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## Technical Report 686

# DIGITAL DATA COMPRESSION ALGORITHM PERFORMANCE COMPARISONS

Proposed NATO standard algorithm provides better  
facsimile in a noisy communications environment  
than present Tactical Digital Facsimile algorithm

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30 April 1981

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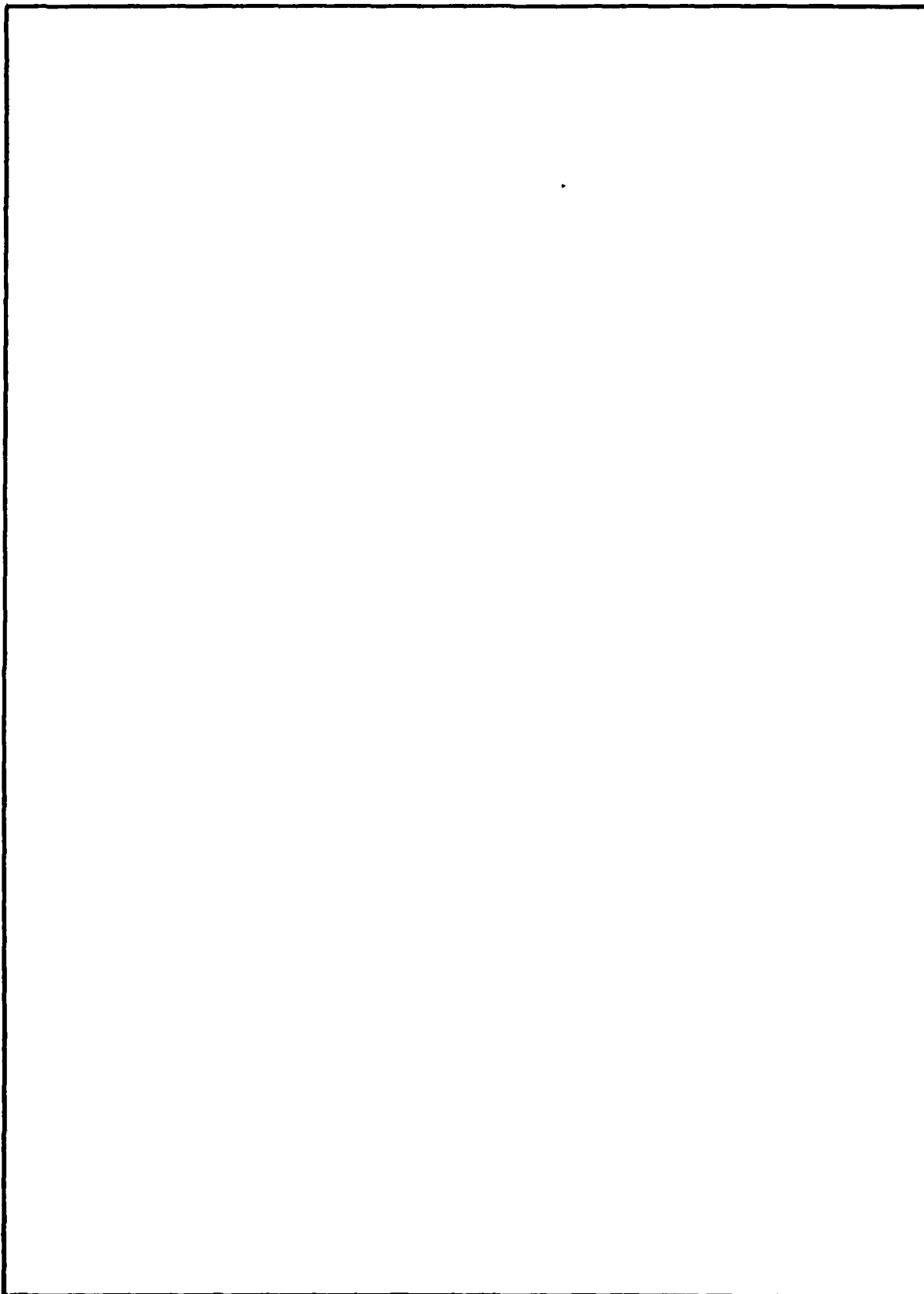
FY 80-81

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>Performance of the NATO data compression algorithm in a noisy communication channel is superior to that of the present TDF data compression algorithm, provided that the noise channel is not too harsh. Text is legible in a noise channel that has a bit error probability on the order of $1 \times 10^{-3}$ (single bit errors). Multiple (burst) errors are not a problem provided the burst length does not exceed ten bits. Where actual burst length greatly exceeds the ten-bit (maximum) average expected in tactical situation noise, data compression algorithm performance may be poor, as with most data compression algorithms without a powerful noise protection algorithm. The NATO algorithm has enough compression to meet the current TDF performance specification, but its compression efficiency is lower than that of the TDF. The two algorithms have about the same complexity. |                                                                                                      |                                             |

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## OBJECTIVE

Compare the performance of the Tactical Digital Facsimile (TDF) data compression algorithm with that of the data compression algorithm for NATO interoperability. The latter is proposed in STANAG 5000, a standard of agreement being drafted by a NATO working group. The performance comparison will help the US decide how to incorporate the NATO algorithm into the TDF. Navy responsibility includes acquiring the TDF and participating as a principal in the investigation of the NATO data compression scheme.

## RESULTS

1. In a noisy communication channel the NATO data compression algorithm performs much better than the present TDF data compression algorithm. Text is legible in a noise channel that has a bit error probability on the order of  $1 \times 10^{-3}$  (single bit errors).
2. Multiple (burst) errors are not a problem provided the burst length does not exceed ten bits. When burst errors are combined with Gaussian errors, a practical burst limit appears to be about five bits.
3. The expected noise in tactical situations consists of Gaussian noise and bursts averaging five or fewer bits. Where the actual burst length greatly exceeds that, data compression algorithm performance may be poor, like that of most data compression algorithms that operate in an excessive noise environment without a more powerful noise protection algorithm.
4. The NATO algorithm has a compression efficiency lower than that of the TDF, but it has enough compression to meet the current performance specification.
5. The NATO data compression technique is no more complex than the present TDF algorithm.

## RECOMMENDATIONS

On the basis of the performance standpoint alone, replace the present TDF algorithm with the NATO algorithm. It will yield improved performance in a noisy communication channel provided the channel characteristics are not extreme. It will provide NATO interoperability in addition to better performance. It will also provide the essence of commercial interoperability, since it utilizes the commercial international standard data compression T-4 tables.

## **PREFACE**

Reference is made in this report to the Gray code, a cyclical binary code invented and patented by F Gray. The discussion also involves gray scales or levels – tonal values between white and black. To help differentiate between these two uses of the word “gray” in this report, we retain “Gray” as the correct spelling of the inventor when we refer to the code and we use the spelling variation “grey” for the tonal scale.

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## PURPOSE

The purpose of this task was to compare the performance of the Tactical Digital Facsimile (TDF) data compression algorithm and the proposed data compression algorithm for NATO interoperability. The latter is proposed in STANAG 5000 – the standard of agreement currently being drafted by a NATO working group. The performance comparison will help the US reach a decision on the method of incorporating the NATO algorithm into the TDF. The Navy is responsible for the acquisition of the TDF and has been a principal participant in the investigation of the NATO data compression scheme.

## BACKGROUND

The TDF contract for preproduction units was awarded in April 1977. The units have been delivered and are undergoing testing for operational suitability. The data compression algorithm used in the the TDF was decided prior to the contract award and was based on earlier studies. When the TDF contract was well under way, the first NATO working group met to develop a NATO interoperability standard. The standard was not finalized technically until mid-1980. Much of the US TDF design was incorporated into the NATO STANAG in the area of signaling protocols. Significant data compression algorithm differences, however, forced the US to study the cost, schedule, and performance impact of integrating the NATO scheme into the TDF. Although an international standard is being developed by the CCITT,\* it cannot be used directly as the NATO standard for two basic reasons. First, the NATO application is for a much noisier communication channel environment; tests performed by the NATO working group showed the CCITT algorithm to be too susceptible to the military noise environment. Second, the NATO standard is intended for a digital interface, which the CCITT T-4 scheme did not specify. The T-4 algorithm was intended to be used with the CCITT T-30 signaling protocols, which are intended for signaling on an analog channel.

So that a form of compatibility with the CCITT standards could be achieved, however, the T-4 portion was made the basis for the NATO standard. Forward error correction (FEC) techniques were employed to provide better noise immunity. Signaling protocols that operate on digital circuits were adopted. A descriptive comparison of the NATO algorithm and TDF algorithm techniques is included as appendix A.

Both the TDF and NATO algorithms were simulated and tested (for the black-white (B-W) mode only) at the Technical University, Hannover (West Germany). Later studies and tests by the Navy confirmed the German data. The grey-scale algorithms were tested by using a computer at NOSC. Various parameters, including the performance in a noisy communication channel environment, were measured and the results are provided in this report.

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\*International Telegraph and Telephone Consultative Committee.

## B-W DATA COMPRESSION PERFORMANCE

The performance specification for the TDF requires that the mean transmission-time reduction (compression ratio) be at least 5:1 for the B-W operation. For the TDF equipment, the reduction was measured on four test charts at various data rates and the measurements were averaged. Since the government specified the charts to be used and was involved at the time with the NATO working group, the test charts specified for the NATO group likewise were specified for TDF. They are included as appendix B. Two of the charts are identical to those used by CCITT in the development of the commercial standards. The chart names used in this report were referred to as Overlay, Message From, Invoice, and NATO Unclassified. Table 1 compares the TDF and NATO compression ratios for these charts.

| Chart             | Compression Ratio |     |                  |
|-------------------|-------------------|-----|------------------|
|                   | NATO (T-4/FEC)    | TDF | Performance Spec |
| Overlay           | 7.1               | 8.2 | 5.0              |
| Message From      | 7.5               | 7.6 | 5.0              |
| Invoice           | 6.6               | 7.6 | 5.0              |
| NATO Unclassified | 6.0               | 7.2 | 5.0              |

Table 1. Compression ratios for B-W mode.

## B-W LEGIBILITY

The TDF performance specification further defined the legibility required at the various resolutions in the compression mode under a bit error probability of  $1 \times 10^{-3}$  (1 error every 1000 bits) under single bit error conditions. For facsimile systems using data compression, this is usually the worst-case error condition, since the errors are separated and thus able to do the most damage to the compression algorithm.

The legibility test charts were designed by NOSC on the basis of criteria developed by IBM in the 1960s. Appendix C discusses the legibility criteria and the three legibility test charts for the TDF. Table 2 summarizes the legibility performance.

| Test Chart | Legibility, %         |                                 |                                  |
|------------|-----------------------|---------------------------------|----------------------------------|
|            | Digitized (Errorfree) | TDF (BER = $1 \times 10^{-3}$ ) | NATO (BER = $1 \times 10^{-3}$ ) |
| OJS        | 99                    | 97.5*                           | 99*                              |
| CEW        | 98                    | 92.3                            | 98*                              |
| WDB        | 100                   | 96.8                            | 100*                             |

\*Meets or exceeds specification

Table 2. Legibility test results.

The NATO legibility and the digitized chart legibility are the same because the NATO scheme corrects all single bit errors at that error rate and leaves no errors to disturb the resulting copy. Any errors that are induced into the errorfree copy are a result of the digitization process. Even if the TDF copy were normalized by using the errorfree results, two of the three resolutions would fall below the performance specification. The NATO technique uses forward error correction and corrects all of the single bit errors with ease. In this technique, multiple errors are worst case. Appendix D illustrates some results of multiple errors. Because of the interleaving with the FEC that is used, the NATO scheme produced more readable copy than the TDF algorithm.

### GREY-SCALE COMPRESSION

The TDF performance specification requires the TDF to achieve a mean transmission time reduction of 3:1 for grey-scale images. The images specified are two photographs termed Rooftop and Ballpark. Four images have been adopted as standards for the NATO working group. Referred to as Substation, Microwave Tower, Transports, and Ship, these images are low-contrast reconnaissance photographs. Table 3 summarizes the compression ratios of five images at 16 shades of grey.

| Image           | Compression Ratio |      |
|-----------------|-------------------|------|
|                 | TDF               | NATO |
| Substation      | 4.8               | 3.7  |
| Microwave Tower | 4.7               | 5.0  |
| Transports      | 3.6               | 3.8  |
| Ship            | 5.8               | 3.5  |
| Rooftop         | 5.0               | 3.8  |

Table 3. Compression ratios at 16 grey shades.

When the five photos were processed by using the actual TDF hardware, the first four gave about 40% higher compression ratios than table 3 indicates for the TDF NOSC simulations. The scanner used for the NOSC simulations may have picture-element (pel) sensitivity variations that create shorter runs in the data and therefore lower compression ratios. But since the same scanner is used for the NATO algorithm, the same problem would apply to its encoding process; thus the relative comparison is valid. In fact, these compression ratios are above specification even with the pel sensitivity problem. The compression ratios should increase if the NATO algorithm is implemented in the TDF hardware.

## GREY-SCALE NOISE PERFORMANCE

The TDF performance specification does not specifically cover performance of grey-level images in a noise channel environment, since it is extremely difficult to specify an acceptable level criterion for grey-level images. Fortunately, two schemes can be compared simply by subjectively observing which is the better image, without regard to some acceptable level. Figures 1-8, consisting of an identical image for each of the two algorithms at four noise conditions, are included for comparison.

The noise that was used was collected by researchers of the Technical University, Hannover. They developed and executed a detailed process for gathering the noise data, which were accepted as valid and applicable by the NATO working group. US researchers examined the data and found similarity to noise data gathered by the US Army. Appendix D summarizes those comparisons.

Only four noise files -- 45, 46, 47, and 55 -- were used in connection with the grey-scale tests. Table 4 lists their important characteristics.

| Noise File Number | Number of Bursts | Avg Burst Length (bits) | Burst Error Rate     | Bit Error Rate       | Avg Errors per Burst |
|-------------------|------------------|-------------------------|----------------------|----------------------|----------------------|
| 45                | 2 465            | 5.6                     | $2.6 \times 10^{-3}$ | $8.4 \times 10^{-3}$ | 3.2                  |
| 46                | 1 768            | 4.5                     | $1.9 \times 10^{-3}$ | $5.6 \times 10^{-3}$ | 2.9                  |
| 47                | 219              | 4.6                     | $2.3 \times 10^{-4}$ | $6.0 \times 10^{-4}$ | 2.5                  |
| 55                | 10 044           | 1.3                     | $2.1 \times 10^{-3}$ | $2.2 \times 10^{-3}$ | 1.1                  |

Table 4. Characteristics of the noise files used for tests.

The process for the TDF did not include the cosmetic correction algorithm. The errors are allowed to remain in the data so that their effects are evident. If an actual TDF were subjected to the same noise, the resulting copy would seem superior since the cosmetic correction (discussed in appendix A) would tend to hide some errors.

## CONCLUSIONS

1. In a noisy communication channel the NATO data compression algorithm performs much better than the present TDF data compression algorithm, provided the noise channel is not too harsh. Text is legible in a noise channel that has a bit error probability on the order of  $1 \times 10^{-3}$  (single bit errors).
2. Multiple (burst) errors are not a problem provided the burst length does not exceed ten bits. When burst errors are combined with Gaussian errors, a practical burst limit appears to be about five bits.

3. The expected noise in tactical situations consists of Gaussian noise and bursts averaging five or fewer bits. Where the actual burst length greatly exceeds that, data compression algorithm performance may be poor, like that of most data compression algorithms that operate in an excessive noise environment without a more powerful noise protection algorithm.

4. The NATO algorithm has a compression efficiency less than that of the TDF, but it has enough compression to meet the current performance specification.

5. The NATO data compression technique is no more complex than the present TDF algorithm.

### RECOMMENDATIONS

On the basis of performance standpoint alone, replace the present TDF algorithm with the NATO algorithm. It will yield improved performance in a noisy communication channel. It will provide NATO interoperability in addition to better performance. It will also provide the essence of commercial interoperability, since it utilizes the commercial international standard data compression T-4 tables.

