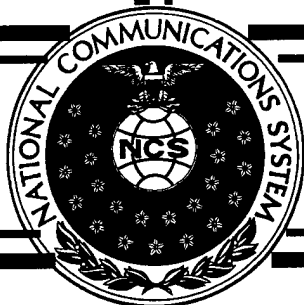# NATIONAL COMMUNICATIONS SYSTEM

TECHNICAL INFORMATION BULLETIN 96-3

HIGH FREQUENCY RADIO FACSIMILE

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The purpose of this project was to continue the development of a standard for gray scale image transmission using High Frequency (HF) radio links. The amateur radio community is presently using a de facto standard to transmit facsimile images using HF radio. This de facto standard is called Fax 480 which uses an analog frequency modulation technique where black and white pixels are transmitted using subcarrier frequencies of 1500 Hz and 2300 Hz. Gray scale values are represented by subcarrier frequencies between the black and white limits. The images transmitted using this standard typically originate in microcomputers, and are often photographic (continuous tone) images as opposed to bi-level images. The 512 by 480 image size can be   displayed with the 640X480VGA mode available on many personal computers, with room on the screen left over for menu options and other data. The transmission of facsimile over HF radio has been limited by the lack of an official standard. A requirement to standardize facsimile transmissions over HF radio, and has been developing this new standard through the TIA TR-29 facsimile committee. A draft standard has been prepared and balloted. This report comprises of three sections: 1-provides a brief description of the objectives; 2-technical discussion; and 3-conclusions.

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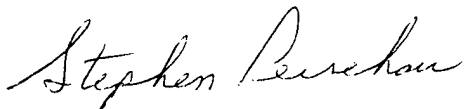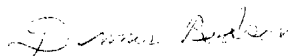<u>NCS TECHNICAL INFORMATION BULLETIN 96-3</u>

High Frequency Radio Facsimile

JANUARY 1996

PROJECT OFFICER   APPROVED FOR PUBLICATION:

STEPHEN PERSCHAU   DENNIS BODSON
Computer Scientist   Chief
Technology and   Technology and
Standards Division   Standards Division

FOREWORD

   Among the responsibilities assigned to the Office of the Manager, National Communications System, is the management of the Federal Telecommunication Standards Program. Under this program, the NCS, with the assistance of the Federal Telecommunication Standards Committee identifies, develops, and coordinates proposed Federal Standards which either contribute to the interoperability of functionally similar Federal telecommunication systems or to the achievement of a compatible and efficient interface between computer and telecommunication systems. In developing and coordinating these standards, a considerable amount of effort is expended in initiating and pursuing joint standards development efforts with appropriate technical committees of the International Organization for Standardization, and the International Telegraph and Telephone Consultative Committee of the International Telecommunication Union. This Technical Information Bulletin presents an overview of an effort which is contributing to the development of compatible Federal, national, and international standards in the area of facsimile. It has been prepared to inform interested Federal activities of the progress of these efforts. Any comments, inputs or statements of requirements which could assist in the advancement of this work are welcome and should be addressed to:

Office of the Manager
National Communications System
Attn: N6
701 S. Court House Road
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TASK 1
TECHNICAL WORK IN THE AREA OF FACSIMILE

SUBTASK 5
HIGH FREQUENCY (HF) RADIO FACSIMILE

FINAL REPORT
CONTRACT DCA100-91-C-0031
OPTION YEAR 4

January, 1996

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Submitted to:
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ARLINGTON, VA

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DIRECTORATE FOR FREEDOM OF INFORMATION
AND SECURITY REVIEW (OASD-PA)
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97-S-1255

TABLE OF CONTENTS

1   INTRODUCTION

This document summarizes work performed by Delta Information Systems, Inc. (DIS) for the National Communications System (NCS), Office of Technology and Standards. This office is responsible for the management of the Federal Telecommunication Standards Program, which develops telecommunication standards, whose use is mandatory for all Federal departments and agencies. The purpose of this project, performed under Task 1, Subtask 5 of contract number DCA100-91-C-0031 during Option Year 4, was to continue the development of a standard for gray scale image transmission using High Frequency (HF) radio links.

