scheme shown in Table 2.7. The digits are sent in a bit reversed order, such that the least significant bit of the least significant digit is the first one transmitted. Facsimile control fields containing a NSF, NSC, or NSS signal are also followed by facsimile information fields. These are used to augment the non-standard capabilities of the sending machine. The coding scheme used in these fields is not standard and is left to the discretion of the manufacturer.

The facsimile control field is followed by a 16 bit **frame check sequence**. This is used by the receiver to detect any errors which may occur during the transmission of the HDLC frame [4]. The information contained in the 16 bit field is given by the one's complement of the modulo 2 sum of the following two values.

1) The remainder of $x^k (x^{15} + x^{14} + x^{13} + ... + x^2 + x + 1)$ divided (modulo 2) by the generator polynomial $x^{16} + x^{12} + x^5 + 1$. $k$ is the number of bits in the frame existing between, but not including, the final bit of the opening flag and the first bit of the frame check sequence. Any zeros which occur in the frame as the result of zero insertion are ignored in this calculation.

2) The remainder after multiplication by $x^{16}$ and then division (modulo 2) by the generator polynomial $x^{16} + x^{12} + x^5 + 1$ of the content of the frame, existing between, but not including, the final bit of the opening flag and the first bit of the frame check sequence. Any zeros which occur in the frame as the result of zero insertion are ignored in this calculation.

**Table 2.3: Facsimile Control Field Data For Post Message Signals Sent From Transmitter To Receiver During Phase D**

| SIGNAL | BIT PATTERN | DESCRIPTION |
|---|---|---|
| **Post Message Commands Sent From Transmitter To Receiver** | | |
| End Of Message (EOM) | X111 XXXX | Indicates the end of a complete page of transmission, and that transmitter will return to beginning of Phase B upon receipt of confirmation. EOM should not be used in the T.4 Error Correction mode. |
| Multipage Signal (MPS) | X111 0001 | Indicates the end of a complete page of transmission, and that transmitter will return to beginning of Phase C upon receipt of confirmation. MPS should not be used in the T.4 Error Correction mode. |
| End Of Procedure (EOP) | X111 0100 | Indicates the end of document transmission, and that transmitter will proceed to Phase E upon receipt of confirmation. EOP should not be used in the T.4 Error Correction mode. |
| Procedure Interrupt - End Of Message (PRI-EOM) | X111 1001 | Indicates the same as an EOM, but also requests operator intervention at receiver. Once operator intervention is accomplished, transmitter will return to beginning of Phase B. PRI-EOM should not be used in the T.4 Error Correction mode. |
| Procedure Interrupt - Multipage Signal (PRI-MPS) | X111 1010 | Indicates the same as an MPS, but also requests operator intervention at receiver. Once operator intervention is accomplished, transmitter will return to beginning of Phase B. PRI-MPS should not be used in the T.4 Error Correction mode. |
| End Of Procedure (PRI-EOP) | X111 1100 | Indicates the same as an EOP, but also requests operator intervention at receiver. Once operator intervention is accomplished, transmitter will return to beginning of Phase B. PRI-EOP should not be used in the T.4 Error Correction mode. |

**Table 2.4: Facsimile Control Field Data For Post Message Signals Sent From Receiver To Transmitter During Phase D**

| SIGNAL | BIT PATTERN | DESCRIPTION |
|---|---|---|
| **Post Message Commands Sent From Receiver To Transmitter** | | |
| Message Confirmation (MCF) | X011 0001 | Indicates that complete message has been received and that additional messages may follow. Upon receiving this signal, the transmitter returns to the beginning of Phase C. |
| Retrain Positive (RTP) | X011 0011 | Indicates that complete message has been received and that additional messages may follow. Upon receiving this signal, the transmitter returns to the beginning of Phase B. RTP is not valid in T.4 Error Correction Mode |
| Retrain Negative (RTN) | X011 0010 | Indicates that complete message was not satisfactorily received, and that retransmission of the message is required following retransmission of the training sequence. RTN is not valid in the T.4 Error Correction Mode. |
| Procedural Interrupt Positive (PIP) | X011 0101 | Indicates that a message has been received satisfactorily, but that further transmission should not continue without operator intervention at the transmitter. Failing the operator intervention, the facsimile procedure returns to the beginning of Phase B. |
| Procedural Interrupt Negative (PIN) | X011 0100 | Indicates that a message was not received satisfactorily, and that further transmission should not continue without operator intervention at the transmitter. Failing the operator intervention, the facsimile procedure returns to the beginning of Phase B. |

**Table 2.5: Facsimile Control Field Data For Line Control Signals**

| SIGNAL | BIT PATTERN | DESCRIPTION |
|---|---|---|
| | **Line Control Signals** | |
| Disconnect (DCN) | X101 1111 | Indicates the initiation of Phase E. |
| Command Repeat (CRP) | X101 1000 | Indicates that previous HDLC sequence received in error and that it should be repeated in its entirety |

At the receiver, the bit stream composed of the HDLC frame data and the frame check sequence is divided by the same generator polynomial described above. As before, the final bit of the opening flag, and any zeros inserted as a result of the zero insertion procedure are ignored in the calculation. The division will result in a remainder of 0001110100001111 ($x^{15}$ through $x^{0}$, respectively) in the absence of any transmission errors.

An example of the bit stream contained in an HDLC sequence sent at the beginning of Phase B by a called receiver is shown in Figure 2.8. This figure illustrates the exact bit stream associated with the HDLC sequence illustrated in Figure 2.4.

**Table 2.6: Facsimile Information Field For DIS, DTC, and DCS Signals**

| Bit Number | Meaning Following DIS or DTC Facsimile Control Field | Meaning Following DCS Facsimile Control Field |
|---|---|---|
| 1 | Group I Transmission | |
| 2 | Group I Reception | Group I Reception |
| 3 | Group I Index Of Cooperation = 176 | Group I Index Of Cooperation = 176 |
| 4 | Group II Transmission | |
| 5 | Group II Reception | Group II Reception |
| 6 | Reserved | |
| 7 | Reserved | |
| 8 | Reserved | |

| | | |
|---|---|---|
| 9 | Group III Transmission | |
| 10 | Group III Reception | Group III Reception |
| 11, 12 | Image Transmission Capabilities | Image Reception Modulation and Data Rates |
| (0,0) | V.27*ter* fallback mode | 2400 bits/sec V.27*ter* |
| (0,1) | V.27*ter* | 4800 bits/sec V.27*ter* |
| (1,0) | V.29 | 9600 bits/sec V.29 |
| (1,1) | V.29 and V.27*ter* | 7200 bits/sec V.29 |
| 13 | Reserved | |
| 14 | Reserved | |
| 15 | Vertical Scanning Resolution | Vertical Scanning Resolution |
| (0) | 3.85 lines/mm | 3.85 lines/mm |
| (1) | 7.7 lines/mm | 7.7 lines/mm |
| 16 | Two Dimensional Image Coding Capability | Two Dimensional Image Coding Capability |
| 17, 18 | Recording Width Capabilities | Recording Width Capabilities |
| (0,0) | 1728 PELS along scan line length of 215 mm +/- 1% | 1728 PELS along scan line length of 215 mm +/- 1% |
| (0,1) | 1728 PELS along scan line length of 215 mm +/- 1%, and 2048 PELS along scan line length of 255 mm +- 1%, and 2432 PELS along scan line length of 303 mm +- 1%. | 2432 PELS along scan line length of 303 mm +- 1%. |
| (1,0) | 1728 PELS along scan line length of 215 mm +/- 1%, and 2048 PELS along scan line length of 255 mm +- 1%. | 2048 PELS along scan line length of 255 mm +- 1%. |
| (1,1) | Invalid | Invalid |

| | | |
|---|---|---|
| 19,20 | Recording Length Capabilities | Recording Length Capabilities |
| (0,0) | A4 (297 mm) | A4 (297 mm) |
| (0,1) | Unlimited | Unlimited |
| (1,0) | A4 (297 mm) and B4 (364 mm) | A4 (297 mm) and B4 (364 mm) |
| (1,1) | Invalid | Invalid |
| 21, 22, 23 | Scan Time Capability | Minimum Scan Time |
| (0,0,0) | 20 ms at 3.85 lines/mm: $T_{7.7} = T_{3.85}$ | 20 ms |
| (0,0,1) | 40 ms at 3.85 lines/mm: $T_{7.7} = T_{3.85}$ | 40 ms |
| (0,1,0) | 10 ms at 3.85 lines/mm: $T_{7.7} = T_{3.85}$ | 10 ms |
| (1,0,0) | 5 ms at 3.85 lines/mm: $T_{7.7} = T_{3.85}$ | 5 ms |
| (0,1,1) | 10 ms at 3.85 lines/mm: $T_{7.7} = 1/2T_{3.85}$ | |
| (1,1,0) | 20 ms at 3.85 lines/mm: $T_{7.7} = 1/2T_{3.85}$ | |
| (1,0,1) | 40 ms at 3.85 lines/mm: $T_{7.7} = 1/2T_{3.85}$ | |
| (1,1,1) | 0 ms at 3.85 lines/mm: $T_{7.7} = 1/2T_{3.85}$ | 0 ms |
| Note: $T_{7.7}$ and $T_{3.85}$ refer to the scan line times for vertical scan modes of 7.7 lines/mm and 3.85 lines/mm respectively. | | |
| 24 | Extend Field | Extend Field |
| 25 | 2400 bits/sec Handshaking | 2400 bits/sec Handshaking |
| 26 | Uncompressed Mode | Uncompressed Mode |
| 27 | Error Correction Mode | Error Correction Mode |
| 28 | Set To 0 | Frame Size: 0 = 256 bytes<br>1 = 64 bytes |
| 29 | Error Limiting Mode | Error Limiting Mode |
| 30 | Reserved | Reserved |

| | | |
|---|---|---|
| 31 | Unassigned | |
| 32 | Extend Field | Extend Field |
| 33<br><br>(0)<br><br>(1) | <u>Validity Of Bits 17 and 18</u><br><br>Bits 17 and 18 are valid.<br><br>Bits 17 and 18 are invalid. | <u>Recording Width</u><br><br>Use recording width indicated by bits 17 and 18.<br><br>Use recording width information in bits 34 - 37. |
| 34 | Recording Width Capability 1216 PELS along scan line of length 151 mm +/- 1% | Use middle 1216 PELS of 1728 PELS |
| 35 | Recording Width Capability 864 PELS along scan line of length 107 mm +/- 1% | Use middle 864 PELS of 1728 PELS |
| 36 | Recording Width Capability 1728 PELS along scan line of length 107 mm +/- 1% | Invalid |
| 37 | Recording Width Capability 1728 PELS along scan line of length 107 mm +/- 1% | Invalid |
| 38 | Reserved | Reserved |
| 39 | Reserved | Reserved |
| 40 | Extend Field | Extend Field |

**Table 2.7: Digit Coding For CSI. CGI, or TSI Facsimile Information Field**

| Digit | Bit Pattern |
|---|---|
| + | 00101011 |
| 0 | 00110000 |
| 1 | 00110001 |
| 2 | 00110010 |
| 3 | 00110011 |
| 4 | 00110100 |
| 5 | 00110101 |
| 6 | 00110110 |
| 7 | 00110111 |
| 8 | 00111000 |
| 9 | 00111001 |
| Space | 00100000 |

