

UNCLASSIFIED

AD NUMBER

ADB042604

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; OCT 1979. Other requests shall be referred to Rome Air Development Center, Attn: ISFA, Griffiss AFB, NY 13441.

AUTHORITY

RADC ltr, 11 Mar 1982

THIS PAGE IS UNCLASSIFIED

AD B042604

AUTHORITY:

PRADC USAF

171, 11 MAR 82



THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

L

RADC-TR-79-275
In-House Report
October 1979

(2)

LEVEL #

AD B 0 4 2 6 0 4

LONG RANGE MICROIMAGE TRANSMISSION TECHNIQUES STUDY FOR AFMPC



Leon McDowell

DDC FILE COPY



DDC
R
DEC 17 1979
A

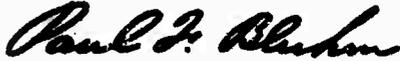
DISTRIBUTION LIMITED TO U.S. GOVERNMENT AGENCIES ONLY; TEST AND EVALUATION; Oct 1979 . OTHER REQUESTS FOR THIS DOCUMENT MUST BE REFERRED TO RADC (ISFA), GRIFFISS AFB NY 13441.

ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

79 12 17 010

RADC-TR-79-275 has been reviewed and is approved for publication.

APPROVED:



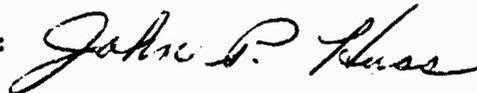
PAUL F. BLUHM, Major, USAF
Chief, R&D Computer Facility
Information Sciences Division

APPROVED:



WENDALL C. BAUMAN, Colonel, USAF
Chief, Information Sciences Division

FOR THE COMMANDER:



JOHN P. HUSS
Acting Chief, Plans Office

If your address has changed or if you wish to be removed from the RADC mailing list, or if the addressee is no longer employed by your organization, please notify RADC (ISFA) Griffiss AFB NY 13441. This will assist us in maintaining a current mailing list.

Do not return this copy. Retain or destroy.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 14) RADC-TR-79-275	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6) LONG RANGE MICROIMAGE TRANSMISSION TECHNIQUES STUDY FOR AFMPC	5. TYPE OF REPORT & PERIOD COVERED In-House Report	
	6. PERFORMING ORG. REPORT NUMBER N/A	
7. AUTHOR(s) 10) Leon/McDowell	8. CONTRACT OR GRANT NUMBER(s) N/A	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Rome Air Development Center (ISFA) Griffiss AFB NY 13441	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 64708F 12660309	17) 03
11. CONTROLLING OFFICE NAME AND ADDRESS Rome Air Development Center (ISFA) Griffiss AFB NY 13441	12. REPORT DATE 11) Oct 1979	
	13. NUMBER OF PAGES 122	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Same	15. SECURITY CLASS. (of this report) UNCLASSIFIED	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	
16. DISTRIBUTION STATEMENT (of this Report) Distribution limited to U.S. Government agencies only; test and evaluation; October 1979. Other requests for this document must be referred to RADC (ISFA) Griffiss AFB NY 13441.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) Same		
18. SUPPLEMENTARY NOTES Permission has been granted by DATAMATION to publish a five-page article entitled, "Protecting Data by Encryption," as Appendix A.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Microimage transmission facsimile microfacsimile long range transmission image transmission		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Facsimile transmission has been around for over fifty years. Historically, the technology has been based primarily on a paper in/paper out type of operation. However, with the increasing use of microfilm as a source medium, the technology has expanded to include the capture of data from a microimage source, the transmission of that data as in conventional facsimile, and the reproduction of that data not only as hard copy (paper product) but also as soft copy (CRT Display) or another microimage (film product). The technology has been investigated extensively by both government and private industry. →		

DD FORM 1473
1 JAN 73

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

301 550

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

The electronic transmission of microimage data is technically feasible. However, indications are that an electronic image transmission system will cost significantly more to operate than a manual system which utilizes the U.S. Postal Delivery Service. This is due primarily to the data transmission cost. Although this technology is not competitive with mail delivery at this time, many experts feel that the cost of electronic transmission is going down and will continue to do so with the growth of satellite communications along with competing ground systems.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

TECHNICAL SUMMARY

This report documents the results of an In-House Study in the area of Long Range Micro Image Transmission Techniques. The requirement for this study is contained in Program Management Directive (PMD) R-2144(4) dated 16 Jun 76. This PMD covers program direction on Project 1266 (Program Element 64708F). The purposes of this study were to determine the capabilities which can be provided by the current state-of-the-art in microfacsimile and related technologies, and to note trends in future capabilities. The study was conducted in support of the Air Force Manpower and Personnel Center's (AFMPC) Microform System located at Randolph AFB, Texas.

Facsimile Transmission, which may be defined as the sending of written, typewritten, printed or pictorial information via electronic transmission, has been around for over fifty years. Historically, the technology is primarily based on a paper-in/paper-out type of operation. However, with the increasing use of microfilm as a source medium, the technology has expanded to include the capture of data from a microimage source, the transmission of that data as in conventional facsimile, and the reproduction at the output of the system not only as hard copy (paper product) but also as soft copy (CRT Display) or another microimage (film product).

The technical feasibility of the electronic transmission of microimage data was investigated extensively by the Naval Ocean Systems Center (NOSC) in San Diego, California, the Electronic Systems Laboratory (ESL) of MIT Cambridge, Massachusetts, and EPSCO Laboratories (now defunct) in Wilton, Connecticut. Their results indicate that the long range electronic transmission and reproduction of microimage data is technically feasible. The results of other investigations in addition to the analysis performed as part of this in-house study support that conclusion.

Although a microfacsimile system is technically feasible, it is a significantly more costly system to implement and to operate than the current system. A primary source of cost is in the Data Communications area. This can be observed from the monthly cost estimates presented in Table 18 of the report. Many experts feel that the cost of electronic transmission is going down and will continue to do so with the growth of satellite communications systems, along with competing ground systems. However, the rate of decline is such that no significant change is foreseen in the immediate future. The NOSC Report (Reference 1) indicated that their MITS (Microfiche Image Transmission System) is not now competitive with mail delivery service,

and that it is not expected to be competitive until at least 10 or more years from now.

The operational concept discussed in the Requirements Section involves the transfer of data on request from AFMPC to the 26 major commands (MAJCOMS). The concept considers the elimination of the paper record subsets at each of the 26 MAJCOMS and providing a query capability for information to be supplied via electronic transmission from the master file at AFMPC. An average of 18 requests per day are made against the record subset at each MAJCOM. An analysis was conducted to determine the average image traffic that would result by responding to all requests electronically. The average traffic was estimated at 835 images per day per MAJCOM. Historically, the workload distribution at AFMPC is such that 34.7% of the requests are performed through an on-line terminal. The remaining 65.3% represents off-line actions. Therefore, assuming the same type of distribution at the MAJCOMS, the on-line traffic for each MAJCOM which represents a requirement for an immediate response to the request is approximately 290 images per day. The remaining traffic of 545 images per day represents requests which do not necessarily require an immediate response. The on-line and off-line traffic concept was used in the report to

explore the economic advantage of a hybrid communication system (a combination of electronic transmission and postal delivery service).

The detailed technical discussion was focused on the following functional areas which comprise a microfacsimile system:

SOURCE INPUT - The Source Input to a microfacsimile system is a microimage which contains either alphanumeric or pictorial data. One bit per pixel (picture element) is satisfactory for coding two levels of intensity as is typical of alphanumeric data. Pictorial data contains multiple intensity levels. Therefore, more than one bit per pixel is required to code each element. Studies indicate that as many as six bits per pixel are required to minimize the effects of "contouring"-a noticeable breaking-up of the image at region boundaries.

DATA CONVERSION - This function converts the source image from the physical form to a coded digital representation by processes of sampling and quantization. A scanner device is used to perform the sampling function which converts each sample point in the image to an equivalent analog voltage. The three types of devices used most often to scan source images and stated in the order of preference are the Solid State Scanner, the Laser Scanner and the CRT Flying Spot

Scanner. The analysis in the report indicated that for good legibility, the scanner should be capable of resolving 2,100 lines over the image height and 1,596 pixels per line. This results (at 1 bit per pixel) in a total of 3.35×10^6 bits per image. This requirement is well within the capability of the three scanner devices mentioned above.

DATA COMPRESSION - This function provides a reduction in the total number of bits to be transmitted without sacrificing image quality by removing the redundancy contained in the image. There are many compression schemes that are utilized. However, the run-length encoding algorithm is the most popular method used for printed and graphic data. The effectiveness of data compression techniques depends on the nature of the document being scanned because the actual compression ratio will vary according to the information density. The literature suggests that data compression ratios of up to six to one can be achieved for a typical business letter, and about three to one for a full page typescript.

DATA TRANSMISSION - This function provides the facilities and services for transmitting the data. Data communication services are made available to the public by ground-line and satellite companies. AT&T and Western Union were used to present typical cost data for communication via ground line and satellite respectively. Ground Line Services are available

in the major categories switched and leased. The Switched Service is charged on the basis of distance and time used. The Lease Service requires a monthly charge based on distance and is independent of usage. Considering the volume of AFMPC data and the distances to the MAJCOMS, the Lease Service is by far the more cost effective of the two. Table 5 in the report presents a summary of AT&T Services including the transmission speed ranges. Cost data for groundline system could be presented in graphic form since cost is a function of distance. Satellite cost data could not be presented in graphic form because the cost is not necessarily a function of distance. The cost between specific zone pair cities are supplied by the carrier. Depending upon the location of the earth stations, ground lines may be required to establish a complete link. Satellite transmission overseas is quite expensive. A single voice grade channel cost between \$7,000/\$22,000 a month to most countries. Also, speed of transmission is limited to 9,600 BPS maximum.

DATA SECURITY - This function involves the protection of data against accidental or unauthorized destruction, modification or disclosure. The protection of data during transmission is best accomplished by data encryption techniques. The NBS encryption algorithm proposed in March 1975 and

approved in July 1977 is the most popular encryption technique. Units are manufactured and sold commercially by IBM, Collins, and Motorola at prices ranging from \$28.00 for a chip to \$3,500 for a complete Cryptographic Unit.

DATA REPRODUCTION - This function provides for the reproduction of the source image as hard copy (paper product), soft copy (CRT Display) or another microimage on film. The commercial facsimile printers available are adequate for reproducing typewritten letters where the character point size is in the neighborhood of eight points. However, for character sizes in the neighborhood of three to four point type, the legibility of the hard copy product is at best marginal. The resolution is limited on the CRT Display such that the small characters are also below the legibility threshold. However, a zoom capability can be incorporated into the design of the Display System to effectively improve the resolution of the small characters to the extent they become legible. The technology of laser recording on film is sufficient to provide the capability of generating a satisfactory microimage on film when operating in a facsimile mode.

The generalized curves reflecting transmission cost data depict the following:

1. The monthly lease cost of different transmission links is a direct function of both bandwidth and distance.

2. The cost per bit of the 230.4 and 50 KBPS data link is less than the 19.2 KBPS link. Beyond a 1,000 mile distance, the 9.6 KBPS data link is the most inexpensive of them all.

3. Considering the average distance of 900 miles between a MAJCOM and AFMPC and the projected hours of transmission time per month, lease lines are more cost-effective than switched lines.

4. The volume of images that can be transmitted during a period of time is dependent on the speed of the link. The curves of Figure 23 were computed using a data compression ratio of 3:1 and assuming 15% of the bandwidth of the data link is used as overhead.

5. U.S. Postal Delivery charges for AFMPC are estimated at \$987 a month to mail approximately 1,196 fiche per day to the 26 MAJCOMS. These fiche correspond to the off-line portion of the traffic in the hybrid concept.

6. Satellite transmission cost is significantly less expensive than ground line for a voice-grade line. However, above a voice-grade line the difference is not significant.