The amateur radio community is presently using a de facto standard to transmit facsimile images using HF radio. This de facto standard is called Fax-480 and it was advanced by Ralph E. Taggart in the amateur radio publication QST. Fax-480 uses an analog frequency modulation technique where black and white pixels are transmitted using subcarrier frequencies of 1500 Hz and 2300 Hz, respectively. Gray scale values are represented by subcarrier frequencies between the black and white limits. The Fax-480 format consists of 480 image lines, each comprised of 512 pixels. The images transmitted using this standard typically originate in microcomputers, and are often photographic (continuous tone) images as opposed to bi-level images. The 512 by 480 image size can be displayed with the 640X480 VGA mode available on many personal computers, with room on the screen left over for menu options and other data.

The transmission of facsimile over HF radio has been limited by the lack of an official standard. In an effort to achieve interoperability in this arena, the NCS has a requirement to standardize facsimile transmissions over HF radio, and has been developing this new standard through the TIA TR-29 facsimile committee. A draft standard has been prepared and balloted. As a result of this ballot the draft standard was revised, and as of this writing is out for an industry ballot.

This report comprises three sections. Section 1.0 provides a brief description of the objectives of the task and an outline of the contents of this report. Section 2.0 is a technical discussion of the issues involved in transmitting a facsimile over HF amateur radio. Section 3.0 provides conclusions and recommendations.

2 TECHNICAL DISCUSSION
2.1 HF FAX Background
2.1.1 Previously Adopted Approaches

Although facsimile is the oldest form of image-transmission technology, it is one of the least used forms of communications in the Amateur Radio Service. Instead, image communications are primarily based on slow-scan television (SSTV) on the HF bands (up to 30 MHz) and fast-scan on the UHF bands (430 MHz and up). This has been due to the relatively limited access to affordable facsimile equipment compatible with the narrow bandwidth available to the amateur radio service in the HF bands. Typical FAX communication stations employed mechanically driven drums with electronics providing the drive signals for the synchronous motors, and used an intensity modulated lamp focused on the drum containing light sensitive paper in the receiver.

Over the years advances in wirephoto systems led to older surplus equipment becoming available but with constantly changing line rates and image formats. Line rates varied from 60 LPM to 480 LPM. The low line rates tended to be incompatible with the Amateur Radio Service, as station identification is required at least every ten minutes. The higher line rates required too wide a bandwidth. This equipment was difficult to maintain, and it required special paper and lamps for continued operation, all of which contributed to the limited appeal of facsimile as a communication mode.

The current wide availability of Group 3 facsimile equipment may be of use on the VHF or UHF bands, but is unsuitable for HF (narrow) band operation due to the wider bandwidth required by the digital transmission mode.

2.1.2 Lack of Standards

It is the lack of standards, within the context of an easily implemented system utilizing the HF bands, that has stymied the Amateur Radio Service's use of facsimile. When the budget constraints of amateur stations are also considered, it becomes evident that existing facsimile standards are incompatible with the objectives of the Service.

2.2 Issues
2.2.1 Transmitter Bandwidth vs. Transmission Time

Two requirements must be addressed by any proposed HF radio facsimile

standard. The first is the need to operate within approximately 2.5 kHz of audio transmission bandwidth, transmitted using an AM (SSB) technique. The second requirement is to keep the transmission time per image to a reasonably short time, both for station identification purposes and to allow for the propagation, interference, and operational realities of HF radio communications.

2.2.2 Transmission Concerns

Operating in the HF bands in general is difficult due to the unpredictable nature of propagation. Long distance communication is the result of refraction of radio waves by the ionosphere. Changes in the ionosphere throughout the day make communications capability vary from nonexistent to excellent on any particular band. Solar activity, multipath interference, and local electrical noise also add to the problem. Adjacent channel interference within the Amateur Radio Service is another problem that occurs. It is as severe or worse than the natural conditions. Operation in the amateur bands is not channelized. Often, multiple transmissions on adjacent frequencies result in overlap of some of the modulation frequencies. Communications may have started with each station unaware of the other but over time the propagation path is established and worsening interference results. This interference is a major problem with operation in the crowded amateur HF bands. Transmission should therefore be kept reasonably short to allow for signal reports to be exchanged often.