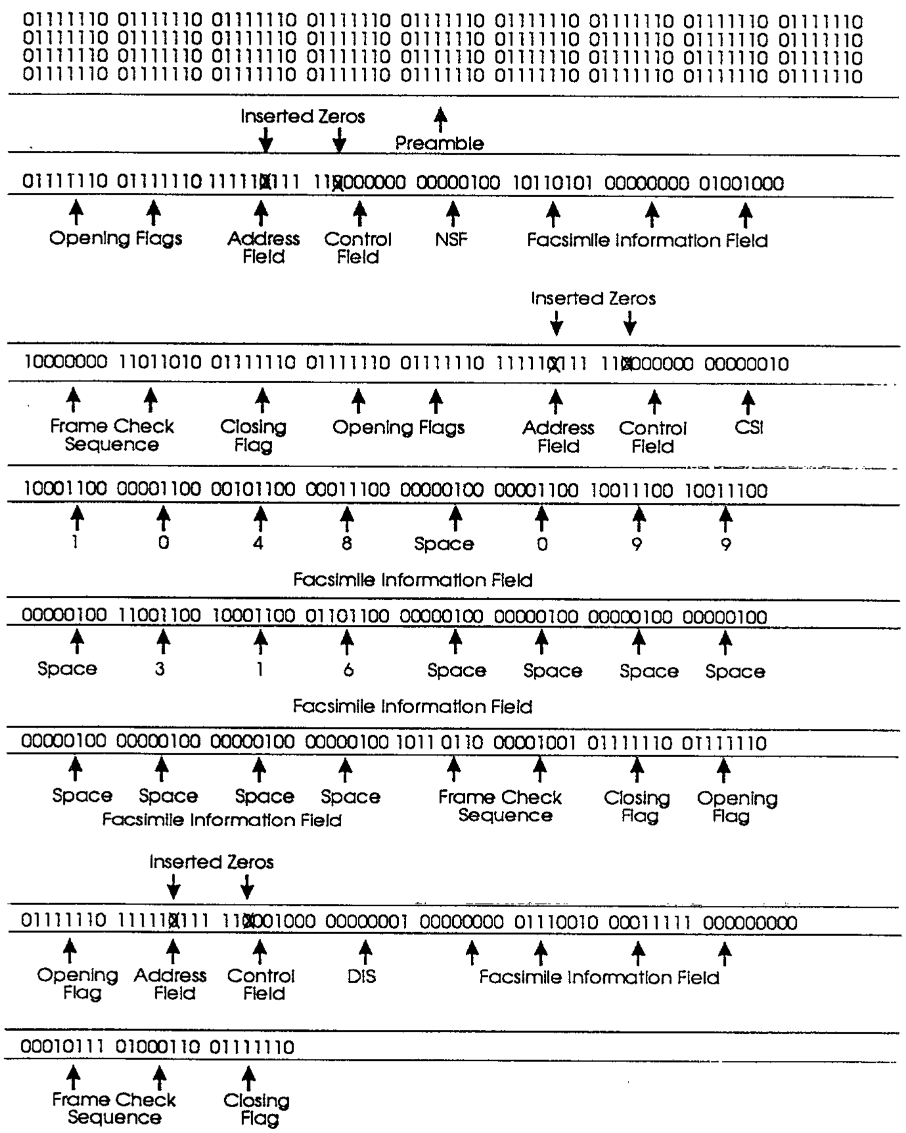



**Figure 2.5: Bit Pattern For HDLC Sequence Shown In Figure 2.4**

## 2.3 V.29 and V.27*ter* Signalling

The facsimile image in a Group III machine is encoded as a digital bit stream and sent using one of two modulation schemes: V.29 or V.27*ter*. The image encoding techniques will be discussed in Section 2.4.

V.29 modulation is an M-ary Quadrature Amplitude Modulation (QAM) scheme employing either 16, 8, or 4 levels for data rates of 9600, 7200, and 4800 bits per second (bps) respectively. The highest data rate possible for the channel conditions will be used. In each case, the transfer of information takes place at a baud rate of 2400 symbols per second. A carrier frequency of 1700 Hz is used. In the 9600 bps case, each transmitted symbol is composed of four bits. The first bit (Q1) determines the relative amplitude of the transmitted element. These amplitudes are measured relative to the unmodulated carrier. Bits Q2, Q3, and Q4 are encoded as a phase change, relative to the phase of the previous symbol. The amplitude and relative phase encoding for the 9600 bps case can be determined from Tables 2.8 and 2.9 respectively. The signal space diagram for the 9600 bps transmission is shown in Figure 2.6

**Table 2.8: Relative Signal Amplitudes For V.29 Transmission**

| Absolute Phase | Q1 | Relative Signal Element Amplitude |
|---|---|---|
| $0^0$, $90^0$, $180^0$, $270^0$ | 0 | 3 |
| | 1 | 5 |
| $45^0$, $135^0$, $225^0$, $315^0$ | 0 | $\sqrt{2}$ |
| | 1 | $3\sqrt{2}$ |

For 7200 bits per second transmission, each transmitted symbol is composed of three bits. The relative phase change for each symbol is determined by using these three data bits as Q2, Q3, and Q4 in Table 2.9. The amplitudes for Q1 = 0, in Table 2.8 are used. The resulting signal has a signal space diagram as shown in Figure 2.6.

For 4800 bits per second transmission, each transmitted symbol is composed of two bits. The relative phase changes are determined by using the data bits as Q2, and Q3 in Table 2.9. Q4 is determined by the inverse of the modulo 2 addition of Q2 and Q3. The resulting signal space diagram is shown in Figure 2.6.

**Table 2.9: Phase Changes For V.29 Transmission**

| Q2 | Q3 | Q4 | Phase Change |
|---|---|---|---|
| 0 | 0 | 1 | $0^0$ |
| 0 | 0 | 0 | $45^0$ |
| 0 | 1 | 0 | $90^0$ |
| 0 | 1 | 1 | $135^0$ |
| 1 | 1 | 1 | $180^0$ |
| 1 | 1 | 0 | $225^0$ |
| 1 | 0 | 0 | $270^0$ |
| 1 | 0 | 1 | $315^0$ |

In order to ensure that the transmitter and receiver both have a common zero phase reference, a synchronizing/phasing signal is used to train the V.29 demodulator. As mentioned in Section 2.2, this training sequence takes place during Phase B of the facsimile procedure. It consists of 4 phases, and is shown in Figure 2.7. The 128 alterations which follow the initial period of silence are used by the receiver to acquire initial synchronization. The first signal symbol transmitted during this set of alterations is used by the receiver to establish the absolute phase reference of $180^0$ [5]. This symbol is shown as the **A** symbol in Figure 2.8. The phase and amplitude of the second symbol (**B**) in the series of alterations varies according to the data rate used. The position of the **B** symbol in the signal space diagram is shown in Figure 2.8 for all three data rates. The series of alterations consists of a repetition of the symbol pattern ABABAB for the duration of Segment 2. Segment 3 of the training sequence consists of the transmission of an equalizer conditioning pattern. During this phase, two symbols are used. Symbol C in Figure 2.8 is used to represent a **0**. Symbol D is used to represent a **1**. The exact pattern of **0**'s and **1**'s is generated according to the polynomial $1 + x^{-6} + x^{-7}$, and continues for 384 symbol intervals. Segment 4 of the training/phasing sequence consists of the transmission of a series of **1**'s, which are scrambled according to the self synchronizing data scrambling algorithm specified for V.29 transmissions. All V.29 compatible modems implement this scrambling/descrambling algorithm, and generally its use is transparent to the user. The scrambling algorithms consists of the division of the data sequence by the generating polynomial $1 + x^{-18} + x^{-23}$. Initial synchronization of the scrambler and descrambler circuits is ensured by loading the scrambler circuit with **0**'s during the transmission of Segments 1, 2, and 3. A more detailed description of the V.29 scrambling algorithm is available in the V.29 specifications [5].

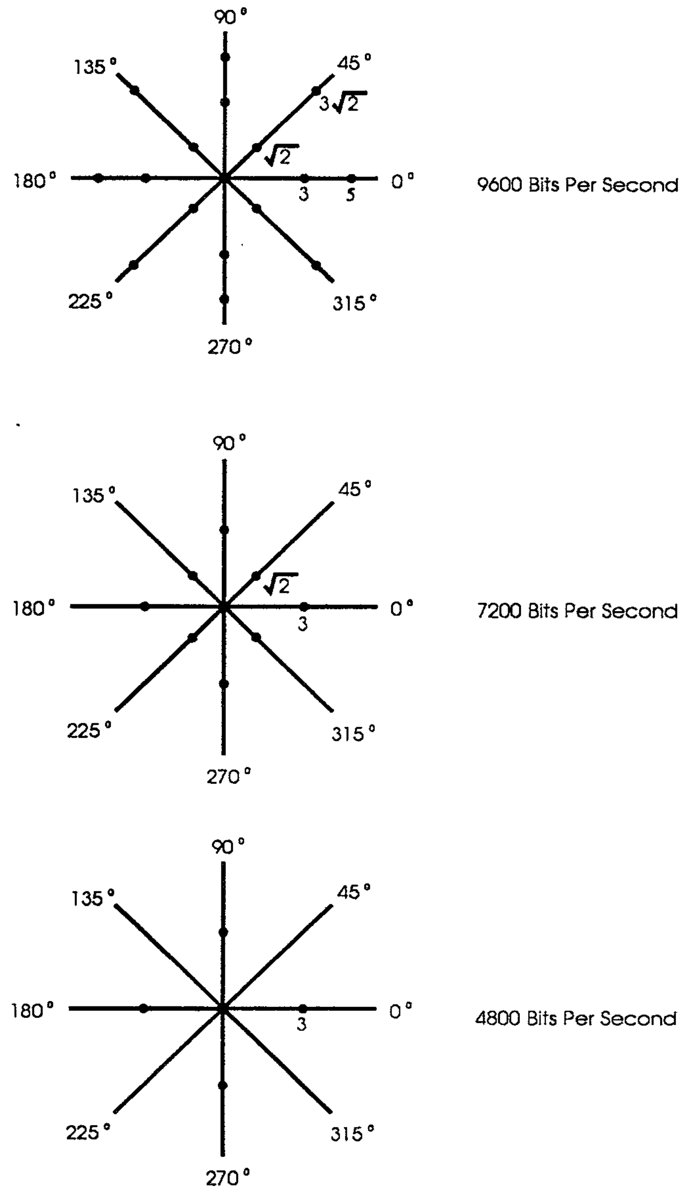



**Figure 2.6: Signal Space Diagram For V.29 Modulation**

| Segment 1 | Segment 2 | Segment 3 | Segment 4 |
|---|---|---|---|
| Silence (48 Symbol Intervals) | Alterations (128 Symbol Intervals) | Equalizer Conditioning Pattern (384 Symbol Intervals) | Scrambled ONES (48 Symbol Intervals) |

**Figure 2.7: V.29 Training/Phasing Sequence**

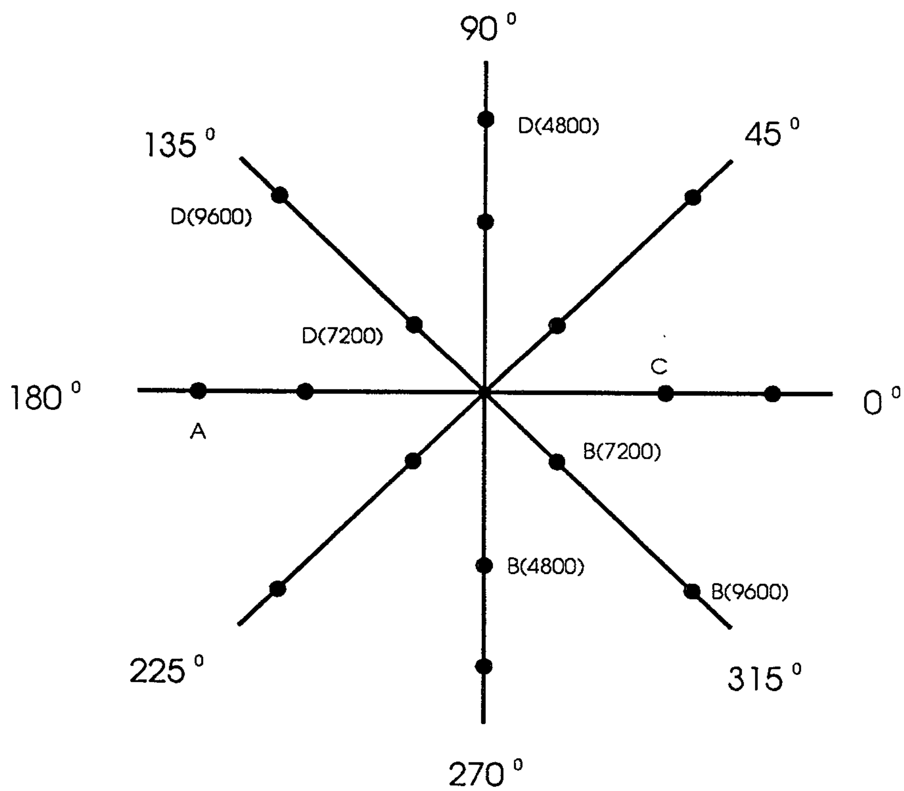



**Figure 2.8: Signal Space Positions For V.29 Training Symbols (9600, 7200, and 4800 Bits Per Second)**

V.27*ter* signalling is the second modulation technique employed for the transmission of image information during the facsimile procedure. V.29 modulation tends to be more common on land-line links, whereas V.27*ter* is used more often on those facsimile transmissions where a radio link is used at some point. V.27*ter* is an M-ary Differential Phase Shift Keyed (DPSK) which employs either eight, or four levels for data rates of 4800, and 2400 bits per second respectively. As in the case of V.29 modulation, the highest data rate compatible with the channel is used. In either case, the symbol rate is 2400 symbols per second.

In the case of 4800 bps transmission, each symbol is composed of three data bits. The phase changes are for each tri-bit combination are shown in Table 2.10.

