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Office of Development, Testing, and Dissemination

Technology Assessment Program Standards Laboratory

Guide to Electronic Facsimile Systems

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Technology Assessment Program
Standards Laboratory

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FOREWORD

The Law Enforcement Standards Laboratory (LESL) of the National Bureau of Standards (NBS) furnishes technical support to the National Institute of Justice (NIJ) Technology Assessment Program to strengthen law enforcement and criminal justice in the United States. The overall NIJ Technology Assessment Program is briefly described on the inside front cover of this guide. LESL's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

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This document is a law enforcement equipment guide developed by LESL under the sponsorship of NIJ. Additional guides as well as other documents are being issued under the LESL program in the areas of protective equipment, communications equipment, security systems, weapons, emergency equipment, investigative aids, vehicles and clothing.

Technical comments and suggestions concerning this guide are invited from all interested parties. They may be addressed to the Law Enforcement Standards Laboratory, National Bureau of Standards, Washington, D.C. 20234.

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INTRODUCTION

Electronic facsimile machines transmit the image of a document, such as a text, drawing, or photograph, to a remote location where it is received and printed by other facsimile machines, usually using special paper. The principal law enforcement users of electronic facsimile systems are Statewide agencies and large metropolitan police forces whose primary applications are the transmission of photographs, police records, and fingerprints. There is reason to believe, however, that the capabilities offered by facsimile equipment will eventually make it a desirable asset for many other law enforcement agencies.

This guide is intended to provide law enforcement agencies with assistance in the selection and use of facsimile systems. The basic concepts and components of facsimile systems are explained, as well as cost and performance variables, so that facsimile equipment and systems can be evaluated.

Note: Printing may degrade the fidelity of a facsimile reproduction of an image; actual facsimiles may be somewhat sharper than those reproduced in this document.

FACSIMILE USES TODAY

Electronic facsimile systems transmit printed information to distant locations, a service which is also performed by television and the postal service. Delivery by mail is the slowest but least expensive system—and television is fast but the most expensive. The speed and cost of facsimile transmission lie in between. Some current applications of facsimile systems are described in the following paragraphs.

BUSINESS CONVENIENCE FACSIMILE

Most facsimile machines are employed for business convenience, in which quick delivery of a few messages each day is desired, but which does not justify the installation of a high performance, more expensive facsimile system. Letters, memos, and orders are typical of the documents that are transmitted, although most business convenience machines can also handle continuous-tone documents, such as photographs, if marginal image quality is acceptable. The facsimile machines that are used for this purpose tend to be portable and relatively low in price; they use the dial-up telephone system for the communications link and produce marginal copy quality. Transmission times are usually 4 or 6 min for an $8\frac{1}{2}$ x 11-in page, although several 3-min systems are now in use. There are significant differences in performance and price among such machines. Business convenience facsimile machines are frequently manufactured in the form of a transceiver so that one machine can function as either transmitter or receiver. A photograph of a typical transceiver is shown in figure 1.

NEWS AND PUBLISHING

Perhaps the most familiar use of facsimile is in daily newspapers. A picture credit such as "Associated Press Wirephoto" indicates that facsimile transmission was used to transmit the photograph to the local newspaper office. The Associated Press and United Press International operate extensive facsimile systems for disseminating news material.

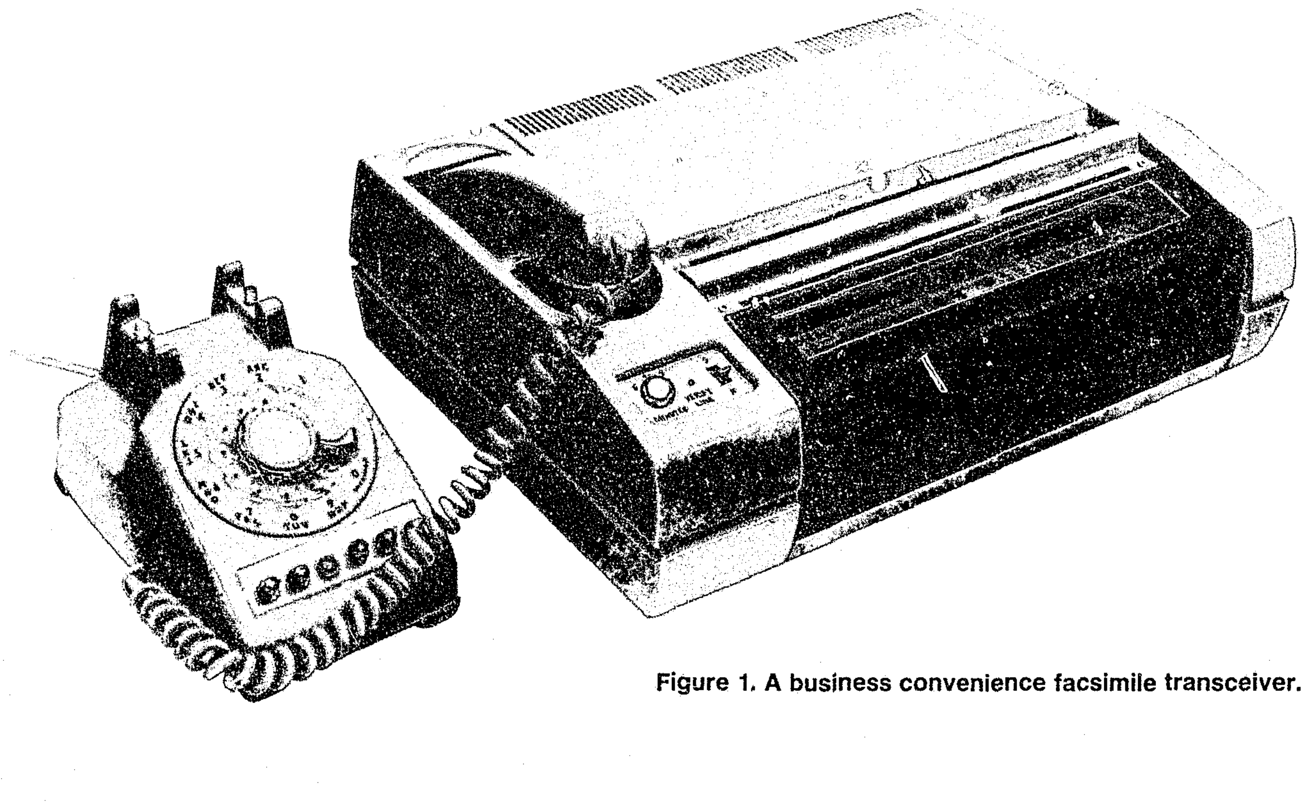


Figure 1. A business convenience facsimile transceiver.

Among the uses of facsimile in publishing is the transmission of finished page makeups to remote printing plants. The facsimile equipment used for this purpose must perform very well because in addition to handling text, it must be able to reproduce the individual dots that make up the half-tone illustrations. The facsimile receiver produces a latent image on photographic film which is then developed in the photo laboratory. This kind of facsimile machine handles copy even larger than a newspaper page so that four magazine pages can be transmitted together. Wide bandwidth communications channels are usually required for transmission of large quantities of high resolution material. Leased wideband telephone lines are suitable for the communications channel but other methods, including communications satellites in stationary earth orbit, are used also. A few facsimile machines have been designed to transmit data more efficiently using a voice-grade communications link.

A specific example of a facsimile system used in publishing is one used by the Wall Street Journal. The system is used to transmit reproduction proofs from Chicopee, MA, where they are prepared, to a regional printing plant in Orlando, FL. A facsimile transmitter scans the original proof and converts its image into an electronic signal which is transmitted by an earth station in Chicopee to a communications satellite 22,300 mi above the earth. The satellite receives the signal, amplifies it, and rebroadcasts it to earth. A receiving station at Orlando delivers the signal to a facsimile receiver in the printing plant. The facsimile receiver produces a page-size reproduction on photographic film which is, in turn, used to make lithographic plates for the actual printing. The transmission time is $3\frac{1}{2}$ min per page.

LAW ENFORCEMENT

Some law enforcement agencies transmit arrest records, fingerprints, photographs, and warrants via facsimile. Although arrest records and warrants would probably be transmitted on a business convenience or other low-priced facsimile machine, fingerprints usually require the use of facsimile equipment that gives better gray-scale reproduction and better spatial resolution. Figures 2 and 3 are photographs of facsimile systems specifically designed for fingerprint transmission. The receiver in figure 2 reproduces an 8 x 8-in fingerprint card

Figure 2. Facsimile receiver for reception of fingerprint cards.

on photographic paper which is automatically developed inside the machine. Figure 3 shows both the facsimile transmitter modified for transmitting fingerprint cards, and a message-type facsimile receiver for reception of arrest records from the identification bureau. Uses of facsimile in law enforcement are covered in more detail in a later section.

OTHER USES

Some banks transmit signatures by facsimile for verification, and although any facsimile system can do this, compact equipment made specifically for this purpose is available and more convenient to use. Another facsimile use is in microfilm retrieval systems that locate desired documents and present a magnified image to a facsimile transmitter which in turn operates a remote facsimile receiver. The receiver produces a hard copy enlargement of the original microfilm image. Sometimes facsimile receivers are used with computer terminals for the purpose of generating hard copy, and they can also serve the same function for slow-scan TV systems.

Some large corporations make extensive use of facsimile to handle intra-company graphic communications, such as engineering drawings and correspondence. These facsimile systems normally link geographically scattered units of the company and usually do not communicate outside the corporation. The communications links may be the common dial-up telephone system: those owned by the company, or those using communications satellites. Large numbers of documents can be transmitted more cheaply by relatively expensive facsimile machines that transmit documents very efficiently, thus reducing the cost of the communications channel.

Mobile facsimile, in which a base station transmits to a vehicle-mounted facsimile receiver, is used in Europe on some public safety vehicles, such as fire engines. This enables enroute and at-the-scene reception of maps, floor plans, orders, etc. Almost any radio channel suitable for voice communication is suitable for these facsimile transmissions; the same channel can serve both. At this time, mobile facsimile is rarely used in the United States.

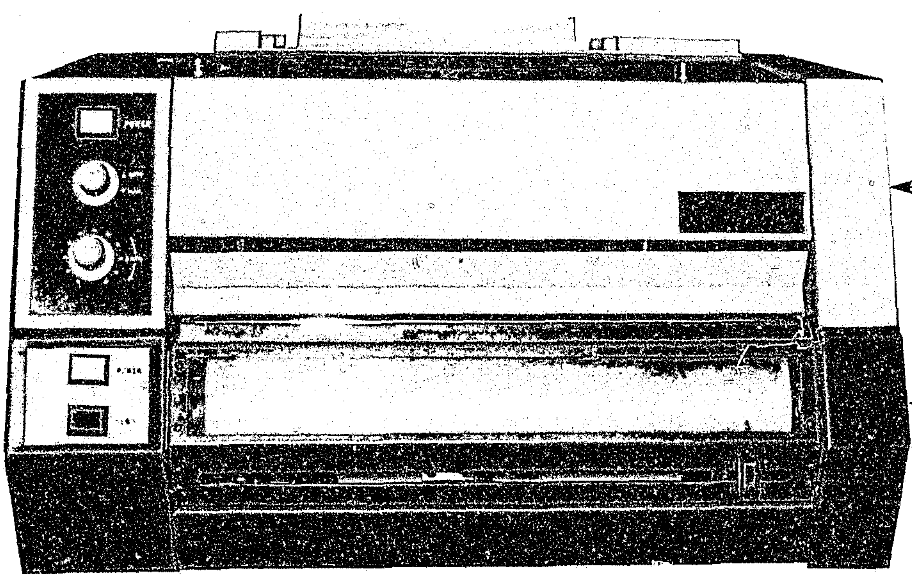


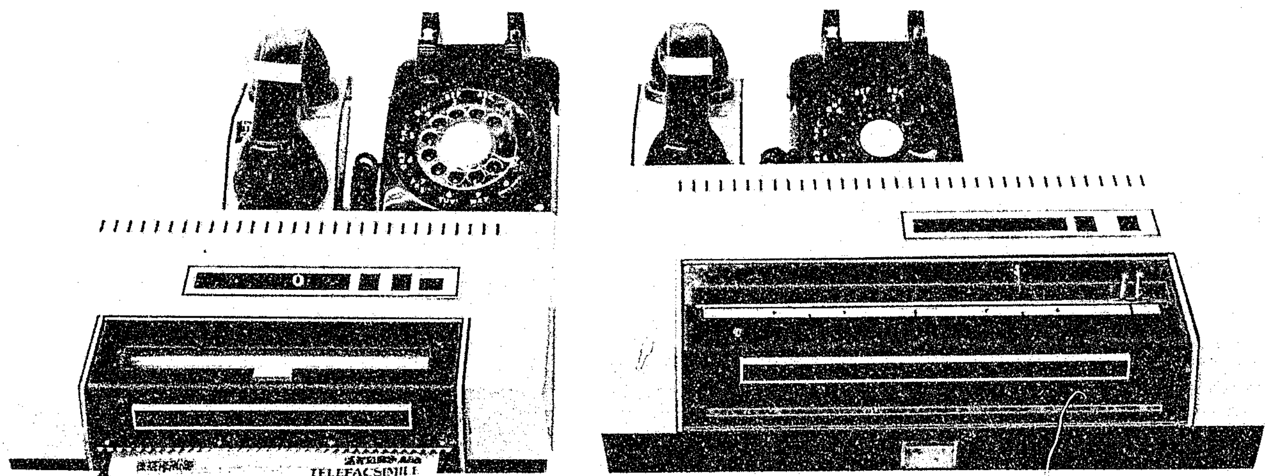
Figure 3. Facsimile device used for fingerprint work.