The purpose of the study as stated in the Program Management Directive was to assess the state-of-the-art in long range microimage techniques rather than to perform a detailed systems analysis aimed at establishing concrete design parameters. However, a cursory analysis was conducted to aid in establishing preliminary performance and cost estimates for three concepts.

Concept No. 1 involves an all-electronic transmission system utilizing a 230.4 KBPS data link and operating over a single shift. Concept No. 2 is an all-electronic transmission system utilizing a 50 KBPS data link and operating over a double shift. Concept No. 3 is a hybrid system utilizing a 50 KBPS data link in conjunction with postal delivery service and operating over a single shift. The system response times (depending upon whether the request is for one image or up to 20 images) range from <1 minute to 4 minutes for Concept No. 1, 1.2 minutes to 11 minutes for Concepts 2 and 3 (Table 16). Further, a calculation of the "mean waiting time" in the user queue (Table 17) at a MAJCOM suggests that a three terminal configuration is most desirable. Table 18 reflects the monthly cost estimates of these systems as compared to the current system. The system concepts discussed are not intended to represent an exhaustive list. There are perhaps other viable concepts which were not discussed. For example, the 24-hour turnaround concept in which the data provided in response to the requests are transmitted within 24 hours of the time the request is made.

A thorough systems analysis should be conducted by AFMPC personnel in conjunction with personnel located at the MAJCOMS who are intimately familiar with the operation of the current records systems. This exercise should precede any further action. It is only after an operational concept has been defined can accurate systems cost be established. For example,

the cost of creating the applications software at the MAJCOMS and the cost associated with the hardware and software modifications to be made at AFMPC are not reflected in Table 18. Although the cost data presented are preliminary estimates, the indications are that the cost of implementing an electronic transmission system will significantly exceed that of the current system. Whether or not the operational benefits gained are of sufficient value to justify the increased cost, can best be determined by the user.

TABLE OF CONTENTS

Section		Page
I	INTRODUCTION	1
II	GENERAL TECHNOLOGY DESCRIPTION	3
III	OPERATIONAL REQUIREMENTS	6
IV	DETAILED TECHNICAL DISCUSSION	10
	A. Source Input	11
	B. Data Conversion	11
	C. Data Compression	37
	D. Data Transmission	44
	E. Data Security	66
	F. Data Reproduction	69
V	TRANSMISSION COST DATA	78
VI	SYSTEM CONCEPTS	90
VII	CONCLUSIONS/RECOMMENDATIONS.....	111
	Appendix A.....	115
	References.....	121

LIST OF ILLUSTRATIONS

Figure		Page
1	Generalized Model Microfacsimile System.....	12
2	Officer Effectiveness Report (Front).....	16
3	Officer Effectiveness Report (Back).....	17
4	Legibility Research.....	19
5	Experimental Images Digitized at Different Sampling Rates.....	25
6	Performing Curves of Candidate Scanning Systems.....	30
7	Solid State Scanner.....	33
8	Laser-Beam Spinning Mirror Scanner.....	36
9	Flying Spot Scanner.....	38
10	Discount Data.....	50
11	Cost vs Transmission Time (Day Rate).....	51
12	Cost vs Transmission Time (Evening Rate).....	52
13	Cost vs Transmission Time (Night Time Rate).....	53
14	Series 2000/3000 Line Cost.....	56
15	56 KBPS Digital Cost.....	59
16	Satellite Access Concept.....	60
17	Scan Lines Versus Character Height.....	71
18	Typical Laser MTF Curve.....	73
19	Hard Copy Output.....	77
20	Monthly Cost of Leased Lines	80
21	Cost Per Bit vs Distance.....	82

LIST OF ILLUSTRATIONS (Continued)

Figure		Page
22	Break-Even Line (Switched vs Lease)	83
23	Volume vs Transmission Time	86
24	Postal Service Cost	87
25	AFMPC/MAJCOM Concept	92

LIST OF TABLES

TABLE		Page
1	Character Sizes (Upper Case).....	18
2	Scanning Requirements vs Character Size.....	22
3	Resolution Summary.....	27
4	R/M Scanner Analysis.....	31
5	AT&T Services.....	47
6	Rate Table (Day Rate).....	49
7	Modem Cost.....	54
8	Series 5000 Cost.....	55
9	Cost of Digital Service Units.....	58
10	Satellite Zone City Pairs.....	63
11	Satellite Zone Charges.....	65
12	Satellite Overseas Cost - IDDS Rate Schedule for Service Between New York, NY and European Points.....	67
13	Break-Even Time.....	84
14	Satellite vs Land-Line Cost.....	89
15	Major Commands.....	91
16	Alternative Concepts.....	95
17	Mean Wait Time in User Queue.....	101
18	Manpower Impact.....	105
19	Monthly Cost Comparison.....	112

I. INTRODUCTION:

This report documents the results of an In-House Study in the area of Long Range Micro Image Transmission Techniques. The requirement for this study is contained in Program Management Directive (PMD) R-2144(4) dated 16 Jun 76. This PMD covers program direction on Project 1266 (Program Element 64708F).

The purposes of this study were to determine the capabilities which can be provided by the current state-of-the-art in microfacsimile and related technologies, and to underscore trends in future capabilities. The study was conducted in support of the Air Force Manpower and Personnel Center's (AFMPC) Microform System located at Randolph AFB, Texas.

The AFMPC maintains microfiche records of all active duty Air Force personnel. The master microfiche records are made of silver halide film, and the work file copies are diazo duplicates. The AFMPC is interested in exploring the technical and economic feasibility of satisfying long range user requests for microfiche data via electronic transmission. It is anticipated that the data presented in this study will aid the AFMPC in assessing the cost/effectiveness of this approach and in establishing reasonable estimates in the areas of performance and cost for future planning purposes.

In support of this study, an investigation of the AFMPC

operational requirements was conducted by the Planning Research Corporation's Image Data Systems Company under the existing system's contract. The results of that effort provided a very valuable input to this study.

The feasibility of transmitting microimage data was investigated extensively by the Naval Ocean Systems Center (NOSC) in San Diego, California; the Electronic Systems Laboratory (ESL) of MIT in Cambridge, Massachusetts; and EPSCO Laboratories (now defunct) in Wilton, Connecticut. The NOSC effort was sponsored by the Bureau of Naval Personnel, the ESL effort was conducted in support of the Library of Congress and the EPSCO Laboratory effort was sponsored by RADC in support of the Foreign Technology Division at Wright-Patterson AFB, OH. The results of those investigations were published in final reports (references 1, 2 and 3 respectively). A more recent publication by NOSC reflecting the state-of-the-art in microfacsimile technology was prepared for the Adjutant General Center (reference 4).

In addition to the above mentioned reports, data for the study was gathered from the following sources:

Literature Search - An extensive literature search was conducted and numerous technical articles from the various trade journals were obtained, along with many technical reports from commercial and military agencies.

Technical Survey - A survey was conducted in which a form letter was distributed among companies considered knowledgeable in any of the technologies required for the Electronic Transmission of Microimage Data. The technology areas for which each responder was requested to provide information in accordance with his area of expertise were data conversion, data compression, data transmission facilities and data reproduction.

Travel - Selected agencies and companies were visited to obtain further data as well as discuss some of the critical aspects of this technology. Also, the author attended the National Micrographics convention in Boston, MA., during the summer of 1978. At that time, very valuable literature was obtained on existing microfacsimile and computer-output-microfilm equipments.

II. GENERAL TECHNOLOGY DESCRIPTION:

Facsimile transmission, which may be defined as the sending of written, typewritten, printed or pictorial information electrically from one location to another has been around for over fifty years. Only recently however, since its technical quality has improved, have businesses begun to realize that in the wake of deteriorating postal service and rising cost, facsimile could offer a valuable alternative means of communicating information. Today's equipment is vastly superior to

that of a few years ago. Transmission time has been reduced and image quality has been significantly improved. Historically, the technology is primarily based on a "paper-in/paper-out" type of operation. Most of the literature published on the subject is written around the standard 8½ x 11 inch business document. However, with the increasing use of microfilm as a source medium, the technology has expanded to include the capture of data from a microimage source, the transmission of that data as in conventional facsimile and the reproduction at the output of the system not only as hard copy (paper product) but also as soft copy (CRT Display) or another microfiche (film product). Thus, the term "microfacsimile" is a more accurate description of the technology to be discussed.

The two major classes of facsimile equipment in use are analog and digital. A significant difference between an analog and digital device is in the speed of operation. The analog device requires about 4 to 6 minutes to transmit an 8.5 x 11 inch letter over voice grade lines. Whereas a digital unit requires only a fraction of a minute to accomplish the same job.

The advantage of speed enjoyed by digital facsimile equipment is due primarily to the fact that digital techniques permit the incorporation of data compression methods to reduce transmission time with no appreciable loss in quality. Compression ratios in the order of 3:1 to 5:1 have been achieved

for a full page of print. As an indication of the significance of compression, references 7, 9 and 12 indicate that the time required to transmit a standard 8.5 x 11 inch business letter in a digital facsimile system without compression is approximately 4 to 6 minutes (same as an analog device). This assumes the generally accepted minimum scan density of 96 scan lines per inch along both axes producing about 860,000 total picture elements to be transmitted. With a conventional voice-grade communication channel whose transmission speed is generally accepted as 2,400 bits per second (reference 5, 6, and 7), approximately 6 minutes would be required for transmission.

The planning of a microfacsimile system requires that a decision first be made as to whether emphasis is to be placed on output quality, speed of transmission or cost. Generally, output quality which is directly related to system resolution is of primary importance since the output product must be human readable. The resolution of a facsimile system determines the number of picture elements (pixels) in both the horizontal and vertical directions a source document can be resolved, transmitted and reconstructed. Therefore, knowing the total number of pixels required per document for minimum legibility and the transmission time which can be tolerated, the required bandwidth of the transmission system can be determined. One of the primary cost in a facsimile system is

in the time of transmission over a given data link. Therefore, it is desirable to reduce this time to a minimum. In order to accomplish this, data compression schemes are used extensively in existing systems. These techniques which reduce the total number of bits to be transmitted without loss of quality result in a more efficient utilization of the available bandwidth of a transmission channel.

III. OPERATIONAL REQUIREMENTS:

The primary purpose of the Requirements Study (Reference 8), conducted by the Planning Research Corporation (developers of the AFMPC Microform System) was to identify viable concepts through which the microform record can be used to replace the paper master record components maintained and used at various locations within the Air Force.

The Requirements Study considered records maintenance and utilization rates for both extended active duty and reserve personnel. This analysis pertains only to the extended active duty force and the records maintenance and utilization impact on the master record file at AFMPC. The data presented in the Requirements Study constitutes a basis for determining the operational parameters of a Long Range Image Transfer System, and for establishing an image traffic pattern which is required in estimating monthly operating cost.

Under the current records maintenance and utilization concept for the extended activity force, the Air Force controlled agencies consist of the AFMPC, the 122 Consolidated Base Personnel Offices (CBPOs), 26 Major Commands (MAJCOMS) and Hq DPG at the Pentagon. The AFMPC maintains the master microform records and provides responses to records users located at AFMPC whose activity is directed against the Master Record File. The CBPOs, MAJCOMS and Hq DPG are users who are located external to AFMPC and retain master record subsets (in paper form) on members assigned to their region. These record subsets consist of documents required to perform the various functions and to respond to user requests. The non-Air Force (and DOD) agencies, such as the V.A. Hospitals, Civil Service Commission, FBI Field Offices and others, represent users who are located external to AFMPC and who do not retain any record subsets at their location. Their records activity is therefore directed against the Master File. The magnitude of their records activity is approximately 9% of the indicated total monthly inquiries directed against the Master Record File at AFMPC.