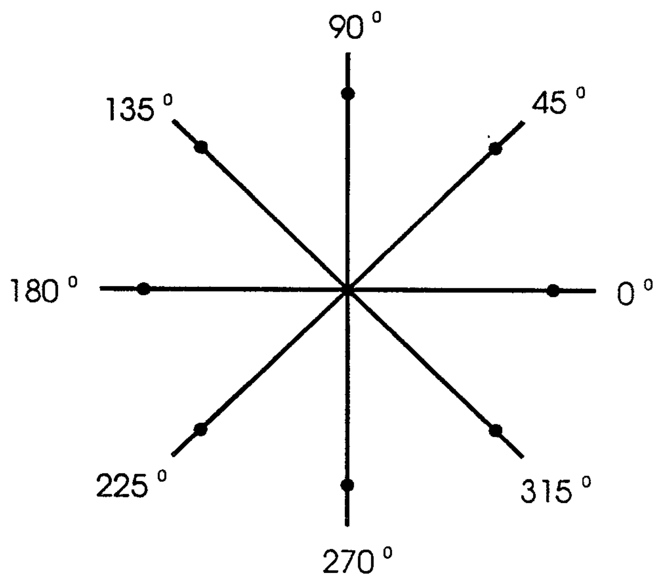
**Table 2.10: Phase Changes For 4800 Bits Per Second, V.27*ter* Modulation**

| Tri-Bit Combination | Phase Change |
|---|---|
| 001 | $0^0$ |
| 000 | $45^0$ |
| 010 | $90^0$ |
| 011 | $135^0$ |
| 111 | $180^0$ |
| 110 | $225^0$ |
| 100 | $270^0$ |
| 101 | $315^0$ |

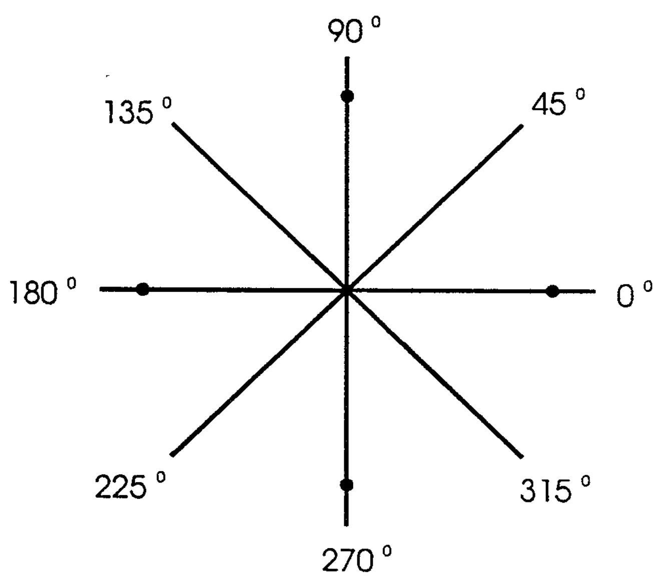
For 2400 bps transmission, each symbol is composed of a group of two data bits. The phase change associated with each one of these symbols is shown in Table 2.11. Signal space diagrams for V.27*ter* transmissions are shown in Figure 2.9 for data rates of 4800 and 2400 bps.

**Table 2.11: Phase Changes For 2400 Bits Per Second, V.27*ter* Modulation**

| Data Bit Pair | Phase Change |
|---|---|
| 00 | $0^0$ |
| 01 | $90^0$ |
| 11 | $180^0$ |
| 10 | $270^0$ |




4800 Bits Per Second




2400 Bits Per Second

**Figure 2.9: Signal Space Diagram For V.27*ter* Modulation**

The training/phasing sequences used for V.27*ter* signalling consists of five phases. These are shown in Figure 2.10. There are two possible training sequences used. The longer sequence is used at the beginning of the call for initial synchronization. The shorter sequence is used during the call to maintain synchronization during the procedure; between pages of text for example. The first two segments of either sequence (the unmodulated carrier and silence intervals) may be omitted if protection against talker echo is not required. The equalizer conditioning pattern is derived from a pseudo random sequence generated by the polynomial $1 + x^{-6} + x^{-7}$. Every third bit of this pseudo random sequence is used to determine the transmitted symbol. When the bit is a **0**, the symbol corresponding to zero degrees in Table 2.10 or 2.11 is transmitted. When the pattern contains a **1**, the symbol corresponding to $180^0$ in Table 2.10 or 2.11 is transmitted. The final segment of the V.27*ter* training sequence consists of a group of scrambled ones. As with the V.29 modulation, a scrambling algorithm is specified for V.27*ter* modulation. The data is scrambled by dividing the message sequence with the generating polynomial $1 + x^{-6} + x^{-7}$. A more detailed description of the scrambling algorithm used for V.27*ter* modulation is available in the V.27*ter* specifications [5].

| Segment 1 | Segment 2 | Segment 3 | Segment 4 | Segment 5 |
|---|---|---|---|---|
| Unmodulated Carrier<br>(185 - 200 msec) | Silence<br>(20 - 25 msec) | 180° Phase Reversals<br>(50 Symbol Intervals) | Equalizer Conditioning Pattern<br>(1074 Symbol Intervals) | Scrambled ONES<br>(8 Symbol Intervals) |

Long Training Sequence

| Segment 1 | Segment 2 | Segment 3 | Segment 4 | Segment 5 |
|---|---|---|---|---|
| Unmodulated Carrier<br>(185 - 200 msec) | Silence<br>(20 - 25 msec) | 180° Phase Reversals<br>(14 Symbol Intervals) | Equalizer Conditioning Pattern<br>(58 Symbol Intervals) | Scrambled ONES<br>(8 Symbol Intervals) |

Short Training Sequence

**Figure 2.10: V.27*ter* Training/Phasing Sequence**

## 2.4 Image Encoding

The facsimile image is digitally encoded using one of two schemes outlined in the CCITT Recommendations T.4 [3]. The encoded bit stream is then sent during Phase C of the transmission using either V.29 or V.27*ter* modulation. All facsimile machines must be capable of encoding and decoding the image using the basic one dimensional format. As an option, a two dimensional encoding scheme is available, which is somewhat more efficient that the single dimensional procedure, but less common. The scheme used in any given transmission is determined during the handshaking which occurs in Phase B of the procedure. Bit 16 of the 40 bit facsimile information field following a DIS, DTC, or DCS signal specifies the encoding capability of the machine. (e.g. see Table 2.6.) Both schemes used for image encoding are discussed below.

### 2.4.1 One Dimensional Image Encoding

In the one dimensional encoding scheme, each 215 mm horizontal scan line is represented by a total of 1728 Picture ELementS (PELS). Each data line, representing one scan line, consists of alternating white and black run codes which specify the number of consecutive white or black PELS. A Huffman encoding scheme is used in which short code words are allocated to those white and black run lengths occurring more often in practice. To ensure that the receiver maintains colour synchronization, each data line begins with a white run length code word. If the scan line begins with a black colour, a white run length of zero is sent.

The code words used are of two types: Terminating Code Words and Make-Up Code Words. Run lengths in the range of 0 to 63 PELS are encoded with their appropriate Terminating Code Word. Run lengths in the range of 64 to 1728 PELS are encoded using both a Make-Up Code Word followed by a Terminating Code Word. The Make-Up Code Word specifies the largest length which is equal to or shorter than that required. The Terminating Code Word which follows specifies the difference between the required length and the run length represented by the Make-Up Code. The code words used to represent Terminating Code Words are shown in Table 2.12. Make-Up Code Words are shown in Table 2.13. These tables were taken from Reference 3.

**Table 2.12: Terminating Code Words**

| White Run Length | Code Word | Black Run Length | Code Word |
|---|---|---|---|
| 0 | 00110101 | 0 | 0000110111 |
| 1 | 000111 | 1 | 010 |
| 2 | 0111 | 2 | 11 |
| 3 | 1000 | 3 | 10 |
| 4 | 1011 | 4 | 011 |
| 5 | 1100 | 5 | 0011 |

| | | | |
|---|---|---|---|
| 6 | 1110 | 6 | 0010 |
| 7 | 1111 | 7 | 00011 |
| 8 | 10011 | 8 | 000101 |
| 9 | 10100 | 9 | 000100 |
| 10 | 00111 | 10 | 0000100 |
| 11 | 01000 | 11 | 0000101 |
| 12 | 001000 | 12 | 0000111 |
| 13 | 000011 | 13 | 00000100 |
| 14 | 110100 | 14 | 00000111 |
| 15 | 110101 | 15 | 000011000 |
| 16 | 101010 | 16 | 0000010111 |
| 17 | 101011 | 17 | 0000011000 |
| 18 | 0100111 | 18 | 0000001000 |
| 19 | 0001100 | 19 | 00001100111 |
| 20 | 0001000 | 20 | 00001101000 |
| 21 | 0010111 | 21 | 00001101100 |
| 22 | 0000011 | 22 | 00000110111 |
| 23 | 0000100 | 23 | 00000101000 |
| 24 | 0101000 | 24 | 00000010111 |
| 25 | 0101011 | 25 | 00000011000 |
| 26 | 0010011 | 26 | 000011001010 |
| 27 | 0100100 | 27 | 000011001011 |
| 28 | 0011000 | 28 | 000011001100 |
| 29 | 00000010 | 29 | 000011001101 |
| 30 | 00000011 | 30 | 000001101000 |
| 31 | 00011010 | 31 | 000001101001 |
| 32 | 00011011 | 32 | 000001101010 |
| 33 | 00010010 | 33 | 000001101011 |
| 34 | 00010011 | 34 | 000011010010 |

| | | | |
|---|---|---|---|
| 35 | 00010100 | 35 | 000011010011 |
| 36 | 00010101 | 36 | 000011010100 |
| 37 | 00010110 | 37 | 000011010101 |
| 38 | 00010111 | 38 | 000011010110 |
| 39 | 00101000 | 39 | 000011010111 |
| 40 | 00101001 | 40 | 000001101100 |
| 41 | 00101010 | 41 | 000001101101 |
| 42 | 00101011 | 42 | 000011011010 |
| 43 | 00101100 | 43 | 000011011011 |
| 44 | 00101101 | 44 | 000001010100 |
| 45 | 00000100 | 45 | 000001010101 |
| 46 | 00000101 | 46 | 000001010110 |
| 47 | 00001010 | 47 | 000001010111 |
| 48 | 00001011 | 48 | 000001100100 |
| 49 | 01010010 | 49 | 000001100101 |
| 50 | 01010011 | 50 | 000001010010 |
| 51 | 01010100 | 51 | 000001010011 |
| 52 | 01010101 | 52 | 000000100100 |
| 53 | 00100100 | 53 | 000000110111 |
| 54 | 00100101 | 54 | 000000111000 |
| 55 | 01011000 | 55 | 000000100111 |
| 56 | 01011001 | 56 | 000000101000 |
| 57 | 01011010 | 57 | 000001011000 |
| 58 | 01011011 | 58 | 000001011001 |
| 59 | 01001010 | 59 | 000000101011 |
| 60 | 01001011 | 60 | 000000101100 |
| 61 | 00110010 | 61 | 000001011010 |
| 62 | 00110011 | 62 | 000001100110 |
| 63 | 00110100 | 63 | 000001100111 |

**Table 2.13: Make Up Code Words**

| White Run Length | Code Word | Black Run Length | Code Word |
|---|---|---|---|
| 64 | 11011 | 64 | 0000001111 |
| 128 | 10010 | 128 | 000011001000 |
| 192 | 010111 | 192 | 000011001001 |
| 256 | 0110111 | 256 | 000001011011 |
| 320 | 00110110 | 320 | 000000110011 |
| 384 | 00110111 | 384 | 000000110100 |
| 448 | 01100100 | 448 | 000000110101 |
| 512 | 01100101 | 512 | 0000001101100 |
| 576 | 01101111 | 576 | 0000001101101 |
| 640 | 01100111 | 640 | 0000001001010 |
| 704 | 011001100 | 704 | 0000001001011 |
| 768 | 011001101 | 768 | 0000001001100 |
| 832 | 011010010 | 832 | 0000001001101 |
| 896 | 011010011 | 896 | 0000001110010 |
| 960 | 011010100 | 960 | 0000001110011 |
| 1024 | 011010101 | 1024 | 0000001110100 |
| 1088 | 011010110 | 1088 | 0000001110101 |
| 1152 | 011010111 | 1152 | 0000001110110 |
| 1216 | 011011000 | 1216 | 0000001110111 |
| 1280 | 011011001 | 1280 | 0000001010010 |
| 1344 | 011011010 | 1344 | 0000001010011 |
| 1408 | 011011011 | 1408 | 0000001010100 |
| 1472 | 010011000 | 1472 | 0000001010101 |

| | | | |
|---|---|---|---|
| 1536 | 010011001 | 1536 | 0000001011010 |
| 1600 | 010011010 | 1600 | 0000001011011 |
| 1664 | 011000 | 1664 | 0000001100100 |
| 1728 | 010011011 | 1728 | 0000001100101 |
| EOL | 000000000001 | EOL | 000000000001 |

The End Of Line (EOL) code word in Table 2.13 signals the end of each line of data. Since this code word is unique, it allows the receiving facsimile to reacquire line synchronization in the event that a transmission error occurs. A new line is started upon reception of an EOL word. An error occurring during a data line is easily detectable, since the decoded information between any two EOL code words should add up to 1728 PELS. At the end of each page of transmission, a series of six consecutive EOLs is sent. This is the Return To Control (RTC) signal which is used to signal to the receiver that the page of information is complete, and that Phase D of the procedure will immediately follow. After sending the RTC signal, the facsimile transmitter will immediately send an HDLC encoded post message procedure signal using the V.21 modulation.