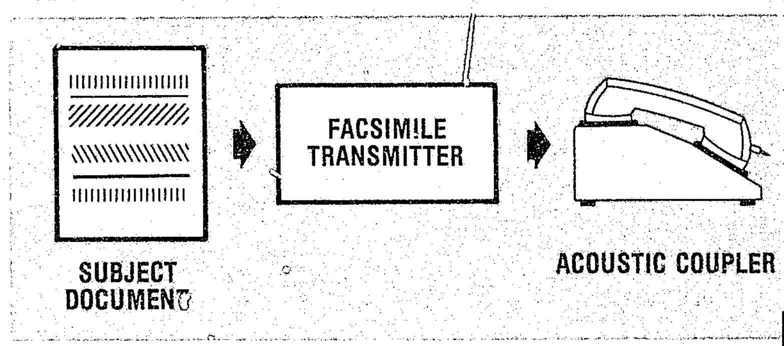
A BASIC FACSIMILE SYSTEM

A simple facsimile system described in this section is representative of the facsimile equipment in use today. In figure 4, the facsimile transmitter is on the right, and the facsimile receiver is on the left. The public dial-up telephone system is used for the communications channel. Each telephone handset is placed in an acoustic coupler, which couples audible signals into and out of the telephone handset. Thus no electrical connection to the telephones is needed. Figure 5 shows a block diagram of the system.

OPERATING PROCEDURE

The person desiring to transmit a document clips it to a drum in the transmitter (the drum rotates at 180 rpm during the transmission), and then uses the telephone to call the facsimile machine operator at the second location. The contact can also be initiated by the person wanting to receive a document. The purposes served by the voice communication are to let it be known that a transmission is desired, and to assure that the correct facsimile machine settings are used. Most facsimile machines can transmit/receive at more than one speed and the operators must decide which to use. After the voice preliminaries, each operator places the telephone handset in the acoustic coupler. The actual transmission begins when the transmitter operator pushes the ON switch on the facsimile transmitter. The document is then transmitted automatically. A signal buzzer alerts each operator when the transmission is finished. The transmitter operator then turns the transmitter off and removes the document, and the receiver operator removes the copy from the receiver. If additional documents are to be transmitted, the operator simply inserts the next document into the





Figures 4 (above) and 5. A basic facsimile system and its block diagram.

facsimile transmitter and it too will be automatically transmitted when the ON switch is pushed again. When the last document has been transmitted, the operators remove the telephone handsets from the acoustic couplers and confirm, by voice, the reception of the documents. Then the handsets are placed back on the telephones and the telephones become available again for ordinary voice communications.

FACSIMILE TRANSMITTER

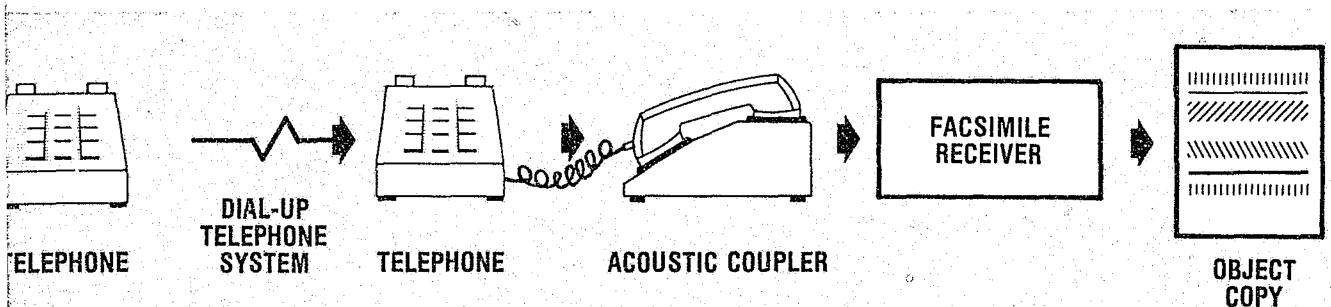
The facsimile transmitter converts an image into an equivalent electrical signal by means of a photodetector which is rapidly scanned across the document in a narrow line. The photodetector converts the variations of optical reflectivity at each point along the scan path into an equivalent electrical signal. When one line has been scanned, another scan is immediately begun parallel to, but slightly displaced from, the previous path. By repeating this process hundreds of times, the entire document is examined and transmitted. Figure 6 shows the scan path. A more thorough description of facsimile transmitter fundamentals is given in the Facsimile Scanner section. The transmitter in figure 4 scans 180 lines per minute (l/m), at either 64 or 96 scan lines per inch (lpi), as selected by the operator. When 96 lpi is used, documents will be "read" at 1.875 column-inches per minute (=180/96). This takes about 6 min for a page 11 in long.

The electrical signal produced by scanning is converted to a frequency modulated (FM) signal by a modulator circuit in the facsimile transmitter. The frequency band of the FM signal is designed to fall within the band of frequencies that can be handled satisfactorily by a voice-grade communications channel. The FM signal is used to drive an acoustic coupler that connects the facsimile signal to the telephone system. Any other voice-grade channel, such as radio or leased telephone lines, can be used.

FACSIMILE RECEIVER

The facsimile receiver converts the FM signal received from the communications channel back into an image resembling the subject copy. The image is produced by a scanning process which is synchronized with the transmitter's scanner. On each scan, marks are made along a narrow line with the darkness produced at any spot being proportional to the optical reflectivity sensed by the photodetector in the transmitter.

The facsimile receiver usually reproduces the transmitted document on special paper. One example is electrolytic paper, which is paper that has been saturated with a chemical solution that turns sepia or black when an electric charge passes through it. The greater the electric charge, the darker the paper becomes. The paper is supplied in a roll that is sufficient for thirty-five $8\frac{1}{2}$ x 11-in copies, and kept in a sealed plastic bag, until used, to prevent it from drying out. No processing is needed; the paper dries quickly after it leaves the receiver, and the image is permanent and durable.



COPY QUALITY

Figure 7 shows the original of a test document transmitted through the facsimile system; figures 8 and 9 show the facsimile copies. The copies are identical except that a raster containing 64 lpi was used for figure 8, while one containing 96 lpi was used for figure 9. This picture pair provides a good example of the trade-offs that occur in facsimile systems. Note that better reproductions can be obtained if more time (more scan lines per inch) is allowed for transmission. At 64 lpi a coarser reproduction is obtained and the individual raster lines are discernible. The transmission time is 4 min for an $8\frac{1}{2}$ x 11-in page. The copy quality is much better at 96 lpi and the individual raster lines are barely visible, but the transmission time has increased to 6 min. The manufacturer's data sheet for this equipment gives the spatial resolution

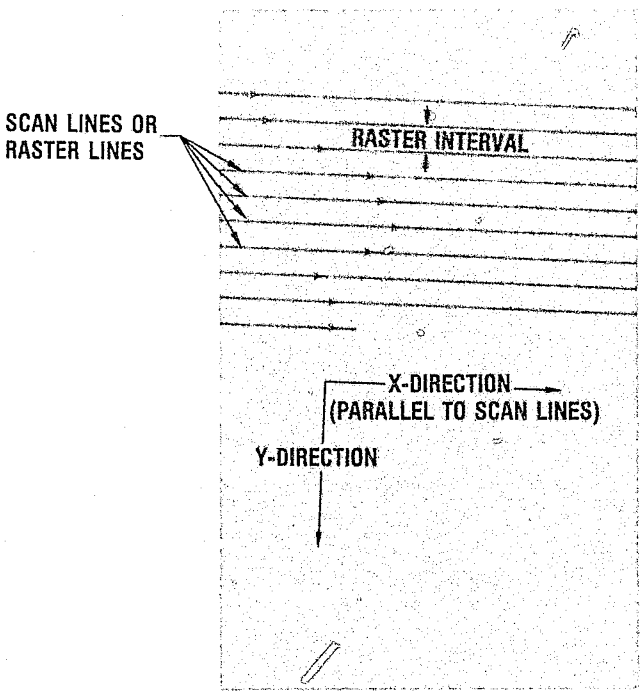


Figure 6. Scan path.

along the length of a scan line (horizontal resolution) as 48 line-pairs per inch (a line-pair equals one black line plus an adjacent white line), regardless of which vertical scan density is used. Except for special situations, the vertical spatial resolution will always be lower than the scan line density, as explained in the Vertical Spatial Resolution section.

The human eye will perceive the displayed information best when the shape of the spot that draws the raster lines is elongated vertically just enough to obliterate the raster line structure (fig. 10). If the spot is enlarged in the horizontal direction, the picture quality suffers.

The term line document, or line drawing, is used to refer to documents that contain only two shades (usually full black and full white), such as engineering drawings. Documents that have one or more intermediate shades of gray, such as photographs, are called continuous-tone documents. Figures 8 and 9 show that this facsimile system can handle both line and continuous-tone documents, including text. Some facsimile machines are designed to handle line documents only, and do not reproduce intermediate shades of gray.

COST

Facsimile systems are expensive to acquire and can be expensive to operate. The U.S. Postal Service can deliver a printed message much cheaper than facsimile can, so facsimile transmission of documents should be used only when a special need prevails, such as speed, convenience (the facsimile receiver makes copies), security against loss or interception, and ease of delivery, such as to ships at sea.

The cost of a simple facsimile system involves equipment, expendables, and the communications

Figure 7. IEEE facsimile test chart. The chart is shown full size, but due to the page size of this guide the outer portions of the chart do not appear.

Figure 8. Facsimile reproduction of test chart at 64 scan lines per inch. The outer portions of the chart do not appear.

Figure 9. Facsimile reproduction of test chart at 96 scan lines per inch. The outer portions of the chart do not appear.

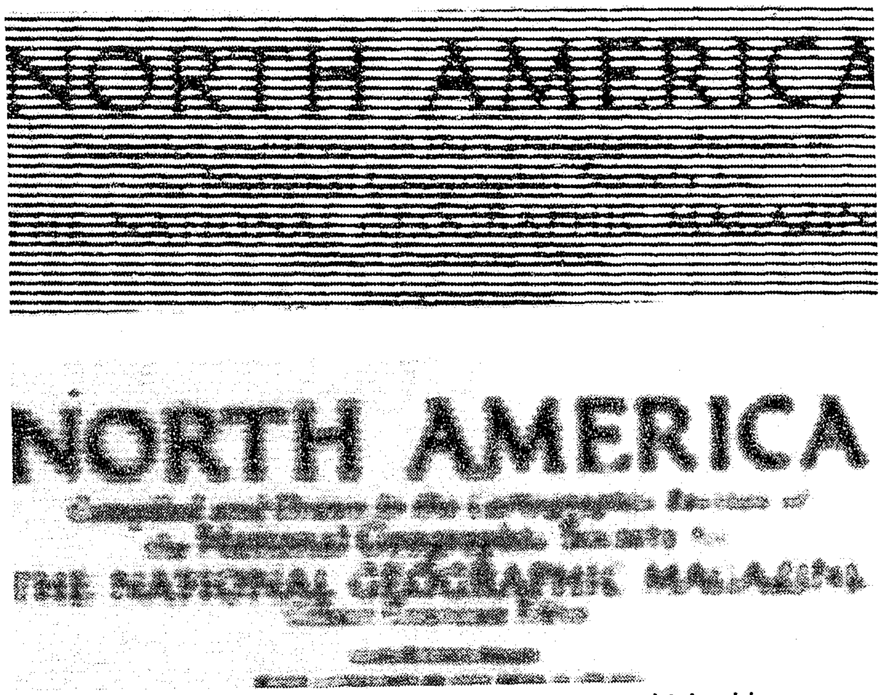


Figure 10. Image enhancement obtained by broadening the raster lines. (*Perception of Displayed Information*, edited by Lucien M. Biberman, 1973, page 256, Plenum Publishing Corporation.)

channel. Maintenance cost is usually fairly low as is the labor cost to operate the equipment.

The major portion of the cost is for the facsimile transmitter and receiver, but two acoustic couplers will also be needed. The principal expendable item is the electrolytic recording paper. The cost of the communications channel is, for an elementary system, the cost of a telephone call. Assuming that a single $8\frac{1}{2}$ x 11-in document is sent, about 1 min of the call is for voice contact, and another 3 to 6 min for the actual facsimile transmission. The telephone charges will depend on the time of day, day of the week and any special long-distance arrangements. It is clear that short transmission times will help reduce the cost of long-distance communications.