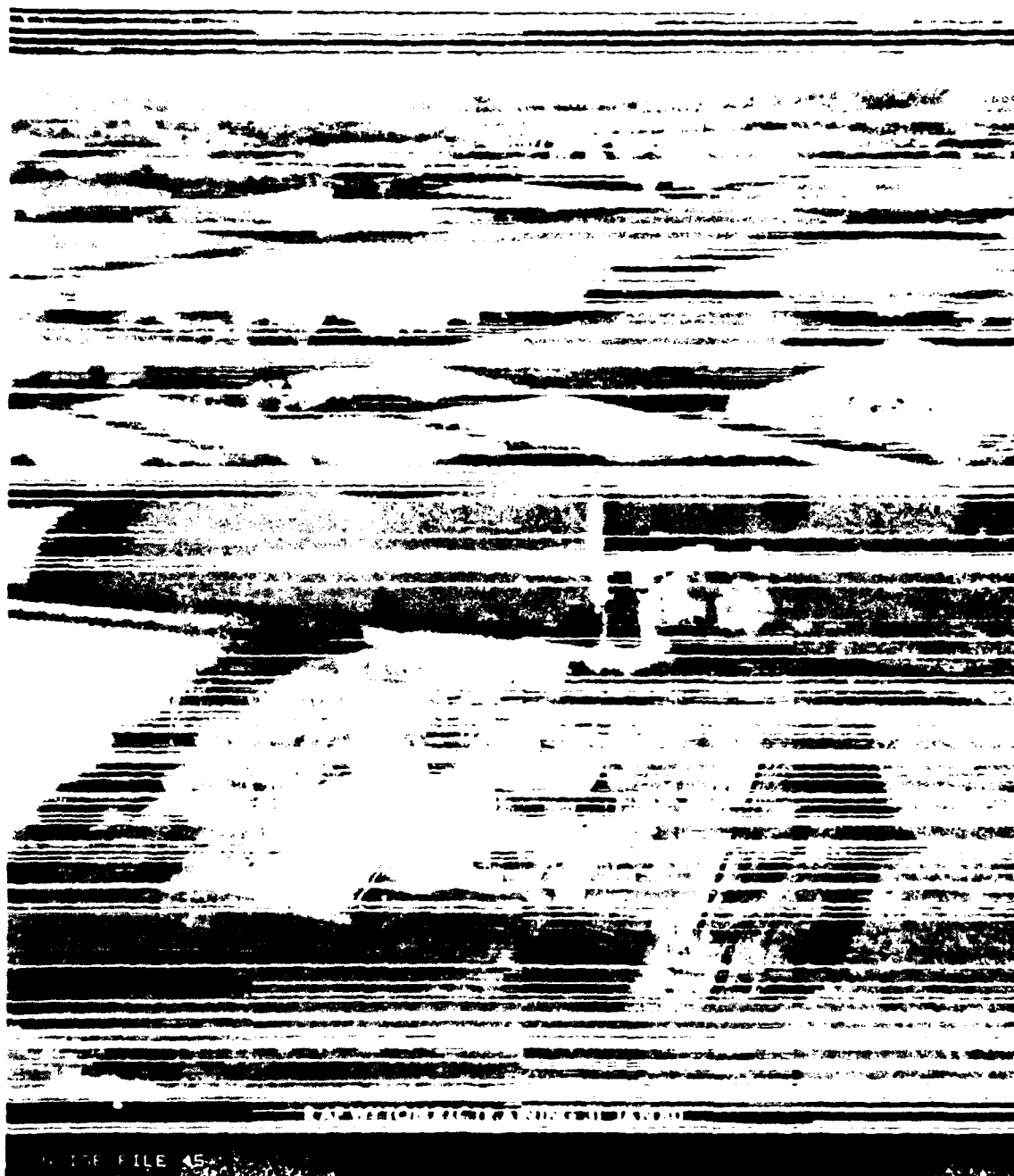


Figure 3 UDI algorithm, noise file 45



Figure 2. NATO algorithm, noise file 4s



NOTE FILE

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Figure 4. NATO algorithm, noise file 46



RAF WYTON 31 JAN 80

FILE 22



Figure 6. NATO algorithm, noise tile 4



Figure 1. DDE algorithm, noise file 55



Figure 8. NATO algorithm noise file 55

## APPENDIX A: FACSIMILE CHARACTERISTICS—TDF VERSUS NATO (STANAG 5000)

This appendix summarizes the similarities and differences between TDF and NATO (STANAG 5000) to illustrate how the TDF would have to be changed to establish interoperability with the NATO standard, if that is desired. The only functional concepts compared are those required for a form of interoperability.

For the sake of comparison, the parameters are categorized as follows:

Physical dimensional characteristics

Protocols

In-message procedures

The first two items are discussed only briefly; most of the discussion focuses on in-message procedures. The B-W mode is discussed first, then the grey-scale mode. In many instances, the grey-scale discussion refers to the B-W mode, since many of the grey-scale concepts are simply extensions of the B-W concepts.

### B-W MODE PHYSICAL DIMENSIONAL CHARACTERISTICS

In table A1, characteristics are associated with physical dimensions. The horizontal resolution is determined by the number of picture elements (pels) contained in a horizontal line divided by the length of the scan line. Vertical resolution is determined by the effective aperture in the vertical dimension, which is usually the same as the line stepping dimension.

| Characteristic  | Dimension                |                          |
|-----------------|--------------------------|--------------------------|
|                 | TDF                      | NATO                     |
| Horizontal pels | 1728                     | 1728                     |
| Scan width      | 215 ± 1.5 mm             | 215 mm                   |
| Scan direction  | left-right<br>top-bottom | left-right<br>top-bottom |
| Resolution      |                          |                          |
| Horiz           | 8.04 pels/mm*            | 8.04 pels/mm             |
| Vert            | 3.94 pels/mm*            | 3.85 pels/mm             |

\*The TDF actually is capable of three B-W resolution modes. Normally this is the resolution associated with B-W.

Table A-1. Summary of physical dimensional characteristics, B-W.

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The differences are minimal. The TDF specifies a tolerance on the scan width, whereas the NATO standard does not. Early in the TDF program, the physical dimensions were changed to be compatible with the proposed CCITT parameters. Previously, the TDF specification was written with slightly different physical dimensional characteristics, and no significant program impact occurred when the changes were made.

## B-W MODE PROTOCOLS

The protocols Start of Message (SOM) and End of Message (EOM) are necessary (1) to provide the receiver with the parameters particular to the subsequent transmission and (2) to signal the end or completion of the facsimile transmission.

### SOM

SOM is a special set of binary patterns that has the capability of both signaling through a noisy channel and indicating a set of conditions required to receive the facsimile data. The SOM used for the NATO standard is the same concept as the TDF. The NATO SOM as adopted, however, has defined modes that are *not* used within the present TDF design. They are designed to indicate the use or nonuse of the error correction for a particular transmission. Figure A1 illustrates the two signaling modes of the NATO SOM: error protection and no error protection. The preamble indication means any data prior to the logical inverted End of Message, indicated as EOM. The three command Start of Message (SOM) frames comprise the command portion of the entire SOM. A command SOM frame consists of the following:

$$S_1 S_0 \text{ X } S_0 S_1$$

where  $S_0$  and  $S_1$  are defined in table A2 and X is a specified number of clock bits. For B-W,  $X = 9$  clock bits. For the TDF SOM, the three command frames are followed by facsimile data. For NATO, as shown in figure A1, the forward error correction (FEC) control requires three additional SOM frames with the same structure as the command SOM frame except that X is equal to either 254 or 255 clock bits. The timing indicated in the figure refers to NATO definitions.

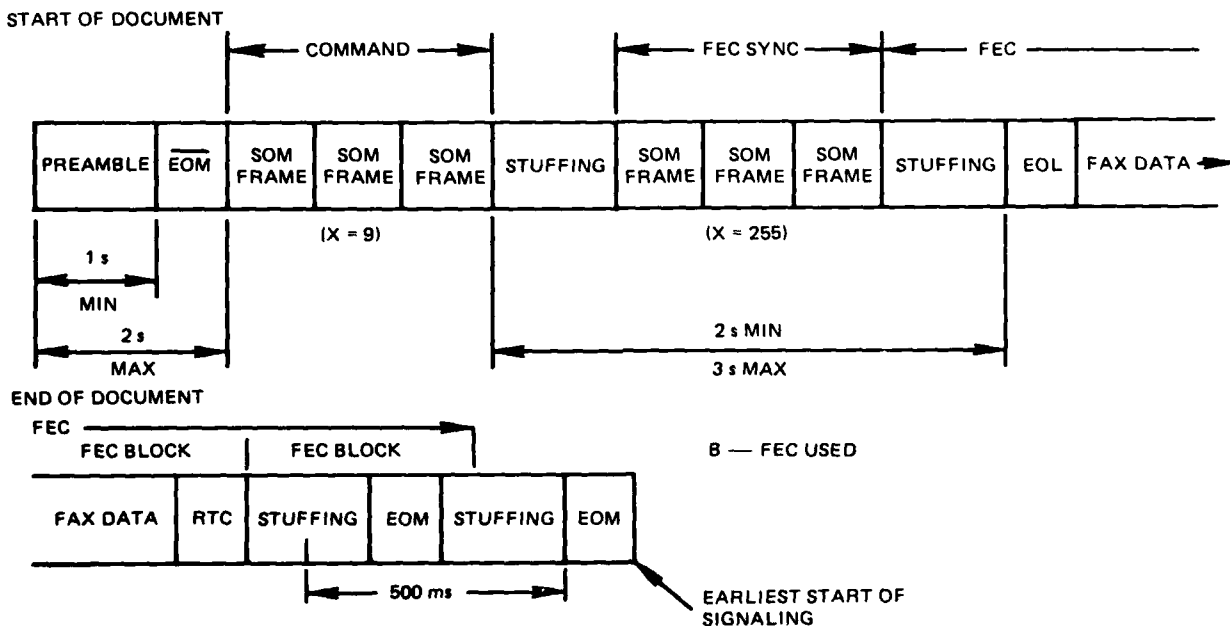
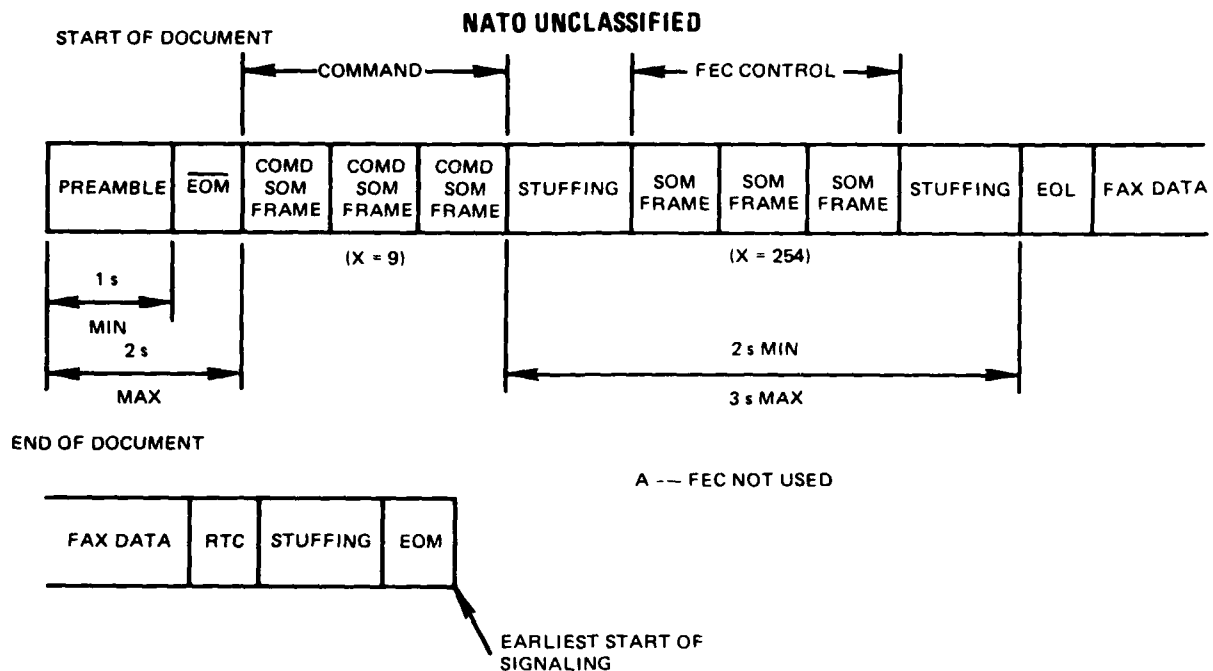
### EOM

The EOM signals the end of the In-message (facsimile message) and is important to prevent continuous transmission without data. It must be capable of signaling through noise and be uniquely detectable at the receiver. The technique is illustrated in figure A1, where the EOM consists of 16 consecutive  $S_1$  words.

## B-W MODE IN-MESSAGE PROCEDURE

### Technique

Figure A2 illustrates, in a very simple flow diagram, the In-message procedure. It is general and applies to both the TDF and NATO techniques. For both TDF and NATO, the data are received from a scanner. The scanner converts the document data into picture



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Figure A1. NATO signal format, compressed mode. NOTE: Stuffing consists of any convenient data.

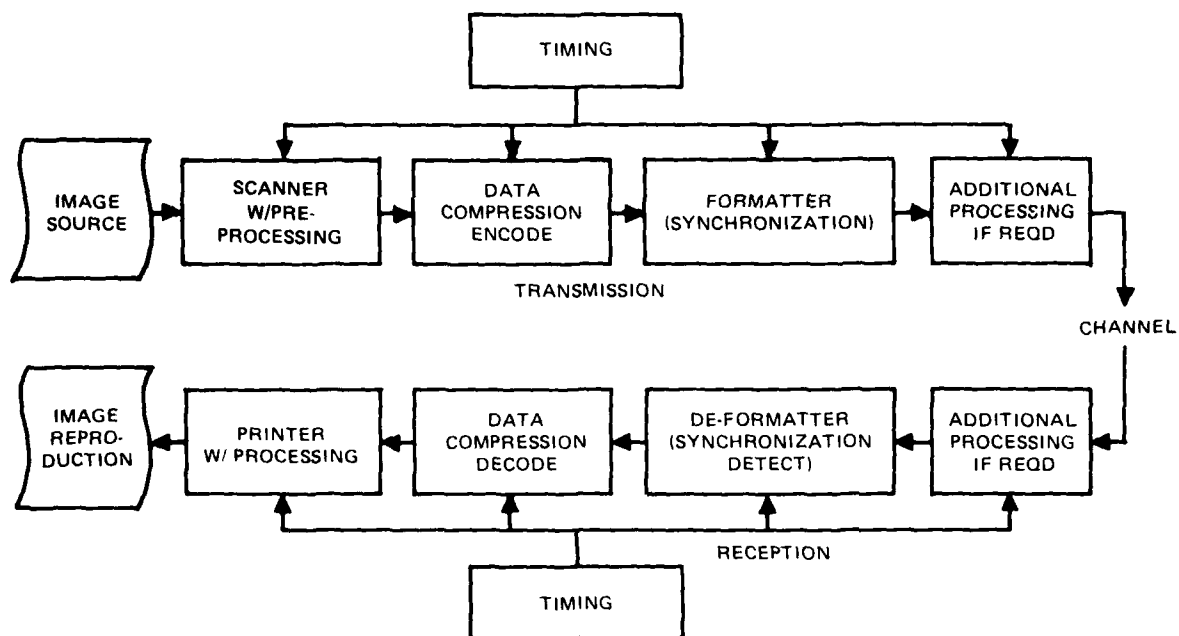


Figure A2. In-message procedure.

elements composed of either 1 or 0. Preprocessing occurs, if necessary, prior to the run-length encoding. The run-length encoding examines the input bit stream for a continuous run of 1s or 0s. Whatever the length is, it is encoded into a binary number representing that run length. There exist limitations to the maximum run that are dependent upon the technique, as explained later. The binary word representing the run length is then used to determine the code(s) to be selected from modified Huffman tables. There is a table for white runs and one for black runs. Each Huffman table is a statistically generated set of binary words varying in length. The shorter words are statistically more likely to occur than the longer ones. These code words are then sent out over the channel with the proper synchronization codes. Data compression is realized by taking the most frequent runs and sending them out over the communication channel as a very short code word. While both the TDF and NATO standards use modified Huffman tables, they are quite different in the actual binary patterns. If error protection is incorporated, it is done under ADDITIONAL PROCESSING in figure A2. The synchronization process is involved with each of the other processes to some degree.

While the physical dimensional characteristics could vary slightly from transmitter to receiver, thus creating distortion, and while the SOM and EOM could be handled manually by operators' setting and starting the machines, the In-message procedure must match exactly between the transmitter and receiver for any copy to be obtained. Therefore while both the TDF and the NATO standard incorporate the concept of run-length encoding with modified Huffman channel coding techniques, there are many differences. Table A2 summarizes these In-message characteristics. A further discussion of In-message characteristics is given to help show their importance and to illustrate the differences between the two techniques.

| Characteristic                 | Description                                                                          |                                                                                         |
|--------------------------------|--------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
|                                | TDF                                                                                  | NATO                                                                                    |
| Technique (general)            | Run length encode<br>Mod Huffman codes                                               | Run length encode<br>Mod Huffman codes                                                  |
| (specific)                     | Litton design                                                                        | CCITT recommendation                                                                    |
| Redundancy reduction dimension | Two dimension (wobble)                                                               | One dimension                                                                           |
| Synchronization code(s)        | Two 15-bit PN sequences:<br>$S_0 = 111100010011010$<br>$S_1 = 111101011001000$       | Eleven 0s + one 1                                                                       |
| Run length max                 | 864*                                                                                 | 1728                                                                                    |
| Base multiplier                | 118                                                                                  | 64                                                                                      |
| Number code tables             | 2 (B-W)                                                                              | 2 (B-W)                                                                                 |
| Max word length                | 12                                                                                   | 13                                                                                      |
| Table statistics source        | Two CCITT plus two NATO documents                                                    | Eight CCITT documents                                                                   |
| Special features               | Autoresolution<br>Multigrey shades                                                   |                                                                                         |
| Noise protection               | Noise-tolerant synchronization codes frequently inserted (internal to the algorithm) | BCH** forward error correction code, 23.5% redundancy added (external to the algorithm) |

\*See White Skipping

\*\*Bose-Chaudhuri-Hocquenghem 63.51 code.

Table A2. Summary of In-message characteristics.