Occasionally, the time required to transmit the Terminating Code Word, Make-Up Code Word, and EOL will be less than the minimum scan time specified in bits 21, 22, and 23 of the 40 bit facsimile information field, following the DCS signal sent by the transmitter. When this condition occurs, the transmitter will insert a sequence of zeros between the scan line data and the EOL character. This variable length string of zero fill ensures that the time to transmit a line of data is never less than the minimum scan time specified.

As can be seen in Table 2.6, there are optional higher resolution scanning capabilities specified, in which a single horizontal scan line may be represented by more than 1728 PELS. In these cases, the additional Make-Up Code Words shown in Table 2.14 are used. The same code words are used for black run and white run lengths. The actual colour is determined by the Terminating Code Word which follows. The last two code words shown in Table 2.13 are not yet used, but are included for future systems.

**Table 2.14: Optional Make Up Code Words**

| Run Length (White Or Black) | Code Word |
|---|---|
| 1792 | 00000001000 |
| 1856 | 00000001100 |
| 1920 | 00000001101 |

| | |
|---|---|
| 1984 | 000000010010 |
| 2048 | 000000010011 |
| 2112 | 000000010100 |
| 2176 | 000000010101 |
| 2240 | 000000010110 |
| 2304 | 000000010111 |
| 2368 | 000000011100 |
| 2432 | 000000011101 |
| 2496 | 000000011110 |
| 2560 | 000000011111 |

### 2.4.2 Two Dimensional Coding Scheme

The two dimensional coding scheme is an optional extension of the one dimensional coding scheme described in Section 2.4.1. If used, the document is not encoded entirely using the two dimensional scheme. In standard vertical resolution mode of 3.85 lines/mm, single dimensional encoding is used on a minimum of every second horizontal scan line. For the higher vertical resolution mode of 7.7 lines/mm, every fourth horizontal scan line is single dimensionally encoded. As in the low resolution case, this figure is a minimum value, and single dimensional encoding may be used more frequently.

The two dimensional encoding method is based on the definitions of various types of changing picture elements, which are PELS whose colour is different than the previous element. The definitions depend on whether they are located in the line being encoded or located in the reference line, which precedes the line being encoded. Once coded, the current line becomes the reference line for the next line to be coded. The definition of the changing picture elements also depends on whether they are the first changing element on the current reference or coding line, or the next changing element on these lines. These changing PELS are defined as follows [3]:

$a_0$ - The reference or starting changing element on the current coding line. At the start of the coding line $a_0$ is set on an imaginary white changing element situated just before the first element on the line.

$a_1$ - The next changing element to the right of $a_0$ on the current coding line.

$a_2$ - The next changing element to the right of $a_0$ and of opposite colour to $a_0$ .

$b_1$ - The first changing element on the reference line to the right of $a_0$ and of opposite colour to $a_0$ .

$b_2$ - The next changing element to the right of $b_1$ on the reference line.

Figure 2.11 illustrates the various changing picture elements which are used in the two dimensional encoding scheme. One of three modes is chosen for the group of picture elements being encoded. The choice of mode depends on the relationship between the picture elements shown in Figure 2.11.

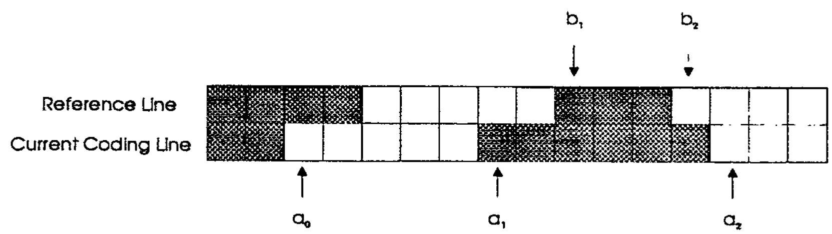



**Figure 2.11: Example Of Changing Picture Elements**

If $b_2$ lies to the left of $a_1$ , the Pass Mode is used. In this mode, the codeword **0001** is transmitted, and $a_0$ is set on the position of the element of the coding line which lies directly below $b_2$ in preparation for the coding of the next group of PELS to the right of the current group. If the conditions of the Pass Mode do not apply, and $|a_1 \; b_1| < 3$, the combination of $a_1$ and $b_1$ are coded using the Vertical Mode. In this mode, codewords are used to specify the relative positions $a_1$ and $b_1$ . The codewords used are specified in Table 2.15. Following the encoding of the current group of PELS, the position of $a_1$ is used as the new starting picture element $a_0$ for the next group of PELS to be encoded. If the conditions of the Pass Mode or the Vertical Mode are not met, the Horizontal Mode is used. In this mode, the colour and lengths of the group of PELS between $a_0$ to $a_1$ and $a_1$ to $a_2$ are encoded using the single dimensional encoding scheme of Table 2.12. These code words are sent following the sequence **001**. These code words are represented by M($a_0$ $a_1$ ) and M($a_1$ $a_2$ ) in Table 3.15. Following the encoding of the current group of PELS, the position of $a_2$ is used as the new starting position $a_0$. An example of the three modes is given in Figure 2.12.

**Table 2.15: Two Dimensional Coding Table**

| **Mode** | **Elements To Be Coded** | | **Code Word** | **Position Of New $a_0$ Following Coding** |
|---|---|---|---|---|
| Pass | $b_1$ , $b_2$ | | 0001 | Element Below $b_2$ |
| Vertical | $a_1$ just under $b_1$ | $\lvert a_1 b_1 \rvert = 0$ | 1 | $a_1$ |
| | $a_1$ to the right of $b_1$ | $\lvert a_1 b_1 \rvert = 1$ | 011 | |
| | | $\lvert a_1 b_1 \rvert = 2$ | 000011 | |
| | | $\lvert a_1 b_1 \rvert = 3$ | 0000011 | |
| | $a_1$ to the left of $b_1$ | $\lvert a_1 b_1 \rvert = 1$ | 010 | |
| | | $\lvert a_1 b_1 \rvert = 2$ | 000010 | |
| | | $\lvert a_1 b_1 \rvert = 3$ | 0000010 | |
| Horizontal | $a_0 a_1$ , $a_1 a_2$ | | 001 + $M(a_0 a_1)$ + $M(a_1 a_2)$ | $a_2$ |

As in the case of one-dimensional encoding, each scan line is terminated with an EOL code. In the case of two dimensional coding however, each EOL sequence is followed by a tag bit which is used to designate the image coding technique which will be used on the next line. A tag bit of 1 indicates that the next line shall be encoded single-dimensionally. A tag bit of **0** indicates that the next line will be encoded using the two-dimensional scheme. As with the one-dimensional coding, fill may be required before the EOL code word to maintain time synchronization.

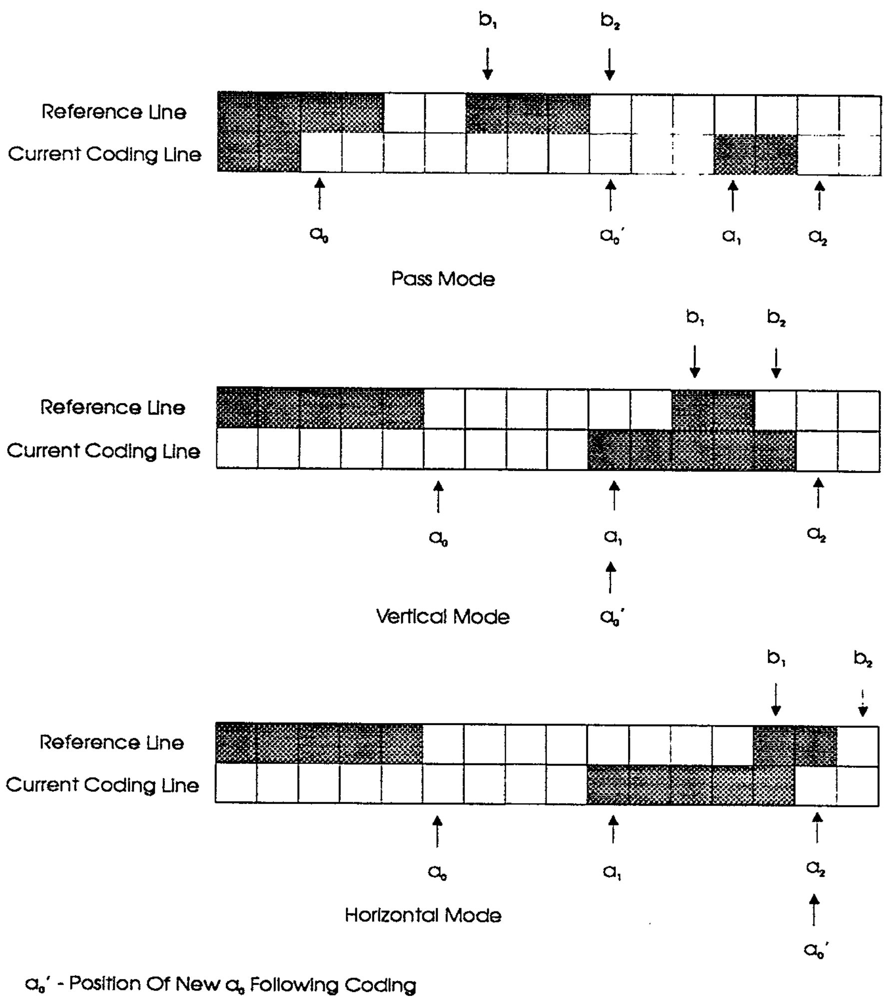



**Figure 2.12: Examples Of Two Dimensional Coding Modes**

## 2.5 T.4 Optional Error Correction Mode

As mentioned in Section 2.1, an optional error correction mode exists for the transmission of the facsimile image information. The T.4 Error Correction Mode of transmission involves the use of HDLC frames similar to those discussed in Section 2.2. The image information is still encoded using one of the schemes outlined in Section 2.4, but the resulting sequence of bits is packed into HDLC frames. These frames are then sent using the V.29 or V.27*ter* modulation.

The structure of an HDLC frame used in T.4 Error Correction Mode is identical to that shown in Figure 2.4. The flag, address, and control sequences are identical to those used in Section 2.2. Frame checking sequences are constructed in a manner identical to that described in Section 2.2. As in the HDLC frames discussed earlier, zero insertion may be used within the frame data to prevent the occurrence of a flag sequence within the frame.

Two types of HDLC frames are used in the error correction mode. If the facsimile control field of the HDLC frame is set to **0110 0001**, the HDLC frame is designated as a Return to Control for Partial page (RCP) frame. There is no facsimile information field following the facsimile control field in an RCP frame. These frames are used to signal the end of a page of image information. Three consecutive RCP frames are used to signal to the receiver that the page of information is complete, and that Phase D of the procedure will follow immediately. Signalling which follows the transmission of these three frames will occur using V.21 modulation.

If the facsimile control field of the HDLC frame is set to **0110 0000**, the HDLC frame is designated as a facsimile coded data frame. These frames contain the image information in the facsimile information field which follows the facsimile control field. The stream of bits which compose the scanned data lines is broken up into frames of either 64 or 256 bytes. This choice is done at the discretion of the transmitting system and is indicated using bit 28 of the facsimile information field following the DCS signal in Phase B. As shown in Table 2.6, a **0** indicates that a frame size of 256 bytes will be used. A **1** indicates a frame size of 64 bytes. The facsimile information field contained in a facsimile coded data frame will contain the 64 or 256 bytes of data, preceded by a single byte indicating the frame number. Since the maximum value of the frame byte is 256, each page of information must be broken up into 256 frames of data bits. Zero fill may be added to the image information as required to align the frame boundaries.

Error correction in the T.4 Optional Error Correction Mode is achieved through the use of a half duplex Automatic Repeat reQuest (ARQ) technique. Detection of errors occurs at the end of each facsimile coded data frame. By analyzing the frame check sequence, the receiver may determine those image frames which were received in error from the first byte of the facsimile information field. If this byte is itself corrupted, the receiver will assume that the required image frames are missing. At the end of a complete page of transmission, the receiver will issue a command to the transmitter requesting a retransmission of those frames received in error, or not at all.

The use of the T.4 Optional Error Correction Mode requires additional handshaking signals sent using V.21 modulation during Phases B and D of the facsimile procedure. As mentioned in Section 3.2, EOM, MPS, EOP, PRI-EOM, PRI-MPS, and PRI-EOP signals are not used in the error correction mode. The end of a complete or partial page of transmission in this mode is indicated by a Partial Page Signal (PPS). Upon receiving a PPS signal, the receiver will respond with either an MCF signal, if no errors were detected, or a Partial Page Request (PPR) signal. This latter signal indicates that certain frames in the previous page were received in error.