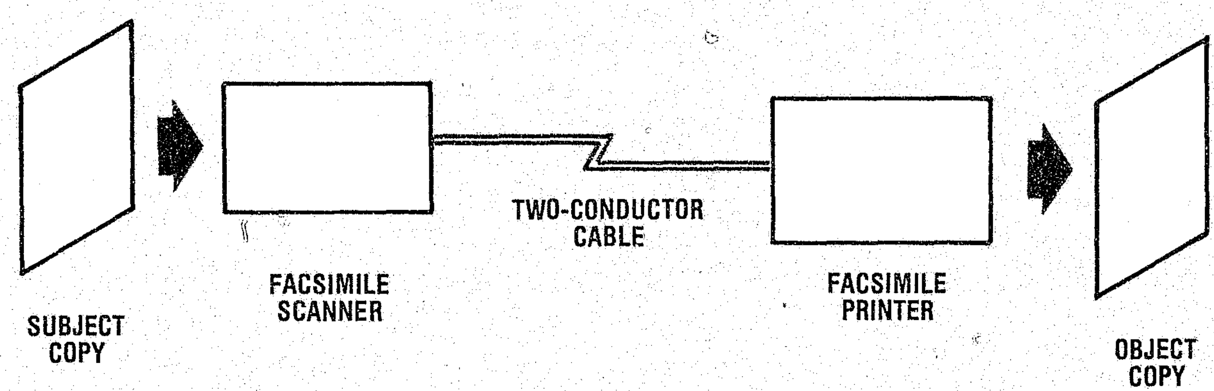
FACSIMILE FUNDAMENTALS

Facsimile systems consist of several subsystems, but the facsimile scanner and the facsimile printer are unique to facsimile and give it its special character. For this reason these will be described first, followed by descriptions of the other subsystems.

A MINIMAL FACSIMILE SYSTEM

Figure 11 is a block diagram of the simplest facsimile system, which consists of three parts: a facsimile scanner, a two-conductor cable, and a facsimile printer. The function of the scanner is to convert the visual data of the document to be transmitted (subject copy) into a corresponding electric signal called the baseband signal. The two-conductor cable serves as a simple communications channel that conveys the facsimile signal from the scanner to the printer. The function of the facsimile printer is to produce, from the baseband signal, a copy of the original document. This simple system is satisfactory when the distance between scanner and printer is short enough to prevent excessive signal degradation, and when the cable can be installed without too much difficulty.

Figure 11. Block diagram of a basic facsimile system using a simple two-conductor cable for the communications channel.



FACSIMILE SCANNER

A facsimile scanner examines the subject copy and converts its image into an electric signal. Figure 12 shows one of the scanning techniques commonly used. The subject copy is wrapped around a transmitting drum, which turns rapidly (180 rpm) during transmission. Simultaneously, a lamp-photodetector assembly is driven slowly along the length of the rotating drum. The photodetector sees only a very small area of the subject copy at any instant and produces an electric current in proportion to the reflectivity of this elemental area. The entire surface of the document is progressively scanned in a spiral path by the photodetector. If the document is removed from the drum and laid flat, the path shows as a grid of closely-spaced parallel lines which are almost parallel to the top edge of the paper. The grid of lines is called a raster, and the individual lines are called raster lines or scan lines.

Figure 6 illustrates several attributes of the raster. The distance between adjacent raster lines is the raster interval, which can be measured in inches or centimeters. The reciprocal of the raster interval is called the raster density or scan density and is expressed as the number of lines per inch or lines per centimeter. Another parameter, called the scan rate, is the number of raster lines produced each minute. For drum-type machines this is the number of revolutions per minute.

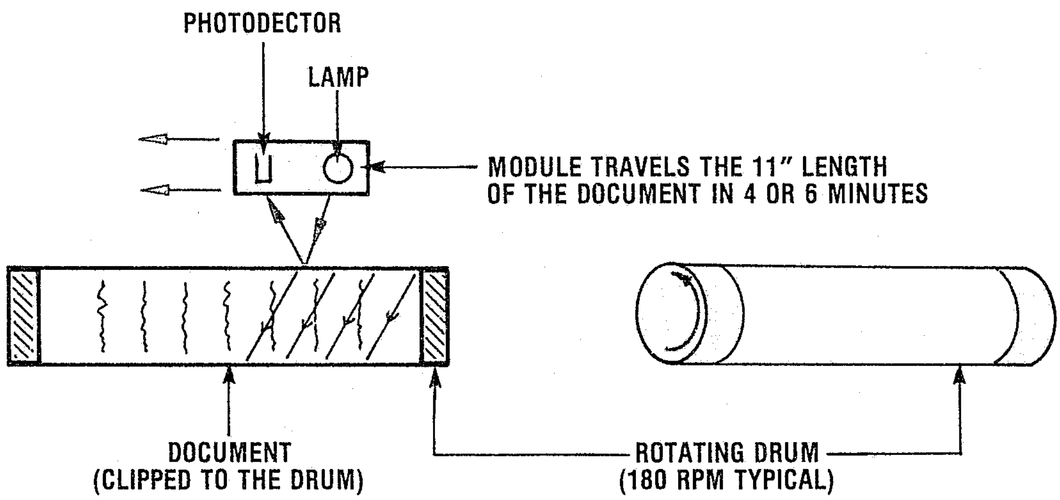
A scanner in which the subject copy is rapidly rotated by a drum is a drum scanner. In addition to drum scanners, there are flatbed scanners which draw the subject copy slowly through the machine while the optical system rapidly scans it from left-to-right to form the raster. (Some flatbed scanners employ a scanning technique in which the subject copy does not move at all.) Many flatbed scanners can handle copy of any size, but drum scanners cannot accept copy that exceeds either the length or the circumference of the drum.

FACSIMILE PRINTER

Facsimile printers reconstruct the image on a point-by-point basis. The only difference between the scanner and printer is that the scanner examines each area of the subject copy with a photodetector, and the printer produces appropriate darkening at the corresponding point on the record medium. The printer shown in figure 12 uses electrolytic paper on which the darkening is produced by an electric charge passing from a scanning electrode through the paper to an electrode on the other side of the paper. The greater the charge, the greater the amount of darkening. The size of the recorded spot is approximately the same as that of the electrode that produces it. A diameter of 0.025 cm (0.01 in) is a common spot size.

A flatbed printer is needed to handle electrolytic paper because the rolls are handled most easily by its transport mechanism. Figure 13 illustrates how the printer uses the intersection between a stationary bar electrode and a rapidly rotating single-turn helix electrode to produce the equivalent of a scanning electrode. Each time the helix makes one revolution, the intersection between it and the straight bar electrode makes one sweep across the entire width of the printing

Figure 12. A common drum-scanning technique.



paper. Since the printer simultaneously pulls the paper slowly past the bar electrode, a new region of the paper is scanned by each revolution of the helix. The paper advances approximately 0.025 cm (0.01 in) during the time a single raster line is drawn.

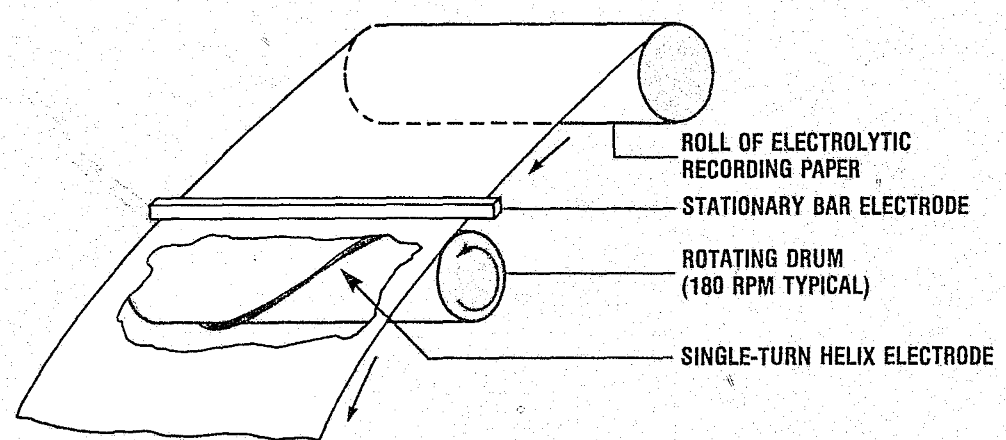
INDEX OF COOPERATION

For an undistorted image, a facsimile scanner must transmit to a printer having the same Index of Cooperation (IOC). The Index of Cooperation is a quantity that is derived from the dimensions of the raster pattern. Data sheets specify the IOC of each particular facsimile machine. However, there are two different definitions of the IOC, and some data sheets do not indicate which definition is used. Any confusion from this can be resolved by calculating the IOC from other information on the data sheet, in accordance with the instructions below.

One definition, called the Scanning Line Index of Cooperation (also known as the IEEE Index of Cooperation), defines the IOC as the ratio of the circumference of the drum to the distance between adjacent raster lines. Another way to arrive at this is to multiply the drum circumference by the raster line density. Either way, the length dimensions can be expressed in any unit desired, provided that the same unit is used for all lengths. For flatbed facsimile machines, the IEEE IOC is the ratio of the length of a raster line to the distance between raster lines.

The other definition of IOC, the International Index of Cooperation, is set forth by the Consultative Committee on International Telegraphy and Telephony (CCITT), located in Geneva, Switzerland. The function of CCITT is to produce recommendations for desirable practices and standards in telecommunications. The CCITT defines the IOC to be $1/\pi$ times the value obtained from the earlier definition of IOC, where $\pi = 3.1416$. For drum-type machines the CCITT value of the index of cooperation is equal to the ratio of the drum diameter (instead of the drum circumference) to the distance between adjacent

Figure 13. Bar and helix recording technique for flatbed printer.



raster lines. For flatbed facsimile machines, the CCITT IOC is the ratio of the length of a raster line to π times the distance between adjacent raster lines.

Suppose that the transmitting scanner has an IOC of 300. As shown in example a of figure 14, utilization of a printer which has the same IOC of 300 results in no distortion. However, elongation in the vertical (y) direction occurs when the printer has an IOC that is less than that of the scanner, as shown in example b of figure 14. Elongation in the horizontal (x) direction occurs when the printer has an IOC that is greater than that of the scanner, as shown in example c of figure 14. The IOC tells nothing about the size or the facsimile image produced. As an example, the image in example d of figure 14 is only half the size of that in example a, although both have the same IOC. In practice, the reproduction is almost always the same size as the original, but some facsimile systems enlarge or reduce the image size.

SYNCHRONIZATION

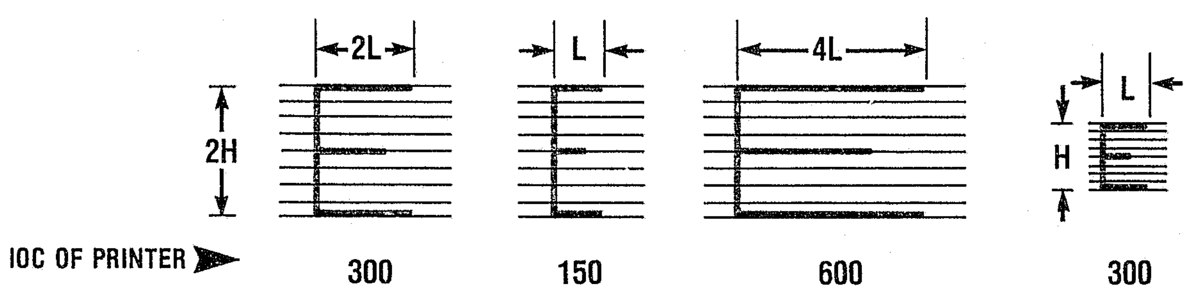
In order to properly reconstruct the subject document it is necessary for the scanner and the printer to start each raster line together. Proper phasing is obtained automatically by transmitting a phasing signal to the facsimile receiver for a few seconds before the start of the actual facsimile transmission. The receiver automatically adjusts the pnase of its rotating helix to agree with the phasing signal. Once the initial synchronization is attained, the transmitter and receiver maintain synchronization because their rotational speeds, usually controlled by a quartz-crystal oscillator in each machine, are the same.

FREQUENCY SPECTRUM AND CONNECTION TO PHONE SYSTEM

The baseband facsimile signal produced by the scanner typically has a frequency spectrum from almost zero to approximately 1000 Hz. However, in a few special purpose machines the higher baseband frequencies extend beyond 10 kHz.

The ordinary telephone system is the communications facility most commonly used for facsimile transmissions because it is an existing communications system that allows almost instant connection between two locations. However, the telephone system transmits signals only within the nominal frequency range of approximately 300 to 3000 Hz. Therefore, it cannot handle facsimile baseband signals directly. The solution to this problem involves the conversion of the baseband signal to a signal in the 300 to 3000 Hz frequency range in a modulator prior to transmission, and the reconversion to the baseband facsimile signal in the receiver.