### Redundancy Reduction Dimension

**TDF Wobble.** In figure A2, the wobble process would be part of the processing associated with the scanner. Figure A3 illustrates the concept of wobble. Wobble is incorporated to take advantage of vertical as well as horizontal redundancy. Under most conditions, greater redundancy reduction is possible. In part A, two lines are read into buffers A and B from the scanner. The vertical and horizontal redundancy is taken advantage of by reading out the bits in the square-wave pattern (wobble) as shown in part B.

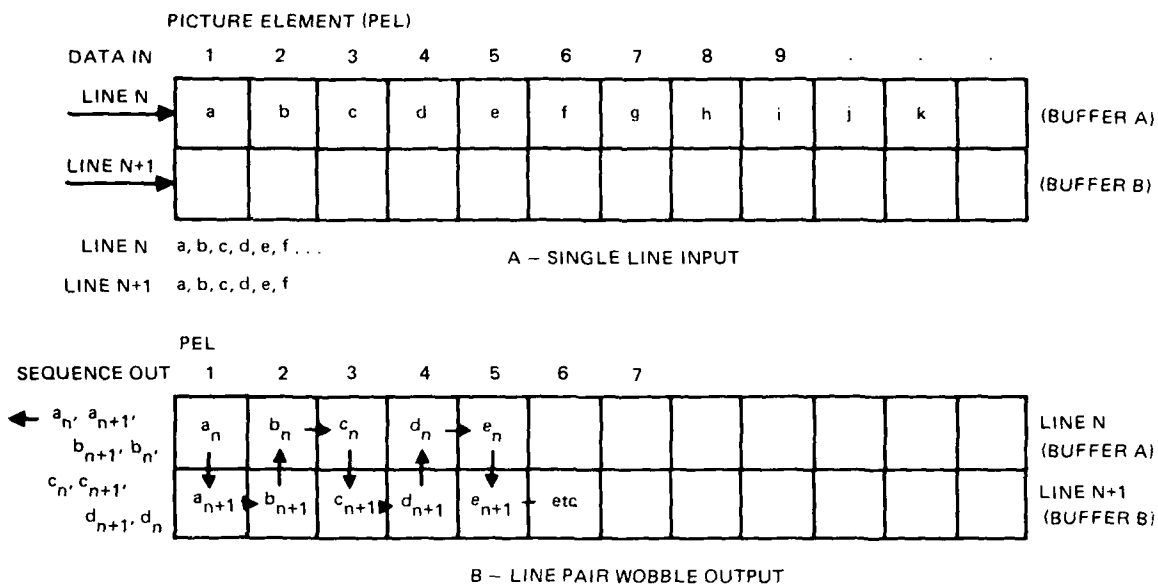


Figure A3. The concept of wobble.

**NATO One Dimension.** The NATO standard for B-W is a one-dimensional process in which only a single line at a time is read and processed. Even if all other In-message parameters are equal, the wobble process alone creates differences enough to require significant change.

### Synchronization Codes

**TDF.** The TDF uses two pseudorandom number (PN) sequences for the various synchronization delimiters. The TDF has the wobble (part B of fig A3), which creates one line pair consisting of two original lines. This line pair is now treated as a line of data, and the synchronization codes must be included. For noise protection, four PN sequences are inserted quarterly into the line at points with equal physical spacing on the page. Figure A4 shows where the codes would be if placed physically. In the decoding process the code words are removed and only the facsimile data are seen on a page. In a noise condition, this has the effect of stopping noise error propagation: whereas an error created in the data stream causes the subsequent data to be decoded improperly, thus propagating the error, the placement of a synchronization code terminates that error by resynchronizing. In a very noisy channel the effect of this process is evident in that at four points across the page, all errors stop and errorfree data are evident for a short distance.

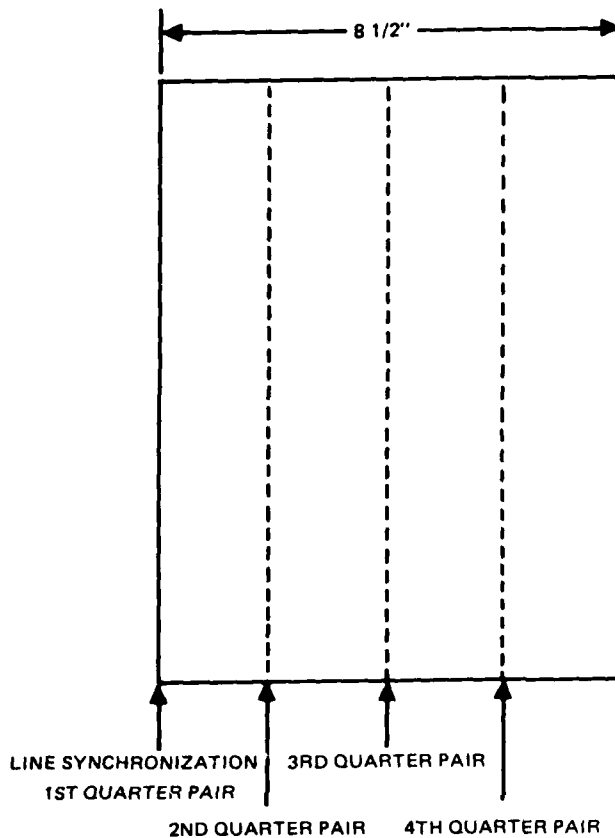


Figure A4. Physical Representation of TDF synchronization codes.

864 (3456/4). If a longer run occurs on the original document, the TDF will treat it first as a run of 864, then after the synchronization code it will process the remainder of the run as though starting a new run.

**NATO.** The CCITT code used in the NATO standard has only one line synchronization code per line and is a one-dimensional coding technique. Therefore the maximum run of one continuous shade is 1728 — the same as the number of horizontal pels.

#### Base Multiplier

**TDF.** In a run-length modified Huffman implementation, the process usually requires one or two words to encode a run of data. The point at which the process requires two words versus one is the base multiplier. For example, the TDF can encode a run from 0 to 117 with one binary word. In this case the decimal equivalent of the binary word is exactly the length of the run. For a run greater than 117, two words are used to encode the run length. One word represents a multiple of 118; the second is the remainder, which will be between 1 and 117. The TDF has multiplier codes sufficient to cover the maximum run length permitted for the TDF.

**NATO.** NATO uses the CCITT-recommended End of Line (EOL) code, which is actually placed at the beginning of each line. The EOL consists of a series of eleven 0s and one 1. This code word is a unique binary pattern, since it does not occur normally in the encoded facsimile data. If an error occurs in the facsimile data, it will propagate throughout the complete line up to the next synchronization word at the beginning of the next line.

#### Run Length Maximum

**TDF.** A run length is the length, in picture elements or bits, of a continuous shade. The maximum potential run of 3456 ( $2 \times 1728$ ) for the TDF could occur only if the two lines were all one shade, black or white. The TDF uses the four synchronization codes for the line pair, which divides the line pair into four segments of 864 each. Thus for the TDF, because of the four synchronization codes, the maximum run of a single continuous shade is

**NATO.** The CCITT code table concept is the same, but the base multiplier is 64 instead. Any run length between 0 and 63, inclusive, is encoded into a single modified Huffman binary word. Runs greater than 63 and up to 1728 are encoded into two words.

#### **Maximum Word Length**

**TDF.** The modified Huffman tables range from a word size of 1 bit to a maximum of 12 bits.

**NATO.** The CCITT minimum word is 2 bits and the maximum is 13.

#### **Table Statistics**

**TDF.** As mentioned before, the modified Huffman coding concept relies upon statistical probabilities of run length occurrences to reduce data redundancy. A document or set of documents must be used to generate the frequency of run occurrences. The TDF code tables were based upon two CCITT standard test charts and two test charts that were created during the development of the NATO standard. The NATO and TDF requirements are similar with respect to the type of documents that would be sent over facsimile. These four charts are digitized and used in a special program that creates the modified Huffman codes.

**NATO.** The CCITT modified code tables were generated on the basis of eight international documents that vary considerably: Japanese script, various sketches, a typical business letter format, etc.

#### **White Skipping**

**TDF.** As stated in the discussion on maximum run length, 864 was the maximum for the TDF. The white run of 864, however, is a special case and is handled as white skipping. A run is usually encoded into the appropriate code word or words. For a run of 864, the fact that the run would be enclosed by synchronization words is utilized. Instead of the code words for a run of 864, the next appropriate synchronization words are sent. Since these words are uniquely detectable, the receiver detects the synchronization words back to back and fills in the run as all white. This process reduces the number of bits required for a run of 864, thus reducing the number of bits transmitted.

**NATO.** The special optional feature for the CCITT algorithm is an additional table that has more codes to accommodate runs longer than 1728, which occur if larger paper widths are used but the resolution remains constant.

## Noise Protection

**TDF.** Noise protection is derived from the use of the particular synchronization codes employed. The frequency of inclusion restricts the error propagation, as discussed under Synchronization Codes. Because of the nature of the PN sequences, the synchronization code can be uniquely decoded in spite of errors that occur within it. The probability of detection decreases with the number of errors in the code. The TDF design that uses the synchronization codes allows for only one error per synchronization code.

**NATO.** Noise protection for the NATO algorithm is totally different from that for the TDF. It is designed so that the noise protection can be either employed (mandatory) or not employed (optional). As shown in figure A1, the noise protection would be implemented as Additional Processing in both the Transmission and Reception sequences. The NATO standard requires the noise protection to be BCH code 63.51. This is composed of a block of 63 bits of which 12 are redundancy bits. Within that block of 63 bits, the receiving circuit can decode the data without any loss of information even though any two bits may be in error because of the communication channel. To prevent a series of error bits (burst) from destroying a block while not causing any errors to adjacent blocks, interleaving is employed. Interleaving takes the BCH-encoded data and creates a 63- by 5-bit matrix. Each matrix is formed by placing the data into the matrix by rows and sending the matrix out onto the communication channel by column. If a burst occurs such that many sequential bits are affected, the errors will be distributed over several blocks and therefore correctable when they are deinterleaved at the receiver. The use of the block BCH code requires an additional synchronization process to achieve block synchronization. This is done in the SOM process and uses code words not used previously in the TDF signaling protocol.

**Cosmetic Correction.** Cosmetic correction is a term used to describe an algorithm for improving the appearance of a received copy that has been subjected to noise. The TDF employs an algorithm which, upon detection of a quarter line pair error, substitutes a previous or following line for the line in error. Since there is high vertical redundancy in facsimile images, this trick works well with moderate noise.

The algorithm is not described since it is not a consideration in the interoperability of different data compression algorithms; cosmetic correction is implemented in a way that depends entirely upon how the receiver process is designed. It can be designed to be quite complex and to make corrections, or it can simply allow all known errors to be printed as is. In both cases, the received data are the same and thus have no bearing on interoperability.

In recognition of this fact, the committee responsible for drafting the NATO standard made no attempt to specify a cosmetic correction algorithm. If one is to be employed by a country, it can be designed to that country's requirement.

## GREY-SCALE MODE

A fundamental intent in facsimile equipment design for both the TDF and NATO standards is to use a technique for grey-scale data compression that employs some of the concepts of the B-W mode. This simplifies the completed machine. To this end, this section refers to many of the B-W concepts and discusses the method of incorporating the grey scales from those particular concepts. The same three categories apply, with the first two discussed only briefly as before.

## GREY-SCALE MODE PHYSICAL DIMENSIONAL CHARACTERISTICS

For all practical purposes, the physical characteristics are the same as for B-W (table A3). The NATO and TDF have the same number of grey scales (4, 8, and 16) and resolution settings. The TDF has been implemented to be able to select any grey setting at any resolution.

| Characteristic  | Dimension                |      |      |                          |      |      |
|-----------------|--------------------------|------|------|--------------------------|------|------|
|                 | TDF                      |      |      | NATO                     |      |      |
| Horizontal pels | 1728                     |      |      | 1728                     |      |      |
| Scan width      | 215 ± 1.5 mm             |      |      | 215 mm                   |      |      |
| Scan direction  | left-right<br>top-bottom |      |      | left-right<br>top-bottom |      |      |
| Resolution*     |                          |      |      |                          |      |      |
| Mode            | 1                        | 2    | 3    | 1                        | 2    | 3    |
| Horiz           | 4.02                     | 8.04 | 8.04 | 4.02                     | 8.04 | 8.04 |
| Vert            | 3.94                     | 3.94 | 8.04 | 3.85                     | 3.85 | 7.70 |

\*Units: Horiz resolution is in pel/mm; vert resolution is in lines/mm.

Table A3. Summary of physical dimensional characteristics, grey-scale.

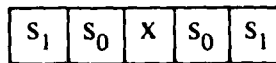
## GREY-SCALE MODE PROTOCOLS

The SOM protocols for the grey-scale mode are the same as for the B-W mode (fig A1). Additional signaling values are specified for grey-scale operation. The complete NATO signaling values are shown in table A4.

## GREY-SCALE MODE IN-MESSAGE PROCEDURE

The extension to grey scales is handled similarly in both the TDF and NATO. The differences between the two remain the same in the run length max and base multiplier (see table A2). The TDF uses a different set of look-up tables for its variable-length encoder. These tables were based on grey image data, for which they were optimized. The NATO variable encoder uses the "black" T-4 code words for runs of both 1s and 0s.

# SOM FRAME



Represents the number of transmitted bits (all 0s or all 1s) defined as follows:

| Number of Clock Periods (X) |                        | Mode Indicated                                                 | SOM Type    |
|-----------------------------|------------------------|----------------------------------------------------------------|-------------|
| Compressed                  | Uncompressed           |                                                                |             |
| 1                           | 33                     | 2 GS<br>3.85 lines/mm feed resolu<br>4.0 lines/mm scan resolu  | Command     |
| 2                           | 34                     | 4 GS<br>3.85 lines/mm feed resolu<br>4.0 lines/mm scan resolu  |             |
| 3                           | 35                     | 8 GS<br>3.85 lines/mm feed resolu<br>4.0 lines/mm scan resolu  |             |
| 4                           | 36                     | 16 GS<br>3.85 lines/mm feed resolu<br>4.0 lines/mm scan resolu |             |
| NATO Type 1<br>9            | Interoperability<br>41 | 2 GS<br>3.85 lines/mm feed resolu<br>8.0 lines/mm scan resolu  |             |
| 10                          | 42                     | 4 GS<br>3.85 lines/mm feed resolu<br>8.0 lines/mm scan resolu  |             |
| 11                          | 43                     | 8 GS<br>3.85 lines/mm feed resolu<br>8.0 lines/mm scan resolu  |             |
| 12                          | 44                     | 16 GS<br>3.85 lines/mm feed resolu<br>8.0 lines/mm scan resolu |             |
| 17                          | 49                     | 2 GS<br>7.7 lines/mm feed resolu<br>8.0 lines/mm scan resolu   |             |
| 18                          | 50                     | 4 GS<br>7.7 lines/mm feed resolu<br>8.0 lines/mm scan resolu   |             |
| 19                          | 51                     | 8 GS<br>7.7 lines/mm feed resolu<br>8.0 lines/mm scan resolu   |             |
| 20                          | 52                     | 16 GS<br>7.7 lines/mm feed resolu<br>8.0 lines/mm scan resolu  |             |
| 254                         |                        | FEC not used                                                   | FEC Control |
| 255                         |                        | FEC used                                                       |             |

Table A4. Detailed signaling values.

## Gray Code

Figure A2 also applies to the grey-scale concept. The data are scanned and are quantized into multiple levels rather than merely two levels, for TDF and NATO, both of which use a Gray code (table A5). The Gray code improves the compression ratio by reducing the number of perturbations on the various planes due to a change of only one grey level.

| Shade      | Binary | Gray Code |
|------------|--------|-----------|
| 0 (white)  | 0000   | 0000      |
| 1          | 0001   | 0001      |
| 2          | 0010   | 0011      |
| 3          | 0011   | 0010      |
| 4          | 0100   | 0110      |
| 5          | 0101   | 0111      |
| 6          | 0110   | 0101      |
| 7          | 0111   | 0100      |
| 8          | 1000   | 1100      |
| 9          | 1001   | 1101      |
| 10         | 1010   | 1111      |
| 11         | 1011   | 1110      |
| 12         | 1100   | 1010      |
| 13         | 1101   | 1011      |
| 14         | 1110   | 1001      |
| 15 (black) | 1111   | 1000      |

MSB ———>      <——— LSB

bit plane 1      bit plane 4

bit plane 2      bit plane 3

Table A5. The Gray code.

## Bit Plane Concept

The concept of planes is illustrated by figure A5, which applies for both TDF and NATO. For purposes of illustration, four bits are required if the image is quantized into 16 levels. If each pel is visualized as consisting of the four bits, these bits could be stored into four buffers (B1-B4) of 1 x 1728 bits. Buffer 1 could have all of the most significant bits; buffer 2, the next; up to buffer 4, with all of the least significant bits. These are called bit planes. Since each of these planes is simply 1728 bits of 1s and 0s, it can be processed just like the B-W data.