The facsimile information field which follows the PPR signal in the HDLC frame contains 256 bits. Each bit corresponds to one of the 256 image frames received during the transmission of the previous page. If the frame was received in error, or not at all, the corresponding bit in this facsimile information field will be set to **1**. The transmitter will then retransmit only those frames which were received in error. If errors again occur, the receiver again responds with a PPR signal. Upon receiving four consecutive PPR signals, the transmitter will issue a Continue To Correct (CTC) Signal, indicating that it will continue to retransmit the data in question.

The facsimile information field contained in a CTC HDLC frame consists of two bytes, which are identical to bits 1-16 of the DCS facsimile information field. (See Table 2.6.) In bits 11 and 12 of this frame, the transmitting facsimile may direct the receiver to fall back to a lower data rate for the reception of the image information. When the receiver has accepted the changes indicated in the CTC signal, it responds with Response for Continue To Correct signal (CTR).

The transmitter, upon receiving a series of PPR signals, may also decide to terminate the retransmission of error frames. In this case, it will issue an End Of Retransmission (EOR) signal. At this point, the receiver responds with a Response for End of Retransmission (ERR) signal and prepares for the reception of the next block of information.

These handshaking signals, and others used in the T.4 Optional Error Correction Mode, are shown in Table 2.16, along with the appropriate facsimile control field data for each one. **X** is defined as in Section 2.2.

**Table 2.16: Facsimile Control Field Data For Signals Used In T.4 Error Correction Mode**

| SIGNAL | BIT PATTERN | DESCRIPTION |
|---|---|---|
| **Commands Sent From Transmitter To Receiver** | | |
| Partial Page Signal (PPS) | X111 1101 | Indicates the end of a complete or partial page of facsimile information. Also indicates a return to the beginning of Phase B or C upon receipt of a valid MCF signal. |

| | | |
|---|---|---|
| Continue To Correct (CTC) | X100 1000 | Sent by the transmitter in response to the fourth consecutive received PPR signal. Followed by a 16 bit facsimile information field which may direct receiver to lower data rate. |
| End Of Retransmission (EOR) | X111 0011 | Sent by the transmitter if it decides to terminate the retransmission of error frames. The transmitter will send the next block of information upon receipt of a ERR signal. |
| Receive Ready (RR) | X111 0110 | Used To Request Status Of Receiver. |
| **Commands Sent From Receiver To Transmitter** | | |
| Partial Page Request (PPR) | X011 1101 | Sent by receiver to indicate that previous message was not received satisfactorily. Followed by a 256 bit facsimile information field which indicates the facsimile fields received in error. |
| Response For Continue To Correct (CTR) | X010 0011 | Acknowledgement for CTC signal. |
| Response For End Of Retransmission (ERR) | X011 1000 | Acknowledgement for EOR signal. |
| Receiver Not Ready (RNR) | X011 0111 | Sent to the transmitter to indicate that the receiver is not ready to receive more data. |

# 3.0 HIGHWIRE HARDWARE

## 3.1 PC Interface Circuitry

The hardware which composes the HIGHWIRE system consists of a single AT sized card resident in an IBM compatible PC. The system takes an analog baseband signal and displays the image of the received facsimile on the PC screen. A description of the system software is given in Section 4.0. Schematic diagrams for the circuitry are shown in Figures 3.1 and 3.2.

The base address selection for the card is hardware programmable via two eight bit switch packages (S1 and S2 in Figure 3.1.) It should be noted that the four least significant bits of the programmable switches are not used in the address comparison. These must be set to **0**. The card occupies 32 locations in PC I/O address space. Each location accesses a unique register in the XR2900 modem. The XR2900 modem will be discussed in Section 3.2. PC address lines are compared with the programmed switch settings using two 74F521 eight bit identity comparators (U14 and U15). PC address lines A15 - A5 are used in the comparison as well as the PC Address Enable (AEN) line. This ensures that the HIGHWIRE board responds only to valid PC read/write bus cycles, and not to DMA cycles. The AEN line is low (**0**) during valid bus cycles and high (**1**) for DMA cycles [5].

The outputs of the identity comparators are OR'd together to provide the Board Enable (BE) signal. This signal is low whenever the HIGHWIRE board is addressed during a PC bus cycle. This signal is used to enable much of the circuitry on the board.

Much of the circuitry shown in Figure 4.1 is used to multiplex the separate address and data lines from the PC for input to the XR2900. The modem chip set requires that address and data be multiplexed on the same line in a manner compatible with Intel 8031 microprocessors [6]. The timing diagram for this multiplexing is shown in Figure 4.3. The PC provides an Address Latch Enable (ALE) signal around which this multiplexing is done. The ALE signal is held high for half a clock cycle just prior to the placement of a valid address on the PC bus. The clock in this case is the PC bus clock which is nominally 8.0 MHz . In Figures 4.1 and 4.3, it is seen that the ALE signal is stretched a half clock cycle using a J-K flip flop (U1A). This creates an address latch signal for the XR2900 modem. The PC ALE may not be used directly since its duration is shorter than the minimum 100 nsec address latch signal required by the XR2900 [6]. The stretched PC ALE signal is used as the XR2900 Address Latch Enable signal (XR-ALE). The rising edge of the XR-ALE signal is used to latch the five least significant address bits from the PC address line using a 74ALS374 octal D-Type flip flop. The XR-ALE signal is delayed half a clock cycle using an inverted PC bus clock and another J-K flip flop (U1B). The delayed XR-ALE signal is used to enable a 74ALS245 bus transceiver (U7), which places the latched address data on the multiplexed address/data bus for a duration of approximately 125 nsec. OR gates (U4) and an inverter (U5B) are used to ensure that the bus transceiver is enabled only during valid bus cycles and after the PC ALE clock has gone low. This arrangement ensures that the address data presented to the XR2900 remains valid at least 40 nsec following the de-assertion of the XR-ALE line. This is a design requirement of the XR2900 [6].