Figure 14. Distortion of the object copy caused by mismatched Index of Cooperation.



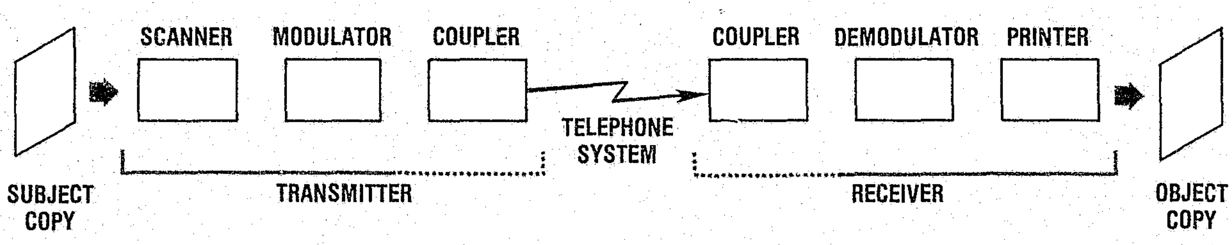


Figure 15. Block diagram of facsimile system showing the communications hardware.

The telephone company does not ordinarily allow the customer's terminal equipment to be wired directly to the telephone lines.* Two methods are generally employed to connect facsimile equipment. One method uses an acoustic coupler, a device that feeds signals to and from any ordinary telephone handset via sound waves, while the other connects a modulated signal directly to the telephone line. The telephone company requires that an intermediary device be connected between the phone line and the facsimile machine. One of these devices called a data coupler or a data access arrangement (DAA) is rented from the telephone company. The DAA protects the telephone lines by coupling the transformer data signal to the telephone wires and limiting, to about 50 V, the maximum signal voltage that can be developed in the telephone line. In addition to protection, some DAA's provide other circuit functions that simplify the job of providing an interface between the facsimile machine and the telephone system, or provide for automatic unattended machine operation. Figure 15 expands the diagram of the basic facsimile system to include the frequency shifting device (modulator) and coupling subsystems described above.

There are many hardware implementations of these subsystems. For example, many facsimile transceivers include an FM modem and an acoustic coupler. If a facsimile machine can handle only the baseband signal, a Data-Phone can be rented from the telephone company. Additional information about modems and couplers is given in later paragraphs.

*As a result of regulations adopted by the Federal Communications Commission (FCC) and recent court decisions, manufacturers of certain types of equipment (including facsimile machines) can provide built-in data couplers if their coupler is registered with the FCC.

COMMUNICATIONS

This section provides additional information about the transmission and reception of the basic facsimile system in figure 15. Because the study of communication channels can be a complex subject, this section will cover only those aspects that pertain to facsimile. There are many ways to provide the communications channel between facsimile machines, but telephone lines happen to be used most frequently.

THE BASIC TELEPHONE LINE

The telephone company provides a pair of wires to connect the local telephone office to the customer's terminal equipment (telephone, facsimile machine, computer terminal, etc.). This connection has been described previously.

COUPLER AND MODEM IMPLEMENTATIONS

It may be difficult to choose modulation and coupling devices because these components are packaged in many ways and because they may include auxiliary features. For example, the modulator, couplers, and demodulator can be housed separately, or they can be an integral part of the facsimile machine. Modems are designed to meet specific requirements for transmission such as speed and type of modulation, so it is important to make sure that the appropriate model is selected.

ACOUSTIC COUPLERS

One of the commonly used devices for connecting facsimile machines to the telephone lines is the acoustic coupler. Acoustic couplers are portable and can be used wherever a telephone is located. They are not subject to rigorous telephone company restrictions in design or installation and are manufactured by many companies.

Acoustic couplers are supplied in three forms. The simplest of these is a separate package that provides only the basic coupling function. The coupler shown in figure 4 is of this type. Modulation and demodulation must be provided by the facsimile machine or other device.

Another design includes a modem in the same package as the acoustic coupler. This requires the facsimile transmitter to provide a baseband facsimile signal. The coupler's modem modulates and transmits the resulting signal from the coupler's speaker to the microphone in the telephone handset. At the facsimile receiver, the signal is coupled from the telephone's handset speaker into the microphone on the acoustic coupler. Then the coupler's modem demodulates the signal and delivers the baseband signal to the facsimile printer. Some acoustic couplers have modems that are designed to handle two-level (digital) signals, and others have modems for handling analog signals. The manufacturer of the facsimile equipment specifies the type of acoustic coupler required.

A third packaging arrangement builds the acoustic coupler directly into the facsimile machine. This design is commonly used with portable facsimile transceivers. Figure 1 shows one such transceiver.

DATA-PHONES

Another way to couple terminal equipment to the telephone line is to use a Bell System Data-Phone. As its name implies, a Data-Phone can be used either as an ordinary telephone or as a data-handling device, although it cannot perform both jobs simultaneously. The Data-Phone contains a modem and a data coupler in a single package, and is available with either a digital or an analog modem. Data-Phones differ from acoustic couplers in that transformer, rather than acoustic, coupling of the terminal equipment to the telephone line is used, and electronic components are used to limit the maximum safe voltage that can be produced in the telephone line. Data-Phones are available only from the telephone company. The customer is charged for installation and, thereafter, a monthly fee, which depends on the particular Data-Phone model chosen.

DATA ACCESS ARRANGEMENT (DAA)

Another commonly used coupling device is the Data Access Arrangement (DAA), which is a data coupler available from the telephone company. The typical DAA is packaged in a plain box usually mounted on a wall. The DAA is essentially a Data-Phone with the modem and the telephone handset and dial removed, leaving only the coupling transformer, voltage-limiting circuit, and some auxiliary circuits. The modulation and demodulation is done by the facsimile machines or by a separate modem, and a separate telephone must be ordered if dialing and voice communication are required. The telephone, if acquired, must have an exclusion key (also used on the Data-Phone) so that the user can switch either the telephone or the facsimile equipment to the DAA. If a telephone is needed, it can be provided and installed by sources other than the telephone company since the DAA protects the phone line.

When a telephone is used in conjunction with the DAA, the operating procedure for using it is the same as that for the Data-Phone. When neither dialing nor voice equipment is provided with the DAA, the facsimile equipment is permanently coupled to the telephone line.

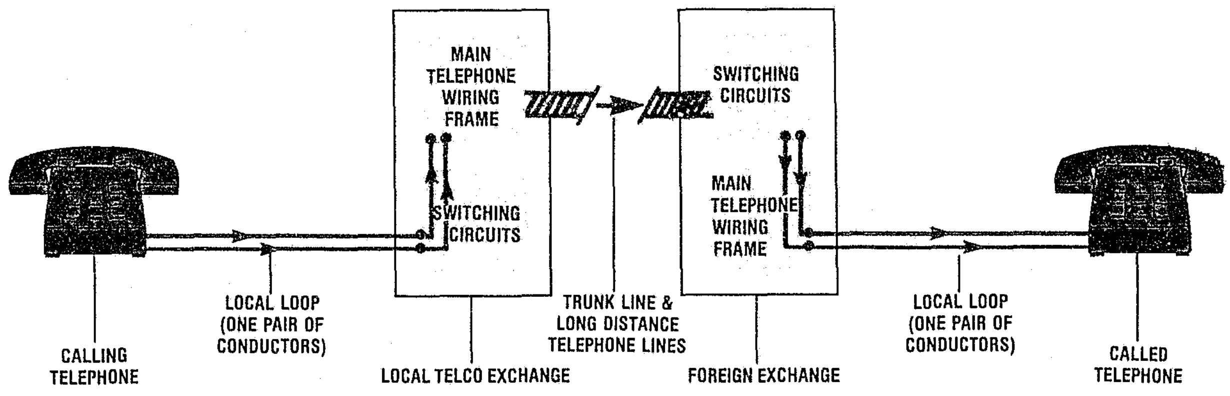
Like the Data-Phone, a DAA is available only from the telephone company, which charges a one-time installation fee and monthly rental which depends upon the model chosen. In addition to the DAAs used with operator-attended terminal equipment, other DAAs are available for use with automatic terminal equipment that can perform the entire communications operation without a human operator. The advantages of DAA are that it allows faster data transmission than an acoustic coupler and is not affected by ambient acoustic noise; it also is less expensive than a Data-Phone.

DIAL-UP SWITCHED TELEPHONE SYSTEM

The telephone system can be divided into two parts, the dial-up switched system, which is used for making ordinary telephone calls, and leased private lines supplied by the telephone company.

The dial-up switched system has the desirable feature of being an existing in-place system that provides communications between any two telephones. Simply dialing a telephone number opens a connecting channel. The switched system is almost always used for facsimile transmissions unless cost or performance dictate otherwise, in which case leased lines or other communications facilities are used. The transmission characteristics of the switched system are only marginally acceptable for facsimile transmission. Copy quality and/or transmission speed are poor, but the system is convenient.

Figure 16. Block diagram of a public dial-up switched telephone system.

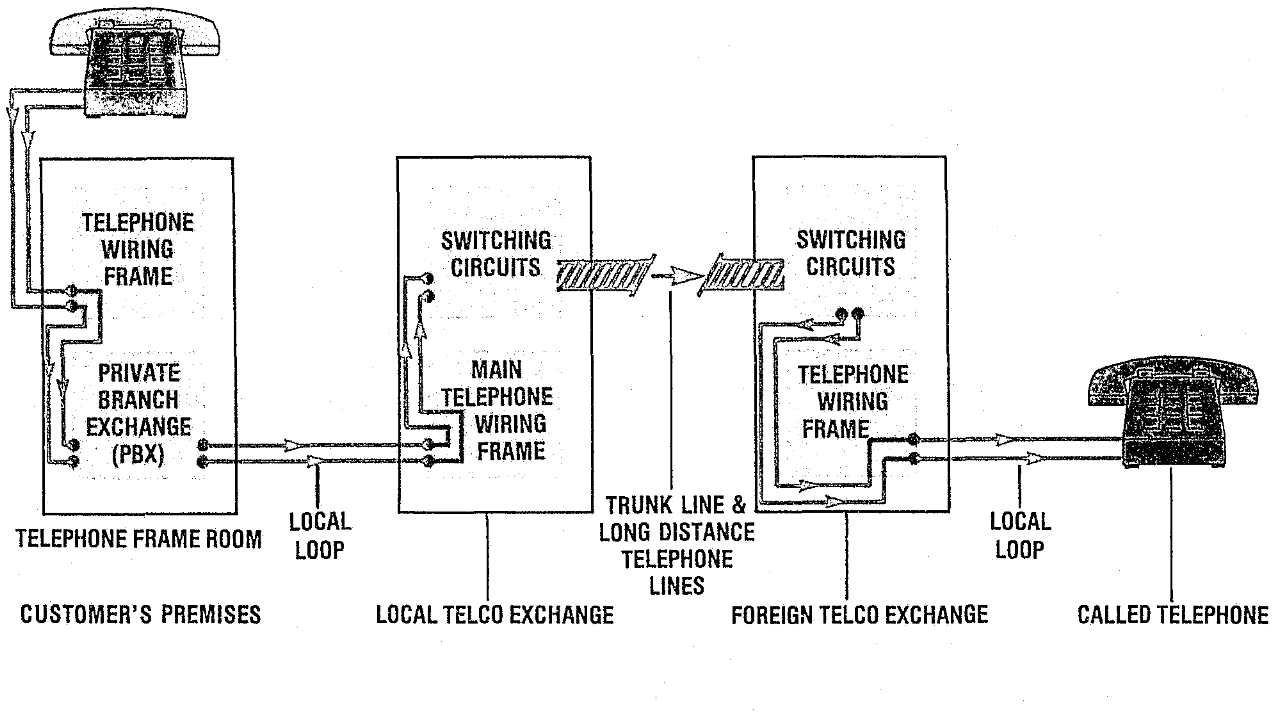


The simplest arrangement of the dial-up switched telephone system occurs when the customer has only a single telephone on the premises, as shown in figure 16. From this telephone a simple pair of wires (local loop), which serve this telephone only, go to the local telephone exchange. The wire pair will usually be contained in a cable having many other wire pairs. Cables having up to 2700 wire pairs are commonly used. At the exchange, the customer's telephone is connected directly to the main telephone frame in the local exchange and the telephone switching system.

The local loop wire pairs are the only telephone company facilities associated with individual telephones. Trunk lines and switching equipment, for instance, are common equipment used to service many telephones. There are usually many routes that can be chosen by the switching equipment to complete a connection. Thus if a user dials a particular telephone number several times, the switching system may select a different route for each call.

When a user has a large number of telephones, the route from an individual telephone to the local telephone company exchange becomes somewhat more complex, as shown in figure 17. A telephone frame room and a private branch exchange (PBX), in effect, a smaller version of the local telephone company exchange, are located on the user's premises. The wire pair for an individual telephone goes only as far as the user's telephone frame room, and from there it enters the PBX switching system. From the PBX there might be many wire pairs going to the local exchange, but fewer than the number of telephones on the user's premises, because only a small number of the telephones are expected to be in use at any moment. This reduction is the main benefit of having a PBX perform switching. When a number is dialed, the PBX connects it to an available outside wire pair which connects with the local exchange. Thereafter, the telephone call is handled as described before.