Two concepts were discussed in the above mentioned requirements study. The Satellite File concept considered replacing the paper record components at all the CBPOS and MAJCOMS with the appropriate copies of diazo duplicates of the

master record, and using the duplicate documents as candidates for electronic transmission. However, the extent of duplication is understandably significant since the Satellite Files are subsets of the Master Record, and therefore the removal of the duplicate documents from the record subsets located at the CBPOs and MAJCOMS would result in a concept very similar to the second concept discussed in the Requirements Study. That concept considered the elimination of the record subsets at the CBPOs and MAJCOMS and providing data on request from the master file at AFMPC. The study further indicated that all of the CBPO's requirements for information cannot be presently satisfied with a microform medium alone. There are documents in the field record which are unique to the CBPOs. A dual media involving both paper and microform is required.

The concept used in the following analysis to determine the image traffic volume involves only the MAJCOMS and AFMPC. The impact of other agencies such as the Pentagon and ARPC may be determined in a similar manner. This concept considers the elimination of the record subsets currently retained at the 26 MAJCOMS, and providing at each MAJCOM a query capability for image data to be supplied by AFMPC.

Exhibit III-9 of the Requirements Study (Record Utilization Requirements Summary) indicates that 9,580 inquiries per month are made against the record retained at the combined

MAJCOMS. The requirements study further indicates that historically 49.7% of the inquiries performed required access to a document subset (all fiche in a family), 21% for an unrelated document collection, 13.5% for a single document and 15.8% for a complete record. On the average, a document subset consist of 2.5 fiche, a complete record consist of 6 fiche, and an unrelated document collection consist of 8 documents. Using conversion factors of 2 images per document and 20 images per fiche, the estimate for the daily volume was determined as indicated:

9,580 (49.7%) = 4,765 Inquiries/mo (Requiring access to all fiche in a family - approximately 2.5 fiche.)

9,580 (21.0%) = 2,000 Inquiries/mo (Requiring an unrelated document collection - approximately 8 documents.)

9,580 (13.5%) = 1,289 Inquiries/mo (Requiring a single document.)

9,580 (15.8%) = 1,526 Inquiries/mo (Requiring a complete record - approximately 6 fiche.)

4,765 (2.5 Fiche/Inquiry)x(20 Images/Fiche)=238,250 Images/mo

2,000 (8 Doc/Inquiry)x(2 Images/Doc)=32,000 Images/mo

1,289 (1 Doc/Inquiry)x(2 Images/Doc)=2,578 Images/mo

1,526 (6 Fiche/Inquiry)x(20 Images/Fiche)=183,120 Images/mo

TOTAL = 455,948 Images/mo

Assuming 21 days per month, the estimate becomes 21,712 Images/Day or an average of 835 Images per day for each MAJCOM.

The Requirements Study indicates that historically the workload distribution at AFMPC is such that 34.7% of the monthly inquiry volume is performed through an on-line terminal. The remaining 65.3% represents off-line actions. Therefore, the on-line traffic for each MAJCOM which represents a requirement for immediate responses to the requests is approximately 290 images per day. The remaining traffic of 545 images per day represents requests which do not require an immediate response.

A similar analysis for all the CBPOs resulted in an average traffic volume of 2,103 images per day for each CBPO. Using the same percentages as above, the on-line and off-line traffic for each CBPO would be 730 and 1,373 images per day respectively.

IV. DETAILED TECHNICAL DISCUSSION:

A Microfacsimile System basically consist of a device which "breaks-up" a microimage source document into an array of dots (picture elements) that are subsequently conveyed as a stream of electrical signals which are related to the density variations in the source document. This process is accomplished by sampling the two dimensional source document in space, and quantizing each sampled point in brightness. The quantization process assigns a coded digital value to the brightness (density) at that point. These signals are transmitted over a communications line to a receiver device. At

the receiver, a decoder recovers the original brightness levels from the received sequence of quantized samples and systematically reconstructs them to a visible "facsimile" of the source document. Figure 1 shows a generalized model of a microfacsimile system which depicts the various functional areas that comprise the total system.

A. SOURCE INPUT

The source input to a microfacsimile system is a microimage which may contain either alpha numeric or pictorial information. In general, alphanumeric or printed data contains only two levels of density (contrast) while pictorial data contains multiple levels of density (gray scale). With only two levels of density contained in a printed page, only one bit is required to code each picture element (pixel). Where multiple levels of density are involved, such as that found in a picture, or to a lesser degree a photograph, more than one bit per pixel is required to reproduce the intermediate levels of density with good quality. Studies indicate that as many as 6 bits per pixel are required to minimize the effects of "contouring," a noticeable breaking-up of the image at region boundaries.

B. DATA CONVERSION

The data conversion function which converts the source image from the physical form to a coded digital

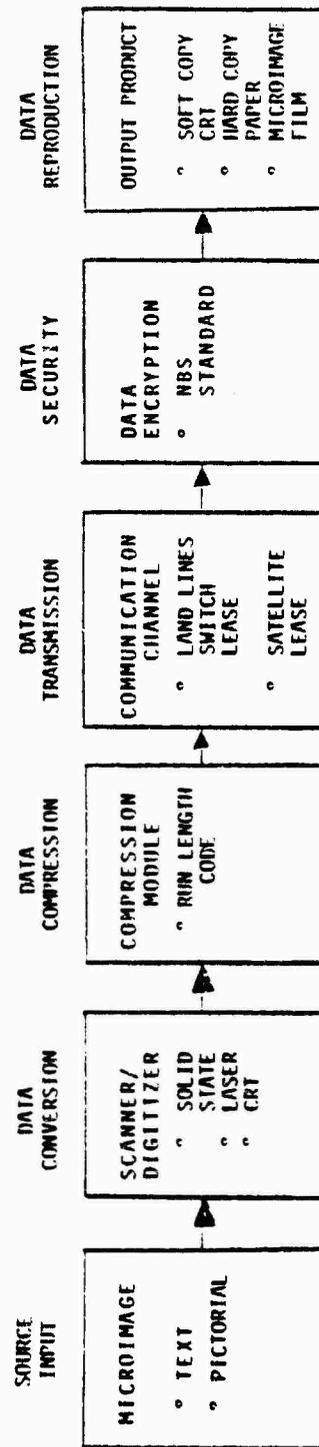


Figure 1 Generalized Model Microfacsimile System

representation is accomplished by the processes of sampling and quantization. The sampling process which converts each sampled point in the source image to an equivalent analog voltage is accomplished by a hardware device called a scanner. This device usually scans the image on a line by line basis. The quantization process which converts the analog voltage representing each sampled point to a coded digital representation is accomplished via circuits techniques. The three types of devices most often used to scan source images in micro-facsimile systems are the CRT, Laser and Solid State Scanner. The output from the converter is therefore a coded digital representation of every sampled point in the source image. This provides opportunities for applying compression schemes to reduce the quantity of bits to be transmitted or stored.

Since the output product must be human readable, legibility is used as the primary basis for establishing performance requirements of the facsimile system. The quality of the output product can only be as good as the data captured at the input. Therefore, the critical performance parameter which determines the adequacy of a scanner device is the resolution. In the film industry, resolution is usually defined as line pairs (a line plus a space) per millimeter, and in the scanner industry, it is defined as scan lines per inch. The relationship is such that two scan lines are

equivalent to one line pair. Most scanners are designed to scan from left to right, and top to bottom. The resolution along the scan axis for a CRT and laser type scanner is determined by the total number of pixels which can be resolved in one scan line. This resolution is determined by the driving electronics and is indicative of the maximum frequency with which the intensity of the scanning spot can be made to change during a single scan. The resolution along the axis normal to the scan axis is determined by the size of the scanning spot. With regards to a solid state type scanner, the resolution along the scan axis is fixed and determined by the number of elements per inch contained in the solid state linear array. The resolution along the axis normal to the scan axis is determined by mechanical positioning of the scanner array in relation to the source image.

Character legibility studies in line scan systems have been performed by many experts. One of the earlier studies (reference 9) concluded that for good legibility, a character should be formed with 6 to 10 lines per character height, depending upon the character size. If the character size (for revised Leroy font) as measured in terms of angular subtense at the eye is 30 minutes of arc, a minimum of 6 lines per character height is required. If the character measures 13 minutes of arc at the eye, a minimum of 10 lines over the character

height is required. Reference 10 has compiled legibility study results from this and other studies which reflect similar results.

In order to determine the resolution requirements of the scanner, a typical Air Force Form (AF707, Officer Effectiveness Report) was examined to determine the sizes of the characters it contains. The data to be scanned consists of both the typewritten and field data. The typewritten data generally measures between 8 and 10-point type. Figures 2 and 3 are copies of the front and back of an Officer Effectiveness Report. The sizes of the characters as indicated in the figures were determined by data provided in Air Force Manual 9-1 (reference 11). It can be seen that the character sizes for the field identifiers, etc. vary from 4-point to 8-point upper case. The data supporting the field identifiers enclosed in parenthesis, measures about 3-point. The height in inches for the various character sizes as reported in reference 11 are listed in Table 1. It should be indicated that the character size data given in Table 1 is provided for "upper case" characters. However, the size of a 3-point upper case character is the same as that for a 6-point lower case character.

I. 5-POINT RATEE IDENTIFICATION DATA (Read AFR 38-10 carefully before filling in any item)						
1. NAME (Last, First, Middle Initial)	3. SSN (Include suffix)					
2. ORGANIZATION, COMMAND, LOCATION, FAS CODE	4. PAFSC					
	5. OAFSC					
	6. ACTIVE DUTY GRADE					
	7. PERMANENT GRADE					
8. PERIOD OF REPORT FROM:						
THRU:						
9. DAYS OF SUPERVISION						
10. REASON FOR REPORT						
11. JOB DESCRIPTION 1. DUTY TITLE: 2. KEY DUTIES, TASKS, AND RESPONSIBILITIES:						
III. PERFORMANCE FACTORS						
Specific example of performance required	NOT OBSERVED OR NOT RELEVANT	FAR BELOW STANDARD	BELOW STANDARD	MEETS STANDARD	ABOVE STANDARD	WELL ABOVE STANDARD
1. <u>JOB KNOWLEDGE</u> (Depth, currency, breadth)	0					
4-POINT	6-POINT	LOWER CASE (EFFECTIVELY 3-POINT)				
2. JUDGMENT AND DECISIONS (Consistent, accurate, effective)	0					
3. PLAN AND ORGANIZE WORK (Timely, creative)	0					
4. MANAGEMENT OF RESOURCES (Manpower and material)	0					
5. LEADERSHIP (Initiative, accept responsibility)	0					
6. ADAPTABILITY TO STRESS (Stable, flexible, dependable)	0					
7. ORAL COMMUNICATION (Clear, concise, confident)	0					
8. WRITTEN COMMUNICATION (Clear, concise, organized)	0					
9. PROFESSIONAL QUALITIES (Attitude, dress, cooperation, bearing)	0					
10. HUMAN RELATIONS (Equal opportunity participation, sensitivity)						
						8-POINT

AF FORM 707 AUG 75 PREVIOUS EDITION IS OBSOLETE.

OFFICER EFFECTIVENESS REPORT

Figure 2 Officer Effectiveness Report (Front)

IV. ASSIGNMENT RECOMMENDATION: 1. STRONGEST QUALIFICATION:							
2. SUGGESTED JOBS (Include AFSC):							
3. ORGANIZATION LEVEL: 4. TIMING:							
V. EVALUATION OF POTENTIAL							
7-POINT → TOP BLOCK CONTROLLED							
Highest ↑							
Evaluate the ratee's capability, relative to that of officers in the same grade in the group being evaluated, for expanded/more diverse responsibility. Indicate your rating by placing an "X" in the designated portion of the appropriate block.							
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>			
<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td><td> </td><td> </td></tr> </table>				<table border="1" style="width: 100px; height: 20px;"> <tr><td> </td></tr></table>			

Table 1 - Character Sizes (Upper Case)

CHARACTER SIZE	HEIGHT (INCHES)
3 point	0.045
4 point	0.055
5 point	0.072
6 point	0.081
7 point	0.095
8 point	0.108

Considering the worst case character size to be 3-point type, and using at least 7 scan lines per character height, a total of 1750 scan lines would be required over the 0.5 inch height of the microimage.