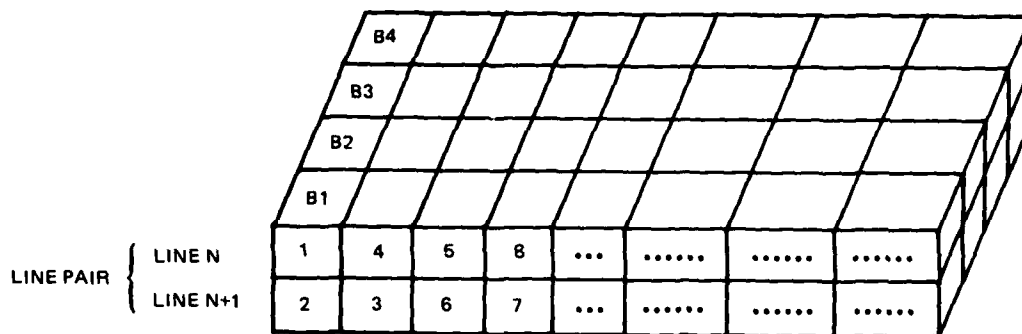


Figure A5. Bit plane concept. Uses the same line pair structure as in B-W. Each pel is represented by a four-bit word indicating the grey-shade level.

This is the bit plane concept. In figure A2, the organization of the data into bit planes can be considered as part of preprocessing. At the receive end the planes can be reassembled such that each pel is again composed of the four bits, and the picture can be printed.

For grey scale, both NATO and TDF do wobble preprocessing of each plane. The wobble technique was explained for the TDF B-W mode. It was not used for the B-W NATO technique. For NATO grey scale, however, it is incorporated to improve the compressibility. Since grey-scale data now comprise multiple planes, the wobble concept is extended to include wobbling of each of the planes. This means that figure A3 would apply to each plane.

### Autoresolution

Automatic resolution (A/R) acts to increase the compression of data by eliminating data changes in areas of low activity. A check is performed on the number of transitions (1 to 0, 0 to 1) on the wobbled data. If the transition number is below some threshold, the data are subjected to the A/R process. To invoke A/R, the wobbled data may be considered to be organized into two-by-two matrices for the processing, as illustrated in figure A6. The data in the two-by-two matrices are changed to be all 1s or all 0s according to the rules given in table A6.

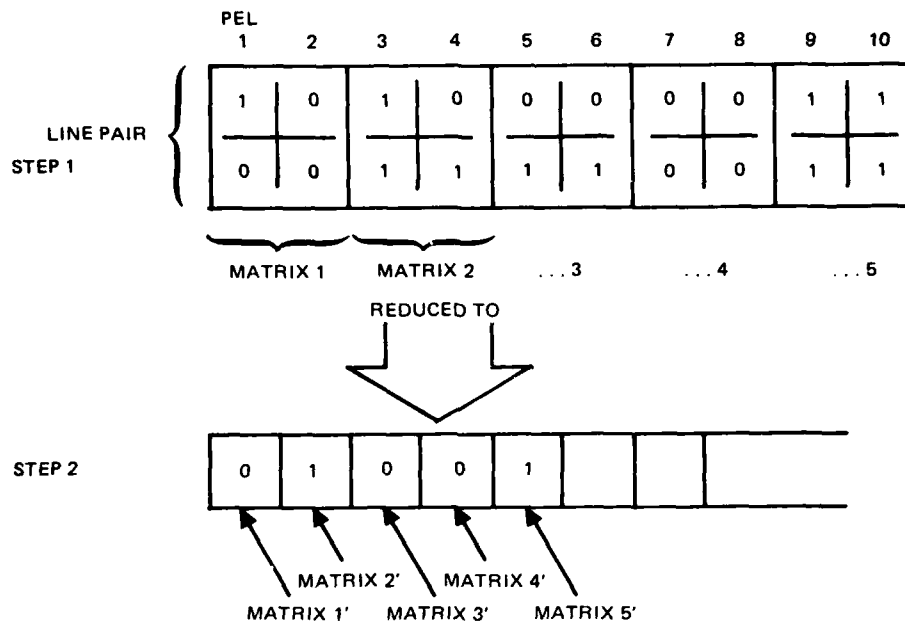


Figure A6. Autoresolution process.

| Rule No | Data Content                 |                             |                             |
|---------|------------------------------|-----------------------------|-----------------------------|
|         | Before Step 1;<br>2x2 Matrix | Intermediate;<br>2x2 Matrix | After Step 2;<br>Single Bit |
| 1       | One 1, three 0s              | Four 0s                     | One 0                       |
| 2       | One 0, three 1s              | Four 1s                     | One 1                       |
| 3       | Two 0s, two 1s               | Four 0s                     | One 0                       |
| 4       | Four 0s                      | Four 0s                     | One 0                       |
| 5       | Four 1s                      | Four 1s                     | One 1                       |

Table A6. Autoresolution matrix rules.

With these rules used in the process, each two-by-two matrix can be replaced with a single bit representing that matrix. These new data then are sent to the run-length and variable-length encoders. The fact that this A/R process took place for the particular segment of data is indicated in the format of the data. At the decode side of the process, the A/R bit is detected in the format and each bit of that segment is expanded by four after the decoding process. The data are dewobbled, reassembled into the bit planes and then into each individual pel, and printed. Note that the original data (step 1 of figure A6) cannot be reconstructed from the expanded decoded data.

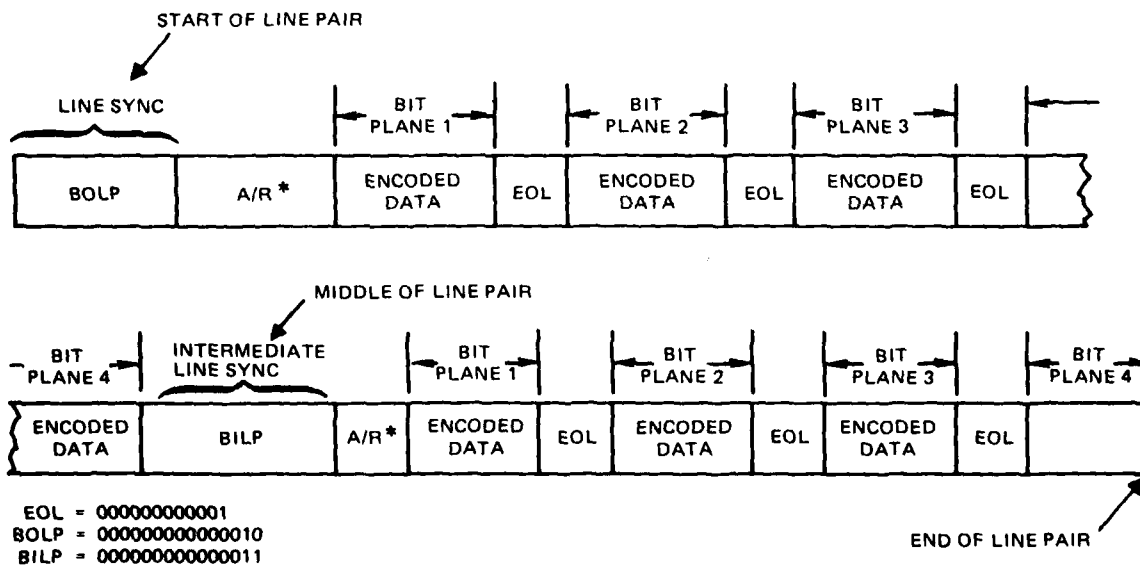
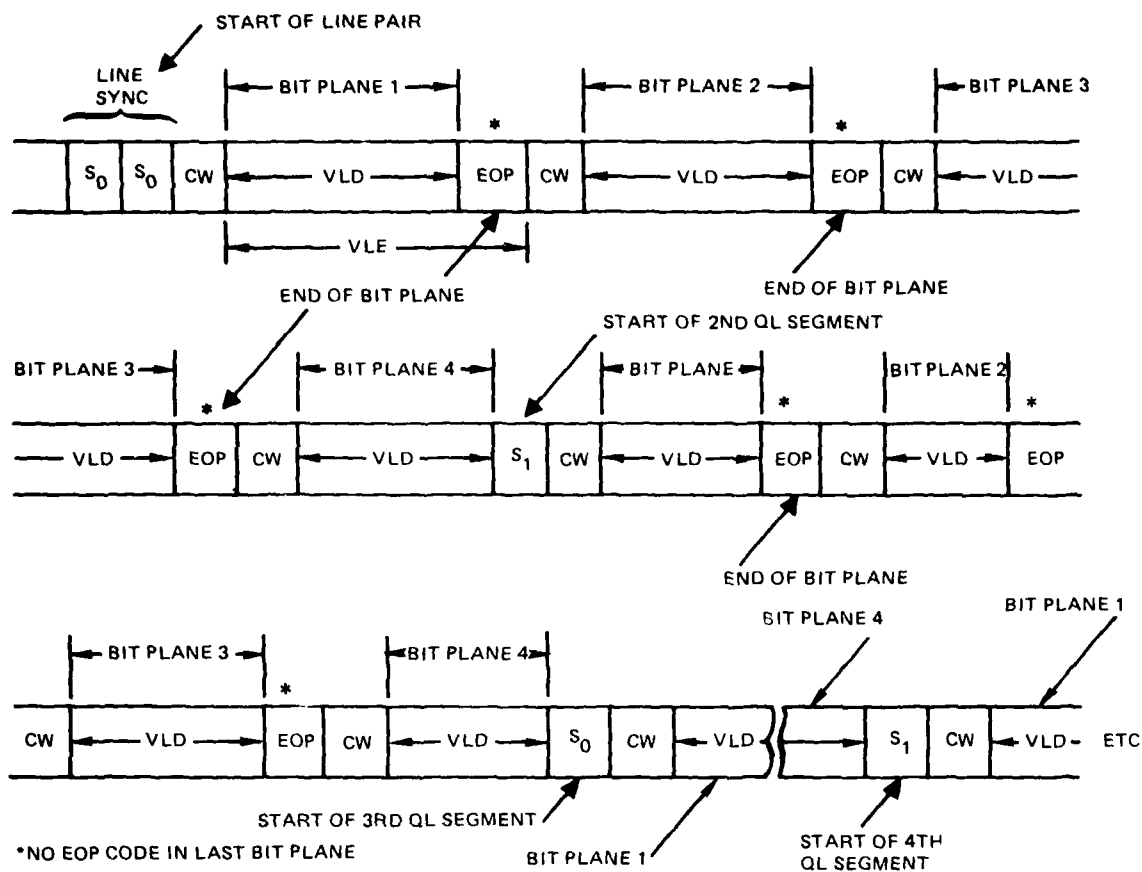
Autoresolution is not always invoked. For 16 levels of grey and four bit planes, the following criteria are used:

|                                 |                                                                                  |
|---------------------------------|----------------------------------------------------------------------------------|
| Bit plane 1 (most significant)  | A/R is never invoked                                                             |
| Bit plane 2                     | Invoked if transition threshold not exceeded                                     |
| Bit plane 3                     | Invoked if transition threshold is not exceeded or if bit plane 2 A/R is invoked |
| Bit plane 4 (least significant) | Always invoked                                                                   |

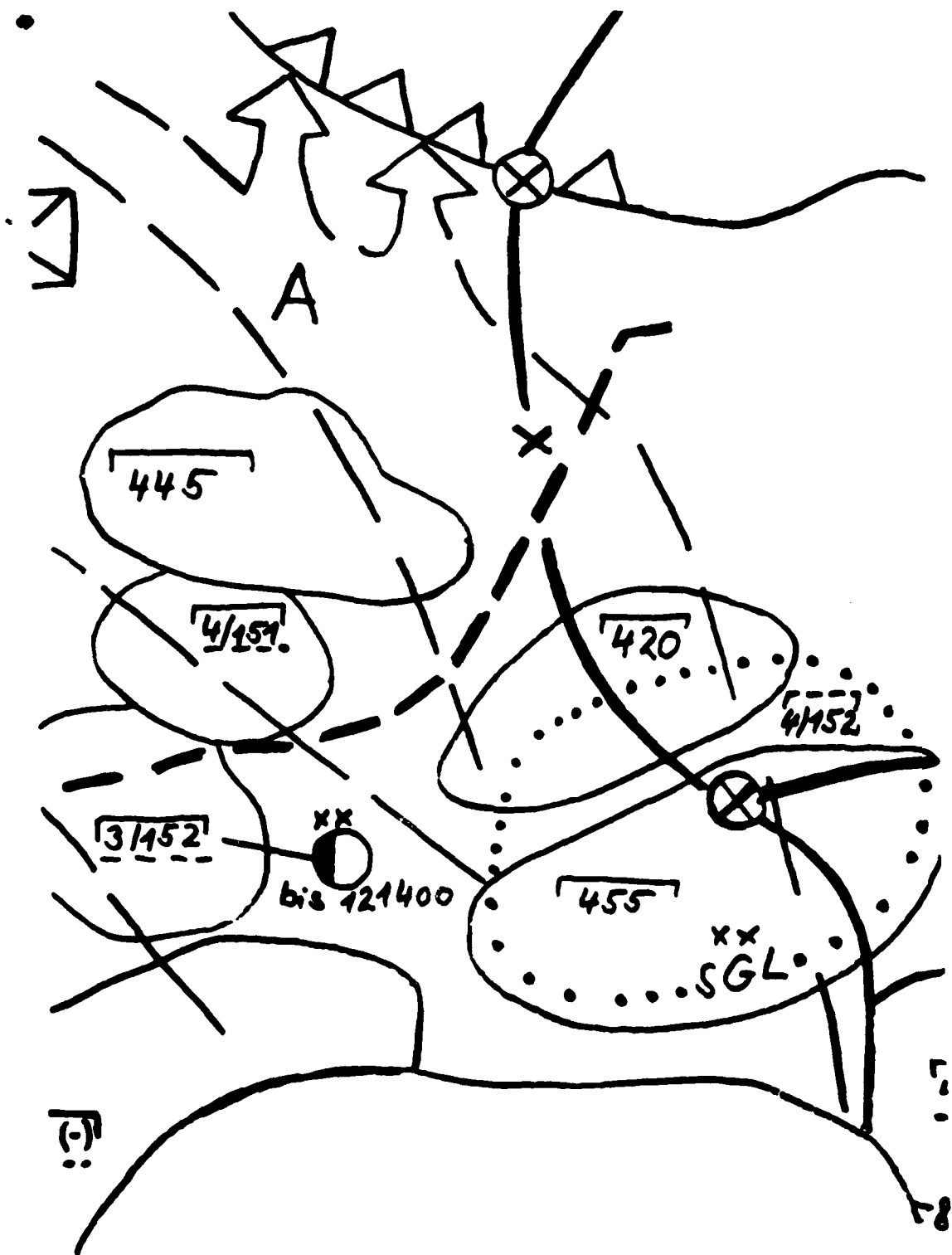
### Format

The data format for the TDF and NATO differ in several ways. The TDF format is illustrated in figure A7. The only difference between the format for TDF grey scale and TDF B-W is the addition of several bit planes of data. The data for both are separated into quarter line-pair segments separated by synchronization codes. Two bits immediately following the synchronization comprise a control word (CW). The first bit indicates the shade of the first run (black or white), and the second bit indicates the A/R status for that segment. Note that the A/R bit is included for all bit planes even though planes 1 and 4 are fixed. This provides flexibility in case some condition later requires a change in the A/R rules.

The NATO format is illustrated in figure A8. Contrary to the NATO B-W mode, the data represent one-half line pair information. The A/R information for each one-half line is contained in one three-bit A/R word.