Figure 17. Dial-up telephone system with private branch exchange (PBX) on customer premises.



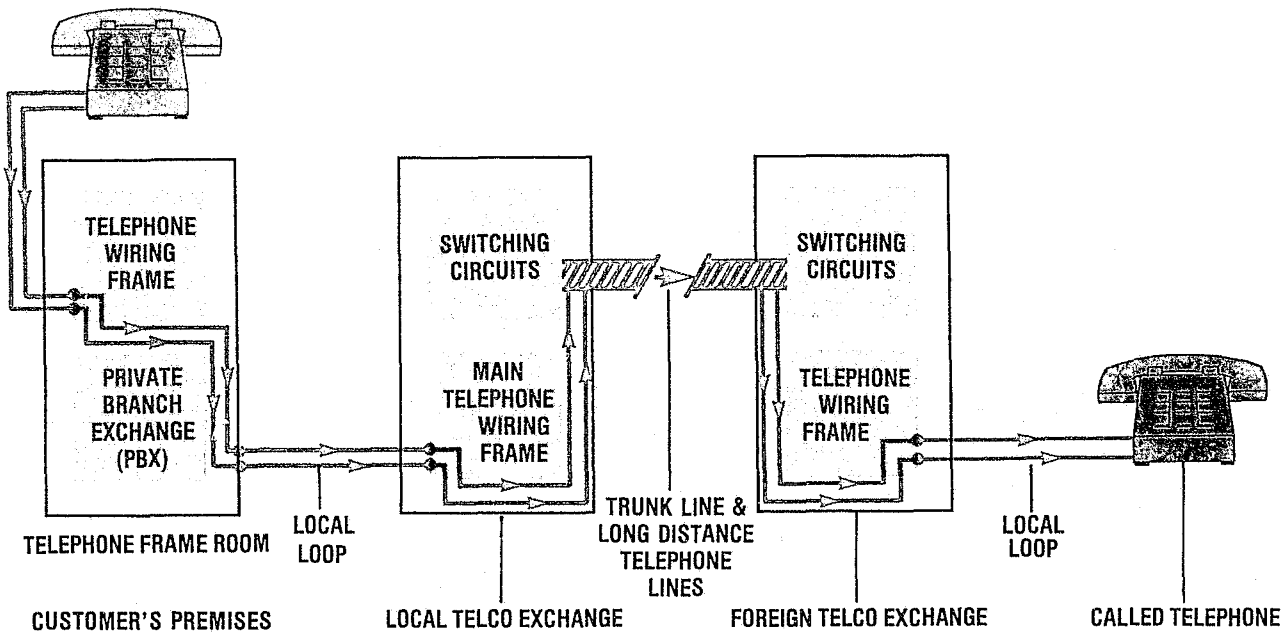
LEASED TELEPHONE LINES

When the dial-up switched telephone system cannot satisfy the telecommunications requirements of a facsimile system, one may lease private lines from the telephone company. Leased lines can provide improved electrical performance, and can also reduce communication costs for high volume users. They provide wider bandwidth, reduced envelope delay distortion, and less electrical noise, all of which increase the rate at which data can be transmitted. Use of the same channel is very important because terminal equipment can be adjusted to compensate for some of the line deficiencies. The switched telephone system's transmission path is likely to be different for each call.

An undesirable characteristic of communication channels is the presence of various noise signals that are not part of the user's signal. Much of the noise in the dial-up switched telephone system is caused by the switching facilities. Switching systems that employ stepping switches create the most interference, crossbar switching systems create less, and electronic switching systems create the least. If switching noise is a problem, the sensitive wire pair can be routed to a better switching system, or the switching system can be bypassed altogether. For example, a PBX can be bypassed by connecting the on-premises telephone (or other terminal equipment) directly to the exchange. This change is made in the customer's telephone frame room, and gives the affected telephone its own wire pair to the local exchange as shown in figure 18. The only drawback of this arrangement is that the outside local loop is dedicated to one telephone.

Many types of leased lines also bypass the switching system at the local telephone exchange

Figure 18. Bypassing the local telephone switching system.



in the same manner. However, bypassing switching limits the number of telephones that can be called. When switching is eliminated altogether, a communications channel can serve only two locations.

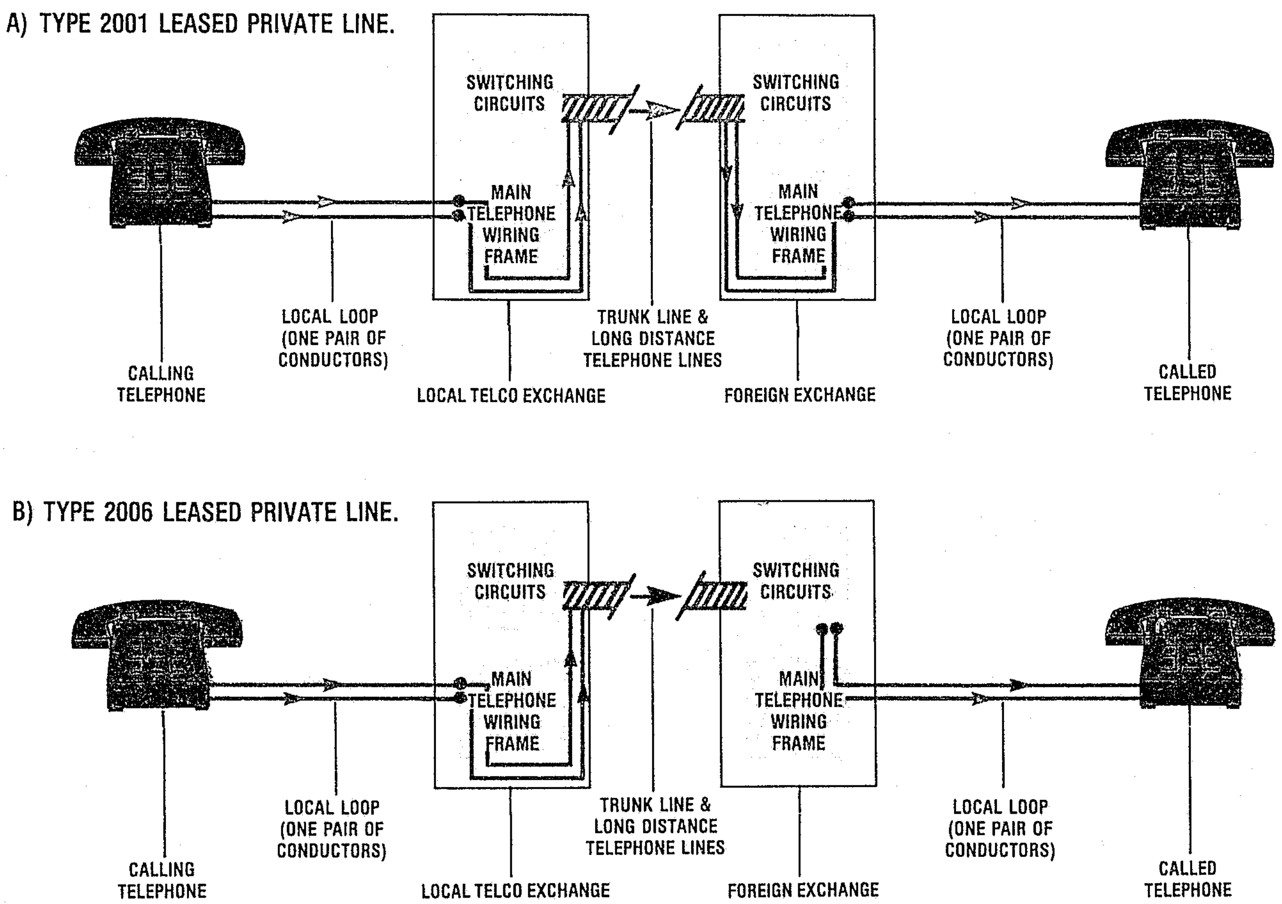
TYPES OF LEASED PRIVATE LINES

The telephone company offers many kinds of leased lines. The characteristics of, and differences between, some typical leased lines used in facsimile transmission follow.

Series 2000 leased private lines provide voice channels between local telephone company exchanges, and offer several kinds of service. Although intended for voice communications, they are also suitable for many facsimile machines and provide better transmission characteristics than the public dial-up telephone system. There are several types of service within the 2000 series and additional options within the types.

Figure 19 shows two basic types. The Type 2001 service provides a dedicated private channel between two telephones and bypasses the switching system of both local telephone company

Figure 19. Transmission paths for type 2001 and 2006 private leased telephone lines.



exchanges. The subscriber decides which telephones are to be used at each end of the channel. Because local switching is bypassed, the 2001 line is quieter than the public dial-up system.

Type 2006 service provides a private line to a foreign telephone company exchange, where the channel is connected to the public dial-up telephone system. This means that the channel is connected to the switching system of the foreign exchange, which enables the subscriber to reach any telephone in the world. However, the subscriber's telephone is the only one that can be reached from the foreign exchange (or anywhere else).

Type 3002 voice-grade channels are intended for digital data transmission, but are also used for analog facsimile when a better transmission path than that provided by the 2000 series channels is needed. The 3002 channel is a point-to-point channel which does not pass through the switching system of local telephone exchanges. In addition to the basic channel, several categories of line conditioning (e.g., C1 through C5) are available which improve the electrical characteristics so that higher data rates can be attained. Since there is no local switching, the 3002 channel connects only two telephones. The telephones need not have dials, and can provide both voice and data communications. To initiate a facsimile transmission, the user picks up the telephone handset and then pushes a ringing switch on the phone, which causes the called telephone to ring. When the attendant for the called phone picks up the handset, the operators proceed with any necessary voice communications. Then both operators initiate the actual facsimile transmission by pulling up the exclusion key (a switch located on the handset cradle).

The Type 4002 line is another voice-grade, point-to-point channel that bypasses local telephone company switching. In addition, it is especially conditioned for analog facsimile use and handles frequencies between approximately 1200 and 2600 Hz. This channel is also known as a telephoto (Schedule 2) line.

COST OF LEASED PRIVATE LINES

The cost of a private line depends on the service options and other details which a user chooses. Generally the monthly charge consists of terminal charges and a mileage charge. These charges depend on, for example, line type (e.g., 2001, 2006, 3002, 4002), line conditioning, whether short lines or long lines are required, whether low density or high density exchanges are involved, and whether multipoint or optional switching arrangements are to be used. Current costs of interstate leased private lines can be obtained from the Long Lines Department of the American Telephone and Telegraph Company; information concerning intrastate private lines can be obtained from local telephone business offices.

OTHER ELECTRONIC COMMON CARRIERS

There are approximately 10 other companies that provide communications services to the public. Among these are American Satellite Corporation, MCI Communications Corporation, and Western Union Telegraph Company. Some of the services offered differ from those provided by the telephone company, while others duplicate telephone company services. Information concerning interstate services and prices of electronic common carriers is provided by the Center for Communication Services [2]*.

* Numbers in brackets refer to references in appendix B.

EVALUATION OF FACSIMILE IMAGE QUALITY

There are some simple, but very useful tests that measure the quality of facsimile reproductions. The tests provide an easy and reliable way to compare facsimile machines and estimate how well the performance criteria suggested in the Image Quality Criteria section are met. The tests consist of transmitting a facsimile test chart and examining the copy produced by the facsimile receiver.

THE IEEE FACSIMILE TEST CHART

The IEEE Facsimile Test Chart is the best known one in the United States [3] (fig. 7). Although only a few of the chart's test patterns will be described in this guide, the reader might find it worthwhile to obtain a copy of the chart to see if some of the other test patterns might be useful.

The test patterns of interest are:

Pattern No.	Name	Use
13	Multiple-line wedge	Measures horizontal resolution
7 or 8	Step density tablet	Measures gray-scale performance
15	Photograph	Indicates pictorial capabilities
25	Type faces	Shows legibility of printed text

HORIZONTAL (x-DIRECTION) SPATIAL RESOLUTION

The x-axis resolution of a facsimile reproduction is the line density along the length of the raster lines for which individual lines are just discernable, using a magnifier if necessary. It is a characteristic which is frequently omitted from data sheets for facsimile machines. The multiple-line wedge pattern (#13 in fig. 7) is used to determine the x-axis resolution.

The calibration numbers adjacent to the pattern give the line density in lines per inch. Here, white and black lines are *both* counted. Thus the calibration number 50 means that there are 25 black lines and 25 white lines in each inch (25 line-pairs per inch). In other cases, only *black* lines are counted. This is the case, for example, for raster density in the y-direction discussed below.