2.2.3 Digital vs. Analog Tradeoffs

PART 97 of the Federal Communications Commission (FCC) Rules and Regulations allow image transmission using essentially any modulation method, within the specific limitations of operating bands. Quantized or digital information is permitted for the signal modulating the main carrier. This opens the possibility of replacing the older analog-based transmission techniques with digital techniques. Digital transmission on HF frequencies must occupy, by regulations, no more bandwidth than the nominal 3 kHz audio bandwidth used for voice transmissions. This rule suggests that digital image transmissions of up to 2400 bit/s are possible.

Part 97.307, subparagraph (f)(3) of the FCC rules restricts "data emission using a specified code" to 300 bauds in the HF bands. This limit refers to the transmission of data and radioteletype (RTTY) only. If a transmission includes solely image data, however, the rules allow the use of *any* data transmission mode with no baud restriction as long as the image data is kept within the 3 kHz bandwidth limit. The data modes used to transmit the image data can include RTTY or any other HF data transmission technique.

Since quantized image data transmission is permissible, adopting a modern image compression technique such as JPEG (Joint Photographic Experts Group) might

reduce the time required for transmission, but only when operating with a perfect circuit. In practice, the high bit error rate that results in HF radio modems would require the adoption of some sort of error recovery since the compressed digital data stream must be delivered errorlessly to achieve proper decoding. Uncorrected errors result in severe multi-line distortions. Adding forward error correcting techniques is counter productive from two standpoints. First, the added overhead is incompatible with the desire to minimize transmission time. Second, forward error correcting algorithms reach the point of diminishing returns with respect to coding gain as the bit error rate of the circuit approaches 10^{-2}, a common situation in HF circuits.

Amateurs currently use the Amateur Teleprinting Over Radio (AMTOR) data transmission mode, which is derived from the Maritime Mobile Service SITOR system. AMTOR Mode A uses an Automatic Repeat Request (ARQ) protocol. It is also transmitted at the 300 baud rate. It uses the 5-bit (BAUDOT) ITA2 code with two additional bits added to maintain a constant ratio of four marks to three spaces. The constant bit ratio facilitates error detection. Unfortunately, the added bits increase the length of the code and thus make it undesirable for the transfer of quantized image data.

Another possibility is the use of packetized transmissions, but this approach also must comply with the 300 baud restriction. Packet transmission is already in use by the Amateur Radio Service. A Draft Recommendation for HF Facsimile for Maritime Mobile Users, has been evaluated in this light, but requires a data modem capable of 1000 bit/s (exceeds 300 baud restriction) and the use of gateways.

The proposed HF-Facsimile standard (See the Appendix) is based on an analog transmission technique. It uses an FM modulated audio subcarrier. FM reduces the problems that fading of the signal during long distance transmission would cause if direct AM modulation were used. The fades would result in the grey level variations throughout the image. The resulting audio signal can be directly interfaced to the microphone input and speaker audio output of the radio transceiver.

2.2.4 Modern Equipment Available

The most significant addition to Amateur Radio Service stations of late has been the personal computer. These have been applied not only for record keeping functions, but also to provide real-time tracking of Amateur communication satellites, antenna pointing, and packetized digital data communications. As the multimedia explosion continues to drive down the price of image capturing devices, computers have become a new resource for use in higher resolution HF facsimile transmission.

This presents an excellent opportunity to replace the mechanical equipment previously associated with facsimile with the display and various sources of image data

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available to the personal computer. The extremely simple and low cost interface required to connect the HF radio to a personal computer using the recommended standard will promote wider use and exploration of this form of image transmission.

2.3 Status

The proposed draft HF radio facsimile standard is included in the Appendix. The proposed standard builds on the current de facto standard in use in HF radios in the Amateur Radio Service using an analog transmission technique. Transmission bandwidth restrictions and the short time per image that is desired do not favor digital data transmission. The recommended approach transmits an image in approximately two minutes 18 seconds.

The proposed standard also takes advantage of video standards, monitor resolutions, and image file formats. The recommended format represents a unique combination of readily available VGA equipment characteristics (640 pixels x 480 lines x 16 gray levels) and timing derived from a simple binary countdown of a readily available precision reference frequency. The resulting 512 pixels x 480 lines generate a square aspect ratio on the display and conveniently leave an area to the side of the screen for status display and command inputs. This simplifies software development by eliminating overlays and windows. The line format provides a 1:1 relationship between pixel and sample clock. Therefore software overhead is reduced, and no scaling or interpolation is required.