**APPENDIX B: FOUR B-W TEST CHARTS**



| MESSAGE FROM                                                                                                                                        |                                                       |                    |                      |                       | CHECK BOX                       |                                                                                                                                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|--------------------|----------------------|-----------------------|---------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| LINE 1                                                                                                                                              |                                                       |                    |                      |                       | Routed by                       |                                                                                                                                    |
| LINE 2                                                                                                                                              | <b>TEST DOCUMENT</b><br><b>for Type I - Equipment</b> |                    |                      |                       | Time <b>1100</b>                |                                                                                                                                    |
| LINE 3                                                                                                                                              |                                                       |                    |                      |                       | Perforated by <b>GRU</b>        |                                                                                                                                    |
| LINE 4                                                                                                                                              |                                                       |                    |                      |                       | Time <b>1130</b>                |                                                                                                                                    |
| ROUTING INDICATORS                                                                                                                                  | Precedence                                            | Action             | Precedence           | Info                  | Date                            | Time Group Month                                                                                                                   |
|                                                                                                                                                     | ROUTINE                                               |                    | Routine              |                       | Sept. 1978                      |                                                                                                                                    |
|                                                                                                                                                     | FROM                                                  | 1 AC 302(SGI) WP/2 |                      |                       |                                 | Transmitted by                                                                                                                     |
|                                                                                                                                                     | TO                                                    | TEST PURPOSE       |                      |                       |                                 | Channel No. System <b>127</b>                                                                                                      |
|                                                                                                                                                     |                                                       |                    |                      |                       |                                 | Time <b>1200</b>                                                                                                                   |
|                                                                                                                                                     |                                                       |                    |                      |                       |                                 | Operator                                                                                                                           |
|                                                                                                                                                     |                                                       |                    |                      |                       |                                 | MESSAGE INSTRUCTIONS                                                                                                               |
|                                                                                                                                                     | INFO                                                  | 4 ABC              |                      |                       |                                 | SECURITY CLASSIFICATION<br>(Message referring to a classified message must be classified RESTRICTED or above)<br><br><b>UNCLAS</b> |
|                                                                                                                                                     |                                                       | 3 DEF GHI          |                      |                       |                                 |                                                                                                                                    |
|                                                                                                                                                     |                                                       | 14/17 KLMNO        |                      |                       |                                 |                                                                                                                                    |
|                                                                                                                                                     |                                                       | 19 PQRST           |                      |                       |                                 |                                                                                                                                    |
| TIME                                                                                                                                                |                                                       |                    |                      |                       |                                 |                                                                                                                                    |
|                                                                                                                                                     | 0900                                                  | 138721             |                      | ABC                   |                                 |                                                                                                                                    |
|                                                                                                                                                     | 0930                                                  | 915246             |                      | NIL                   |                                 |                                                                                                                                    |
|                                                                                                                                                     | 1000                                                  | 768541             |                      | TACB                  |                                 |                                                                                                                                    |
|                                                                                                                                                     | 1030                                                  | 219333             |                      | MINIMAL               |                                 |                                                                                                                                    |
|                                                                                                                                                     | 1200                                                  | 492771             |                      | PERMANENT             |                                 |                                                                                                                                    |
|                                                                                                                                                     | 1327                                                  | 321456             |                      | ABCDEFGH              |                                 |                                                                                                                                    |
|                                                                                                                                                     | 1430                                                  | 191727             |                      | NIL                   |                                 |                                                                                                                                    |
|                                                                                                                                                     | 1457                                                  | 888912             |                      | NIL                   |                                 |                                                                                                                                    |
|                                                                                                                                                     | 1500                                                  | 191517             |                      |                       |                                 |                                                                                                                                    |
|                                                                                                                                                     |                                                       |                    |                      |                       | FILE NUMBER OR REFERENCE        | <b>17/52</b>                                                                                                                       |
|                                                                                                                                                     |                                                       |                    |                      |                       | DRAFTER'S NAME IN BLOCK LETTERS |                                                                                                                                    |
| refers to a classified message<br>This message (tick appropriate box)<br>does not refer to a classified message <input checked="" type="checkbox"/> |                                                       |                    |                      |                       | TELEPHONE NUMBER                | <b>323</b>                                                                                                                         |
|                                                                                                                                                     |                                                       |                    |                      |                       | BRANCH                          |                                                                                                                                    |
|                                                                                                                                                     |                                                       |                    |                      |                       | RELEASING OFFICER'S SIGNATURE   | RANK                                                                                                                               |
| FILING TIME / TOR                                                                                                                                   | SYSTEM                                                | OPERATOR           | FINAL CHECK OPERATOR | NAME IN BLOCK LETTERS |                                 |                                                                                                                                    |

ETABLISSEMENTS ABCDEP  
 SOCIÉTÉ ANONYME AU CAPITAL DE 300 000 F  
 25, RUE DU SYMBIOTISME F 60000 NTBCLAG  
 Tél. (35) 24 48 32 Ad. Tg. NRVLJROLM  
 Télex 31586 F IN 718490070257  
 Transporteur (ou Transitaire)  
 M. M. DUPONT Frères  
 8 quai des bâteaux F 60000 NTBCLAG

Not directeur

| CLASSEMENT              | FACTURE INVOICE | Exemplaire 15  |
|-------------------------|-----------------|----------------|
| CODE CLIENT<br>2 04 559 | DATE<br>7-7-74  | NUMERO<br>06   |
|                         |                 | FEUILLET<br>01 |

Votre commande du 74-2-2 numéro 438

Notre offre AZ/B7 du 74-1-1 numéro 12

LIVRAISON

5, rue XYZ  
 99000 VILLE

FACTURATION

12, rue ABCD BP 15  
 99000 VILLE

DOMICILIATION BANCAIRE DU VENDEUR

CODE BANQUE CODE GUICHET COMPTE CLIENT

ORIGINE

Page 1

TRANSPORTS  
 DESTINATION

Etat 2

MODE

Air

PAYS D'ORIGINE

PAYS DE DESTINATION

CONDITIONS DE LIVRAISON DATE 74-03-03

LICENCE D'EXPORTATION NATURE DU CONTRAT (Importation)

CONDITIONS DE PAIEMENT FAB

| MARQUES ET NUMEROS<br>MARKS AND NUMBERS                              | NOMBRE ET NATURE DES COLS<br>DENOMINATION DE LA MARCHANDISE<br>NUMBER AND KIND OF PACKAGES<br>DESCRIPTION OF GOODS | NOMEN-<br>CLATURE<br>STATISTICAL<br>NO. | MASSA NETTE<br>NET WEIGHT<br>K.G. | UNITE<br>UNIT                | QUANTITE<br>QUANTITY<br>ORDERED<br>AND UNIT |
|----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|-----------------------------------------|-----------------------------------|------------------------------|---------------------------------------------|
| 74.21.455.44.2 A                                                     | 1 Composante                                                                                                       | 1234                                    | 5 KG                              | 1                            | 1                                           |
| QUANTITE<br>COMMANDEE<br>ET UNITE<br>QUANTITY<br>ORDERED<br>AND UNIT | N° ET REF.<br>DE L'ARTICLE                                                                                         | DESIGNATION                             | UNITE<br>UNIT                     | PRE-<br>CATARE<br>UNIT PRICE | MONTEANT<br>TOTAL<br>AMOUNT                 |
| 2                                                                    | AF-809                                                                                                             | Circuit integre                         | 10                                | 20,00 F                      | 200,00 F                                    |
| 10                                                                   | 58-T+                                                                                                              | Connecteur                              | 10                                | 20,00 F                      | 200,00 F                                    |
| 25                                                                   | Z107                                                                                                               | Composant intermediaire                 | 20                                | 20,00 F                      | 500,00 F                                    |

| Costs          | Debits                      | Plus    | Net total |
|----------------|-----------------------------|---------|-----------|
| Paid           | Emitted                     |         | 92,14     |
| Freight        | Transport                   |         |           |
| Insurance      | Assurances                  |         |           |
| Total amount   | Montant total de la facture | 1431,80 |           |
| Net to be paid | Net to be paid              | 1431,80 |           |

NATO UNCLASSIFIED

ANNEX I  
TEST SHEET  
AC/302 (SG-1) WG-2

TRI-SERVICE GROUP ON COMMUNICATIONS AND ELECTRONIC EQUIPMENT

SUB-GROUP ON TACTICAL AREA COMMUNICATIONS

WORKING GROUP ON TACTICAL AREA COMMUNICATIONS

FACSIMILE TEST SHEET

1. This typewritten sheet is accepted by the members as one of the official test sheets to be used for the trial runs.
2. In order to couple the output of a radio transmitter to space or to couple the input of a receiver to space, it is necessary in each case to use some type of structure capable of radiating electromagnetic waves or receiving them, as the case may be. An antenna is such a structure and may be described as a metallic object, often a wire or a collection of wires, used to convert high-frequency current into electromagnetic waves.
3. The mechanism of radiation may be explained quantitatively by means of Maxwell's equations. Upon examining the behavior of the RF current in a wire, it is found that not all of the energy at one end finds its way to the other; some is radiated. See Fig 11.1. The transmission line theory will be used.
4. If the open-circuited transmission line of Fig 11.2 is considered, it is seen that the forward and reverse travelling waves combine to form a standing-wave pattern on the line. This has already been discussed (in Chap. 8, 9, and 10), but it was not mentioned at the time that only part of the forward energy is reflected by the open circuit; it will be shown (in Chap. 13, 14, 15 and 16) that a small portion of the electromagnetic energy escapes from the system and is radiated.
5. The various characteristics of antennas are not normally quoted as absolute figures, but rather in comparison to those of "standard" antennas. The latter are theoretical simplifications, which need not necessarily exist in practice but which have properties that are easy to visualize and calculate. One such reference Antenna is the infinitesimal dipole; another reference antenna is the elementary doublet.
6. The radiation field is not the only field surrounding the elementary doublet, or any other antenna, for that matter. Magnetic and electric fields exist also and are collectively referred to as the induction field. Such a field surrounds any current-carrying wire and, in fact, is stronger than the radiating field in the immediate vicinity of the radiator. However, the induction field diminishes very rapidly with distance from the doublet and becomes insignificant a few wavelengths away. The importance of the induction field lies not in its ability to convey information over long distances, but in the fact that if antennas are placed in close proximity, the interference effects caused by the induction field must be taken into account.

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## **APPENDIX C: ERROR SENSITIVITY AND CHARACTER LEGIBILITY FOR FACSIMILE SYSTEMS**

### **INTRODUCTION**

Character legibility is the primary factor of merit in facsimile systems. Legibility is the driving factor for choosing the proper resolution of a system. Excessive resolution unnecessarily increases data to be transmitted, whereas decreasing the resolution to reduce transmitted data decreases the legibility of the data at the receive terminal. In a non-noise situation, legibility is affected by the choice of a low resolution; conversely, for a fixed resolution, legibility suffers when the print is small.

In a noise environment such as subjected to facsimile data during transmission, legibility suffers when the noise affects the data. The degree of legibility degradation is related to the error sensitivity of the type of facsimile data compression algorithm used and/or to the error protection employed on the communication link.

Because of these considerations, the Tactical Digital Facsimile (TDF) specification incorporated a paragraph stipulating that the equipment be capable of producing 97.5% legible copy 95% of the time under a noise condition of 1 error in 1000.

The purpose of this appendix is to document the rationale for choosing a valid and fair method to test the TDF or any facsimile system with similar requirements.

### **BACKGROUND**

A definitive series of studies was conducted by IBM in the late 1960s to determine the acceptable degree of legibility for typescript transmitted by facsimile. The characteristics analyzed in those studies consisted of the horizontal and vertical resolution of the equipment, the shape of the sampling aperture, and the effects of error resulting from compression coding (ref C1-C4).

The reference C1-C4 analyses of legibility versus resolution yielded the following results:

1. Across all conditions, scan orientation caused an average difference in perceived legibility of less than 1%.

- C1. Laboratory Memorandum ASDJ-M-097, Digital Facsimile: Transmission Economy and Copy Quality, by RB Arps et al, IBM Corporation, Los Gatos, CA, 31 May 1966.
- C2. Character Legibility and Digital Facsimile Resolution, by BL Erdman and AS Neal, Human Factors, vol 10, no 5, p 465-474, 1968.
- C3. Word Legibility as a Function of Letter Legibility, with Word Size, Word Familiarity, and Resolution as Parameters, by BL Erdman and AS Neal, Journal of Applied Psychology, vol. 52, no. 5, p 403-409, 1968.
- C4. Character Legibility Versus Resolution in Image Processing of Printed Matter, by RB Arps et al, IEEE Transactions on Man-Machine Systems, vol 10, no. 3, p 66-71, September 1969.

2. Legibility is directly proportional to sampling and pitch dimensions and to character height. If the criterion is 97.5% legibility, resolution of 110 by 110 elements per inch is estimated to be a minimum requirement for standard typescript with capital letters about 100 mils high. To approximate 100% legibility for most typescript copy, resolution of 125 by 125 elements per inch is required.
3. The engineer has some latitude in choosing the aperture geometry as long as the scanning element area remains about 9 by 9 mils. Distortion of character shape increases with deviation from the square aperture. A safe design limit is estimated to be a deviation of no greater than 20% of square aperture.
4. A solid guideline for system design is to make pitch and sampling distance equivalent to 9% of character height. This will result in 97.5% legibility.

### **TDF APPLICATION**

The TDF has three horizontal-by-vertical resolutions: 200 by 200, 200 by 100, and 100 by 100 lines per inch. Background item 4 is the principal guideline used to choose the character height for the tests. The TDF was designed to tolerate noise, and its legibility should remain constant up to and including an error rate of 1 in 1000 random single bit errors.

The IBM noise studies (ref C1) do not apply to the TDF. The IBM study purpose in respect to noise was "To investigate the way noise-induced errors affect image quality. . ."

### **CHARACTER LEGIBILITY TEST CHARTS**

The enclosed test charts, fig C1-C3, were created on the basis of guidelines from the IBM literature. Test chart OJS is intended for 200 by 200 resolution, test chart CEW for 200 by 100 resolution, and test chart WDB for 100 by 100 resolution. With table 1 in reference 2 and the 97.5% legibility criterion taken as guidelines, the print size (uppercase) was chosen to be 120-mil (12-point), 80-mil (8-point) and 60-mil (6-point), respectively. A block format type of print (ie having no fancy curls) of medium weight was chosen. The characters were assembled at random so as to remove any contextual clues in the resulting words. From table 1 in reference C2, the three entries chosen are for 57, 76, and 114 mils. The next larger size type was chosen for the test charts.

### **TEST PROCEDURES**

On the basis of the criteria used to choose the print size, the TDF should be able to equal or exceed 97.5% legibility for the appropriate resolution and print size under noise-free conditions. This should be verified by actual testing to insure that the test charts are valid and fair.

The tests should then be repeated under the noise conditions specified. The noise protection designed in, if adequate, should assure the production of legible copy that equals or exceeds the 97.5% criterion.

The tests should include multiple runs with the noise inserted and, on an individual basis, the output should be given to personnel to read, character by character.

X68VNL6UTT

YSN9X7FD1K

SOGSS03LQK

OLX04NEWX3

T5W7VFB3SM

H3V6OJLU6V

TQFKOOINEO

WX2P1KU5PY

Y4AREG4DU3

DMOTR73IAR

IG9XEMLCYF

J3N3UVF8RB

W1UOFCB9H7

6L2UVEK7RA

LJX11TGHWE

SB1PY850UM

DIQYAX9MK8

D5OERBY8F5

HIK1AVBPNY

JACXC67YSO

AOFVDE7H21

XYQ8SUYRFS

UCLY8POGXO

EIMLQ3VNOY

6QM3OX61H1

ADLSY03MPL

GMSY1A83R4

BPP6DEM71S

FDVA9P7MO7

A6TXCV6NO1

YEAU11D8MX

H8V59VESPN

HGU48LEJ9A

YF99U83M5O

8OUBQS21F3

HUHH29PFJ6

V18B35NOVL

Y3QVJ83BUC

UUOBYFXJ8J

T2JGP5KNOW

**FACSIMILE LEGIBILITY  
TEST CHART No. OJS (7/28/80)**

**ABCDEFGHIJKLMNOPQRSTUVWXYZ0123456789**

Figure C1. Facsimile legibility test chart OJS.

|            |            |
|------------|------------|
| 1NA7C8TB9D | JJRS2QHSG6 |
| 7CN1P7FKPL | 1R1PFMEU3E |
| XBV4D53TNG | LSKP6SPYD1 |
| 6IEN1ODJCT | AM8ONS29V5 |
| O2GDRIICWV | MU47APQLT9 |
| JLFX0UVM9K | 3QDXR0S1Y1 |
| WD85FD1GJ4 | B7VBSUE37F |
| 6GJQ2YE2NL | 100395LQBC |
| XYWPXY3M6J | Y091CFELGB |
| DE302HY6RM | 5C0UOQIJ21 |
| 5D6PU4D4YD | PPA15LXHVS |
| UFTT1B2Q2S | TU6CNMJES1 |
| VLFHR083WC | I6NBCUR5UU |
| LBXY760AVW | 70MZR5HPJL |
| O5TKB6NOL8 | Y2NQW3F411 |
| 6PCRYXOX8E | PXOSUWFPYJ |
| 57HB3EPVRA | Y1F3DFS8LW |
| IGXK4TYCGM | RTC9EPTVMB |
| HFJFW9BCQF | T6Y158YGRG |
| UODR2YRO88 | BA7FU5QFXE |

# **FACSIMILE LEGIBILITY TEST CHART No. CEW (7/28/80)**

**ABCDEFGHIJKLMNOPQRSTUVWXYZ0123456789**

Figure C2. Facsimile legibility test chart CEW.

EETBU4AY8F  
918OSA2IBN  
BDL72B1T8A  
GLIUDC60V7  
GENFS42IU2  
UHO9OVT4SI  
T2DXFB19XG  
R954UIA300  
OSCST0BC3F  
5A132KG6TJ  
RAUZCJIW73  
D5K1EXF2RP  
VS18NFC6VT  
AAO5WE40II  
V1UP9TE6XY  
Q5SJI7S6XG  
IN47QGA1YL  
H8PYSLFFO1  
BYP8CKSTE2  
PY76B1E41D

FCPPL1Q00A  
L30BS7FALO  
3IFJRKQ5GD  
7DVCJU36C8  
FC2MXX17HJ  
UL8PSNU1NI  
PGH02TIBGO  
S5SCFF2AEK  
FIBSV2HARN  
VFLUITW1X2  
OK2JDH738I  
PC2YJKOT9B  
3JSTBR1YN2  
M7JLY2692N  
VOVX1JLUK0  
SDKPT2CS15  
9QDL1J3SP9  
VA1UB1TXJP  
40JAXF7PCN  
1Z015UC8HC

**FACSIMILE LEGIBILITY  
TEST CHART No. WDB (7/28/80)**

**ABCDEFGHIJKLMNOPQRSTUVWXYZ0123456789**

Figure C3. Facsimile legibility test chart WDB.

## APPENDIX D: NOISE TAPES ANALYSIS

### PURPOSE

This analysis of vhf noise tapes provides guidance to the US delegation to NATO Working Group 2 of Study Group 1 of Committee AC/302. It identifies the similarity between the German and US noise tapes and indicates the effectiveness of the forward error correction technique proposed as part of the interoperability standard. The task was initiated as a result of a US action item at the 8th WG-2 meeting, January 1980.