VERTICAL (y-DIRECTION) SPATIAL RESOLUTION

It is characteristic of raster display systems that the raster structure can interact with certain kinds of picture elements and produce a copy that is different from the subject copy. There are several ways that this kind of interaction can manifest itself, but that illustrated in figure 20 is of special interest because it demonstrates that the y-direction spatial resolution will vary according to the combination of test details that exists at the moment. The test pattern of alternating black and white bars is reproduced correctly when the transmitter scan lines pass along the centers of the bars on the subject copy. If the bar pattern is displaced slightly so the scan lines pass along the edges of each bar, the scanner sees equal amounts of black and white and interprets this as gray and the printer draws every raster line a uniform gray. If the printer's line width is the same as the center-to-center spacing of successive raster lines, the bar pattern is reproduced as an area of uniform gray with the bar pattern completely lost. Note that under one set of test conditions a facsimile system might completely fail to reproduce a bar test pattern. A slight change in the position of the pattern with respect to the transmitting scanner could result in a perfect reproduction. Other facsimile machines and test patterns can also be expected to produce variable results for y-direction spatial resolution. Y-direction spatial resolution is not a clear-cut value and is difficult to work with. This may be why facsimile equipment data sheets do not specify the y-direction spatial resolution. As a working approximation, the y-direction spatial resolution, in line-pairs per unit length, can be taken to be equal to 0.35 times the

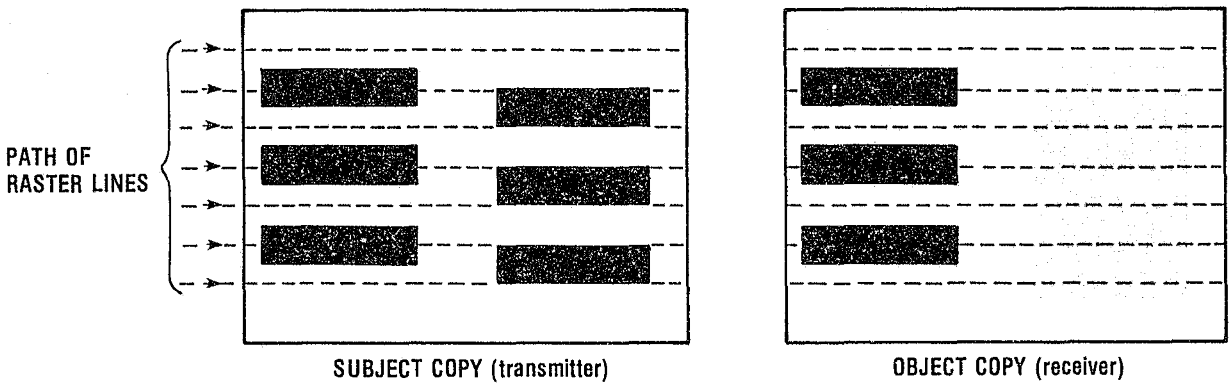


Figure 20. An example of the ambiguity of y-axis spatial resolution measurements.

raster line density. For example, if the raster density is 200 scan lines per inch, then the y-direction spatial resolution would be approximately 70 line-pairs per inch.

Some facsimile machines exhibit the same problem in the x-direction. The problem occurs in scanners that examine the subject document at fixed locations along each scan line rather than scanning continuously along the line. Some of the newer scanners use a fixed, miniaturized photodetector array to examine the subject document. The array has 1728 separate photocells in a single line and because the individual photocells are fixed in position, the same deleterious effect on spatial resolution occurs as with the fixed raster structure. The 1728 evaluation points along each raster line scan a little more than 200 points per inch for an 8.5-in line. Because of the discrete nature of this scan process the useful x-direction spatial resolution is probably around 70 line-pairs per inch rather than the 100 line-pairs per inch that otherwise would be obtained.

GRAY-SCALE REPRODUCTION

The step density tablet, figure 7, test pattern #7 or #8, provides a good test of the ability of a facsimile machine to handle photographs and other continuous-tone material. The numbers 5 and 10 beneath pattern #8 identify the individual steps in these patterns. The reflection density makes each step produce approximately equal visual change. The copy is evaluated by visually estimating how many distinct shades of gray are discernible in the tablet reproduction. It is to be kept in mind that different observers are likely to differ in their judgments of the number of discernable shades of gray, and thus the test results are somewhat crude unless a densitometer is used to measure the reproduced gray scale. It is customary to count full black and full white each as a shade of gray.

The photograph, pattern #15, is used to display how well the facsimile system reproduces continuous-tone material. A comparison of figures 21 and 22 demonstrates that picture quality is improved when the gray-scale capability of a facsimile system is improved. This pair of facsimile copies was made on facsimile equipment that has a front panel switch for selecting either high or low contrast transmission. An estimate using the step density tablets reveals that the original copy (fig. 21) contains 5 or 6 shades of gray and the facsimile copy (fig. 22) contains 8 to 10. Note that figure 21 is somewhat better in reproducing text, while figure 22 is superior in photographic reproduction.

LEGIBILITY OF TEXT

Test pattern #25 of figure 7, which includes elite and pica type, is used to determine the ability of facsimile equipment to reproduce printed material legibly.

Figure 21. High-contrast facsimile reproduction. The outer portions of the chart do not appear.

Figure 22. Low-contrast facsimile reproduction. The outer portions of the chart do not appear.

IMAGE QUALITY CRITERIA

It is important that a system produce satisfactory copy quality. This section discusses the image quality required for texts, continuous-tone documents, and fingerprints. A complication that arises when trying to establish criteria is that human judgment is involved, and people have different ideas about what is acceptable. The primary image parameters that should be considered are spatial resolution, gray scale, and the reproduction fine structure.

QUALITY FOR TEXT

The image quality for satisfactory reading of text depends upon the degree of legibility required. In some cases, each individual letter and number must be clearly recognizable, and in others, some individual illegible characters might be acceptable, provided that the words containing them are recognizable. A generally accepted guideline [4] is that characters will be individually recognizable when they are vertically composed of at least 10 raster lines (it is assumed that the raster lines do not significantly overlap one another). If each letter is composed of only five raster lines, some of the individual letters will not be recognizable, but the words they form probably will be recognized [4]. When reproducing numerals, it is almost always essential that each digit be clear. The horizontal spatial resolution should be good enough to resolve about five line pairs within the dimension of the character. If the original document is of poor legibility, such as a poor copy or a poor handwritten document, then the facsimile system should have even better spatial resolution.

If the text is computer generated, the characters will probably be presented to the facsimile printer in the form of a 5 x 7 dot matrix (fig. 23), in which only seven vertical raster lines are required to produce individually recognizable characters. Horizontally, the facsimile must be able to produce five discernible dark lines (nine lines if the sum of black and white lines is counted). Figure 24 shows a sample of computer generated text. The reason

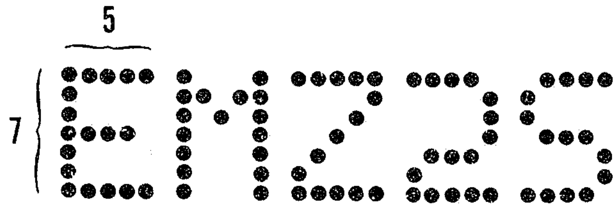


Figure 23. Examples of alphanumeric characters formed from a 5 7 dot matrix.

that the computer generated text works well with characters only seven raster lines high is that each character is entered into the computer in perfect form by teletype or an equivalent means and is then reproduced by seven (sometimes more) consecutive raster lines. On the other hand, with most facsimile transmitters, some of the character detail tends to fall between the scan lines and be lost. In order to compensate for this loss, more scan lines per character are required. This was examined from a slightly different viewpoint earlier.

Text and line drawings are reproduced most sharply when the facsimile system has very high contrast. Facsimile transmitters that are designed specifically for such documents usually produce only a two-level output, one level for black and another for white. Facsimile machines that use digital techniques to eliminate redundant data are of this type because the speed of the operation would be reduced substantially if gray-scale information were transmitted also. If a facsimile system is used to transmit both continuous tone and line documents, two choices are available: a system having some gray-scale capability, or a system that can operate in both modes.

The best way to determine what constitutes acceptable facsimile quality is to transmit typical samples of the document types to be handled. Test pattern #25 of figure 7 is useful for checking performance on text materials, and a test using the expected color, size, and legibility is appropriate for checking reproduction of handwriting.

CONTINUOUS-TONE DOCUMENTS (PHOTOGRAPHS)

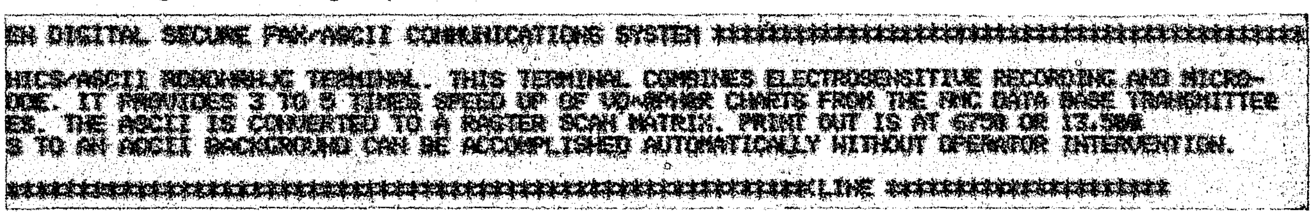
The ability of a facsimile system to satisfactorily reproduce the original gray scale of photographs and other continuous-tone documents is also important. The object copy produced by many facsimile machines has much higher contrast than the subject copy. This causes all detail in shadow and in highlight areas to be lost (to reproduce as a uniform black or white). Use of a gray-scale test pattern (#7 or #8 of fig. 7) provides the easiest and most reliable way to evaluate gray-scale characteristics. When transmitted over a facsimile system it clearly shows the gray levels at which shadow and highlight detail are lost. If six shades of gray from pattern #7 or #8 of figure 7 can be reproduced, the system is likely to be satisfactory for casual continuous-tone documents although quality will not be good. Eight or more shades of gray will usually produce a copy of good quality. The spatial resolution required for satisfactory picture reproduction is so dependent upon the type of picture and the use to be made of it, that no specific suggestions will be offered.

FINGERPRINTS

Better than average facsimile equipment is required for the successful transmission of fingerprints. A raster density of 200 lpi and an x-direction resolution of 100 line-pairs per inch are required. Fairly good gray-scale reproduction, perhaps seven or more shades of gray, is important, so that detail in areas that are either smudged or lightly inked will not be lost. The type of facsimile equipment now preferred for transmission of fingerprints meets the above requirements for spatial resolution and gray-scale reproduction. Figure 25 shows the results of transmitting some fingerprints and test patterns through a public dial-up telephone system. The object copy was produced with a raster density of 192 lpi on photographic paper. The test chart showed the x-direction resolution to be 90 line-pairs per inch; 11 or 12 shades of gray were reproduced.

It is not always necessary to use fingerprint-quality facsimile machines for transmission of fingerprints. An alternative is to transmit a photographic enlargement two or more times larger than the original fingerprints via a business convenience or other available facsimile machine. Use of the enlargement will require that the fingerprint card be sent piecemeal because it will be too large for the facsimile machine. If the original fingerprints are properly inked and free of smudges, the poorer tonal performance of the convenience facsimile machine might not matter, and a 2X enlargement transmitted at 96 lpi might produce about the same detail as a high-grade fingerprint facsimile system.

One company has developed a prototype facsimile system whose transmitter accepts the original size fingerprints and whose receiver produces a 2.4X enlargement. The enlargement technique eliminates the need for photographic enlargements. This system prints the object copy on electrolytic paper at 100 lpi, 50 line-pairs per inch in the


EN DIGITAL SECURE FAX/ASCII COMMUNICATIONS SYSTEM **

HICS/ASCII [illegible] TERMINAL. THIS TERMINAL COMBINES ELECTROSENSITIVE RECORDING AND MICRO-
ODE. IT PROVIDES 3 TO 5 TIMES SPEED UP OF [illegible] CHARTS FROM THE [illegible] DATA BASE TRANSMITTER
ES. THE ASCII IS CONVERTED TO A RASTER SCAN MATRIX. PRINT OUT IS AT [illegible] OR 13.[illegible]
S TO AN ASCII BACKGROUND CAN BE ACCOMPLISHED AUTOMATICALLY WITHOUT OPERATOR INTERVENTION.

LINE ******************

Figure 24. Hard copy produced by a facsimile receiver being used as a digital printer.

Figure 25. Object copy produced by a fingerprint-grade facsimile system. The outer portions of the chart do not appear.

x-direction, and approximately six shades of gray from the IEEE Facsimile Test Chart. It is similar to the copy shown in figure 9. The system, which produces a 2.4X enlargement, scans the fingerprint original with 240 lpi. A sample of a fingerprint photographically enlarged to 3X is shown in example b of figure 26. The clearly visible raster lines tend to compete with some of the visual detail, but the system seems to be satisfactory for many fingerprint needs.