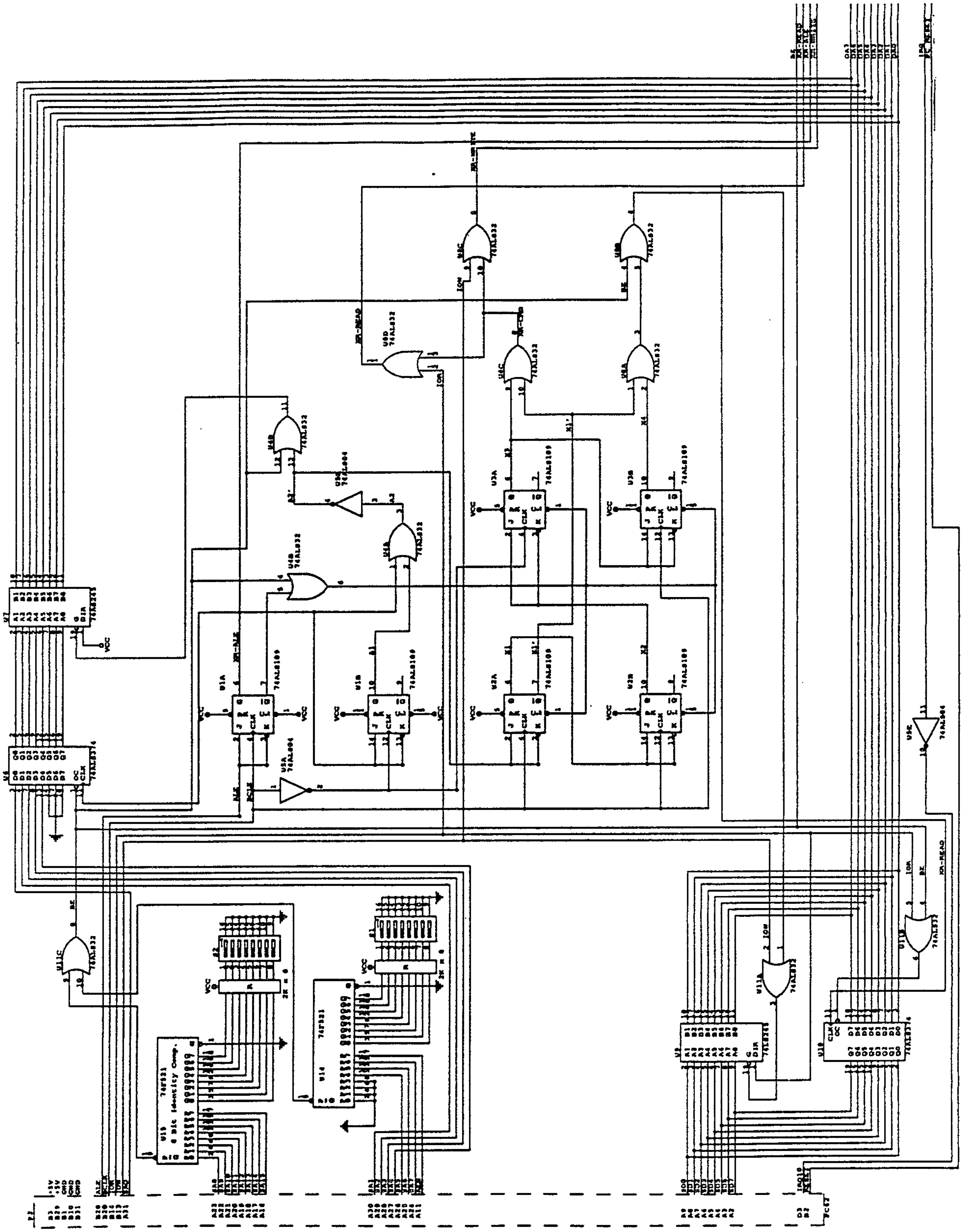


**Figure 3.1: HIGHWIRE Interface Circuitry**

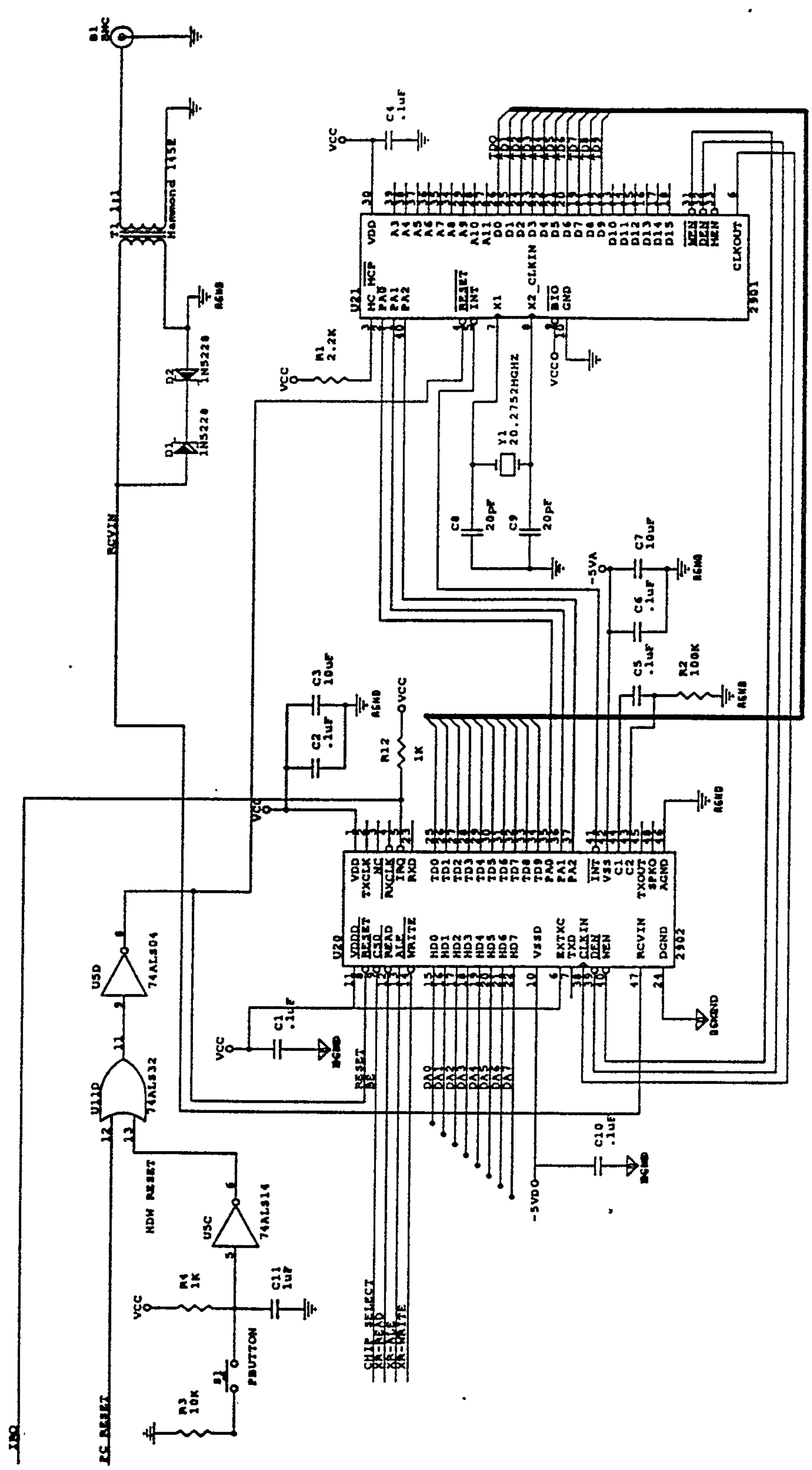



Figure 3.2: HIGHWIRE Modem Circuitry

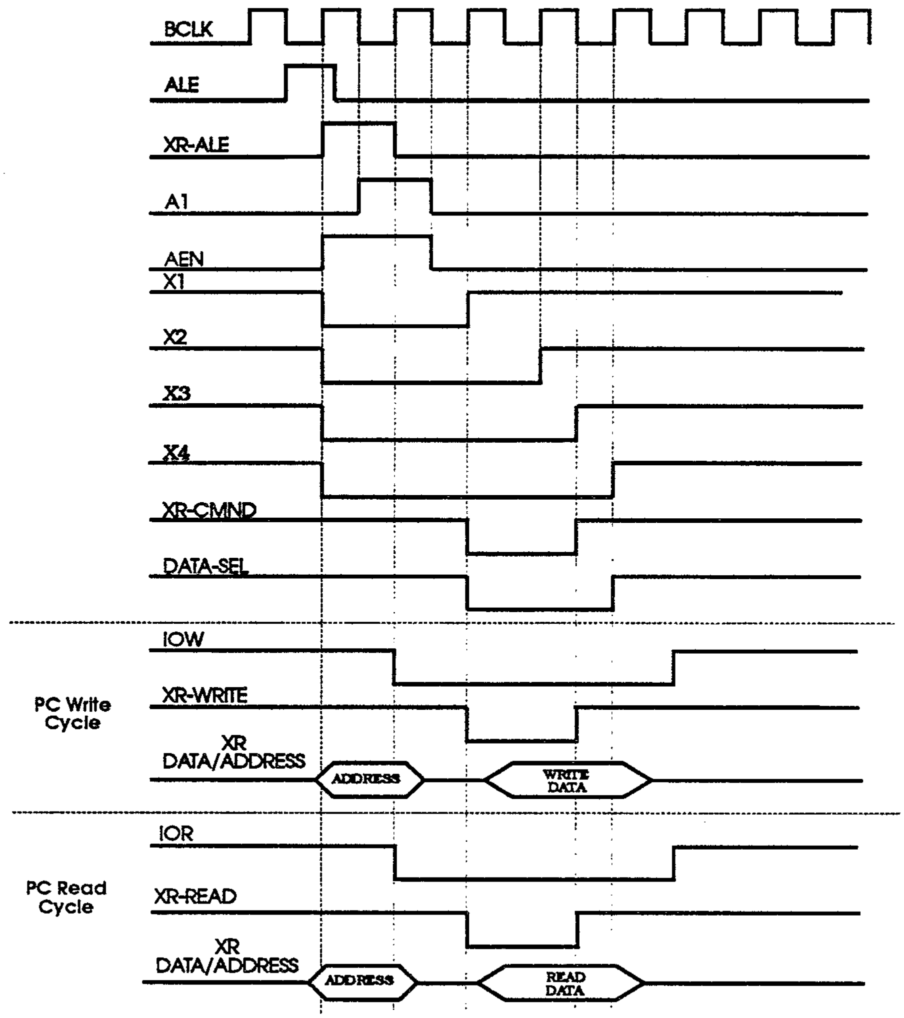



**Figure 3.3: Timing Diagram For PC Interface Circuitry**

The XR-ALE signal continues to be stretched using a sequence of J-K flip flops (U2 and U3). OR'ing the stretched pulses with the unstretched pulses allows delayed pulses to be generated. The widths of the pulses in Figure 4.3 are chosen to satisfy XR2900 timing requirements. The XR-CMD signal is used to generate the separate XR-READ and XR-WRITE signals by OR'ing it with the PC IOR and IOW signals respectively. THE XR-CMD signal is used to ensure that the XR-READ or XR-WRITE signals occur approximately 120 nsec following the de-assertion of the XR-ALE signal. This more than satisfies the EXAR specified minimum of 60 nsec [6]. It also ensures that the minimum XR2900 write pulse width of 140 nsec is met.

The XR-CMD signal is stretched an additional half clock cycle resulting in the DATA-SEL signal, which is OR'd with the BE signal and the PC IOW line to create an active low signal that is asserted during a PC write cycle. This is used to enable a 74ALS245 bus transceiver (U9), allowing the data from the PC to be placed on the XR2900 multiplexed address/data bus. Using the DATA-SEL signal to enable the bus transceiver ensures that the data is held on the XR2900 bus a minimum of 40 nsec following the positive transition of the XR-WRITE signal [6]. Data read from the XR2900 is placed on the multiplexed bus following a negative transition of the XR-READ signal. On a read cycle, the PC does not latch the data until the rising edge of the IOR signal. This may occur a significant period of time following the rising edge of the XR-READ signal, and there is no guarantee that the XR2900 will keep valid data on the address/data bus. As a result, the rising edge of the XR-READ signal is used by U10 to latch the data from the XR2900. U9 is tri-stated during PC read cycles, and U10 is tri-stated during PC write cycles. This ensures that neither chip interferes with the data transfer function of the other.

### 3.2 Modem Circuitry

The HIGHWIRE modem circuitry is built around the EXAR 2900 fax/data modem chip set. The two chips that make the set are the XR-2901 (U21) and the XR-2902 (U20). The XR-2901 is a digital signal processor based chip supporting primarily the modulation/demodulation function. The XR-2902 is a combination analog and digital chip. Its analog portions support the transmit and receive filters, A/D and D/A functions, transmit level attenuator, and programmable gain amplifier. The digital portion of the XR-2902 supports the transmit clock, async/sync converter, interface circuitry between the XR-2901 and the host controller, and a receive clock digital phase-locked loop. Both chips utilize CMOS technology for low power operation. The power required is a single +5 Volt supply for the XR-2901, and ±5 Volts for the XR-2902. Both levels are available on the PC bus. The crystal used for the XR-2901 is a 20.2752 MHz clock. This value is somewhat critical and appears to be the only value allowed for use with the XR2900 [6].

Resetting of the XR2900 modem is accomplished with a push button switch and a Schmidt trigger debouncer (U5). This signal is OR'd with the PC RESET signal ensuring that the modem reset also occurs during the resetting of the PC. An inverter is used to achieve an active low RESET signal, as required by the XR2901.

The remaining circuitry shown in Figure 3.2 is the analog conditioning circuitry. The front end of the circuit has a connection to the external environment via a BNC connector. The 1:1 transformer is used to isolate the modem circuitry from any external amplifier circuitry. In parallel with the transformer is a pair of opposing diodes which are used for surge suppression. The node on the positive voltage side of the transformer is connected to the RCVIN pin of the XR-2901. This pin acts as the point of entry for the signal to be processed by the XR-2900.

Operation of the modem chip set is accomplished via the programming of the 32 registers contained in the 2902. Setting these registers allows control over all modem functions including modulation, baud rate, and data transfer mode. Status registers allow detection of signal energy, CED tones, and received data. The applicable registers are discussed in the following section.

# 4.0 HIGHWIRE SOFTWARE

## 4.1 Driver Software

HIGHWIRE System software is divided into two levels. This section discusses the low level driver software which is used to directly access registers in the XR2900. All driver routines were written in C using the Borland C++™ development package version 3.0. Software listings are not provided in this report but are available upon request to the Defence Research Establishment Ottawa.

Both transmit and receive driver routines were written. Although the transmit functions would not be used in a typical ESM application, they are available for testing purposes. A list of driver routines followed by a brief description of each one follows. Other routines are being continuously added. Many of the driver routines directly manipulate bits in the various control registers of the XR2900. A complete description of these control registers may be found in the XR2900 data sheet [6]. It was the authors' experience however that many of the features of the XR2900 modem chip set were poorly documented, and a considerable amount of trial and error was spent during the development of these routines. It should also be noted that many of the routines reverse the bit order of received data. This is necessary since the XR2900 data register presents a byte in reversed order. That is, the least significant byte is first.

**unsigned char byte_rev(unsigned char byte)**
A byte of data is accepted from the calling program, and then the order of the bits is reversed. The resulting byte is passed back to the calling program.

**void check_reg(void)**
This routine displays the contents of all unreserved registers for debugging purposes.

**void DTMFtone_gen(unsigned char digit, unsigned duration)**
Dual Tone Multiple Frequency (DTMF) tones are generated by this function. These tones are transmitted from the TXOUT pin (Pin 45) of the XR2902 chip. Although this line is not

available as an output on the present card, future versions of the card will bring the TXOUT line to a BNC connector on the back panel.

The variable **digit,** which is passed to this function, holds an ASCII character which corresponds to a DTMF tone pair that the XR2900 can generate. Table 4.1 provides a summary of the ASCII characters and the DTMF tones they generate. If **digit** holds an ASCII character other than those listed in the Table 4.1, an error message will be generated.

**Table 4.1: Table Of ASCII Characters and DTMF Tone Pairs For Routine DTMFtone_gen**

| digit Character | Low Frequency Tone (Hz) | High Frequency Tone (Hz) |
|---|---|---|
| '0' | 941 | 1336 |
| '1' | 697 | 1209 |
| '2' | 697 | 1336 |
| '3' | 697 | 1477 |
| '4' | 770 | 1209 |
| '5' | 770 | 1336 |
| '6' | 852 | 1477 |
| '7' | 852 | 1209 |
| '8' | 852 | 1336 |
| '9' | 852 | 1477 |
| '*' | 941 | 1209 |
| '#' | 941 | 1477 |
| 'A' or 'a' | 697 | 1633 |
| 'B' or 'b' | 770 | 1633 |
| 'C' or 'c' | 852 | 1633 |
| 'D' or 'd' | 941 | 1633 |

This routine will generate the desired DTMF tone pair for the period of time specified by the value **duration**. The unit of this value is milliseconds.

**void fprint_binc(unsigned char *p, int bits, FILE *fp)**

This routine writes the binary contents of a byte of data to a data file. The byte of data is pointed to by **p**, and the value **bits** indicates the number of bits that are in the value pointed to by **p**. The data file written to is pointed to by **fp**, and each byte of data is written as 8 ASCII characters (**1**'s and **0**'s), and a space to separate the bytes of data. For example, the hexadecimal value 28 would be written as **0010 1000**.

**int fprint_binc_rev(unsigned char *p, int bits, FILE *fp)**

This function performs the same tasks as the fprint_binc() function with the exception that it writes the binary contents of each byte written to the data file in reverse order. For example, the hexadecimal value 28 would be written as **00010100**.

**int freq_det(void)**

This function determines which of a 2100 Hz, 1100 Hz, or a 462 Hz tone is present on the receive line of the XR2900. If none of the above three frequencies are present, the function returns a value of -1. If one of the three frequencies is present, the value of the frequency detected is passed back to the calling program in integer form. This routine is employed to determine the beginning of a facsimile procedure by detecting the 2100 Hz CED tone. The 1100 Hz, and 462 Hz tones are used in other non-facsimile modem standards.

**int rdbit_MDAO(void)**

This function returns the value of the Modem Data Available (MDAO) bit to the calling program. The MDAO bit is high when the XR2900 has data available or is ready to transmit. The received data is available in TXRXD register (Register 0) of the XR2900 and may be accessed by the HIGHWIRE board over the PC bus by performing a read to the base address.

**int rd_CDET(void)**

This routine returns the value of the carrier detect bit (CDET) to the calling function in the form of an integer. The CDET bit in register 5 of the XR2900 and is set low whenever energy is detected in the received pass band of the modem and a valid training sequence has been read. This status bit is slightly different from the true energy detect (FED) status bit which is also available. The latter is low whenever energy is present in the filter pass band. Assertion of the FED bit is not qualified by the detection of a valid training sequence as in the case of the CDET bit..

**unsigned long rd_data(FILE *fp, int format)**

This function is used to read in the fax message during Phase C of the facsimile procedure. Since there is the potential for a very large amount of data to be accepted during this phase, the data is written to an output file immediately after it is read. It has been observed that facsimile data often begins with a long sequence of **1**'s. Since this sequence is not required, it is discarded. Once a byte of data other than a hexadecimal FF is identified, all data read when the MDAO bit is high is written to a data file pointed to by a file pointer passed in the function argument list. This process continues until the energy detect bit is high for a specified number of times in a row. This number is specified in the XR2900.H file as FED_THRESH.

The data written to the output file may be written in ASCII form with the bits reversed so the binary form can be visualized, or it may be written in true binary form. The form it is written in is determined by the integer passed to the function in the variable **format**. A **-1,** which may be passed with the user defined constant VIEW_BIN, will result in the file being ASCII as described above. A **0**, which may be passed by the constant GEN_IMAGE, will result in the form where an image may be generated.

When control is passed back to the calling program, an integer representing the number of bytes written to the output file is passed back. The bytes of **1**'s that are discarded at the beginning are not included in this sum.