The use of 7 scan lines per character height was decided on the basis of the results of the legibility research reported in reference 9 and presented in Figure 4. This figure indicates the number of recognition errors versus the number of scan lines per symbol height. It can be seen that the "8-line" point represents one of the two break-points in the graph which pertains to the recognition accuracy of separate or out-of-context characters. The reference also indicates that a lesser number would suffice for characters presented in a "word" context.

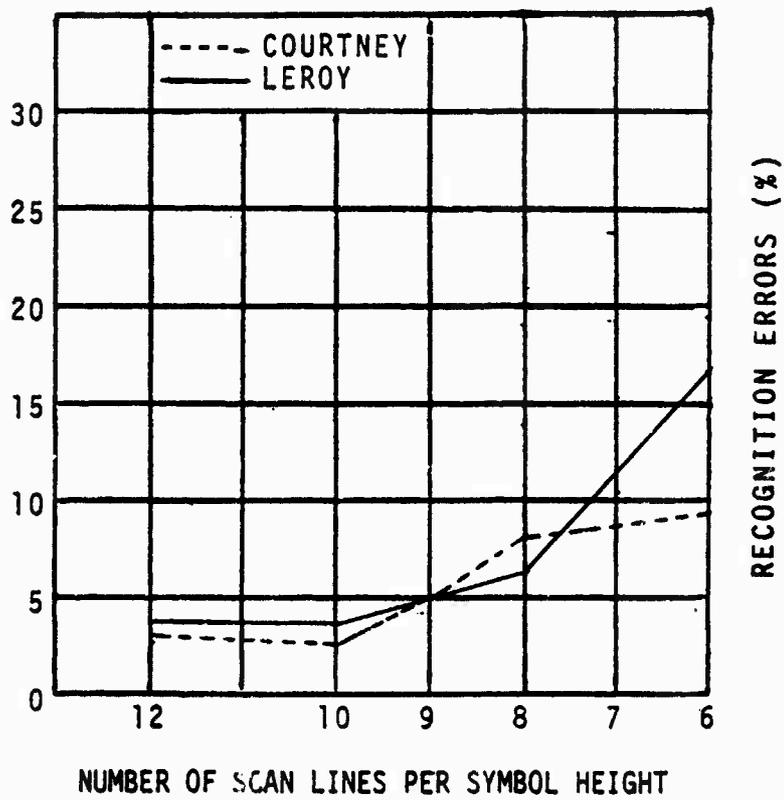


Figure 4 Legibility Research

Another parameter which must be accounted for in scan systems is known as the Kell factor. Reference 12 defines the Kell factor as an expression of the degree of degradation attributable to the segmenting of an image by scanning. He notes that for systems up to 1,000 scan lines, the Kell factor is approximately 0.70 (30% of the scan lines are ineffective) and for high definition systems of 1,000 to 2,000 scan lines, the value is 0.80. Therefore, considering the effects of the Kell factor, a total of 2,100 scan lines would be required over the microimage height. The image area of the AFMPC microimage expressed in millimeters (mm) is 12.7mm high by 10mm wide. The total number of 2,100 scan lines referenced over the microimage height of 12.7mm results in a required resolution of 165 scan lines or pixels per millimeter.

The NMA Standard (reference 13) presents resolution requirements for both document facsimile and engineering graphics facsimile. For document facsimile, the standard recommends a minimum of 809 scan lines along the short dimension of the standard 8.5 x 11 inch document, and 1,043 scan lines along the long dimension. This corresponds to a resolution of 94.8 scan lines per inch referenced at the source document. Assuming 7 lines are required per character height, a character with a minimum height of 0.074 inches (between 5 and 6-point) is the smallest size that could be scanned and produced legibly

at the output. The standard does not discuss a minimum character size in this section, however, reference 5 indicates that the resolution requirement of 96 lines per inch document facsimile was intended for a minimum character size of 10 point. This resolution is more than adequate for 10 point upper case characters. For the engineering graphics facsimile, the standard recommends a minimum of 1,385 scan lines along the short dimensions and 1,773 scan lines along the long dimension. This represents a resolution 1.7 times that of the document facsimile system. Consequently, the minimum character size which can be effectively scanned is 0.058 inches (between 4 and 5-point). The standard indicates a minimum character size of 6-point in their discussion of the resolution requirements for engineering graphics.

As noted previously in the report, other agencies have conducted an in-depth study of the problems associated with the scanning of microimage data. Their findings are considered relevant to this study. Therefore, the results of the following studies will be discussed and evaluated in the light of their requirements: Naval Ocean Systems Center in San Diego, CA; Electronic Systems Laboratory of MIT, Cambridge, MA and EBSO Laboratories formerly of Wilton, CT.

The Naval Ocean Systems Center (NOSC) conducted both a feasibility study and an options analysis study for the Bureau

of Naval Personnel (BUPERS) to examine the technical and economic feasibility of transmitting microfiche personnel records from BUPERS central files in Washington, DC to major Navy Centers such as San Diego, CA and Norfolk, VA. The NOSC Study Report (reference 1) includes the results of the investigation to determine the required resolution for a legible output. This investigation was conducted in the laboratory and the results were derived empirically. The objective was to determine the legibility requirements for material which was both "in" and "out" of context. The scanning requirements for the various type sizes are shown in Table 2 below as they appeared in reference 1:

Table 2
Scanning Requirements vs Character Size

Type Size (points)	Required Number of Scan Lines/Millimeter (lines/inch)	
	Material in Context	Material Out of Context
11	3.11(79)	3.86(98)
10	3.39(86)	4.25(108)
8	4.25(108)	5.31(135)
6	5.67(144)	7.09(180)

The study concluded that the resolution of the system should be 6.3 lines per millimeter (160 lines per inch) for legible reproduction of lower case 6-point typewritten characters (0.042 inch

high). As noted in the report, the 6.3 lines per millimeter determination was based on an averaging of the in-context and out-of-context legibility requirements. This resolution is referenced at the source document. The equivalent resolution referenced at the microimage is 151 scan lines or pixels per millimeter.

The report further states that the legibility predictions of particular type sizes as a function of scanning resolution were confirmed by having a group of NOSC personnel read in a microfiche viewer the output microimages which were generated by selective scanning of an input microimage.

The Electronic Systems Laboratory (ESL) of the Massachusetts Institute of Technology conducted a technical-feasibility study of an on-line text-access system for the Library of Congress (reference 2).

The goal was to augment the current computer-based information system by providing a capability to obtain by electronic means the full text of cited documents at terminals located in various buildings on Capitol Hill. The documents are microfilmed on the standard 4 x 6 inch microfiche in the NMA format (98 images of the standard 8.5 x 11 inch document reduced by a factor of x24 and positioned in a 14 x 7 matrix). The legibility requirement for this program was that the 8-point type referred to the standard 8.5 x 11 document be legible

on a full size display. Experiments were conducted in the laboratory to determine the effects of the number of picture elements per unit area on image quality.

Figure 5 shows examples of text images scanned at different sampling rates (as indicated in the figure). This figure was taken directly from reference 2. The study recommended that a sampling resolution of 200 elements per inch in both horizontal and vertical direction would be required for satisfactory image quality.

At 200 elements per inch, and assuming 8-point type (lower case - 0.056 inch high characters) on an original document, characters are formed with 11.2 lines per character height. Consequently, the 200 elements per inch scan resolution as referenced at the source should be more than adequate to provide legible 8-point lower case type. This judgment can be confirmed by an examination of Figure 5. The quality of the characters scanned at a resolution less than 200 lines per inch is still fairly good. The NOSC study indicated that the average resolution required for the "in and out-of-context" usage of 8-point type was 121 scan lines/inch.

The EPSCO Labs of Wilton, CT (now defunct) conducted a study for RADC to define an information transfer system which provides an efficient interface between a microfiche storage center and a number of remote users. The study was in support

Advances led
by about a 3-to
on the Big Boar
Exchange's c
stock index adv
to 43.21

(a) 80 elements/inch

Advances led
by about a 3-to
on the Big Boar
Exchange's c
stock index adv
to 43.21.

(b) 100 elements/inch

Advances led
by about a 3-to
on the Big Boar
Exchange's c
stock index adv
to 43.21.

(c) 130 elements/inch

' about a :
: the Big E
cchange's
ck index
43.21

(d) 200 elements/inch

about a
the Big l
change's
ck index

(e) 240 elements/inch

Figure 5 Experimental Images Digitized at
Different Sampling Rates

of the Foreign Technology Division, Wright-Patterson AFB. This effort was conducted via of analysis and computer simulation experiments. The scanner requirements were established in consideration of both the legibility requirements of the data to be scanned and the resolution of the output CRT Display. This investigator considers 7 lines per character height as adequate since the recognition of the letters is done within the context of a "word." The FTD data base contains lower case letters as small as 0.03 inch high (less than 3-point type). Therefore, for a 0.03 inch high character, and using 7 lines per character height as a criterion, a total of 2,500 scan lines are required for good legibility. This represents a resolution of 227 scan lines per inch referenced at the source document.

Table 3 represents a summary of values obtained for the resolution requirements via the analysis, in addition to the values found by other investigators. Also included for comparative purposes is the NMA resolution requirement. The results are reasonably close. Much of the difference results from the variation in the size of the character to be scanned. It should be noted that the resolution results of the study and NOSC as reflected in the table are not proportional. Even though the same size character was used, the optical reduction between the document and microimage planes used in the study was x21 (COSATI Standard), whereas the optical reduction used in the NOSC results was X24 (NMA Standard). Using the same character size of 0.030

Table 3 Resolution Summary

RESULTS	MINIMUM CHARACTER SIZE (PT) (LOWER CASE)	MINIMUM CHARACTER SIZE REFERENCED AT		RESOLUTION REFERENCED AT	
		ORIGINAL DOCUMENT (INCHES)	MICROIMAGE PLANE (INCHES)	ORIGINAL DOCUMENT (PIXELS/IN)	MICROIMAGE PLANE (PIXELS/MM)
STUDY	6 pt.	0.045	0.00214	200	165
NOSC	6 pt.	0.045	0.00214	160	151
ESL	8 pt.	0.056	0.00234	200	187
EPSCO	< 6 pt.	0.030	0.00125	227	214
NMA (REQ)					
DOCUMENT	10 pt.*	0.072	0.0030	96	90
GRAPHICS	6 pt.	0.045	0.00214	163	154

*ASSUMED

inches to provide a common reference, the resolution requirements referenced at the microimage plane are as noted:

STUDY	247	Pixels/mm
NOSC	211	Pixels/mm
EPSCO	214	Pixels/mm
ESL	336	Pixels/mm

Recall that the ESL results is based on a recommendation rather than a minimum requirement. This is why that value appears out of line.

The following set of tentative specifications were established for the scanner portion of the system based on data provided in the operational requirements section and the required resolution for a legible output:

Scan Format	9.65 x 12.7mm
Pixels per line	1596
Lines per Image	2100
Data Rate	1.5 M BITS/SEC
Scanner Throughput (AVG)	10 SECS/IMAGE (ESTIMATE)*
Bits per Pixel	1
Total Bits per image	3.35×10^6

The results of the investigation indicate that these requirements are well within the capability of the state-of-the-art scanning techniques.

*This estimate includes the time to load and unload a fiche, mechanical positioning time to next image and a scan time of 3 seconds per image.

Reference 3 examined via computer simulation the performance characteristics of the various scanners that are currently in use. Mathematical models of the scanners were developed and the scanner performance studied from the models. The results were presented graphically depicting performance as a function of spatial frequency at the microfiche plane, and using signal-to-noise ratio as an indicator of performance. Figure 6 is a set of performance curves reflecting the relative performance of the five different types of scanners considered. This figure was taken from reference 3. The superiority of the solid state, laser, and CRT flying spot scanners is readily apparent and they are capable of performing the scanning function. The analysis further showed that in order to realize nearly 100 percent accurate digitization of the output data, the scanner should have an output signal-to-noise ratio of at least 20:1 at a resolution of 130 line pairs per millimeter (260 pixels/mm). The signal-to-noise ratio will be less for lower resolution.