The recommended format represents a significant increase in horizontal and vertical resolution over previously used facsimile and SSTV formats. Note that the pixel clock of 1952.125 Hz is faster than the individual subcarrier frequencies which transfer the information. There will be some reduction in resolution from the actual 512 pixels. The response time of the receiving audio frequency discriminator is the primary determining factor. However, the most noticeable increase in resolution comes in the vertical scan direction with twice the number of lines available. This increased resolution should promote wider use and exploration of applications.

The similarities and differences between the de facto FAX-480 standard and the TIA TR-29 draft standard are summarized in Table 1.

TABLE 1 - COMPARISON OF STANDARDS

Specifications	FAX-480	TR-29 Draft Standard
Image aspect ratio	1:1	1:1
Image size (pixels)	512 x 480	512 x 480
Direction of horizontal scan	left to right	left to right
Direction of vertical scan	top to bottom	top to bottom
Pixel clock	1953.125 Hz	1953.125 Hz
Pixel clock accuracy	not specified	25 ppm
Synchronization frequency	1200 Hz	1200 Hz
Black frequency	1500 Hz	1500 Hz
White frequency	2300 Hz	2300 Hz
Gray Scale representation	range of frequencies between black & white	range of frequencies between black & white
Line synchronization	5.12 ms of 1200 Hz	5.12 ms of 1200 Hz
Frame start signal	black and white frequencies alternate every 2.048 ms	black and white frequencies alternate every 2.048 ms
Number of phasing lines	20	20
Phasing line format	10 clock cycles of sync & 512 clock cycles of white	10 clock cycles of black & 512 clock cycles of white

As of this writing, the draft standard is out for an industry ballot. When approved, it will become a TIA/ANSI standard.

2.4   Outstanding Issues

High resolution (150 dots per inch and above) image transfer may be possible with only a moderate increase in transmission time if JPEG type compression techniques are employed. The amount of compression and the ability to enhance the radio link with the application of Digital Signal Processing (DSP) techniques could combine to make an all digital approach viable. The DSP contribution could be in the

area of removing adjacent channel interference and in-band heterodyne signals. Regulatory restrictions based on the type of radio service used need to be further explored as well.

3   RECOMMENDATIONS

It is recommended that additional study be given to the area of using digital communications in the HF bands for transmitting images. With the increasing popularity of packet data communication modes, the very low cost of widely available terminal node controllers (TNCs) placed between the HF radio and the personal computer is actually less than implementing the proposed analog-based approach. Where stations already have established digital capability, image communication may be possible with the addition of application software.

In addition to the HF bands, there is a tremendous ability in the Amateur Radio Service to link widely separated geographical sites using VHF and UHF repeaters. These include Digital Repeaters. To promote interoperability, further investigations should include these bands as well. The VHF/UHF bands are characterized by better communications reliability and wider bandwidth.

REFERENCES:

R. E. Taggart, "A New Standard for Amateur Radio Analog Facsimile," QST, Feb 1993, pp. 31-36.

ITU-R, Doc. 8/124E, Automatic HF Facsimile and Data System for Maritime Mobile Users.

FCC, Rules and Regulations, Part 97.

ARRL, The ARRL Handbook for the Radio Amateur, 1996,
     Chapter 3, Modes.
     Chapter 12, Modulation Sources.

Appendix

HF Radio Facsimile Draft Standard

DRAFT STANDARD

High Frequency Radio Facsimile

SP-3394

Prepared by

TR-29 Facsimile Systems and Equipment Engineering Committee

August 31, 1995

SP-3394

Contents

SP-3394

(This Foreword is not part of this standard)

FOREWORD

This standard defines a bilevel and gray scale image transmission method using HF radio links.

Its purpose is to establish a standard to allow for wider acceptance and use of this form of image and text transmission. It also provides a foundation for the investigation of higher quality HF facsimile transmission. It is based on the use of personal computers to provide the display graphics, input scanning, printing, and image storage facilities. The computer software can also contribute to the cost effectiveness of implementation by performing the line and image formatting and synchronization functions and thereby reducing the radio-computer interface functions.