### BACKGROUND

The NATO working group (WG-2 of SG-1 of AC/302) had its first meeting in April 1978 and has since been writing a standard on facsimile interoperability (STANAG 5000). The major effort has been directed toward agreeing on a data compression technique as part of the In-message procedure. A compression algorithm using modified Huffman codes was considered first because that technique is being adopted internationally by the CCITT. It is very efficient in terms of compression but has poor performance in a noisy environment. Additionally, US, Germany, and UK submitted algorithms for consideration and a compromise algorithm was developed by the working group. After much testing and debate on the merits of each technique, the working group chose the German-proposed algorithm using the CCITT algorithm in conjunction with a Bose-Chaudhuri-Hocquenghem (BCH) code and interleaving to a depth of 5 as the best apparent choice. A summary of the BCH code is given in table D1. The interleaving process is shown in figures D1 and D2 and a block diagram of the proposed technique is included as figure D3, which indicates a choice of communicating in an uncompressed, compressed, or standard mode.

|                             |                                                   |
|-----------------------------|---------------------------------------------------|
| Block length                | 63 bits                                           |
| Information bits            | 51 bits                                           |
| Check bits                  | 12 bits                                           |
| Error correcting capability | 2 bits                                            |
| Redundancy                  | 23.5%                                             |
| Generator polynomial        | $G = X^{12} + X^{10} + X^8 + X^5 + X^4 + X^3 + 1$ |

Table D1. Parameters of the BCH code.

The choice of the particular BCH code and interleaving depth was based, in part, on the nature of the communication channels encountered in Germany. Those vhf channels were proposed as representative of channels that would apply to NATO communication channels; therefore the NATO facsimile interoperability algorithm should operate satisfactorily in that noise environment.

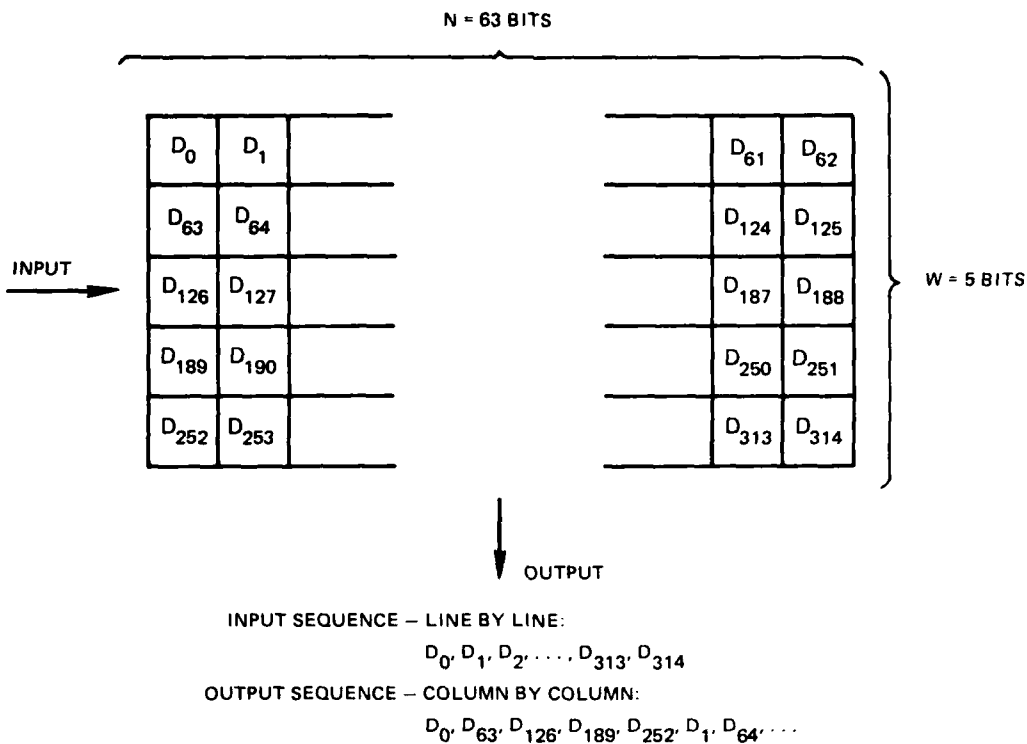


Figure D1. Interleaving buffer at the transmitter.

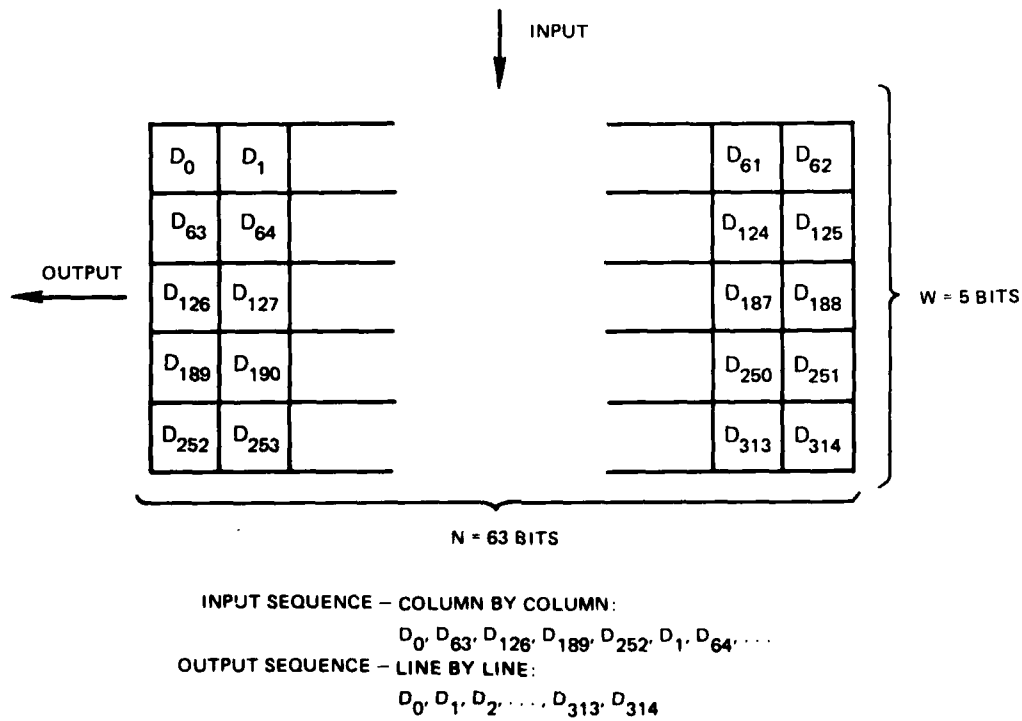
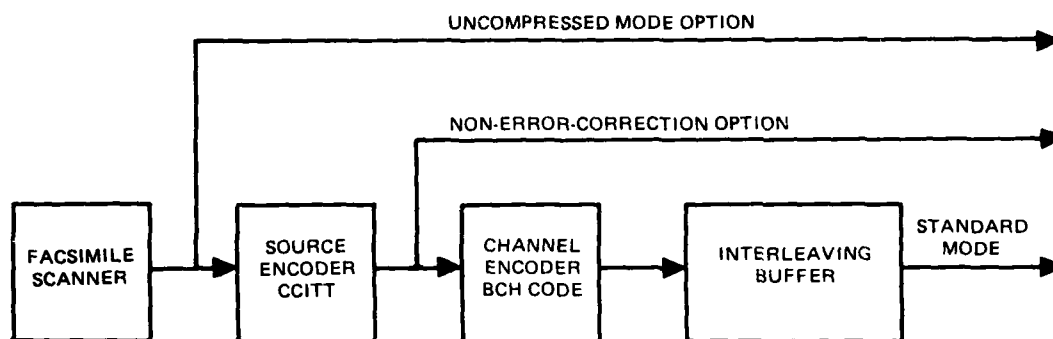
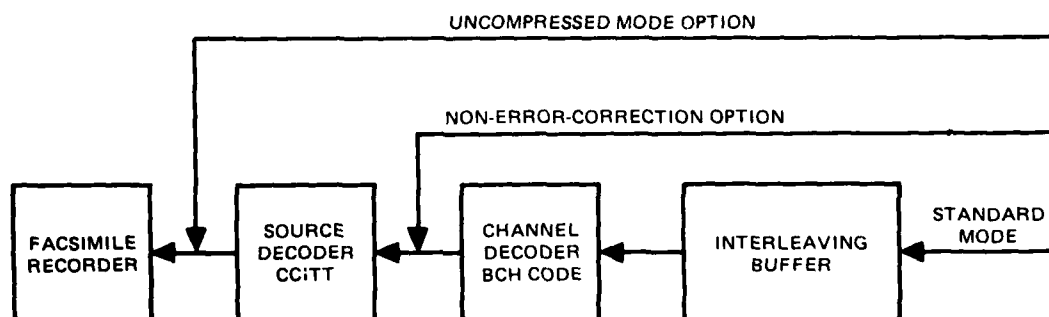


Figure D2. Interleaving buffer at the receiver.



A — TRANSMISSION



B — RECEPTION

Figure D3. Block diagram.

The working group determined that it was necessary to test all the algorithms in one location to remove unwanted variables. The testing took place at Technical University, Hannover (West Germany), and employed a PDP 11 computer. The various data compression algorithms were subjected to the burst model developed by WG-2 and to the German noise tapes representing real existing noise conditions. The resulting copies, representing many bit error rates, algorithms, and several different test charts, were presented at the 7th and 8th WG-2 meetings. Figures D4-D7 represent only a partial sample of the total tests. These results used a portion of the German vhf noise tape file 55. The particular portion used had an average BER of  $3 \times 10^{-3}$ . These charts are supplemented with some NOSC-generated test results to complete the examples.\* The NOSC test results used a single bit error pattern that had a BER of  $2 \times 10^{-3}$ . Other tests indicate that this bit error pattern more closely matches the vhf errors than does the burst model developed for the NATO algorithm tests.

Unfortunately, since Germany and the US treated the lines in error differently, there are some cosmetic differences. Since the process of using or not using lines in error is not an interoperability parameter, it is therefore subject to national prerogative. The German researchers removed any line that was in error and replaced it with all white. If the line was correct up to a point and then corrupted, the valid information was lost as a result of this process. For the particular tests exhibited by figures D8 and D9, the US did not replace lines or remove the objectionable black streaks resulting from errors. As a result of this different process and a lower bit error rate, figure D9 appears to be better than figure D7, when in fact it should appear inferior. Other tests without variables did show the CCITT to exhibit slightly worse readability than the NATO CCITT.

In spite of the variations, it is dramatically evident that the CCITT-BCH/interleaving (fig D4) is significantly better than the others. The transmission times at 2400 bits per second varied from about 116 seconds for the CCITT to about 145 seconds for the CCITT-BCH/interleaving. The exact times vary, depending upon the scanner used and the document tested. The  $3 \times 10^{-3}$  BER for figures D4-D7 (German tests) and the  $2 \times 10^{-3}$  BER for figures D8 and D9 (US tests) are very harsh conditions; but as can be seen by both the German and US noise statistics (see Results), this condition does occur frequently.

## RAMIFICATION

If the German noise condition is realistic, then the only data compression algorithm that has a good chance of performing well most of the time on actual channels is the CCITT-BCH/interleaving technique. Thus the US government had an action item to confirm or repudiate the validity of the German vhf tapes versus US vhf noise sources.

\*These are all the results of computer simulations. In reference to the TDF algorithm simulations, there are deliberate omissions from the algorithm for submission to the NATO group. The cosmetic corrections are not incorporated. The actual TDF hardware under development on the TDF program will provide copy with a different appearance. The noise susceptibility, however, will be the same. Therefore, the simulations and evaluations for NATO are valid.

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ANNEX I  
TEST SHEET  
AC/302 (SG-1) WG-2

TRI-SERVICE GROUP ON COMMUNICATIONS AND ELECTRONIC EQUIPMENT

SUB-GROUP ON TACTICAL AREA COMMUNICATIONS

WORKING GROUP ON TACTICAL AREA COMMUNICATIONS

FACSIMILE TEST SHEET

1. This typewritten sheet is accepted by the members as one of the official test sheets to be used for the trial runs.
2. In order to couple the output of a radio transmitter to space or to couple the input of a receiver to space, it is necessary in each case to use some type of structure capable of radiating electromagnetic waves or receiving them, as the case may be. An antenna is such a structure and may be described as a metallic object, often a wire or a collection of wires, used to convert high-frequency current into electromagnetic waves.
3. The mechanism of radiation may be explained quantitatively by means of Maxwell's equations. Upon examining the behavior of the RF current in a wire, it is found that not all of the energy at one end finds its way to the other; some is radiated. See Fig 11.1. The transmission line theory will be used.
4. If the open-circuited transmission line of Fig 11.2 is considered, it is seen that the forward and reverse travelling waves combine to form a standing-wave pattern on the line. This has already been discussed (in Chap. 8, 9, and 10), but it was not mentioned at the time that only part of the forward energy is reflected by the open circuit; it will be shown (in Chap. 13, 14, 15 and 16) that a small portion of the electromagnetic energy escapes from the system and is radiated.
5. The various characteristics of antennas are not normally quoted as absolute figures, but rather in comparison to those of "standard" antennas. The latter are theoretical simplifications, which need not necessarily exist in practice but which have properties that are easy to visualize and calculate. One such reference antenna is the infinitesimal dipole; another reference antenna is the elementary doublet.
6. The radiation field is not the only field surrounding the elementary doublet, or any other antenna, for that matter. Magnetic and electric fields exist also and are collectively referred to as the induction field. Such a field surrounds any current-carrying wire and, in fact, is stronger than the radiating field in the immediate vicinity of the radiator. However, the induction field diminishes very rapidly with distance from the doublet and becomes insignificant a few wavelengths away. The importance of the induction field lies not in its ability to convey information over long distances, but in the fact that if antennas are placed in close proximity, the interference effects caused by the induction field must be taken into account.

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Figure D4. CCITT-BCH/interleaving.

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ANNEA 1  
TEST SHEET  
AC/302 (SG-1)-WC-2

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SUB-GROUP ON TACTICAL AREA COMMUNICATIONS

WORKING GROUP ON TACTICAL AREA COMMUNICATIONS

FACSIMILE TEST SHEET

1. This typewritten sheet is accepted by the members as one of the official test sheets to be used for the trial runs.
2. In order to couple the output of a radio transmitter to space or to couple the input of a receiver to space, it is necessary in each case to use some type of structure capable of radiating electromagnetic waves or receiving them, as the case may be. An antenna is such a structure and may be described as a metallic object, often a wire or a collection of wires, used to convert high-frequency current into electromagnetic waves.
3. The mechanism of radiation may be explained quantitatively by means of Maxwell's equations. Upon examining the behavior of the RF current in a wire, it is found that not all of the energy at one end finds its way to the other; some is radiated. See Fig 11.1. The transmission-line theory will be used.
4. If the open-circuited transmission line of Fig 11.2 is considered, it is seen that the forward and reverse traveling waves combine to form a standing-wave pattern on the line. This has already been discussed (in Chap. 8, 9, and 10), but it was not mentioned at the time that only part of the forward energy is reflected by the open circuit; it will be shown (in Chap. 13, 14, 15 and 16) that a small portion of the electromagnetic energy escapes from the system and is radiated.
5. The various characteristics of antennas are not normally quoted as absolute figures, but rather in comparison to those of "standard" antennas. The latter are theoretical simplifications, which need not necessarily exist in practice but which have properties that are easy to visualize and calculate. One such reference antenna is the infinitesimal dipole; another reference antenna is the elementary doublet.
6. The radiation field is not the only field surrounding the elementary doublet, or any other antenna, for that matter. Magnetic and electric fields exist also and are collectively referred to as the induction field. Such a field surrounds any current-carrying wire and, in fact, is stronger than the radiating field in the immediate vicinity of the radiator. However, the induction field diminishes very rapidly with distance from the doublet and becomes insignificant a few wavelengths away. The importance of the induction field lies not in its ability to convey information over long distances, but in the fact that if antennas are placed in close proximity, the inductive effects caused by the induction fields must be taken into account.

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Figure D5. Muirhead (UK).

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ANNEX 1  
TEST SHEET  
AC/302 (SC-1) WG-2

TRI-SERVICE GROUP ON COMMUNICATIONS AND ELECTRONIC EQUIPMENT

SUB-GROUP ON TACTICAL AREA COMMUNICATIONS

WORKING GROUP ON TACTICAL AREA COMMUNICATIONS

FACSIMILE TEST SHEET

1. This typewritten sheet is accepted by the members as one of the official test sheets to be used for the trial runs.
2. In order to couple the output of a radio transmitter to space or to couple the input of a receiver to space, it is necessary in each case to use some type of structure capable of radiating electromagnetic waves or receiving them, as the case may be. An antenna is such a structure and may be described as a metallic object, often a wire or a collection of wires, used to convert high frequency current into electromagnetic waves.
3. The mechanism of radiation may be explained qualitatively by means of Maxwell's equations. Upon calculating the behavior of the EM current in a wire, it is found that not all of the energy at one end finds its way to the other; some is radiated. See Fig 11.1. The transmission line theory will be used.
4. If the open circuited transmission line of Fig 11.1 is considered, it is found that the forward and reverse travelling waves combine to form a standing-wave pattern on the line. This has already been discussed (in Chap. 8, 9, and 10), but it was not mentioned at the time that only part of the forward energy is reflected by the open circuit; it will be shown (in Chap. 13, 14, 15 and 16) that a small portion of the electromagnetic energy escapes from the system and is radiated.
5. The various characteristics of antennas are not normally quoted as absolute figures, but rather in comparison to those of "standard" antennas. The latter are theoretical simplifications, which need not necessarily exist in practice but which have properties that are easy to calculate and compare. One such reference antenna is the infinitesimal dipole; another reference antenna is the elementary doublet.
6. The radiation field is not the only field surrounding the elementary doublet, or any other antenna, for that matter. Magnetic and electric fields exist and are collectively referred to as the induction field. Such a field surrounds any current-carrying wire and, in fact, is stronger than the radiating field in the immediate vicinity of the radiator. However, the induction field diminishes very rapidly with distance from the doublet and becomes insignificant a few wavelengths away. The importance of the induction field lies not in its ability to convey information over long distances, but in the fact that if antennas are placed in close proximity, the interference effects caused by the induction field must be taken into account.