Reference 3 also conducted a reliability and maintainability analysis for the above three scanner types. The results of that analysis is shown verbatim in Table 4 with the normalized results in parenthesis.

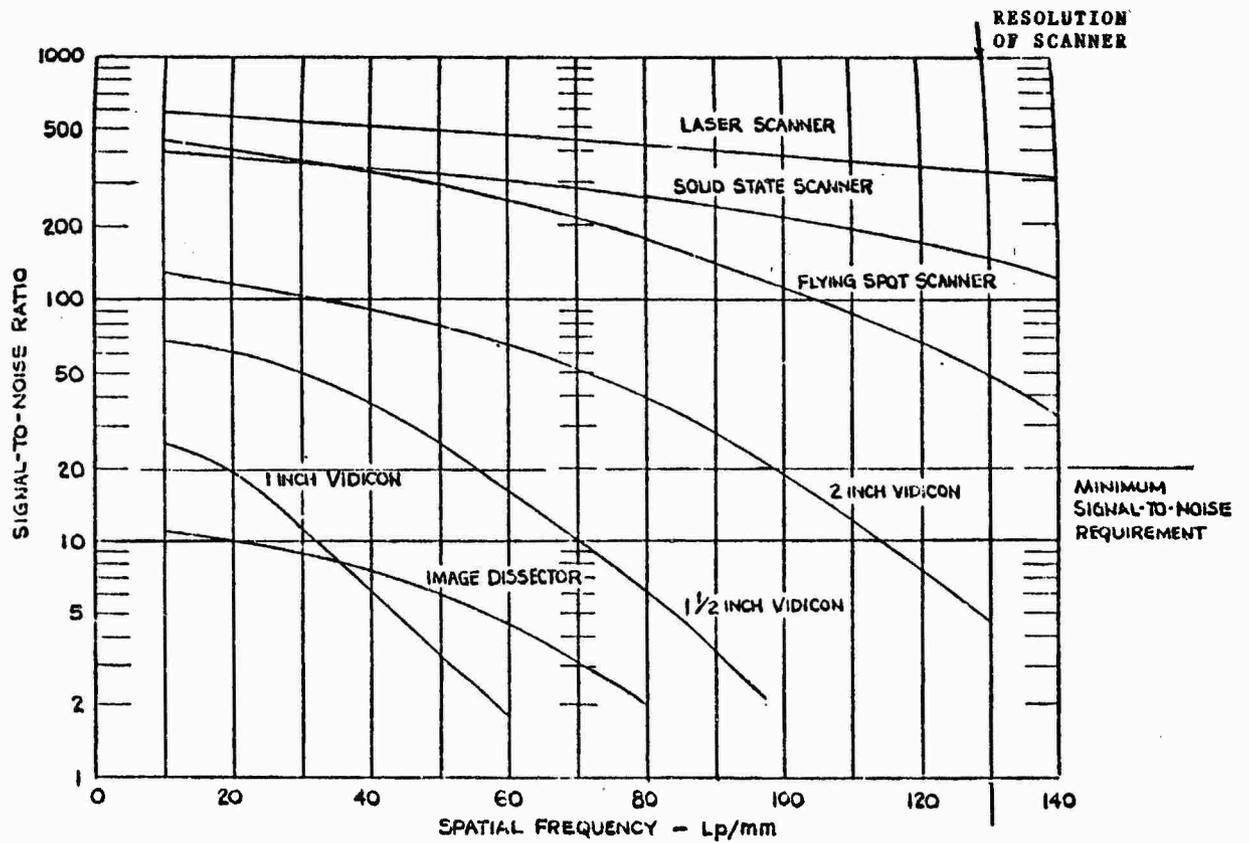


Figure 6 Performing Curves of Candidate Scanning Systems

Table 4 R/M Scanner Analysis

SCANNER TYPE	RELIABILITY (MTBF)	MAINTENANCE TIME MANHOURS/YRS
SOLID STATE	1860 (1.4)	79 (1)
LASER	1880 (1.4)	120 (1.5)
FLYING SPOT	1330 (1)	100 (1.3)

The results of Table 4 indicate the order of preference of the scanner types. Although the solid state scanner and laser scanner are more reliable than the flying spot scanner, the solid state scanner requires significantly less time for maintenance. Other investigators (Reference 14) concur in this order of preference. The Solid State, Laser, and CRT Flying Spot Scanners exhibit both high resolution and high speed. Numerous reports have been published which provide a technology description of these scanners. References 1, 3, 4, 14, 15, 16 and 17 are the most notable. The following paragraphs provide a technology description for each device:

SOLID STATE SCANNER:

"Solid State Scanner" is a category which includes both charge coupled arrays and photodiode arrays. These arrays can either be in the form of line or matrix arrays. In this

application, only the line arrays have enough elements to become potential candidates. While there are certain differences between a charge coupled array and a photodiode array, their operation and the operation of scanners utilizing these arrays can be similarly described as in Figure 7. The page to be scanned is illuminated from the back and the first line of that page is focused onto the array. Electrons are accumulated within each element of the array in proportion to the intensity of the light focused onto each element. The light intensity is determined by the film density in the image. These electron "bundles" are then transferred, one by one, out of the array and into the signal processing electronics. The only motion required is to pass the fiche between the array and a light source at a controlled speed. The array itself creates the scan line as it is oriented parallel to the lines of text and contains a sufficient number of sensing elements to represent the desired number of picture elements in these lines.

Although only prototype solid state scanners have been built to date, the extension to an off-the-shelf solid state fiche scanner is being pursued actively by a number of companies, including RCA and the Planning Research Company (PRC). The latter has built a prototype system called "Telefiche," which uses a CCD scanner in a currently hard-wired demonstration facsimile system, with output to a display terminal or

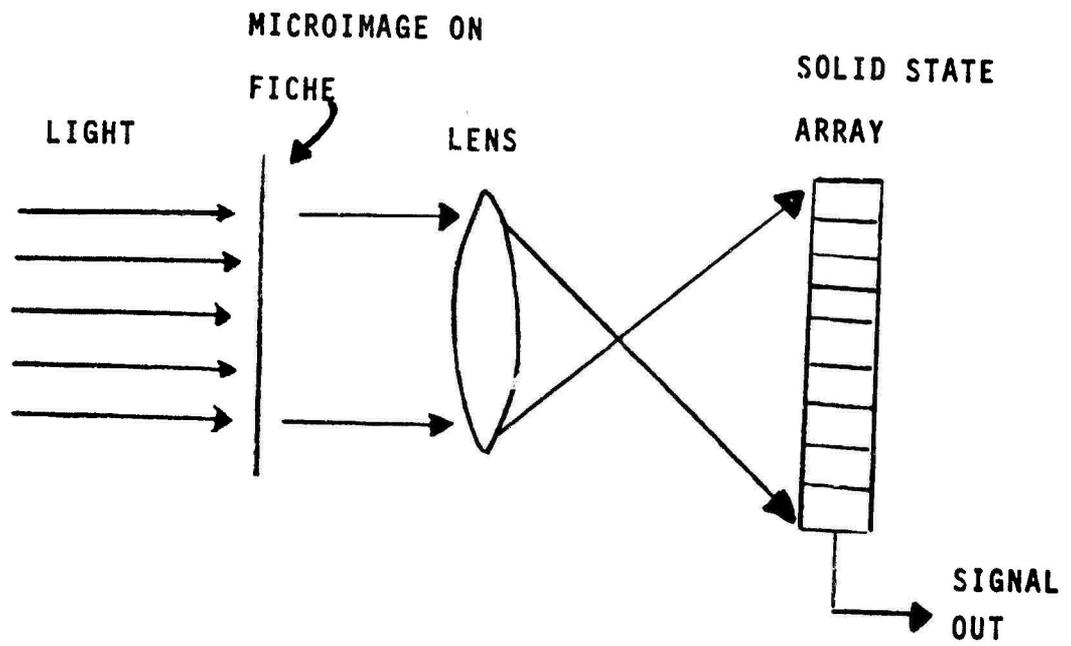


Figure 7 Solid State Scanner

paper copy. This system was demonstrated at the 1978 National Micrographics Association Convention in Boston, MA. In addition, researchers at the Naval Ocean Systems Center (NOSC), have built a CCD drum scanner for analysis of the digital characteristics of different types of text (reference 16). In this case, the input is paper, but the technique is identical. Using commercially available Fairchild 1,728-element arrays, the NOSC researchers have performed statistical surveys of the digital output from a variety of document types to study image data processing effects. Fairchild Semiconductor personnel indicated that in the near future they plan to manufacture and market commercially linear arrays of 2,048 elements. These arrays should provide more than adequate scanning resolution. The currently available 1,728 linear arrays are designed with a cell size of 13 microns (0.51 mils) by 17 microns (0.67 mils) on 13 micron centers (reference 18). The 2,048 chip is expected to have the same geometry.

THE LASER SCANNER:

The concept of the Laser Beam Scanner utilizing the spinning mirror as the deflection mechanism (as opposed to the galvanometer approach) is depicted in Figure 8. It is very similar in operation to the flying spot scanner. However, in the case of this scanner, a laser is used to generate the scanning spot. The scanning spot is obtained by first passing the laser beam through a set of optics. The function of these

optics is to generate a spot of light that is uniform in intensity. The beam is then directed onto a scanning spinner. The spinner deflects the beam through a given angle at a uniform angular velocity. The beam then passes through an objective lens and a field flattening lens. Thus, as the beam moves through a given angle, a focused spot moves across the width of a page on the fiche. During each line scan interval, the fiche is moved in the direction of the page height, a distance equal to the width of the scanning spot. In this way, the entire page can be scanned. As with the flying spot scanner, the light transmitted through the fiche is focused onto the face of a photo detector and the resulting signal fed into the signal processing electronics. Reference 4 reports that this type of scanner has been built by Ampex, Goodyear, Harris, RCA and Singer Corporations. Further, it is the most widely selected for high-speed and high resolution applications. Reference 19 states that laser scanners and recorders have demonstrated a capability of providing well over 5,000 pixels per inch of scan line. This far exceeds this requirement since a scan line is approximately 0.4 inch (microimage width). This would result in over 2,000 pixels.

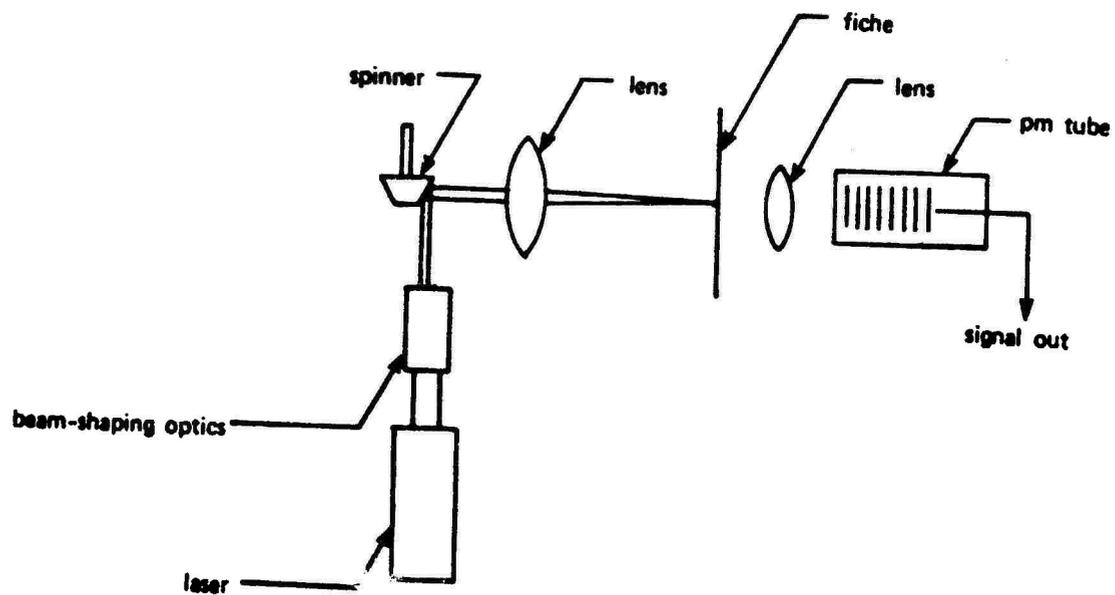


Figure 8 Laser-Beam Spinning Mirror Scanner

FLYING SPOT SCANNER:

The concept of the Flying Spot Scanner is depicted in Figure 9. It consists of a CRT which generates a spot of light at its phosphor screen. This spot of light is then demagnified and focused optically onto an image (page) on the microfiche. The motion of the spot which constitutes the scanning aperture is controlled by the CRT drive electronics, and usually scans the microimage in a line by line sequence. The light from the CRT spot is then transmitted through the microimage, and the resulting intensity is detected by a photo detector device placed on the opposite side of the microfiche. Therefore, any variations in density of the microimage film being scanned will be detected as variations in light intensity of the transmitted spot as seen by the photo detector. This variation in light intensity will in turn be converted to an appropriate video signal. CRT Flying Spot Scanners are capable of providing over 2,000 pixels per scan.