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SP-3394

1 Scope

This standard defines the image format, line format, synchronization method, and modulation method suitable for the transmission of images over noisy, low-bandwidth audio channels, especially HF radio links.

Although substantial increases in picture quality (resolution and gray scale) could be obtained by utilizing modern quantization and compression techniques, the transmission time and complexity of implementing the required error free channel run counter to the stated intent of this standard.

1.1 Additional Information

This standard builds upon the current de facto standard in use in HF radios in the Amateur Radio Service using analog transmission techniques. Transmission bandwidth restrictions and the short time per image required by FCC regulations for periodic station identification and HF band conditions do not favor digital data transmission. This standard also takes advantage of computer video standards, monitors and image file formats.

Line by line synchronization is unreliable during typical HF radio communications due to the high error rate. Much better results are obtained by using a long start/phasing interval to synchronize local crystal based timing elements to the transmitter and allowing the receiver to subsequently 'flywheel'. Thus, noise bursts, interference and deep fading will affect only individual video pixels, and will not cause loss of line synchronization.

This method uses simple, low cost equipment to generate and recover the image using a digital interface to the computer and audio tone interface to the HF radio. A standard facsimile and SSTV audio FM modulation format takes advantage of existing interface equipment. The image aspect ratio and frame/line rates match the widely available VGA standard mode of 640 pixels/line by 480 lines/image x 16 levels of gray scale or color. The 512 pixels/line specified leaves an area to the side of the image useful for status and control presentation.

2 Normative References

None

3 Definitions

For the purposes of this Standard, the following definitions apply.

HF Radio - A radio operating within the frequency band of 3 MHZ through 30 MHZ.

4 Formats
4.1 Image Format
4.1.1 Aspect Ratio

The image aspect ratio is 1:1 (square).

4.1.2 Direction of Scanning

The vertical scan direction is from top to bottom.
The horizontal scan direction is from left to right.

4.1.3 Image Format

There are 480 lines in each image.
There are 512 pixels per line.

4.2 Line Format

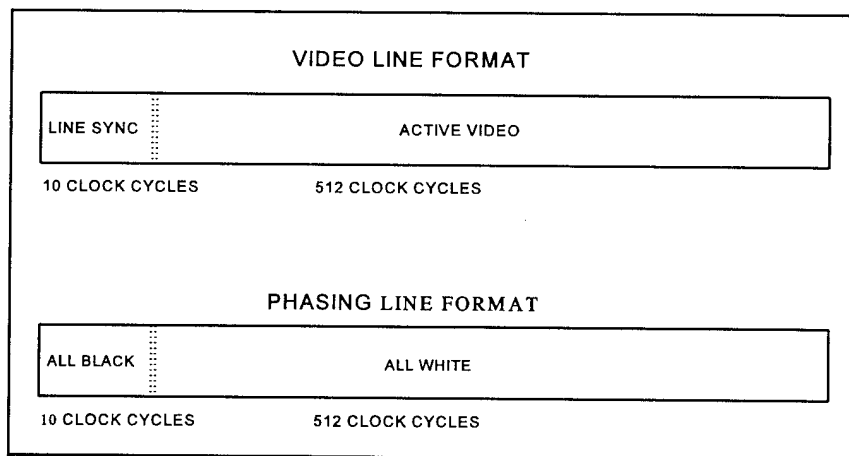Each line comprises a line synchronization interval followed by active video as

```
+-------------------------------------------------------+
|                 VIDEO LINE FORMAT                     |
|  +-------------------------------------------------+  |
|  | LINE SYNC :|          ACTIVE VIDEO              |  |
|  +-------------------------------------------------+  |
|  10 CLOCK CYCLES      512 CLOCK CYCLES                |
|                                                       |
|                 PHASING LINE FORMAT                   |
|  +-------------------------------------------------+  |
|  | ALL BLACK :|           ALL WHITE                |  |
|  +-------------------------------------------------+  |
|  10 CLOCK CYCLES      512 CLOCK CYCLES                |
+-------------------------------------------------------+
```

Figure 1–Line format

2

illustrated in Figure 1. There are no other elements within each line. The lines are constructed based on a pixel clock of 1953.125 Hz.

The line synchronization interval is 10 clock cycles (5.12 milliseconds) in duration. During Video Lines, the line synchronization interval is set to 1200 Hz. During Phasing Lines, the line synchronization interval is set to the black frequency.