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Figure D6. NOSC modified TDF (single line).

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ANNEX I  
TEST SHEET  
AC/302 (SC-1) WC-2

TRI-SERVICE GROUP ON COMMUNICATIONS AND ELECTRONIC EQUIPMENT

SUB GROUP ON TACTICAL AREA COMMUNICATIONS

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FACSIMILE TEST SHEET

1. This specification sheet is accepted by the members as one of the official test sheets to be used for the trial runs.
2. In order to couple the output of a radio transmitter to space or to a wire or cable, it is necessary to use a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves. This device is called an antenna. It is a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves. It is a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves. It is a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves.
3. The antenna is a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves. It is a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves. It is a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves. It is a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves.
4. If the open circuit transmission line of Fig 11.2 is considered, it is seen that the forward and reverse traveling waves combine to form a standing wave pattern on the line. This has already been discussed (in Chap. 9, 10, and 11), but it was not mentioned at the time that only part of the forward energy is reflected by the open circuit; it will be shown (in Chap. 12, 13, 14 and 15) that a small portion of the electromagnetic energy escapes from the system and is radiated.
5. The antenna is a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves. It is a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves. It is a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves. It is a device which is capable of converting the electrical energy of the transmitter into electromagnetic waves.
6. The radiation field is the field surrounding the antenna, and it is the field which is responsible for the radiation of electromagnetic waves. It is a field which is capable of converting the electrical energy of the transmitter into electromagnetic waves. It is a field which is capable of converting the electrical energy of the transmitter into electromagnetic waves. It is a field which is capable of converting the electrical energy of the transmitter into electromagnetic waves. It is a field which is capable of converting the electrical energy of the transmitter into electromagnetic waves.

NATO UNCLASSIFIED

Figure D7. NATO modified CCITT.

THE SERVICE GROUP ON ELECTRONIC WARFARE AND ELECTRONIC EQUIPMENTSUB-GROUP ON ELECTRONIC WARFARE COMMUNICATIONSWORKING GROUP ON ELECTRONIC WARFARE COMMUNICATIONSPACIFIED TEST SHEET

1. This type of test sheet is to be used for the trial runs of the test sheets to be used for the trial runs.
2. In order to couple the output of a radio transmitter to space or to couple the input of a receiver to space, it is necessary to use each case to use some type of structure capable of radiating or receiving electromagnetic waves or converting them, as the case may be. An antenna is such a structure and may be described as a mechanical system, often a wire or a collection of wires, used to convert high-frequency currents into electromagnetic waves.
3. The mechanism of radiation may be explained qualitatively by means of Maxwell's equations. When transmitting, the alternating electric field, it is found that the electric field of the antenna and finds its way to the other, some distance away. See Fig 12.1. The transmission line theory will be used.
4. If the open-circuited transmission line of a dipole is considered, it is found that the forward and backward traveling waves tend to form a standing wave pattern on the line. This has already been discussed (in Chap. 9, 9.2 and 10). It was also mentioned at the time that only part of the forward energy is reflected back, as will be shown in Chap. 15 and 16 that a small portion of the electromagnetic energy escapes from the system and is radiated.
5. The various characteristics of antennas can be generally quoted as various figures, but rather in comparison to the "standard" antennas. The latter are theoretical simplifications, which need not necessarily exist in practice but which have properties that can be calculated and calculated. The such reference antennas should be defined as follows: the reference antenna is the elementary dipole.
6. The radiation field is not the only field surrounding the elementary dipole, as any other antenna, or other matter. Magnetic and electric fields exist also and are collectively referred to as the induction field. Such a field surrounds any current-carrying wire and, in fact, is stronger than the radiating field in the immediate vicinity of the radiator. However, the induction field diminishes rapidly with distance from the dipole and becomes insignificant as the distance goes away. The importance of the induction field lies not in its ability to convey information over long distances but in the fact that if antennas are placed in close proximity, interference effects must be taken into account.

ANNEX I  
TEST SHEET  
AC/302 (S2-1) AC-1

**FACSIMILE TEST SHEET**

1. This typewritten sheet is accepted by the committee as not being an official test sheet to be used for the trial run.
2. In order to couple the output of a rectifier circuit to a load, it is necessary to couple the input of a resonant circuit to the output of the rectifier. To use some type of resonant circuit for coupling is equivalent to using a transformer or receiving them, as the case may be, as transformers and the resonant circuit may be described as a magnetic object, which will be used to convert high-frequency current into electromagnetic waves.
3. The mechanism of radiation may be explained quantitatively by means of Maxwell's equations. Upon examining the operation of the antenna circuit in a wire, it is found that not all of the energy is radiated in its way to the other; some is reflected. The only way to explain this line theory will be to use the following:
4. If the open-circuited transmission line of light is considered, it is seen that the forward and reverse waves are standing waves. Chap. 8, 9, and 10, but it was not mentioned at the time that the forward energy is reflected by the open circuit; it will be shown (Chap. 13, 14, 15 and 16) that a wave is reflected and it will be shown that it escapes from the system and is radiated.
5. The various characteristics of antennas are not normally given as absolute figures, but rather in comparison to those of a standard antenna. The latter are theoretical simplifications, which are not necessarily exact. In practice, however, which have properties that are not necessarily exact. One such reference antenna is the half-wave dipole antenna, which is the elementary antenna.
6. The radiation field is not the only field surrounding the antenna; a doublet, or any other antenna, for that matter, magnetic and electric fields exist also and are referred to as the induction field. Both the field and the current-carrying wire are used, as shown in the diagram, to radiate the field in the immediate vicinity of the antenna. However, the induction field distribution, very rapidly, with distance from the antenna, becomes insignificant a few wavelengths away from the antenna. The field lies not in its ability to convey information, but in the fact that it antennas are placed in close proximity, the effects caused by the induction field must be taken into account.

**NATO UNCLASSIFIED**

**Figure D9. CCITT.**

## APPROACHES CONSIDERED

The BCH/interleaving is proposed as an add-on to the CCITT data compression algorithm, to make up a complete package of data compression with error protection. While the effects of inserted errors on the CCITT data compression algorithm have been determined, the effectiveness of reducing the errors by using BCH/interleaving has not been fully determined for other noise sources. The effectiveness of the BCH/interleaving technique is a function of the nature of the noise and its distribution. Several approaches were possible to determine the effectiveness for other noise sources.

Perhaps the best approach is analyzing the effectiveness of this technique against various noise environments would be to construct a breadboard system of the CCITT-BCH/interleaving, subject it to the various noise signals, and compare its performance to other techniques tested in the same manner. In the time frame of concern, this approach was not possible.

A second approach would be to simulate the CCITT-BCH/interleaving on the computer, subject it to the noise, and compare actual copies. This approach would be more attractive because the noise is in computer tape format; NOSC already has simulated some of the other algorithms and can produce copy available for comparison. This would still require months of programming effort to achieve the BCH/interleaving simulation more time than is available to meet the needs of the US on its decision to the working group.

The third approach was the most appropriate, because of the following rationale. Several processing techniques were written for the computer at NOSC during the noise tapes evaluation that occurred between the 7th and 8th WG-2 meetings. The processing algorithms operated on the raw noise data and generated statistics of each file. Parameters such as bit error rate, burst error rate, average burst length, etc were compiled for each run. Additionally, two other algorithms were developed to measure the effectiveness of the BCH/interleaving. These algorithms were already implemented at the time of the 8th meeting, when it was decided that the US would compare US noise tapes to those furnished by the West German government. The West Germans had already demonstrated the effectiveness of the BCH/interleaving on actual test documents by simulating the BCH/interleaving process and subjecting the encoded data stream to selected portions of the noise tapes, as shown earlier. The US further analyzed the West German tapes and found that all the noise appeared to be similar to the selected portions (for a given BER).

This third approach meant that if the US analysis of the US noise tapes showed them to be similar to the West German noise tapes, then the BCH/interleaving process would quite likely be effective against the US noise environment. This approach was undertaken and completed. The next section describes the processes used.

## DATA PROCESSING

### Statistics Generation and Parameters Computed

Both the West German and US tapes have the noise data in a run length format. In other words, the spaces between noise bits is encoded to give the length of the spaces. In this way, the raw data representing many thousands of bits may be compressed and stored more conveniently without losing information. The exact format of each noise source – US and West German – was different, but the principle was the same. A burst of noise was defined to be any noise bits (1 = noise error, 0 = non-error) that are separated by nine or fewer 0s. If there are ten or more 0s between two error bits, then the noise bits are not of the same burst. This arbitrary definition was defined initially by the West Germans.

Under this assumed definition, the number of bursts per noise file was determined from the raw data. Additionally, the burst error rate (number of bursts divided by the total number of bits), the average burst length, and the average number of errors per burst were tallied. At the same time a histogram of the error data was created to provide a detailed view of the error structure.

As an initial check, the results obtained at NOSC on the West German data were compared with statistics furnished by the Technical University, Hannover (West Germany). Complete agreement existed prior to proceeding with all files. In an equivalent test on the US tapes, some portions of the US noise statistics were compared with Ft Monmouth data to confirm correct tape reading.

### BCH/Interleaving Effectiveness

To grasp the principle of this concept, first imagine the BCH encoder and decoder in effect without the interleaving process. Compressed data (actually any data) are encoded into the 63-bit blocks and sent over the communication channel, where noise is injected. From the nature of this BCH code, one or two errors within a 63-bit block can be corrected, and the decoded data are further decoded, without errors, by the compression algorithm. Alternately, with an exact record of the error pattern or noise, the noise data can be grouped into consecutive 63-bit blocks; any time one or two errors occur within a 63-bit block, the block can be considered as a correctable error pattern. For each noise file, a histogram can be tabulated that shows the number of times 0 to 63 errors occur in a block. Various computations can then be made, including a calculation of the percentage of 1- and 2-bit error/block occurrences out of all blocks in error. This will give a percentage of improvement obtained by using the BCH code versus no code\*. Note that all of this computation is operating on the *noise* data, with knowledge of the error-correcting algorithm.

For the inclusion of interleaving, the process is repeated and expanded by grouping the noise data into 315-bit blocks, then dividing the 315 bits into 63-bit blocks by using the interleaving sequence depth of 5. Only a long burst (greater than 10 bits) will possibly

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\*The effect of a fewer number of required bits if no BCH coding is used is secondary and would be ignored.

create more than two errors in a decodable BCH block. This concept was implemented with the noise tapes and histograms were made for each noise file. Calculations were made for each file.

An additional algorithm was implemented to measure the distribution of the burst effects on the decoded data. A tally in the form of another histogram was made of consecutive blocks with three or more errors. If a fixed number of errors is assumed per transmission in facsimile, it is desirable to have the errors grouped. If an error occurs in a line of encoded facsimile data, the balance of that line will not be decoded properly and errors immediately following the first will create no further significant loss of information. Thus, if the errors occurred such that consecutive 63-bit blocks rather than isolated single blocks were in error, the effect would be less damaging. This algorithm did not serve as a direct measure of the effectiveness of the BCH/interleaving technique. The results were examined but not included in a numerical tally. Generally, the data did not bunch except where the noise was excessive and the burst lengths were extremely long.

#### **Organization of the Noise Data for Tabulation**

**West German Noise Data.** The West German noise data were contained on one computer tape consisting of 17 files. The first nine files represented data taken at 2.4 kb/s; the last eight files, data taken at 15 kb/s. Each file represented a transmission measurement of about 5 minutes. Therefore, many more data bits were included for the 15-kb/s files. The equal time for each file made the analysis easier, since each file was given equal weight in the resultant tabulation.

**US Noise Data.** The US noise data were contained on three computer tapes consisting of 30 files, at a mix of 1.2 and 19.2 kb/s. The noise data files represented a range of transmission times, from 0.9 to 30 minutes, with many files representing 5 minutes. The 0.9-minute file was excluded, as were other files that had conditions not applicable to the comparisons. Furthermore, one of the tapes was faulty and could not be read completely. The long transmissions were divided into equal subfiles of about 5 minutes each.

The results of all this exclusion and division gave nineteen 19.2-kb/s transmissions and thirty-six 1.2-kb/s transmissions. Some "30-minute" files were actually closer to 35 minutes; consequently the last slice came closer to 10 minutes than to the intended 5 minutes. These were not rerun but simply were noted on the tabulation sheet.

## RESULTS

Table D2 summarizes the analysis of the West German noise tape, and table D3 does the same for the US tapes.

Explanation of each entry:

Column 1 – file number. The number in parentheses denotes a subfile for analysis.

Column 2 – data rate of channel for noise data. Key: 1 = 1.2 kb/s, 1A = 2.4 kb/s, 2 = 19.2 kb/s, and 2A = 15 kb/s.

(Note: Columns 3–7 are derived from the statistics algorithm.)

Column 3 – the total number of bursts for the file or subfile. Bursts are defined in the previous section.

Column 4 – the average burst length. The average length of a burst in this file or subfile. A burst length is defined as the number of error and non-error bits that occur within the defined burst.

Column 5 – burst error rate. The total number of bursts divided by the total number of bits in that file or subfile, expressed in a probability format. The first one,  $1.5 \times 10^{-3}$ , means that out of every 1000 bits, it is probable that 1.5 bursts will occur.

Column 6 – bit error rate. The total number of error bits divided by the total number of bits. With an error structure such that each burst is exactly one bit long, the burst error rate equals the bit error rate.

Column 7 – average error per burst. The number of error bits on the average, per burst.

(Note: Columns 8–10 are derived from the BCH/interleaving effectiveness algorithm.)

Column 8 – percent errorfree 63-bit blocks. The number of 63-bit blocks free from any error bits prior to any correction.

Column 9 – percent errorfree blocks after correction. Includes blocks that had only one or two errors—and thus were correctable—plus the errorfree blocks.