C. DATA COMPRESSION:

The data compression function provides a reduction in the total number of bits to be transmitted without sacrificing any of the information contained in the source image. There are numerous compression algorithms utilized in the compression of digital data. The application of a particular scheme is often determined by the source of the data such as

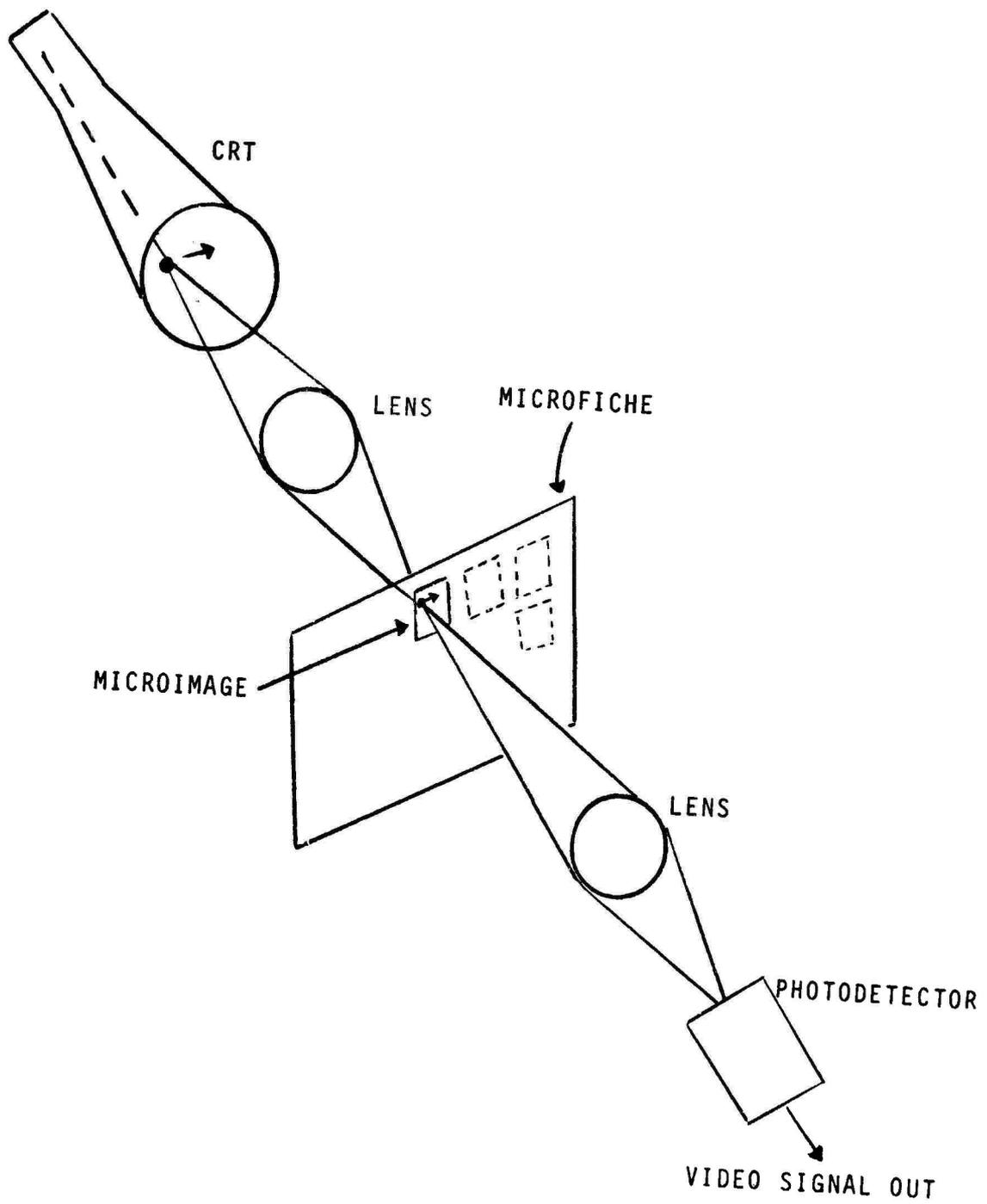


Figure 9 Flying Spot Scanner

telemetry data, or TV camera data as opposed to data obtained from the scanning of a document or picture, and the amount of compression desired within certain error limits. The techniques of data compression are very involved and is a technology in its own right. It is therefore beyond the scope of this report to discuss in any significant detail the many compression techniques reported in the literature. Rather it is considered more appropriate to present a general classification of the techniques and to discuss that technique which in the opinion of the experts is most applicable to the compression of digital data obtained from scanning a source image containing printed and/or graphic data.

Data compression works on the principal of eliminating the redundancies (unnecessary data) from the scanned image of a page being transmitted. Nearly all the background area of graphic material is predominantly of one tone, usually white. Uninterrupted stretches of the one tone carry no information and are therefore redundant. Conventional analog facsimile systems not only scan these redundant areas, but also transmit signals which correspond to these areas. The use of data compression or, as it is otherwise known, redundancy reduction techniques, eliminates these unnecessary signals, thus substantially decreasing the total data to be transmitted.

Data compression methods have been classified in numerous ways in the literature. Reference 20 groups the various methods into entropy encoding, spatial encoding and transform encoding which is thought to be an acceptable grouping.

Entropy Encoding - Redundancy of data bits manifest itself in several ways. If each character is represented by a fixed number of bits and if some characters appear more frequently than others, representation of each character by the same number of bits will result in redundancy. For example, in the English language the letter "E" occurs more frequently than the letter "Z." Entropy encoding therefore seeks to reduce redundancy by assigning the shorter codes to the symbols which occur most frequently, and the longer codes to those symbols that rarely occur. Huffman coding is an example of this approach. According to this reference, these techniques rarely reach 2:1 compression ratios. Reference 21 points out that data redundancy may be desirable in noisy communication channels where it will enable lost or garbled information to be recovered. Examples of this type of redundancy are parity bits, hamming codes or cyclic redundancy code bits. In these cases, the redundancy is added by the encoder before transmission. In contrast, the types of redundancy previously mentioned are inherent in the source data. Since they do not lend themselves to improvement in data recovery, their elimination can result in savings in transmission time or storage space.

SPATIAL ENCODING - Another type of redundancy occurs in a string of identical symbols. This type of redundancy is prominent in text type material in which a data set may consist of all "zeros" (spacing between the lines). Therefore, coding the symbol type and the number of repetitions is more efficient than coding all the symbols with the required 8-bit byte. The spatial approach class subdivides into:

Integrating - The classical run-length encoding technique is probably the best known technique which falls in this class. Compression is achieved by giving the intensity value and a code describing the length of the "run" of contiguous pixels which share that intensity.

Differential - This class of technique is best represented by the classical differential pulse code modulation (DPCM) technique and its many variations employing both fixed and adaptive coding strategies. In this technique, compression is achieved by coding only the differences between elements.

The Spatial Encoding techniques are capable of achieving compression ratio in the range of 3 to 6:1.

TRANSFORM ENCODING - These techniques are significantly more complex to implement than the spatial methods and exhibits reasonably good performance up to compression ratio about 6:1. Rapid degradation occurs when attempts are made to go beyond this point.

The most popular data compression methods used for transmitting printed and graphic data is the run-length encoding algorithm. In the run-length encoding data compression, the number of dots, or picture elements, along a scan line of one tone type, that is all black or all white, are counted. The binary number corresponding to the count is transmitted rather than transmitting a series of ones or a series of zeros depicting each white dot or black dot. For example, a patch of white background is being scanned and the scanner picks up a run of 214 white picture elements before the start of text. Instead of sending 214 ones, the compressor would generate the number or code 11010110, the binary equivalent with only eight digits. Since in this example an eight digit code is generated in place of 214 digits, a compression ratio of more than 25 to 1 is obtained.

The longer the run-length of one type dot, the greater the compression ratio. The shorter the run, which is associated with a higher page information density, the larger the number of coded digits or bits generated. Thus, the output is high for photographs made up of fine screen half-tone material or for text made up of small point type, while advertisements with large areas of white background produce a relatively low output rate.

Reference 22 suggest that the compression ratio may be computed from the following relationship:

$$\frac{\text{original bits}}{\text{compressed bits}} = \frac{\text{Bits/Line} \times \text{Lines/Image}}{\text{Number of runs} \times \text{bits/run}}$$

Considering a more realistic example, if the scanner generates 2,000 picture elements per line (and 2,000 lines per image) then run lengths would have values ranging from 1 up to 2,000 bits (corresponds to a completely blank line). Therefore, at least 11 bits would be required to code the longest run as well as all other possible run lengths. It can be seen from the above relationship that as the number of runs decrease as would be the case with a large amount of blank space, the compression ratio increases. Whereas the value of the quantity "BITS/RUN" is fixed in a given application (11 Bits/RUN in the above examples), the "number of runs" parameters is statistical in nature. Consequently, the effectiveness of compression schemes depends on the nature of the document because the actual compression ratio will vary according to the information density.

Another approach reported in the literature involves the use of a variable length code to code the different "runs" rather than a fixed length code. The advantage of this approach over the other approach is that a shorter length code can be used for the run-lengths which occur most often, and the long codes which is required to code the longest runs can be used less frequently. The disadvantage of this approach is that a

body of statistical data on the source material must first be accumulated in order to establish a probability of occurrence for the numerous run-lengths. Subsequent to this, the size of the code words are assigned to the run-lengths based on the frequency of occurrence. Since these codes are not easy to calculate, they must be stored in a look-up table.

The literature does not reflect a major difference in the compression results obtained using a variable length code as opposed to a fixed length code. Data compression ratios of up to 6 to 1 can be achieved for a typical business letter, and about 3 to 1 for full page typescript.

D. DATA TRANSMISSION:

Data Communications Services are made available to the public by ground-line and satellite system companies. There are numerous companies which advertise their services with certain conditions stated such as a limited distribution, and perhaps others unstated. The response to the survey for cost data in this area was not as anticipated. However, it is felt that sufficient data was acquired to establish cost estimates for transmitting data in both ground-line and satellite configurations. Two companies were chosen as representatives of the ground-line and satellite carrier business. AT&T was used to present typical cost data for data communications via ground line for two reasons. First, the Bell

System's service has the largest distribution, and second, AT&T was most generous in responding to the survey letter requesting information. Western Union satellite data was used to represent data communications cost via satellite because the description of their services as contained in reference 23 was comprehensive and little difference in cost was found to exist between Western Union and other companies such as RCA American Communications Inc. and American Satellite Corporation.