**int rd_fsk_data(unsigned char *array)**

This function is used to read the V.21 FSK portions of the facsimile procedure (Phase B). It waits for the data available (MDAO) bit to go high before reading a byte of data from the TXRXD register. When the byte is read it is stored in an array passed to the routine by a pointer in the argument list. Once the energy detect bit (FED) goes consistently high for FED_THRESH times in a row, control is passed back to the calling program and an integer, representing the number of bytes read,. is returned.

**int rd_V29 train(unsigned char *array)**

This function reads the facsimile training data into an array passed in the argument list. It then returns the number of bytes read into the array back to the calling program. The XR2900 must be configured to the V.29 mode before this function is called to read the V.29 data. The data is read whenever the MDAO bit is high. The routine terminates when the FED bit is high (indicating no energy detected) for at least FED_THRESH times in a row. As control is transferred back to the calling program, an integer representing the number of bytes read is returned.

**void send_tone(unsigned int send_freq, unsigned duration)**

This routine is used to transmit a single frequency tone. The tone frequency is specified by the value **send_freq**. The routine transmits the tone for a period of time specified by the value of **duration**. The unit of **duration** is in milliseconds.

**void setup(void)**

Whenever the modem configuration must be changed, the new configuration must be clocked in by setting the SETUP bit. This routine sets the SETUP bit and then waits for the bit to be reset before control is passed back to the calling program.

**void set_MCFN(unsigned int mode)**

This function configures the XR2900 fax/modem chip set by writing the proper bits to the XR2900 Modem Configuration register (MCFN). The code written to the register depends on the integer value passed to the routine by the variable **mode**. Table 4.2 indicates the modem configuration corresponding to input integer values. Any integer choice other than those listed in Table 4.2 will result in an error message.

**Table 4.2: Modem Configuration Settings For Routine set_MCFN**

| "mode" Value | XR2900 Modem Configuration |
|---|---|
| 1 | V.29 Modulation, 9600 Bits Per Second |
| 2 | V.29 Modulation, 7200 Bits Per Second |
| 3 | V.29 Modulation, 4800 Bits Per Second |
| 4 | V.27*ter* Modulation, 4800 Bits Per Second |
| 5 | V.27*ter* Modulation, 2400 Bits Per Second |
| 6 | V.21 Modulation, 300 Bits Per Second |
| 7 | Single Tone Transmit |
| 8 | DTMF Transmit |
| 9 | Bell 103, 300 Bits Per Second |
| 10 | V.22*bis*/Bell212A |

**void set_pdmode(void)**

This function sets the XR2900 chip set in to parallel data transfer mode. This is the mode used by the HIGHWIRE board to transfer data from the modem to the PC.

**void set_txl(unsigned char level)**

This routine accepts the variable **level** which corresponds to a decimal value from 0 to 15, inclusive. The values from 0 to 15 represent the magnitude of attenuation from the nominal transmitter output in units of dB.

**int shift(FILE *fp, unsigned char *data, int count)**

**shift()** treats the FSK data read from a facsimile procedure so the bits are properly aligned at byte boundaries. The data is passed to the function by the pointer **data**, and the number of bytes stored in the pointer is passed in the argument list by the variable **count**. In treating the data, the first task the function completes is the reversal of the bit order of each of the bytes of data passed to the function. This task is completed with the help of the routine **byte_rev()**. The routine then identifies the preamble of multiple flag sequences. As discussed in Section 2, a flag is **0111 1110**. The routine identifies the number of bits that each byte of the array must be shifted to synchronize the data so the bits are properly aligned. Once the proper amount of shifting is identified, the function proceeds to execute the shifts and then writes the resulting data to an output file identified by a file pointer passed in the argument list.

**void train_enable(void)**

This routine sets the training disable bit (TDIS) low so the XR2900 is able to train on the V.29 training sequence during the facsimile procedure.

**int txdata(unsigned char datum, unsigned char level)**

If data is to be transmitted by the XR2900, this function is employed. The function is passed a byte of data to be transmitted and also is passed an output level. The definition of **level** is identical to that used in the routine **set_txl()**. The byte to be transmitted is written to the TXRXD register whenever the MDAO bit is high. If the byte is transmitted successfully, the function returns an integer value of 1, and if it is not successful, a 0 is returned.

**void tx_off(void)**

This function resets the Request To Send (RTS) bit thereby taking the XR2900 out of transmit mode. It is required to stop a transmission sequence initiated by the **tx_on()** function.

**void tx_on(void)**

This function sets the RTS bit thereby setting the XR2900 to transmit mode. This routine is required to send a tone, generate DTMF tones, and transmit data from the TXRXD register.

**void wr_trdata(FILE *fp, unsigned char *array, int count)**

This routine takes the data saved in an array during the training, reverses the bits in each byte, and writes the data to a file. The data is converted to an ASCII representation of the binary form of the data before it is written to the output file. The data is passed to the function by the pointer array, and the number of bytes stored is passed in the variable "count". The output file is also given in the argument list by the file pointer "fp".

**void wt_FEDdt(void)**

This routine waits until the energy detect bit (FED) goes low consistently before passing control back to the calling program. The definition of "consistently" is left up to the user since the function waits until the FED bit is low for FED_THRESH times in a row, where FED_THRESH is defined in the header file XR2900.H. If the function waits longer than 10 seconds, the calling program is terminated, and an appropriate error message is generated. If the function waits for the FED bit with success, the control is passed back to the calling program. FED_THRESH has been effective at a value of 5.

**void wt_FEDndt(void)**

This routine waits until the energy detect bit (FED) goes high consistently before passing control back to the calling program. The definition of "consistently" is left up to the user since the function waits until the FED bit is high for FED_THRESH times in a row, where FED_THRESH is defined in the header file XR2900.H. If the function waits longer than 10 seconds, the calling program is terminated, and an appropriate error message is generated. If the function waits for the FED bit with success, the control is passed back to the calling program. FED_THRESH has been effective at a value of 5.

**void wt_PNdetect(void)**

This function waits for the XR2900 Pseudo Noise DETect (PNDET) bit to go low. This occurs when the series of alterations is detected during a modem training sequence. The routine will exit the program if it waits for longer than two seconds for the PN detect bit to go low. If the program is terminated with the exit() function, an appropriate error message will be generated. The software determines whether the series of alterations has been recognized by polling the PNDET bit.

**void wt_P2detect(void)**

This function waits for the XR2900 P2DET bit to go low This occurs when the pattern of scrambled ones has been detected during a modem training sequence. The routine will exit the program if it waits for longer than two seconds for the P2DET bit to go low. If the program is terminated with the exit() function, an appropriate error message will be generated. The software determines whether the series of scrambles ones has been recognized by polling the P2DET bit.

**int wt_2100(void)**

wt_2100() waits for the XR2900 to consistently identify a received signal as being a 2100 Hz CED tone. To be defined as consistent, the 2100 Hz tone must be identified as being present THRESH_2100 times in a row, and THRESH_2100 is defined by the user in the XR2900.H header file. THRESH_2100 is currently defined as 7, and this value has proved to be effective in distinguishing rings from a constant 2100 Hz tone.

## 4.2 User Software

The user software for HIGHWIRE was written in C++ using Borland C++™ version 3.0 and the TurboVision™ Application Framework development tools. TurboVision provides a consistent architectural structure for developing text mode, DOS based applications such as this fax receiver. TurboVision provides an object-oriented environment that the programmer extends by deriving new classes and overriding the inherited member functions. For example, to display the list of faxes available for viewing, the class TFaxListBox is derived from the TurboVision base class TListBox. TListBox member functions handle the display of the box and the user's commands to scroll through the list and to select a fax image for viewing. TFaxListBox merely has to handle the formatting of each entry, storing the description of the fax image, the time and date, and some other peripheral information in a text string for TListBox to display.

The PC based application software that controls the HIGHWIRE modem board consists of a central controller and four major blocks as shown in Figure 4.1. The fax demodulator module is a collection of the low level routines discussed in Section 4.2. It controls the fax demodulator board in order to demodulate and store fax transmissions in T.4 Group III compressed format. The fax converter is a utility to convert the compressed fax data from the fax demodulator into a black and white bit map image. The fax viewer allows the user to display the bit map images on the screen. Finally, the user interface provides menus, dialogue boxes, and keyboard and mouse support to allow the user to control the various aspects of the application.

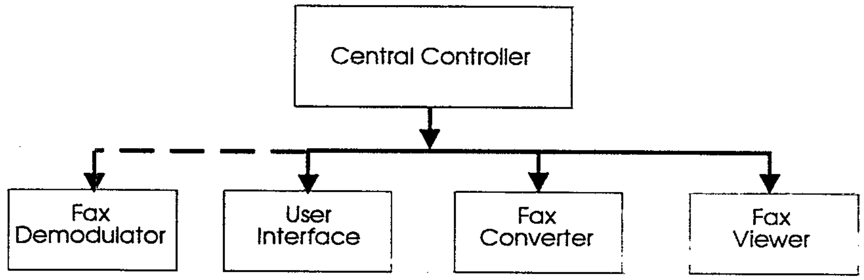



**Figure 4.1: Block Diagram Of HIGHWIRE User Software**

### 4.2.1 The Central Controller and User Interface

The central controller directs the instructions from the user interface to the fax converter and fax viewer modules. It is closely interlinked with the user interface which provides pull down menus, dialogue boxes, and keyboard and mouse support to obtain user commands and to display the current state of the application.

The application allows the user to associate certain information with each fax image at any time. The user can enter comments or a description of the image. The date, time, location, and name of the unit which receives the fax transmission can be stored for future reporting. Finally, the image size and quality of the received image are automatically stored by the application. All of this information is displayed in a dialogue box when the user selects a fax image for viewing.

### 4.2.2 The Fax Demodulator

Currently, the demodulation of the facsimile image is performed outside of the main application software. The demodulation software will be incorporated into newer versions of the software as a submenu under control of the central controller module. It is assumed that a two-wire link is targeted. It should be noted however that both two-wire links, and four-wire links may be targeted by the Electronic Support Measures (ESM) system in a tactical environment. Two-wire links are those communications links in which both sides of the conversation are carried on a single channel. Four-wire links separate the two sides of the conversation using two separate channels. The term "wire" is a hold over from telephony terminology where the terms originated. In spite of the wire implications of the terms, in the tactical environment, the channels are exclusively wireless RF channels. Control software for handling a four-wire reception will be written in the near future.

It is also assumed that the entire facsimile procedure is received. The control software follows the facsimile procedure from the transmitter CED tone through to the EOP of the transmitted image. The facsimile transmitter and receiver signal are separated, and both V.21 and V.29 signals are stored. V.21 signals are stored as a pattern of binary ones and zeros. The V.29 signals are stored in T.4 format for subsequent analysis. V.27*ter* demodulation capability is presently being added. Currently, only single-dimensional encoding is supported, but two-dimensional capability will be added. Work is also continuing on software tools which will allow an analyst to reconstruct a partial image from a received signal in which the entire facsimile procedure is not present.

### 4.2.3 The Fax Converter Module

The fax converter module converts compressed fax data in the T.4 Group III data format into black and white bit map images for displaying on the screen or on a printer. The fax converter is essentially a finite state machine processing an input bit stream in T.4 data format and producing an output bit stream of black and white run lengths. The treatment of bit errors in the input bit stream is also an important consideration in this module. As discussed in Section 2, a fax machine scans a document from left to right and from top to bottom, dividing the image into lines with a standard vertical resolution of 3.85 lines/mm. Horizontally, each line of width 215 mm is quantized into 1728 PELS. This results in approximately 250 kilo-bytes of data per page. As discussed in Section 2.4, a Huffman encoding scheme is used to compress the transmitted data.

The T.4 compression codes are grouped into six classes: white run length make-up codes, white run length terminating codes, black run length make-up codes, black run length terminating codes, an end-of-line (EOL) resynchronization code, and a dummy or fill code which contains no information. Each page is preceded by an EOL code. Each line starts with a white run length code and alternates between white and black codes until the end of the line. At the end of the line, the EOL code is transmitted. The fill code can be transmitted just before the EOL code at the end of any line. A white sequence of 64 or more PELS is transmitted with a white make-up code and then a white terminating code, while a sequence of 0 to 63 PELS is transmitted with just a white terminating code. Similarly for a black sequence, either a black terminating code or a black make-up code followed by a black terminating code are transmitted.

Thus, in converting the T.4 data stream, it is not necessary to compare the input stream with every code, rather only the codes that belong to the expected classes of codes. For example, if a white make-up code is received, then the next code must be a white terminating code and anything else is invalid. Figure 4.2 shows the relationships between the classes of codes.