Column 10 – percent improvement. Indicates the improvement between columns 8 and 9. If column 8 indicates 100% for a given file number, there can be no improvement and column 10 must be 0%.

| File Number | Data Rate | Number of Bursts | Avg Burst Length | Burst Error Rate     | Bit Error Rate       | Avg Error per Burst | Percent Errorfree (before) | Percent Errorfree (after) | Percent Improvement |
|-------------|-----------|------------------|------------------|----------------------|----------------------|---------------------|----------------------------|---------------------------|---------------------|
| 45          | 1A        | 2 465            | 5.6              | $2.6 \times 10^{-3}$ | $8.4 \times 10^{-3}$ | 3.2                 | 72.0                       | 95.0                      | 84.0                |
| 46          | 1A        | 1 768            | 4.5              | $1.9 \times 10^{-3}$ | $5.6 \times 10^{-3}$ | 2.9                 | 84.0                       | 95.0                      | 66.0                |
| 47          | 1A        | 219              | 4.6              | $2.3 \times 10^{-4}$ | $6.0 \times 10^{-4}$ | 2.5                 | 98.0                       | 99.7                      | 90.3                |
| 48          | 1A        | 43               | 2.8              | $4.3 \times 10^{-4}$ | $8.0 \times 10^{-5}$ | 1.8                 | 99.5                       | 100.0                     | 100.0               |
| 49          | 1A        | 79               | 2.6              | $8.5 \times 10^{-5}$ | $1.5 \times 10^{-4}$ | 1.8                 | 99.0                       | 100.0                     | 100.0               |
| 50          | 1A        | 35               | 3.6              | $3.6 \times 10^{-5}$ | $8.2 \times 10^{-5}$ | 2.2                 | 99.4                       | 100.0                     | 100.0               |
| 51          | 1A        | 12               | 2.9              | $1.2 \times 10^{-5}$ | $2.4 \times 10^{-5}$ | 2.0                 | 99.8                       | 100.0                     | 100.0               |
| 52          | 1A        | 12               | 2.7              | $1.2 \times 10^{-5}$ | $2.4 \times 10^{-5}$ | 2.0                 | 99.8                       | 100.0                     | 100.0               |
| 53          | 1A        | 10               | 2.5              | $1.0 \times 10^{-5}$ | $1.7 \times 10^{-5}$ | 1.7                 | 99.8                       | 100.0                     | 100.0               |
| 54          | 2A        | 5 075            | 1.3              | $1.0 \times 10^{-3}$ | $1.2 \times 10^{-3}$ | 1.1                 | 92.5                       | 99.9                      | 99.7                |
| 55          | 2A        | 10 044           | 1.3              | $2.1 \times 10^{-3}$ | $2.2 \times 10^{-3}$ | 1.1                 | 87.2                       | 99.8                      | 98.5                |
| 56          | 2A        | 29 342           | 1.6              | $6.1 \times 10^{-3}$ | $2.4 \times 10^{-3}$ | 1.2                 | 70.9                       | 95.7                      | 85.2                |
| 57          | 2A        | 24 760           | 2.8              | $5.2 \times 10^{-3}$ | $8.9 \times 10^{-3}$ | 1.7                 | 64.1                       | 96.2                      | 89.4                |
| 58          | 2A        | 554              | 1.1              | $1.1 \times 10^{-4}$ | $1.2 \times 10^{-4}$ | 1.1                 | 99.2                       | 99.9                      | 99.6                |
| 59          | 2A        | 175              | 4.1              | $3.6 \times 10^{-5}$ | $9.0 \times 10^{-5}$ | 2.5                 | 99.5                       | 99.9                      | 91.7                |
| 60          | 2A        | 42               | 1.1              | $8.5 \times 10^{-6}$ | $9.1 \times 10^{-6}$ | 1.1                 | 99.9                       | 100.0                     | 100.0               |
| 61          | 2A        | 14               | 1.4              | $2.9 \times 10^{-6}$ | $4.0 \times 10^{-6}$ | 1.4                 | 99.9                       | 100.0                     | 100.0               |

Table D2. West German data.

| File Number | Data Rate | Number of Bursts | Avg Burst Length | Burst Error Rate     | Bit Error Rate       | Avg Error per Burst | Percent Errorfree (before) | Percent Errorfree (after) | Percent Improvement |
|-------------|-----------|------------------|------------------|----------------------|----------------------|---------------------|----------------------------|---------------------------|---------------------|
| 209V501 (1) | 2         | 8 721            | 4.1              | $1.5 \times 10^{-3}$ | $2.7 \times 10^{-3}$ | 1.8                 | 92.3                       | 98.5                      | 81.0                |
| (2)         | 2         | 5 418            | 1.4              | $9.4 \times 10^{-4}$ | $1.0 \times 10^{-3}$ | 1.0                 | 94.3                       | 99.8                      | 98.0                |
| (3)         | 2         | 3 213            | 1.2              | $5.5 \times 10^{-4}$ | $5.8 \times 10^{-4}$ | 1.0                 | 96.4                       | 99.9                      | 99.9                |
| (4)         | 2         | 3 500            | 1.2              | $6.0 \times 10^{-4}$ | $6.3 \times 10^{-4}$ | 1.0                 | 96.2                       | 99.9                      | 99.5                |
| (5)         | 2         | 3 330            | 1.2              | $5.7 \times 10^{-4}$ | $6.2 \times 10^{-4}$ | 1.1                 | 96.2                       | 99.9                      | 99.5                |
| (6)         | 2         | 15 393           | 9.3              | $2.6 \times 10^{-3}$ | $9.5 \times 10^{-3}$ | 3.6                 | 86.0                       | 95.0                      | 67.0                |
| 209V502 (1) | 2         | 386              | 10.8             | $1.1 \times 10^{-3}$ | $4.3 \times 10^{-3}$ | 4.1                 | 92.8                       | 96.6                      | 53.0                |
| (2)         | 2         | 469              | 8.3              | $1.3 \times 10^{-3}$ | $4.3 \times 10^{-3}$ | 3.3                 | 91.3                       | 96.4                      | 58.0                |
| (3)         | 2         | 362              | 10.5             | $1.0 \times 10^{-3}$ | $4.1 \times 10^{-3}$ | 4.1                 | 93.1                       | 96.6                      | 51.0                |
| (4)         | 2         | 425              | 11.8             | $1.1 \times 10^{-3}$ | $5.5 \times 10^{-3}$ | 4.7                 | 91.8                       | 95.8                      | 48.0                |
| (5)         | 2         | 617              | 11.8             | $1.7 \times 10^{-3}$ | $7.4 \times 10^{-3}$ | 4.3                 | 89.8                       | 94.1                      | 42.0                |
| (6)         | 2         | 322              | 10.2             | $8.9 \times 10^{-4}$ | $3.5 \times 10^{-3}$ | 4.1                 | 94.1                       | 97.6                      | 60.0                |
| 208V005 (1) | 1         | 97               | 1.0              | $2.6 \times 10^{-4}$ | $2.8 \times 10^{-4}$ | 1.0                 | 98.0                       | 100.0                     | 100.0               |
| (2)         | 1         | 618              | 9.1              | $1.7 \times 10^{-4}$ | $7.1 \times 10^{-3}$ | 4.1                 | 84.0                       | 94.6                      | 65.0                |
| (3)         | 1         | 120              | 1.0              | $3.3 \times 10^{-4}$ | $3.4 \times 10^{-4}$ | 1.0                 | 98.0                       | 100.0                     | 100.0               |
| (4)         | 1         | 120              | 1.1              | $3.3 \times 10^{-4}$ | $3.5 \times 10^{-4}$ | 1.0                 | 98.0                       | 100.0                     | 100.0               |
| (5)         | 1         | 99               | 1.0              | $2.7 \times 10^{-4}$ | $2.9 \times 10^{-4}$ | 1.0                 | 98.0                       | 100.0                     | 100.0               |
| (6)*        | 1         | 280              | 1.0              | $2.9 \times 10^{-4}$ | $3.0 \times 10^{-4}$ | 1.0                 | 98.0                       | 100.0                     | 100.0               |
| 208V006 (1) | 1         | 747              | 7.1              | $2.0 \times 10^{-3}$ | $5.8 \times 10^{-3}$ | 2.8                 | 85.0                       | 97.0                      | 79.0                |
| (2)         | 1         | 28               | 1.1              | $7.7 \times 10^{-5}$ | $8.3 \times 10^{-5}$ | 1.0                 | 99.5                       | 100.0                     | 100.0               |
| (3)         | 1         | 37               | 1.0              | $1.0 \times 10^{-4}$ | $1.0 \times 10^{-4}$ | 1.0                 | 99.3                       | 100.0                     | 100.0               |
| (4)         | 1         | 206              | 2.1              | $5.7 \times 10^{-4}$ | $7.4 \times 10^{-4}$ | 2.1                 | 96.7                       | 99.6                      | 90.2                |
| (5)         | 1         | 46               | 1.0              | $1.2 \times 10^{-4}$ | $1.3 \times 10^{-4}$ | 1.0                 | 99.1                       | 100.0                     | 100.0               |
| (6)*        | 1         | 206              | 1.7              | $2.1 \times 10^{-4}$ | $2.5 \times 10^{-4}$ | 1.2                 | 98.7                       | 99.9                      | 95.0                |
| 208V007 (1) | 2         | 20 241           | 3.3              | $4.3 \times 10^{-3}$ | $6.2 \times 10^{-3}$ | 3.3                 | 80.0                       | 95.0                      | 77.0                |
| 208V008 (1) | 1         | 746              | 4.6              | $2.0 \times 10^{-3}$ | $6.5 \times 10^{-3}$ | 3.1                 | 71.9                       | 97.5                      | 91.9                |
| (2)         | 1         | 627              | 4.8              | $1.7 \times 10^{-3}$ | $5.7 \times 10^{-3}$ | 3.2                 | 74.6                       | 98.6                      | 95.0                |
| 208V009 (1) | 1         | 31               | 1.0              | $8.6 \times 10^{-5}$ | $8.6 \times 10^{-5}$ | 1.0                 | 99.5                       | 100.0                     | 100.0               |
| (2)         | 1         | 23               | 9.7              | $6.3 \times 10^{-5}$ | $2.8 \times 10^{-4}$ | 4.4                 | 98.9                       | 99.8                      | 81.3                |
| (3)         | 1         | 12               | 15.0             | $3.3 \times 10^{-5}$ | $2.0 \times 10^{-4}$ | 6.0                 | 99.5                       | 99.8                      | 70.0                |
| (4)         | 1         | 0                | 0.0              | 0.0                  | 0.0                  | 0.0                 | 100.0                      | 100.0                     | 0.0                 |

\*13-minute subfile

Table D3. US data.

| File Number | Data Rate | Number of Bursts                                             | Avg Burst Length | Burst Error Rate     | Bit Error Rate       | Avg Error per Burst | Percent Errorfree (before) | Percent Errorfree (after) | Percent Improvement |
|-------------|-----------|--------------------------------------------------------------|------------------|----------------------|----------------------|---------------------|----------------------------|---------------------------|---------------------|
| 208V010 (1) | 1         | 0                                                            | 0.0              | 0.0                  | 0.0                  | 0.0                 | 100.0                      | 100.0                     | 0.0                 |
| (2)         | 1         | 0                                                            | 0.0              | 0.0                  | 0.0                  | 0.0                 | 100.0                      | 100.0                     | 0.0                 |
| (3)         | 1         | 0                                                            | 0.0              | 0.0                  | 0.0                  | 0.0                 | 100.0                      | 100.0                     | 0.0                 |
| (4)         | 1         | 0                                                            | 0.0              | 0.0                  | 0.0                  | 0.0                 | 100.0                      | 100.0                     | 0.0                 |
| (5)         | 1         | Not computed - small number of errors at end of transmission |                  |                      |                      |                     |                            |                           |                     |
| 208V011 (1) | 2         | 2 520                                                        | 1.0              | $4.3 \times 10^{-4}$ | $4.4 \times 10^{-4}$ | 1.0                 | 97.2                       | 100.0                     | 100.0               |
| (2)         | 2         | 3 549                                                        | 1.1              | $6.1 \times 10^{-4}$ | $6.3 \times 10^{-4}$ | 1.0                 | 96.1                       | 99.9                      | 99.6                |
| (3)         | 2         | 3 112                                                        | 1.0              | $5.4 \times 10^{-4}$ | $5.4 \times 10^{-4}$ | 1.0                 | 96.6                       | 99.9                      | 99.8                |
| (4)         | 2         | 4 413                                                        | 1.1              | $7.3 \times 10^{-4}$ | $7.5 \times 10^{-4}$ | 1.0                 | 95.3                       | 100.0                     | 100.0               |
| 208V012 (1) | 2         | 8 955                                                        | 1.9              | $1.5 \times 10^{-3}$ | $1.8 \times 10^{-3}$ | 1.2                 | 91.1                       | 99.4                      | 91.4                |
| 000V001     | 1         | 30                                                           | 1.0              | $8.7 \times 10^{-5}$ | $9.3 \times 10^{-5}$ | 1.0                 | 92.0                       | 99.0                      | 92.0                |
| 000V002     | 1         | 108                                                          | 1.1              | $3.1 \times 10^{-4}$ | $3.4 \times 10^{-4}$ | 1.0                 | 98.0                       | 99.9                      | 98.0                |
| 000V003     | 1         | 1 329                                                        | 1.6              | $3.8 \times 10^{-3}$ | $4.3 \times 10^{-3}$ | 1.1                 | 81.0                       | 98.0                      | 93.0                |
| 000V004     | 1         | 1 077                                                        | 2.0              | $3.1 \times 10^{-3}$ | $3.8 \times 10^{-3}$ | 1.2                 | 82.0                       | 99.0                      | 93.0                |
| 000V005     | 1         | 50                                                           | 1.2              | $1.4 \times 10^{-4}$ | $1.5 \times 10^{-4}$ | 1.0                 | 99.3                       | 99.9                      | 87.0                |
| 000V006     | 1         | 43                                                           | 3.0              | $1.2 \times 10^{-4}$ | $1.6 \times 10^{-4}$ | 1.3                 | 99.1                       | 99.9                      | 93.0                |
| 000V007     | 1         | 58                                                           | 1.4              | $1.6 \times 10^{-4}$ | $1.8 \times 10^{-4}$ | 1.1                 | 99.1                       | 99.9                      | 93.0                |
| 000V008     | 1         | 20                                                           | 1.5              | $5.7 \times 10^{-5}$ | $6.0 \times 10^{-5}$ | 1.1                 | 99.7                       | 100.0                     | 100.0               |
| 000V009     | 1         | 21                                                           | 4.9              | $5.0 \times 10^{-5}$ | $9.1 \times 10^{-5}$ | 1.8                 | 99.7                       | 99.9                      | 78.0                |
| 000V010     | 1         | 1 139                                                        | 1.5              | $2.6 \times 10^{-3}$ | $3.1 \times 10^{-3}$ | 1.2                 | 83.0                       | 99.5                      | 97.0                |
| 000V011     | 1         | 3 343                                                        | 2.7              | $7.6 \times 10^{-3}$ | $1.1 \times 10^{-2}$ | 1.5                 | 57.9                       | 92.8                      | 83.0                |
| 000V012     | 1         | 54                                                           | 9.4              | $1.6 \times 10^{-4}$ | $6.5 \times 10^{-4}$ | 3.9                 | 98.9                       | 99.4                      | 45.0                |
| 000V013     | 1         | 53                                                           | 13.6             | $1.7 \times 10^{-4}$ | $1.0 \times 10^{-3}$ | 5.9                 | 98.1                       | 99.5                      | 76.0                |

Table D3 (Continued).

## CONCLUSIONS

The most noticeable difference between the West German noise data and that of the US is the variation. The former varied in bit error rates but hardly varied in average burst length. Within one file (208V009), the average burst length varied from 0 to 15 within one transmission or between transmissions that were within minutes of each other. Other less dramatic examples exist in the US data. Perhaps this variation is the result of the noise-gathering method. The West German government report that gave an overview of the noise-gathering program included the conditions of the various tests. It suggested in general terms that no effort was made to find either extreme cases of noise or quiet or non-noise conditions. Apparently they tried to simulate the various conditions that the military might operate in, on the average, and gathered the noise in the process.

While no report was available for the US noise conditions, discussions with Ft Monmouth indicated that the US might have been looking for some hostile environments for their noise gathering. As an example, some tests seem to have been conducted in which a deliberate attempt was made to include lightning interference. While it is not known whether any portions of the data on the furnished tapes were generated in this manner, some of the files examined but not used contained some extremely long (1801 bits) average burst lengths.

This is not to say that either method is right or wrong, but the difference tends to make comparisons difficult. Computing the average burst lengths of both US and West German noise files gives a reasonable similar value. Table D4 summarizes the averages. Note that the total averages for both noise files are under the maximum number (5) desired for the BCH code used. A burst of greater than 10 (interleaving depth times number of correctable bits per block) could cause the errors to distribute within the same block and to exceed the correctable amount.

| Noise File | Data Rate               | Average Burst Length |
|------------|-------------------------|----------------------|
| German     | 2.4 kb/s<br>(9 files)   | 3.5                  |
|            | 15 kb/s<br>(8 files)    | 1.8                  |
|            |                         | <hr/> 2.7*           |
| US         | 1.2 kb/s<br>(36 files)  | 3.1                  |
|            | 19.2 kb/s<br>(18 files) | 5.1                  |
|            |                         | <hr/> 3.7*           |

\*Total average weighted according to number of files.

Table D4. Summary of average burst lengths.

Examination of the effectiveness of the BCH algorithm (tables D2 and D3, last three columns) shows that the proposed scheme is effective most of the time. Note US file 208V005, where the BER is fairly constant but the burst length increases drastically for one subfile and the effectiveness drops dramatically. Files 000V002 and 000V003 have short average burst lengths but differ in bit or burst error rates by a factor of 10; yet the percent improvement for both is in the 90 percentile. Other files give varied results, which brings up one last point: without detailed information on the US noise-gathering process, it is fruitless to analyze these data further. The data seem to vary, but whether the variation is due to the type of equipment, placement, or external environmental conditions is unknown. The burst length seems to be the most critical parameter in performance and did influence the West Germans to choose the particular code and interleaving depth; therefore, table D4 is given as the only summary of comparison. However, tables D2 and D3 also serve as a summary from which any desired comparison of parameters can be made.

## GLOSSARY

|        |                                                              |
|--------|--------------------------------------------------------------|
| A/R    | autoresolution                                               |
| BCH    | Bose-Chaudhuri-Hocquenghem (code)                            |
| BER    | bit error rate (same as bit error probability)               |
| BILP   | beginning of intermediate line pair                          |
| BOLP   | beginning of line pair                                       |
| B-W    | black-white (mode)                                           |
| CCITT  | International Telegraph and Telephone Consultative Committee |
| CEW    | name of one of the test charts                               |
| CW     | control word                                                 |
| EOL    | end of line                                                  |
| EOM    | end of message                                               |
| EOP    | end of plane                                                 |
| FAX    | facsimile                                                    |
| FEC    | forward error correction                                     |
| GS     | grey shade                                                   |
| LSB    | least significant bit                                        |
| MSB    | most significant bit                                         |
| NATO   | North Atlantic Treaty Organization                           |
| OJS    | name of one of the test charts                               |
| pel    | picture element                                              |
| PN     | pseudorandom number                                          |
| QL     | quarter line                                                 |
| RTC    | return to control                                            |
| SG     | study group                                                  |
| SOM    | start of message                                             |
| STANAG | standard of agreement                                        |
| TDF    | Tactical Digital Facsimile (an algorithm)                    |
| VLD    | variable-length decoder                                      |
| VLE    | variable-length encoder                                      |
| WDB    | name of one of the test charts                               |
| WG     | working group                                                |

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