1. Ground-Line Services for data communication are available to the public in two major categories: switched (dial-up) and dedicated (leased) line. The Dial-Up service is charged on the basis of both distance and time used. The Leased Line category requires a monthly charge based on distance and is independent of usage. Since the demand (at least until the present) for data communication could not justify the construction of specialized networks for the transmission of data, it was necessary to utilize the voice-oriented telephone network to move data. Although this method was relatively inefficient, the telephone network had the important characteristic of widespread coverage. Some specialized carriers are developing networks just for data and more sophisticated ways are being found to improve the speed of data transmission over the common

voice telephone network. The services applicable to this study that are provided by the Bell System are summarized in Table 5. As can be observed, the two major categories are switched and dedicated. The dedicated category is further subdivided into subcategories (analog and digital), and they in turn are divided into two speed ranges (voice grade and wide band). These groupings facilitate the discussion of the various services. Each service category will be referred to the table such as Service I.A.2 will represent switched-analog-wideband and Service II.B.1 will represent dedicated-digital-voice grade.

The performance of the Data Communication Channel will be governed by the link and the attached modem. At asynchronous speeds up to 1200 bits per second, ordinary voice grade lines are adequate. At synchronous speeds some type of special conditioning in the lines and/or equalizing circuits in the modem are required for satisfactory operation. On most dialed connections, transmission speeds from 3600-4800 bits per second may be achieved with the appropriate modem. Speeds up to 9,600 bits per second require highly conditioned lines and automatically equalized modems. The 3 KHZ bandwidth of voice lines restrict the practical data rate to 9,600 bits per second. The final selection of a service is not only made on the basis of transmission speed (which has cost associated

Table 5 AT&T Services

SERVICE	TRANSMISSION RATE IN KILOBITS PER SECOND
<p>I. SWITCHED (DIAL-UP)</p> <p>A. ANALOG</p> <p>1. Voice Grade</p> <p>2. Wideband</p> <p>II. DEDICATED</p> <p>A. ANALOG</p> <p>1. Voice Grade</p> <p>2. Wideband</p> <p>B. DIGITAL</p> <p>1. Voice Grade</p> <p>2. Wideband</p>	<p>1.2, 2.4, 4.8 and 9.6</p> <p>50</p> <p>1.2, 2.4, 4.8, and 9.6</p> <p>19.2, 50 and 230.4</p> <p>1.2, 2.4, 4.8, 9.6</p> <p>19.2 and 56</p>

with it in terms of modem charges per month), but also line charges and the geographic coverage or distribution.

Service Category I.A.1 offers a speed range of 1.2 to 9.6 kilobits per second. The cost is determined by the transmission line cost, transmission time and speed of transmission. Table 6 contains line cost data obtained from Reference 24. The table is the day rate for station to station dialing. Discounts are provided for evening, nighttime and weekends, as noted in Figure 10. The data in Table 6 is presented in graph form for a more rapid assessment of cost for almost any situation. Refer to Figures 11, 12 and 13. Figure 11 is a plot of the hourly cost in dollars for the indicated distances at the day-rate. Figure 12 plots cost at the evening rate and Figure 13 plots cost at the weekend and nighttime rate. In addition to line cost, there is a monthly cost for modems which is determined by the speed of transmission. Table 7 contains the monthly cost of each modem in the speed range 2.4 to 9.6 (KBPS). As an example, at a speed of 9.6 KBPS over a distance of 1,000 miles, transmitting during the daytime and for four hours per day duration, the monthly cost would be about \$87.50 for line charges (refer to Figure 11), plus the modem rental fee of \$249.00 per month.

Service Category I.A.2:

The 50 kilobit switched service is a measured use, high speed data transmission service. The bandwidth of the channel

Table 6 Rate Table (Day Rate)

FCC TARIFF NUMBER 263 - DIAL STATION-TO-STATION

<u>RATE MILEAGE</u>	<u>INITIAL 1 MINUTE (\$)</u>	<u>EACH ADDITIONAL MINUTE</u>
1-10	0.19	0.09
11-16	0.23	0.12
17-22	0.27	0.14
23-30	0.31	0.18
31-40	0.35	0.21
41-55	0.39	0.25
56-70	0.41	0.27
71-124	0.43	0.29
125-196	0.44	0.30
197-292	0.46	0.32
293-430	0.48	0.34
431-925	0.50	0.34
926-1910	0.52	0.36
1911-3000	0.54	0.38

NOTE: Since the cost data presented is not static but changes with time, its purpose is to serve as a planning function rather than an exact pricing function.

	SAT	SUN	MON	TUES	WED	THUR	FRI
8AM to 5PM							
5PM to 11PM							
11PM to 8AM							
	DAY RATE						
	EVENING RATE 35% DISCOUNT						
	WEEKEND AND NIGHTTIME RATE 60% DISCOUNT						

Figure 10 Discount Data

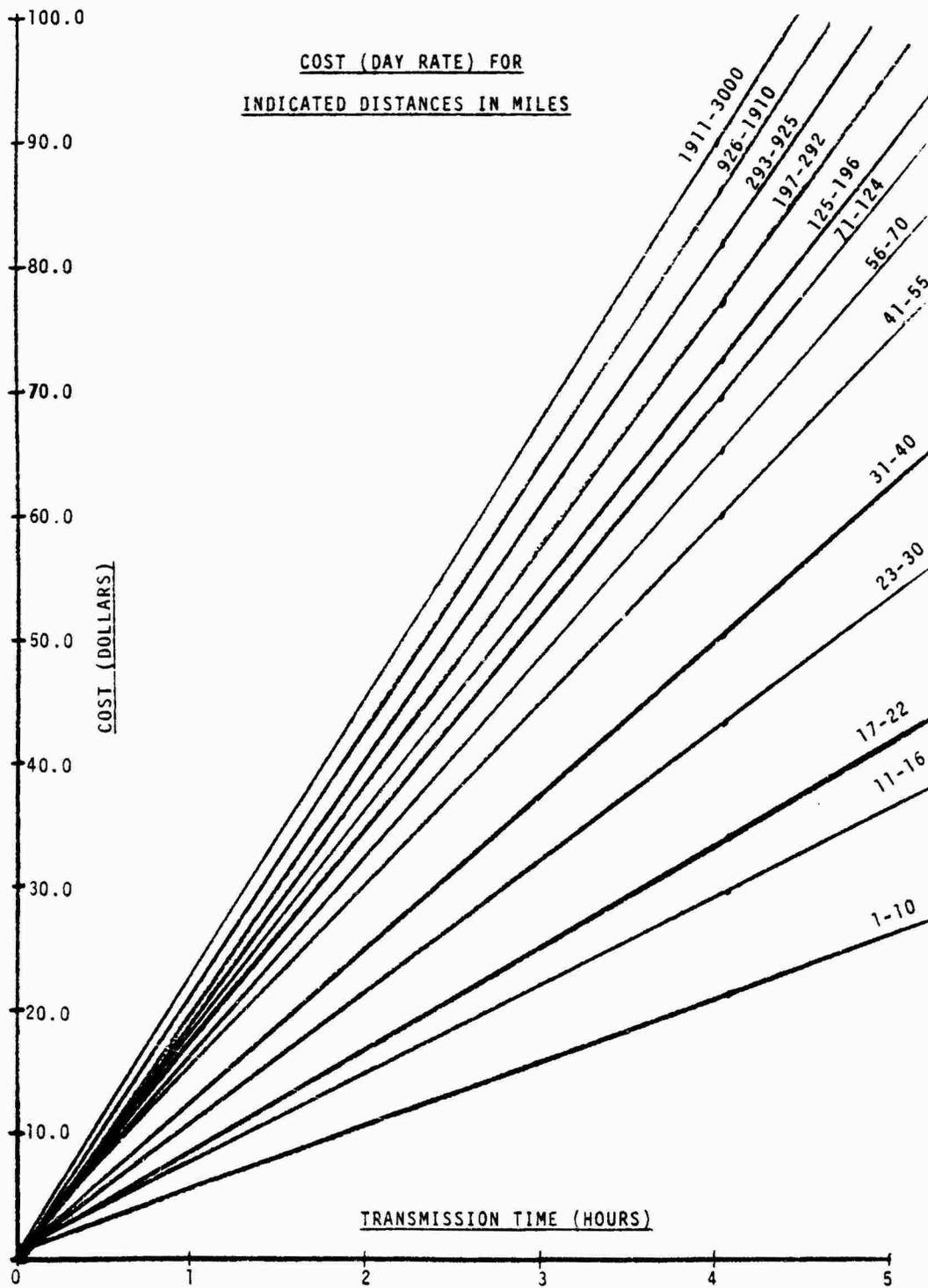


Figure 11 Cost vs Transmission Time (Day Rate)

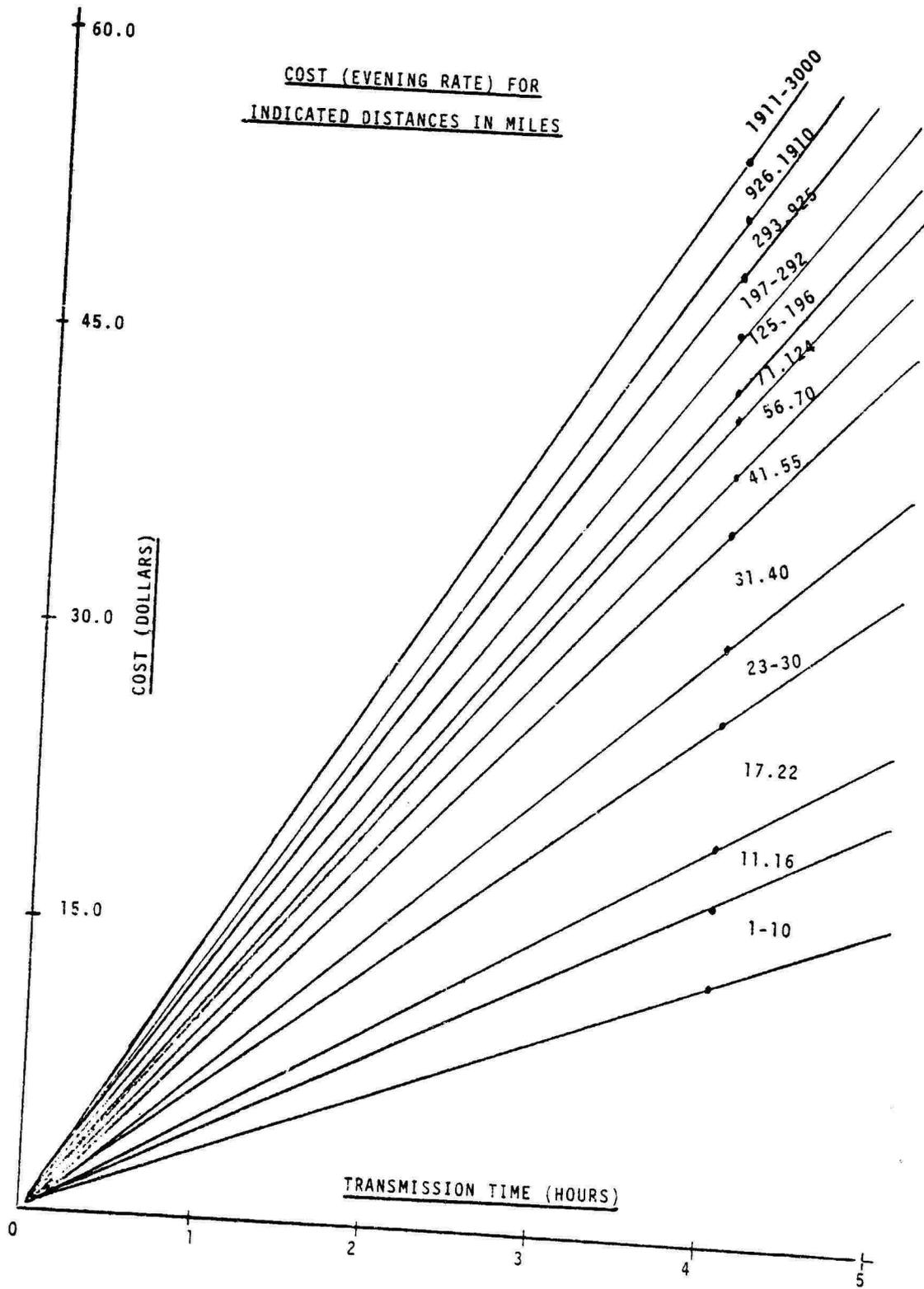


Figure 12 Cost vs Transmission Time (Evening Rate)