The active video segment of each line is 512 clock cycles in duration. Each of these clock cycles represents an image pixel. This results in an active video segment of 262.144 milliseconds. During Phasing Lines, the video segment is set to the white frequency.

The total line period is 522 clock cycles or 267.264 milliseconds. The line rate is therefore 3.7416 Hz.

4.3 Frame format

Each frame contains a Start Signal, a clock phasing interval, and active lines. Figure 2 presents the frame structure.

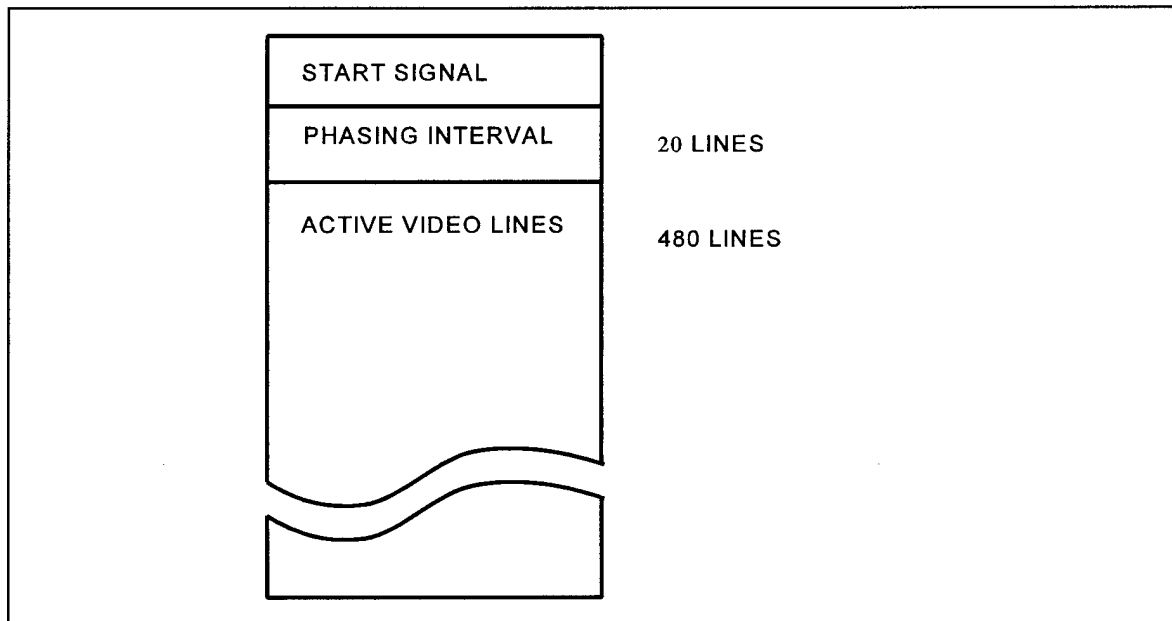| START SIGNAL | |
| PHASING INTERVAL | 20 LINES |
| ACTIVE VIDEO LINES | 480 LINES |

Figure 2–Frame structure

SP-3394

The Start Signal consists of black and white tone frequencies alternated every 2.048 milliseconds, for a total of 1220 cycles (4997.12 milliseconds). The black frequency is sent first.

There are twenty Phasing lines. Each Phasing line consists of 10 clock cycles at black frequency followed by 512 clock cycles at white frequency. The Phasing lines are present for 4.34528 seconds.

There are 480 active video lines. The duration of video is 128.28672 seconds.

The Frame interval is therefore 137.62912 seconds (2 min. 17.6 seconds)

4.4 Synchronization

The primary means of synchronization is based on the Start Signal and Phasing lines. Subsequent operation depends on the accuracy of the transmitter and receiver equipments' 1953.125 Hz clocks. Line synchronization information is included to permit operation in certain instances with tape recorders and compatibility with certain existing SSTV system interfaces.

The transmitter and receiver pixel clocks shall each have a combined accuracy and stability of 25 ppm or better.

5 Tone Frequencies

The output tone frequencies are:

Synchronization:	1200 Hz.
Black:	1500 Hz.
White:	2300 Hz.
Gray Scale:	Linear representation of Black to White scale as range of frequencies between Black and White frequencies.