Example d of figure 26 shows the result of transmitting fingerprints through a facsimile system which has the same raster scan density (200 lpi) as the preferred system (example c of fig. 26), and essentially the same x-direction resolution and gray-scale capability, but does not reproduce fingerprints as satisfactorily because of the fine structure produced by facsimile printers. This fine structure, which is similar to the dots that make up the halftone pictures in newspapers and magazines, is distracting and degrades the picture image the same way a distinct raster pattern does. Except for a slightly visible raster pattern, the preferred facsimile system has no discernible fine structure because it uses a high-quality photographic printing technique.

The image quality required for fingerprints depends upon the use to be made of the fingerprints and upon the preferences of the identification personnel using them. As usual it is best to make transmission tests with both good and poor fingerprints. The evaluation of the facsimile images should be performed by the identification personnel who will actually be using the received fingerprints. If the fingerprints are to be read by automated fingerprint reading machines, then it is essential to conduct tests to determine whether or not the facsimile reproductions are compatible with the automated reader.

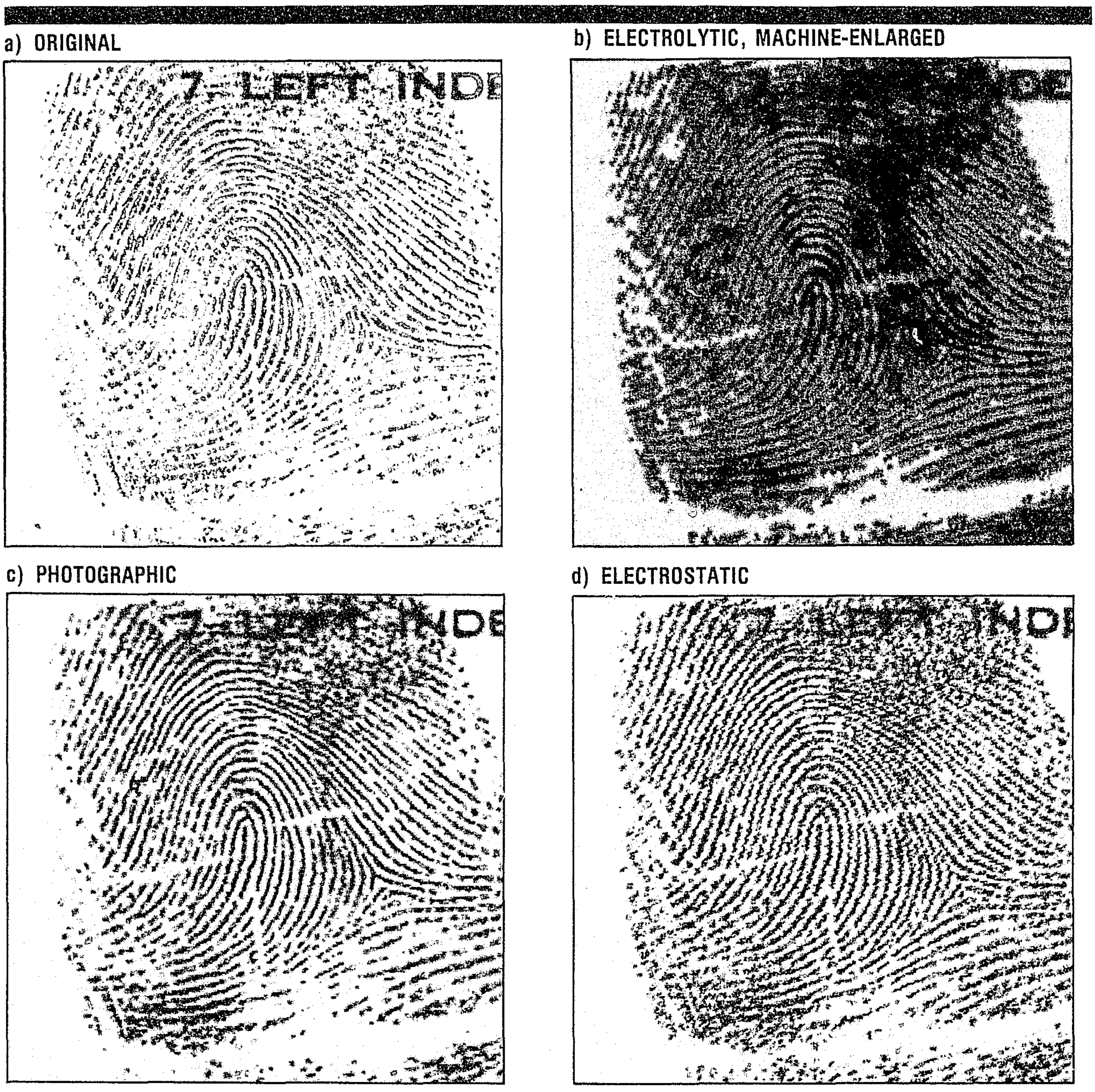


Figure 26. Facsimile reproduction of fingerprint minutiae.
To satisfactorily display the minutiae, the images in figure 26 are three times the size of the original fingerprint. Figure a is an ordinary ink-on-paper fingerprint. Figures b, c, and d are facsimile reproductions of the fingerprint original. Figure b was produced by a facsimile system that itself gives a 2.4X enlargement, uses a raster scan density of 240 lpi with respect to the fingerprint original, and reproduces six shades of gray from the IEEE test chart. Figures c and d are from systems that use a 200 lpi raster, reproduce 10 or more shades of gray, and do not provide enlargement. The facsimile printing media are electrolytic paper, photographic paper, and dielectric (electrostatic) paper for b, c, and d, respectively.

LAW ENFORCEMENT USES OF FACSIMILE

The most common law enforcement uses for facsimile are for rapid transmission of messages and fingerprints. They can also be used to transmit identification photographs and to function as teletype or computer output printers for text and graphics. In some cases, mobile facsimile can be used in police cars.

MESSAGE FACSIMILE

Criminal records and warrants are successfully transmitted by facsimile. Although facsimile copies of warrants are legally valid in some areas of the United States, they might not be acceptable everywhere. One locality in Florida speeds warrants to their destination via a mobile facsimile receiver, an arrangement that saves both time and fuel. A satisfactory message facsimile system must be able to reproduce the smallest print on the documents to be transmitted. Before equipment for such a system is selected, a survey should be made of all documents that might be transmitted in order to determine the minimum print size, and also to establish the maximum overall page size. The best choice may not be a marginally legible system because more time is needed to read it, and reading errors occur.

FINGERPRINT FACSIMILE

The traditional 8 x 8-in fingerprint card is still the preferred storage medium for fingerprints, although computer-controlled fingerprint reading and storage machines have been introduced. Desirable characteristics of cards, such as flatness and flexibility, and the permanence of printer's ink have been very difficult to improve upon. For this reason facsimile reproductions are not normally used in permanent files. Facsimile copies produced on photographic paper tend to curl and the photographic emulsion might crack. Copies that consist of a black toner are sometimes degraded by the toner fading or brushing off after a period of time.

Some fingerprint facsimile systems are intended to be used only when a rapid response is considered important, while others are routinely used for all fingerprint cards. Two of the fingerprint facsimile systems in use are an emergency system and an all-purpose system.

One fingerprint facsimile system used for quick response is the one operated by the FBI, which consists of a fingerprint facsimile receiver in the FBI Building in Washington, DC, and facsimile transmitters located in participating law enforcement agencies. The FBI receives one or two facsimile fingerprint cards per participant per day on this system. These are given priority handling, and if an identification is made then the arrest record is transmitted to the requesting agency via a separate message facsimile machine. Economy dictates that the public dial-up telephone system be used for the facsimile communications channel. The requesting agency is required to pay for the telephone call(s), but the fingerprint search is provided at no charge, as are all FBI fingerprint searches. Because this system uses the public dial-up telephone system, any other agency can join it by acquiring a fingerprint transmitter that is compatible with the receiver used by the FBI.

The New York State Division of Criminal Justice Services uses a fingerprint facsimile system to send all fingerprint cards, non-rush as well as rush, to a central identification bureau in Albany, NY. The more densely populated areas of the State routinely send their new fingerprint cards to the bureau via facsimile. The purpose of this system is to get new cards into the files quickly and to make fast identifications. More than 24 fingerprint facsimile receivers are in use at the Albany location, and over 40 transmitters are employed throughout the system by participating agencies. Albany receives more than 20,000 transmitted facsimile cards each month, and because utilization is high, leased private lines are used for the communications channels. The facsimile reproductions are stored only temporarily; the original fingerprint card is mailed to Albany after the facsimile transmission has been made and eventually replaces the facsimile copy.

COMBINED ALPHANUMERIC AND GRAPHIC PRINT-OUT

Recently the capabilities of some facsimile receivers have been extended so that they can function both as receiver and printer for a teletypewriter and/or computer terminal. Early indications are that this dual capability will be attractive in the marketplace. This capability is added to a facsimile receiver by an electronic interface device that converts the digital coding of the incoming alphanumeric characters into the raster display form that the facsimile printer requires.

The printing speed for teletype and small computer terminal printers is usually between 100 and 300 words per minute. The printing speed for a facsimile printer can be estimated by simple calculations based on known facsimile characteristics. As an example, assume that an ordinary business convenience facsimile receiver is to be used to print characters in the format of a 5 x 7 dot matrix (fig. 23). (A 5 x 7 dot matrix can produce all 10 digits and all upper and lower case letters.) This requires that the facsimile printer produce five resolvable dots horizontally and seven dots vertically within the area of a maximum size letter. In order to provide separation between individual characters in a line, and also between lines, the equivalent of two dots between successive characters and three dots between lines are added for spacing. This results in each character claiming a 7 x 10 dot matrix area. To determine the printing speed obtained with this arrangement it is necessary to know the horizontal spatial resolution, the length of a raster line, and the number of raster lines scanned per minute. Business convenience machines generate 180 raster lines per minute, have a printing line length of around 8 in, and a spatial resolution of about 50 line-pairs per inch (50 resolvable dots per inch). Thus, about 400 resolvable dots can be produced on each line, which corresponds to 57 (= 400/7) characters per line. Because 10 vertical dots are needed, 10 raster lines per line are required, so 57 complete characters with the necessary spacing will be printed in the time required to draw 10

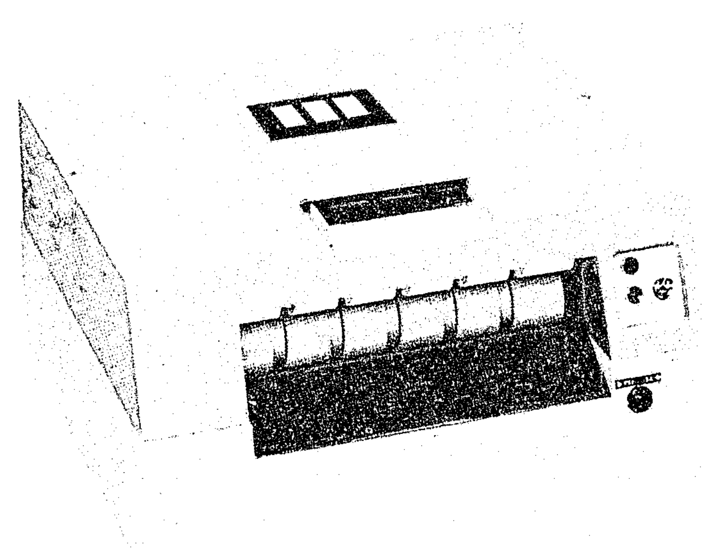


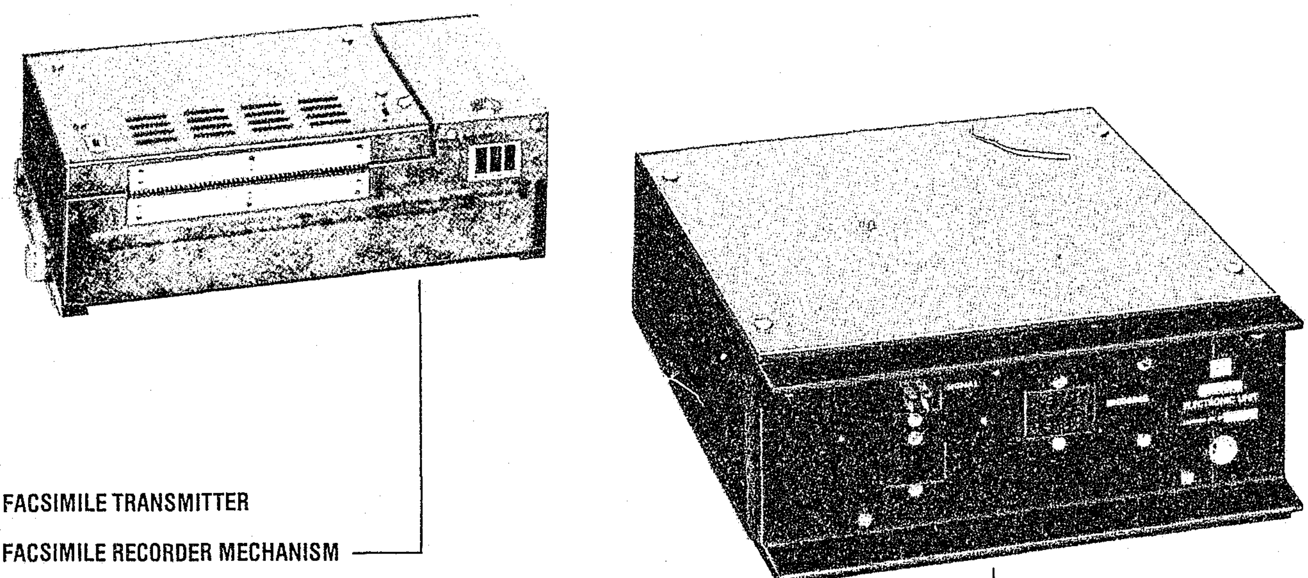
Figure 27. Equipment for a mobile facsimile system.

raster lines, giving a printing speed of 57 x 180/10 characters per minute, i.e., 1026 characters per minute. This is equivalent to 171 words per minute. Even the least expensive facsimile machine is able to print characters in matrix format at respectable speed. Better print quality can be obtained by increasing the character size so that a larger matrix, such as 7 x 9 or larger, (these numbers are for the characters and do not include allowance for spacing) can be used, although this reduces the printing rate.