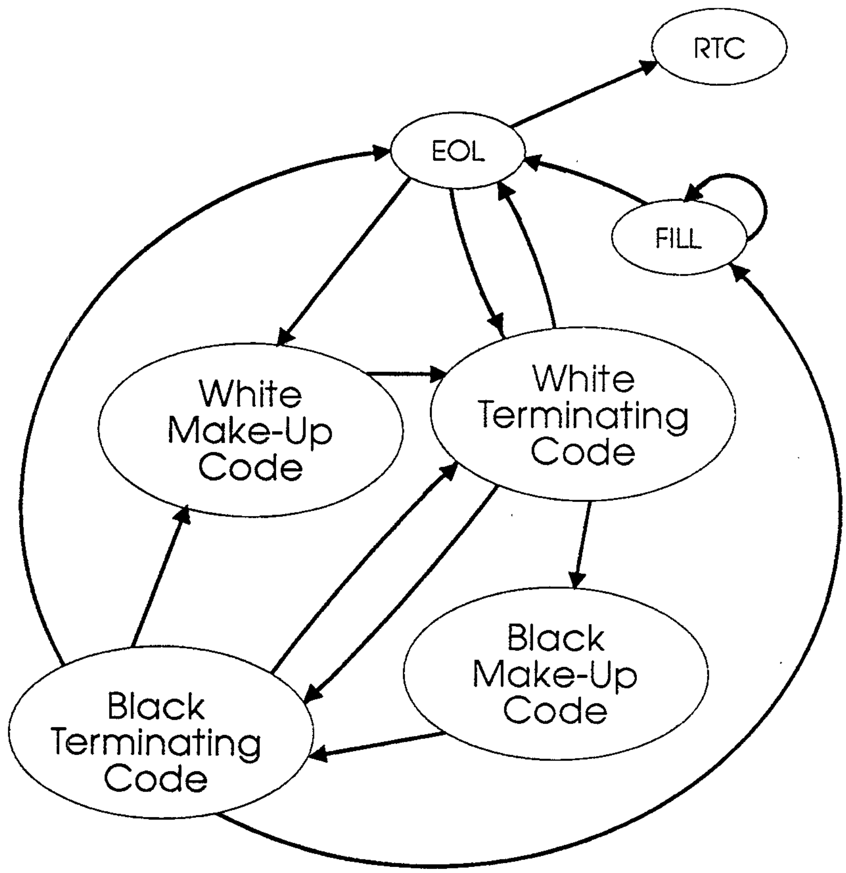



**Figure 4.2: T.4 Data Code State Diagram**

The fax converter, viewed as a finite state machine, has states associated with the different classes of codes and also with the software implementation. Figure 4.3 shows the state diagram of the fax converter. There is an initial state where the fax converter searches for the initial EOL code that signifies the start of the fax data. There is also a sequence of end states which correspond to the six consecutive EOL codes comprising the return to control (RTC) code that signifies the end of the data transmission. The end-of-data state, which occurs if the RTC code was not received before the end of the input bit stream, is effectively equivalent to the RTC. Finally, there is a state for invalid codes caused by a bit error in the fax demodulator.

When an invalid code appears, there are two choices for handling the current line. The first way is to assume that the start of the line is correct, and the remainder of the line is unknown and hence should default to black. Note that the bit error may occur before the invalid code appears since the bit error could change a valid code into another valid code. Since each line is often similar to the lines immediately before and after it, another way to handle the current line is to use one of the neighbouring lines to fill in the remainder.

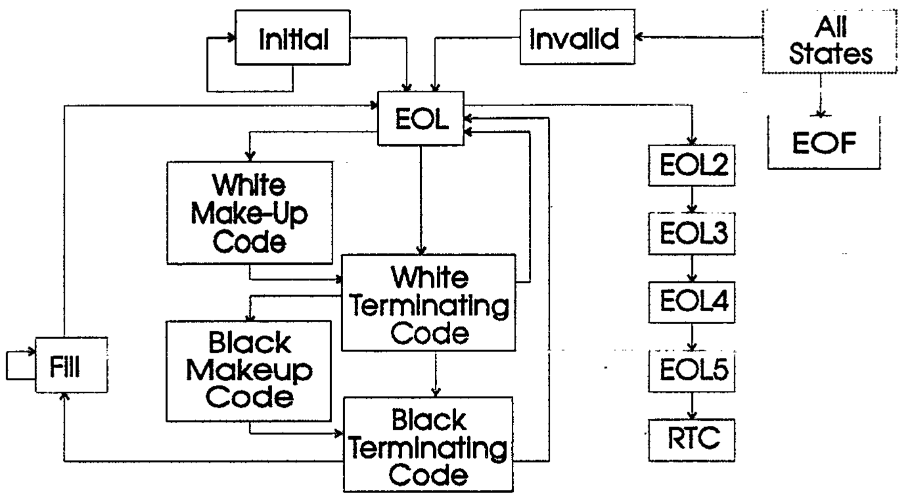



**Figure 4.3: State Diagram Of Fax Converter**

A bit error may not cause an invalid code to appear, but it will almost certainly change the length of the line even if the bit error occurs near the end of the line. Thus if a line is shorter or longer than the other lines, this indicates that at least one bit error has occurred. The corrupted line can be treated in the same manner as discussed above for invalid codes. An overly long line should be truncated while the remainder of a short line should default to black or be reconstructed from a neighbouring line. The fax converter maintains a count of the number of invalid lines to provide the user with a measure of the quality of the received transmission. Currently, short lines which are received in error default to black.

### 4.2.4 The Fax Viewer Module

The fax viewer displays the converted black and white bit map images on the screen. It can display the entire image or any portion thereof at integral scale factors. The user can scroll across the image and rescale the image using keyboard or mouse control. The fax viewer has an option to display faxes transmitted at standard vertical resolution (3.85 lines/mm) and at high vertical resolution (7.7 lines/mm). Vertical and horizontal scaling are handled independently, although this level of control need not be provided to the user.

The fax viewer consists of a central controller and various peripheral functions to handle the user's commands. Figure 4.4 shows a block diagram of the fax viewer. The fax viewer operates in a tight loop getting keyboard and mouse commands from the user and handling these commands. The complete fax image is stored in a file in black and white bit map format as produced by the fax converter. The display routines read in the appropriate portions of this file, scale the image, convert the image to EGA format, and display the image on the screen. Printer support is under development.

## 4.3 System Operation

In order to minimize the interaction among the fax demodulator, converter and viewer, the application uses a serial approach, storing all necessary data in external files rather than in RAM memory before invoking the next module. For example, to handle a new fax image, the fax demodulator is invoked, which uses the fax board software drivers to start the hardware fax demodulator. The T.4 formatted data produced by the fax demodulator is stored in a temporary file. Once the fax demodulator is finished, the central controller passes the name of the temporary file to the fax converter. The fax converter reads the T.4 fax data, converts it, and stores the black and white bit map output stream in another file. When the converter is finished, the name of the image file is passed to the fax viewer, which then reads in the appropriate portions of the file, converts the image to EGA format, and displays it on the screen. While this serial approach is more time-consuming than the parallel approach of on-the-fly conversion and display, the simple, clean interfaces of the serial approach make system integration and software maintenance far easier.

The interaction between the TurboVision Framework and the fax viewer is complicated by the different screen modes required by the two modules. TurboVision works in text mode, which is far faster than graphical mode. However, the fax viewer must operate in graphical mode in order to display the bit map image. It is therefore necessary for the TurboVision Framework to suspend its operation while the fax viewer is operating.

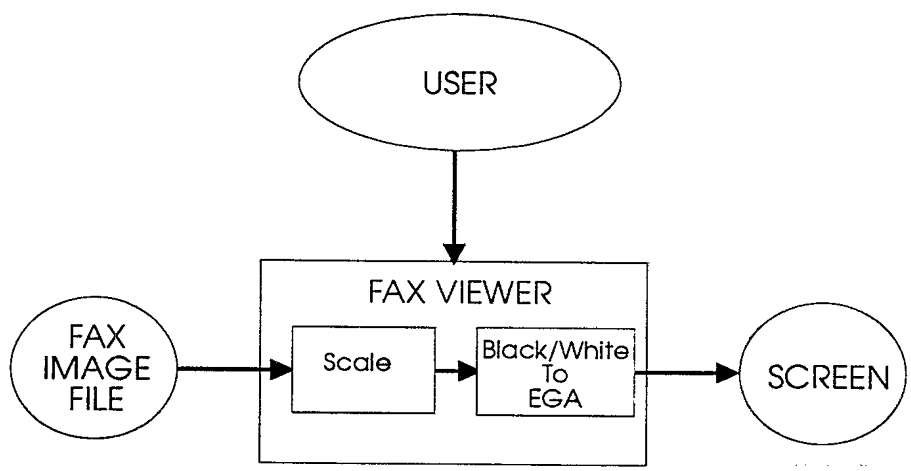



**Figure 4.4: Block Diagram Of Fax Viewer**

# 5.0 CONCLUSIONS

This report has examined the requirements of tactical facsimile Electronic Warfare Support Measures (ESM). A detailed description of the most commonly used standard, CCITT Group III Recommendations, was given. Both modulation schemes and image encoding formats were discussed. A detailed description was then given of HIGHWIRE, which is a prototype system developed in the Electronic Warfare Division to demonstrate the feasibility of facsimile ESM in a tactical environment.

Preliminary results indicate that ESM against facsimile transmissions is feasible, but much more work needs to be done before its reliability be ascertained. HIGHWIRE will form a platform upon which much of this investigative work can be performed. First however, additional enhancements must be made to the system. V.27*ter* demodulation capability must be added, and the ability to demodulate signals within the user interface and not off line must be incorporated. A two-dimensional demodulation capability, and the ability to demodulate facsimile signals encoded using the T.4 Error Correction Mode must also be added. Work in these areas is ongoing.

Once the basic system capabilities have been implemented, study can begin on more practical problems related to tactical facsimile ESM. Recording techniques must be examined since it is unlikely that standard cassette recorders used will preserve a facsimile signal. Although the standard recorders provide the necessary bandwidth, amplitude stability may be a problem. Another issue which must be examined is the effects of a low Signal to Noise Ratio (SNR) on the integrity of the received facsimile image. Normally, a received SNR of 30 dB is required for the reproduction of a high quality image [8]. The received SNR at which a facsimile image becomes unintelligible must be determined. Finally, tools for an analyst to reconstruct a partial image from a corrupted signal must be developed.

## 6.0 REFERENCES


[1] Brendler, J. A., Tactical Military Communications, IEEE Communications Magazine, January 1992.

[2] Pugh, A., Facsimile Today, Electronics and Communications Engineering Journal, October 1991

[3] International Telegraph and Telephone Consultative Committee, CCITT Blue Book, Recommendation T.4

[4] International Telegraph and Telephone Consultative Committee, CCITT Blue Book, Recommendation T.30

[5] Royer, J., Handbook Of Software & Hardware Interfacing For IBM PCs, Prentice Hall, 1987.

[6] EXAR Corporation, Data Sheet For XR-2900 Fax/Dat Modem Chip Set, Exar Corporation, 1992

[7] Solari, E., AT Bus Design, Annabooks, 1990

[8] Freeman, Roger L., Telecommunications Systems Engineering, John Wiley and Sons, 1989

[9] Freeman, Roger L., Reference Manual For Telecommunications Engineering, John Wiley and Sons, 1985

[10] Friedman, H., The Facts On Fax, Radio Electronics Magazine, November 1988

# DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)
DEFENCE RESEARCH ESTABLISHMENT OTTAWA
DEPARTMENT OF NATIONAL DEFENCE
SHIRLEY BAY, OTTAWA, ONTARIO K1A 0K2 CANADA

2. SECURITY CLASSIFICATION (overall security classification of the document. including special warning terms if applicable)
UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title.)
THE FEASIBILITY OF TACTICAL VHF/UHF FACSIMILE ESM (U)

4. AUTHORS (Last name, first name, middle initial)
MUDRY, ANDREW, LEE, DAVID AND POULIN, BRAD

5. DATE OF PUBLICATION (month and year of publication of document)
DECEMBER 1993

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)
59

6b. NO. OF REFS (total cited in document)
10

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)
DREO REPORT 1217

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)
DEFENCE RESEARCH ESTABLISHMENT OTTAWA
DEPARTMENT OF NATIONAL DEFENCE
SHIRLEY BAY, OTTAWA, ONTARIO K1A 0K2 CANADA

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)
041LK

9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)

10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)
DREO REPORT 1217

10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(XX) Unlimited distribution
( ) Distribution limited to defence departments and defence contractors; further distribution only as approved
( ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
( ) Distribution limited to government departments and agencies; further distribution only as approved
( ) Distribution limited to defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availabilty (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

13. ABSTRACT ( a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). It is not necessary to include here abstracts in both offical languages unless the text is bilingual).

(U) This report examines the requirements for performing Electronic Warfare Support Measures (ESM) on VHF/UHF facsimile transmissions in the tactical environment. A complete description of the CCITT Group III recommendations is given. These specifications apply to over ninety percent of the facsimile machines currently in use. Both modulation techniques and image encoding formats are discussed thoroughly. A description is then given of the HIGHWIRE system. HIGHWIRE is a communications Electronic Warfare Support Measures System which has been developed in the Electronic Warfare Division at the Defence Research Establishment Ottawa to investigate the feasibility of tactical facsimile ESM. Current capabilities of the system are described, and future work is discussed.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)