For use with HF radio, the tones shall modulate the RF carrier using a form of Amplitude Modulation (typically SSB).

4

Annex – Implementation example

(Informative)

A.1 System elements

Figure A.1 illustrates the functions required to implement this standard to transmit facsimile using personal computers and HF transceivers.
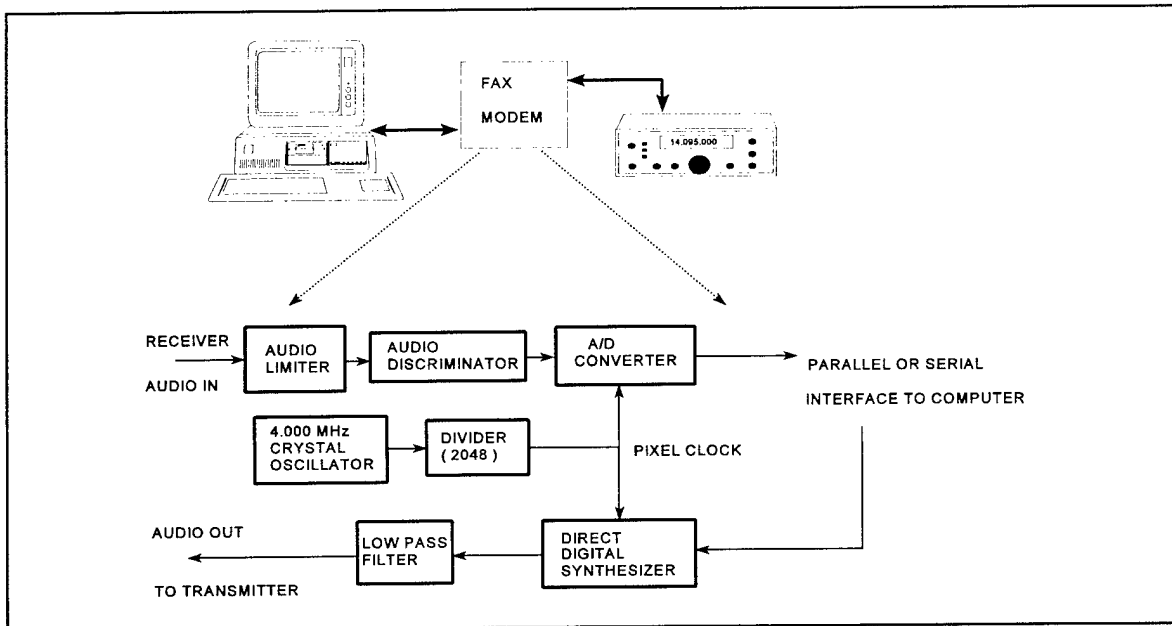

Figure A.1–System Elements

In the receiving instance, a frequency discriminator is adjusted to provide a monotonic voltage output corresponding to the specified frequency range. This analog voltage is converted by an A/D converter with 4 to 8 bits resolution into digital form. The A/D samples the incoming data at a rate of 1953.125 samples/second. This information is input to the personal computer where application software performs format synchronization, image start, image display, and possible storage or printout.

In the transmitting instance, the application software converts selected image file formats into a serial stream of commands which generate the frequencies. The command rate must be 1953.125 Hz. These commands may be digital values that are input to a D/A converter. The resulting analog voltage is then applied to an audio VCO that produces the desired frequencies. An alternative which requires far fewer adjustments would utilize a Direct Digital Synthesizer that would accept the digital

SP-3394

commands as input and produce an analog output. These audio tones can be routed to the audio input of the HF transmitter with nothing more elaborate than a gain control network.

The need for an accurate Pixel Clock is not difficult to achieve. It can be readily derived by dividing the output of a 4.0 MHZ crystal oscillator by 2048.

A.2 Compatibility with standard personal computer image formats

Because the images ultimately are placed in the microcomputer's display memory, one of the many image capture software packages can be used to convert the received image to a standard file format, such as .PCX or .GIF. These files then can be stored or manipulated using image processing and drawing software. The same approach works in the transmit direction. Images captured by scanners, frame grabbers, or generated by drawing packages can be read and converted to the serial output stream as greyscale images.