It has been demonstrated that even when no effort is made to optimize performance, inexpensive facsimile machines give a respectable printing speed. Interface devices needed to convert incoming digitally coded characters into a raster matrix are manufactured for a number of high performance facsimile receivers, but are not available for most business convenience machines. A sample of text printed in raster-matrix form by a commercially available interface and facsimile receiver is shown in figure 24. The characters are formatted in a 5 x 7 dot matrix and have the equivalent of two additional dots of space between. Depending upon the details of the system, up to 12,000 characters per minute can be printed.

MOBILE FACSIMILE

Figure 27 is a photograph of a commercially available facsimile system designed specifically for mobile use. The equipment is packaged in three separate units: a facsimile transmitter at a fixed base station, an electronics package in the trunk of a vehicle, and a printing head in the passenger compartment of the vehicle. These units can be easily incorporated into an existing voice radio system. The facsimile transmitter supplies an



FACSIMILE TRANSMITTER

FACSIMILE RECORDER MECHANISM

REMOTE RECORDER ELECTRONICS

audio frequency FM-modulated facsimile signal that can be connected directly to the audio input of a base station radio transmitter, and the vehicle mounted facsimile receiver obtains its input signal directly from the audio output of a vehicle's existing radio receiver.

Facsimile equipment other than that specifically manufactured for mobile use should be considered because this increases the number of options from which to choose. Units that are small and require only a voice-grade communication channel for the facsimile signal are likely candidates. It is also necessary to consider the effect of mechanical shock, vibration, temperature extremes, etc. on the facsimile equipment. Most of these units need an inverter to convert the vehicle's 12 V dc power into 117 V ac. There are a few facsimile machines that can operate directly from the vehicle's dc power source.

Several possible uses for mobile facsimile are listed below. All of these uses require a facsimile receiver in the vehicle(s) and a facsimile transmitter at the base station.

1) Reception in the vehicle of printed documents such as warrants, criminal data, and maps.
2) Reception in the vehicle of identification photographs.
3) Reception in the vehicle of identification fingerprints.
4) Printer for mobile digital communications terminal.

Some police cars have been equipped with a digital communications terminal that includes an alphanumeric keyboard for entering data for transmission to the base station, and an alphanumeric display device for temporarily displaying the information sent to and received from the base station. Sometimes a printer is also provided in the vehicle. A facsimile printer could serve as this hard copy printer and also provide capabilities one, two, and three listed above.

A mobile facsimile system can be implemented, step-by-step, starting with a simple system that is only used, for example, for the reception of printed documents. Later, the system can be expanded to include the other capabilities on the list.

The major drawbacks to use of mobile facsimile tend to be lack of radio channel air time, lack of equipment funds, and lack of space in the vehicle. Depending upon the amount of information to be sent and how efficiently the system can transmit it, the time taken by a single facsimile transmission is likely to be approximately a few seconds to 6 min. The transmission time will probably be more than 1 min for items one, two, and three of the above list. Therefore, a radio communications system that is already operating near capacity will not welcome facsimile as an additional load.

The problem of obtaining funds to purchase facsimile equipment is a common problem. Leasing should be considered, as it avoids the large initial outlay, and also takes care of equipment servicing and maintenance.

Finally, one must consider whether there is enough space in the vehicle to accommodate the facsimile equipment comfortably. If, for example, a squad car is already equipped with a mobile digital terminal, there may not be room for a facsimile system. However, one manufacturer claims that, if the need exists, a facsimile printing head could be built to fit in the glove compartment.

EQUIPMENT SELECTION CRITERIA

System requirements:

- Uses to be made of the facsimile system
- What communications equipment and personnel are used now and how will the facsimile system interface with them?
- Acceptable initial, operating, and maintenance costs

Facsimile transmitter and receiver:

- Copy quality
- Transmission time per document or maximum number of documents per hour (includes loading time)
- Convenience and ease of use
- Reliability, maintenance, and service life
- Initial, operating, and maintenance costs

Communications channel:

- Bandwidth
- Reliability
- Type (telephone, radio, etc.)
- Cost

Compatibility with other existing or future systems.

APPENDIX A
IMAGE QUALITY ON A NOISY RADIO CHANNEL

In March 1976, tests were conducted at the Boulder, CO, laboratories of the National Bureau of Standards to determine the signal-to-noise ratio at which the image quality of a particular facsimile system becomes degraded. The Muirhead Mercury IV Mobile Facsimile System, the only off-the-shelf facsimile equipment manufactured specifically for mobile use, was chosen for the test. Its facsimile receiver is designed to be mounted in a vehicle; the facsimile transmitter is intended to be used at a base station. In normal use, the signal (an FM-modulated audio signal containing frequencies between 300 and 3000 Hz) from the facsimile transmitter is fed into the audio input of a base

station radio transmitter. The facsimile receiver is driven from the vehicle's existing radio loudspeaker terminals.

The tests used a well-shielded signal generator in place of a base station transmitter. The signal from the facsimile transmitter was connected to a modulation input terminal of the signal generator, and the generator's controls were adjusted to produce a narrow-band FM signal in the vhf high-band frequency range. The generator's rf output was connected by coaxial cable directly to the antenna input of a mobile radio receiver. The testing reduced the level of the rf signal reaching the receiver's antenna until some facsimile degradation occurred. By reducing the signal level, any desired signal-to-noise ratio could be obtained at the input to the receiver antenna.

The term Sinad, from **Si**gnal + **N**oise **a**nd **D**istortion, refers to a method frequently used to measure the performance of FM receivers under weak signal conditions. Twelve decibels Sinad tends to be accepted as the point below which voice communication cannot be conducted. The tests demonstrated that the facsimile system was unusable with radio signal levels that resulted in a 12 dB Sinad performance (signal=0.4 μV for the receiver used), but signals 8 dB higher (signal=1 μV) produced picture quality as good as that produced by much stronger signals. The quality of the facsimile image improved very rapidly as the signal strength was increased above the 12 dB Sinad level (fig. A-1).

Figure A-1. Picture quality over noisy radio channel.

APPENDIX B
ANNOTATED REFERENCES AND BIBLIOGRAPHY

1. Lucian M. Biberman, ed., **Perception of Displayed Information,** (Plenum Press, New York, NY, 1973).

This book contains a detailed analysis of visual images produced by television raster displays. Topics include the display, the response of the eye to raster displays, and system requirements. A technical background is essential for full understanding, but readers who lack technical expertise will benefit from the easier portions of the text.

2. **The Guide to Communication Services.**

This is a looseleaf handbook for which updating pages are periodically issued. It describes interstate communication services provided by electronic common carrier companies, as well as their principal technical characteristics. An annual subscription is available from:

Technical Editor
Center for Communications Management, Inc.
P.O. Box 324
Ramsey, NJ 07446

3. **IEEE Facsimile Test Chart,** IEEE Standard #167A-1975, (Institute of Electrical and Electronic Engineers, 1975).

The IEEE Chart is the facsimile test chart most commonly used in the United States. It is an $8\frac{1}{2}$ x 11-in glossy photograph containing numerous test patterns and an information sheet describing the patterns. The test chart is available as Catalog #SH11676 from:

IEEE Service Center, Attention: SPSU
445 Hoes Lane
Piscataway, NJ 08854

4. Daniel M. Costigan, **Fax, The Principles and Practice of Facsimile Communication,** (Chilton Book Company, Philadelphia, PA, 1971).

This book on the general subject of electronic facsimile includes chapters on facsimile uses, theory, costs, standards, and a 60-page illustrated listing of commercial equipment.

5. George F. Stafford, **Police Communications by Alden,** (1975).

This booklet concerns itself with the facsimile transmission of text, fingerprints, and photographs using equipment manufactured by Alden. Mobile facsimile systems and digital transmission of text are among the subjects discussed. This booklet is available from:

Alden Electronic & Impulse Recording
Equipment Co., Inc.
Alden Research Center
Westboro, MA 01581

6. **Definitions of Terms on Facsimile,** IEEE Standard 168-1956, (Institute of Electrical and Electronic Engineers, 1971).

This short publication is useful as an introduction to many of the terms and concepts of facsimile. The IEEE Standard is the same as ANSI Standard C16.30, and is available as Catalog #SH00984 from:

IEEE Service Center, Attention: SPSU
445 Hoes Lane
Piscataway, NJ 08854

7. **Test Procedure for Facsimile,** IEEE Standard 167-1966, (Institute of Electrical and Electronic Engineers, 1966).

This publication describes tests for measuring a large number of facsimile characteristics and is addressed to readers who possess a technical background. This IEEE Standard is identical to ANSI Standard C16.37-1971, and is available as Catalog #SH00976 from:

IEEE Service Center, Attention: SPSU
445 Hoes Lane
Piscataway, NJ 08854

8. Planning Division of the Cranston Department of Police, (Cranston, RI, 1976).

This is a directory that lists the names and addresses of criminal justice agencies in the United States that possess facsimile transmitters. No information is given as to the kind of transmitter(s) possessed. The agencies are grouped by State and city. The publication is available from:

Planning Division
Cranston Department of Police
275 Atwood Avenue
Cranston, RI 02920

9. **Guide to Facsimile Equipment,** (Auerbach Publishers, Inc., Philadelphia, PA, 1975).

This publication describes commercially available facsimile machines. It contains an introduction, tabular data, and descriptions of facsimile equipment from 18 manufacturers. Selected facsimile equipment is described in greater detail, including maintenance, system design, and price. The guide is available from:

Auerbach Publishers, Inc.
121 N. Broad Street
Philadelphia, PA 19107

APPENDIX C
FACSIMILE EQUIPMENT MANUFACTURERS*

Alden Electronic & Impulse Recording Equipment Co., Inc.
1 Washington Street
Westboro, MA 01581
(617) 366-8851

Burroughs Corporation
Corporate Drive
Commerce Park
Danbury, CN 06810
(203) 794-0191

Compression Labs
4300 Stevens Creek Blvd.
San Jose, CA 95129
(408) 985-0777

Faxon Communications Corporation
P.O. Box 125
Purchase, NY 10577
(914) 694-1177

Harris Corporation
Government Communication Systems Division
P.O. Box 37
Melbourne, FL 32901
(305) 727-4000

Infolink Corporation
1925 Holste Road
Northbrook, IL 60062
(312) 291-2900

Litton Industries
Datalog Division
1770 Walt Whitman Road
Melville, NY 11747
(516) 694-8300

Muirhead, Incorporated
1101 Bristol Road
Mountainside, NJ 07092
(201) 233-6010

NEC America
532 Broad Hollow Road
Melville, NY 11746
(516) 752-9700

Panafax Corporation
185 Froehlich Farm Boulevard
Woodbury, NY 11797
(516) 364-1400

Qwip Systems
927 Fern Street
Altamonte Springs, FL 32701
(305) 830-2400

Rapicom, Inc.
2972 Stender Way
Santa Clara, CA 95051
(408) 727-7200

SP/Distributed Message Systems
1700 Old Meadow Lane
McLean, VA 22101
(703) 734-7121

Stewart-Warner Datafax Corporation
1300 North Kostner Avenue
Chicago, IL 60651
(312) 292-3000

Talos Systems Inc.
7419 East Helm Drive
Scottsdale, AZ 85260
(602) 948-6540

Telautograph Corporation
8700 Bellanca Avenue
Los Angeles, CA 90045
(213) 776-5022

Xerox Corporation
Office Products Division
1341 West Mockingbird Land
Dallas, TX 75247
(214) 689-6000

3M Company
Facsimile Products
Business Communications Products Dept.
3M Center
St. Paul, MN 55144
(612) 733-1110

**Communications News* has been publishing annually a list of facsimile equipment manufacturers and types of equipment available. See, for example, the September 1980 issue. For a periodic update, contact the Editor, Communications News, 124 South First Street, Geneva, IL 60134. Phone (312) 232-1400.

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