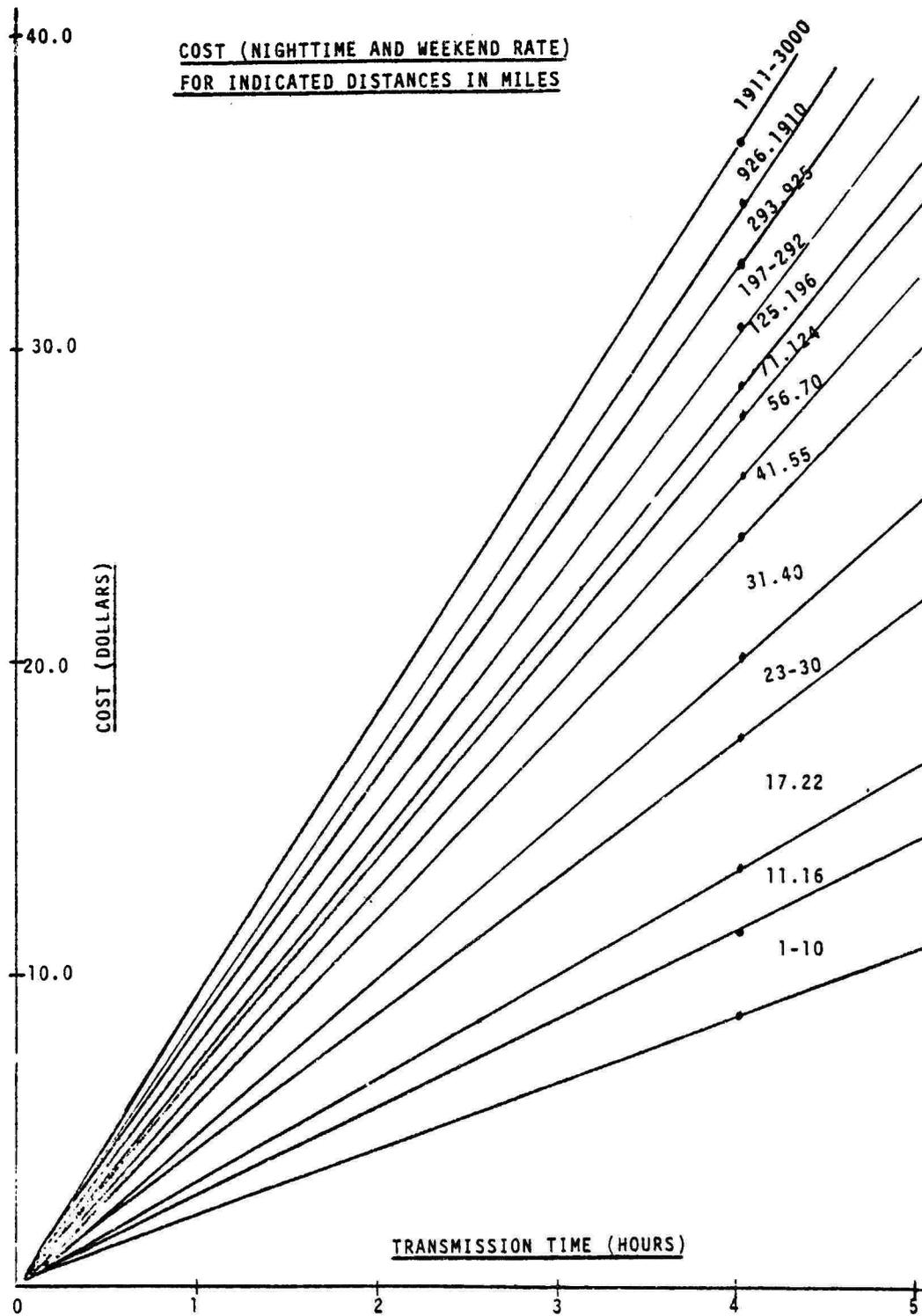


Figure 13 Cost vs Transmission Time (Nighttime Rate)

provided on this dial-up service is 48,000 Hz, which is equivalent to 12 voice grade lines. This service is especially useful for high speed data communications and facsimile transmission. However, its distribution is so severely limited that no further discussion is warranted on this service.

Table 7 Modem Cost

<u>DATA SET NO.</u>	<u>SPEED</u>	<u>INSTALLATION</u>	<u>MONTHLY COST</u>
201	2.4	81.20	\$ 59.55
208	4.8	163.00	\$135.00
209	9.6	216.00	\$249.00

Service Category II.A.1 offers a dedicated line with many of the same speeds provided in the dial-up situation. The difference between the two services, however, is the line charges. This service, referred to as the series 3000 is used primarily for data communications. The rates are based on the inter-exchange mileage and the charges are on a per mile basis. The charges are based on the category of the city (category A or B). There are 380 cities in Category A (refer to Reference 24), all others are in Category B. Schedule I covers charges

between Category A cities, Schedule II covers rates between Category A and Category B cities, and Schedule III covers rates between Category B cities. Figure 14 contains a graph summary of the monthly line cost of utilizing these lines for Schedules I, II and III. The modem rental cost are the same as those required in the switched category.

Service Category II.A.2 is referred to as the Series 5000. It is a wideband service with provisions similar to the series 3000. The cost as noted in Table 8 is based on a monthly termination charge and a mileage rate.

Table 8 Series 5000 Cost

<u>TYPE</u>	<u>SPEED (KBps)</u>	<u>INSTALLATION</u>	<u>MONTHLY FEE</u>	<u>MILEAGE/RATE</u>
5703	19.2	\$216.00	\$460.00	\$3.30/mile
5706	50	\$216.00	\$460.00	\$6.60/mile
5751	230.4	\$216.00	\$703.00	\$33.00/mile

This is a very popular service and as such will be discussed further in the next section of this report.

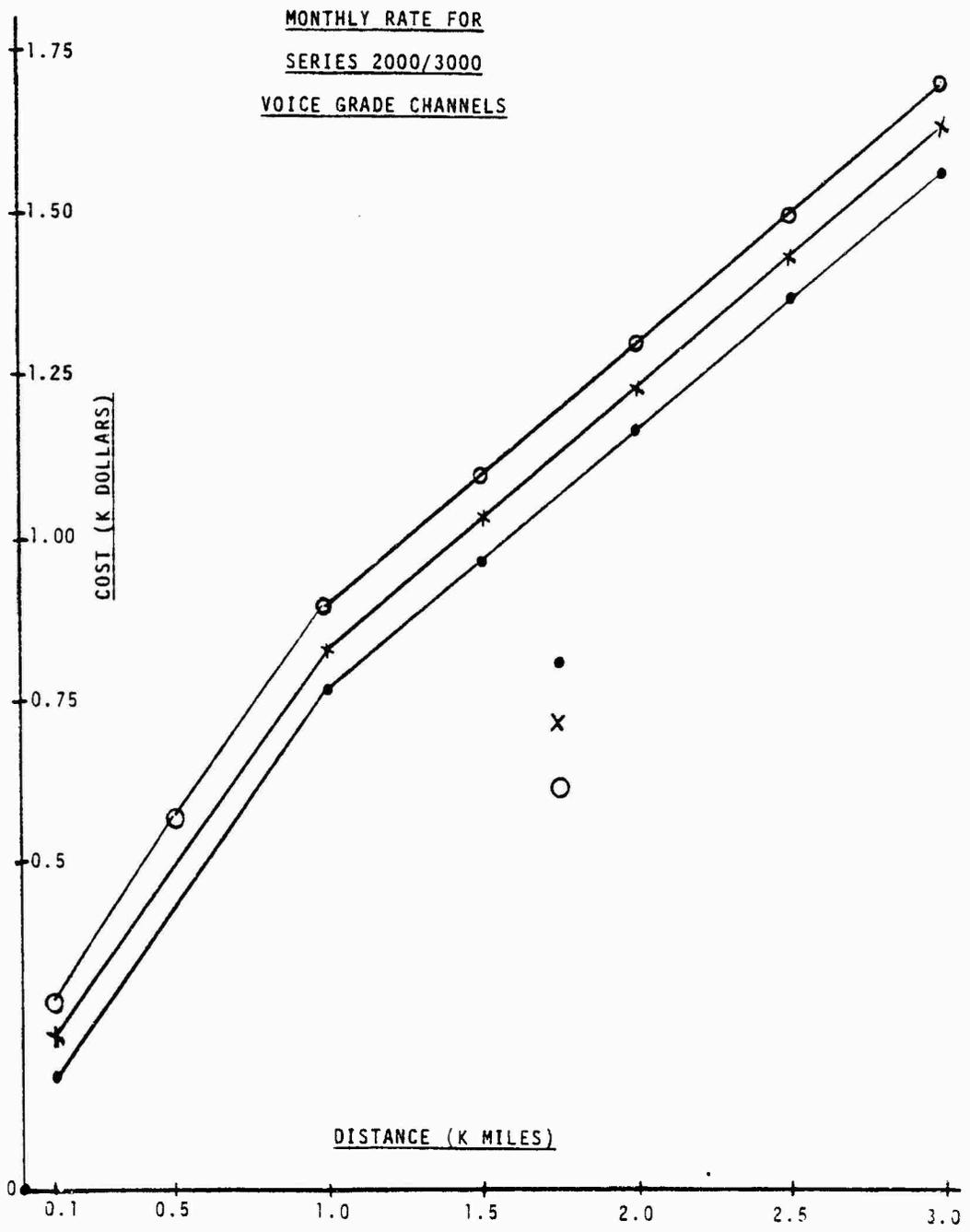


Figure 14 Series 2000/3000 Line Cost

Service Category II.B is referred to as Dataphone Digital Service by AT&T. This communication facility is used for the transmission of digital signals without the necessity for converting to analog form. Regenerative repeaters are employed every several 1,000 feet to refresh the digital pulse train. The major advantage in using digital techniques for transmission is that noise and distortion are no longer amplified as in analog transmission. Rather than amplifying the digital signal, the signal is regenerated at regular intervals thus reconstructing clean pulses.

Although the digital network is still growing, service is available in only a limited number of metropolitan cities. Therefore, a user of digital service between two locations not in the digital network would have to obtain regular voice-grade line service at the end of the network. The total monthly cost of digital service is composed of the inter city line mileage, and the service terminal interface equipment. Table 9 contains the cost of the digital terminal units for the indicated speeds.

Table 9
Cost of Digital Service Units

<u>TRANSMISSION SPEED KBPS</u>	<u>MONTHLY CHARGE</u>	<u>INSTALLATION</u>
2.4	\$ 84.55	\$128.75
4.8	\$160.00	\$128.75
9.6	\$281.33	\$218.75
56.0	\$650.00	\$180.75

The line charges for speeds 2.4 to 9.6 KBPS are identical to Schedule 1 of Figure 14. Figure 15 is a graph of the line charges for the speed 56 KBPS service.

2. Satellite Communication Service is provided through domestic satellites in combination with conventional land line facilities which are necessary to reach smaller cities. Figure 16 is a diagram which shows the concept of satellite communication (Reference 25). It can be seen from the figure that interconnecting to a satellite can be accomplished via direct access as indicated on the left side of the figure or via terrestrial links as indicated on the right side. Direct satellite access will require the user to lease facilities from the carrier; thus, in effect the user would have his own private earth station. The terrestrial interconnection means the use of a local loop between the customer

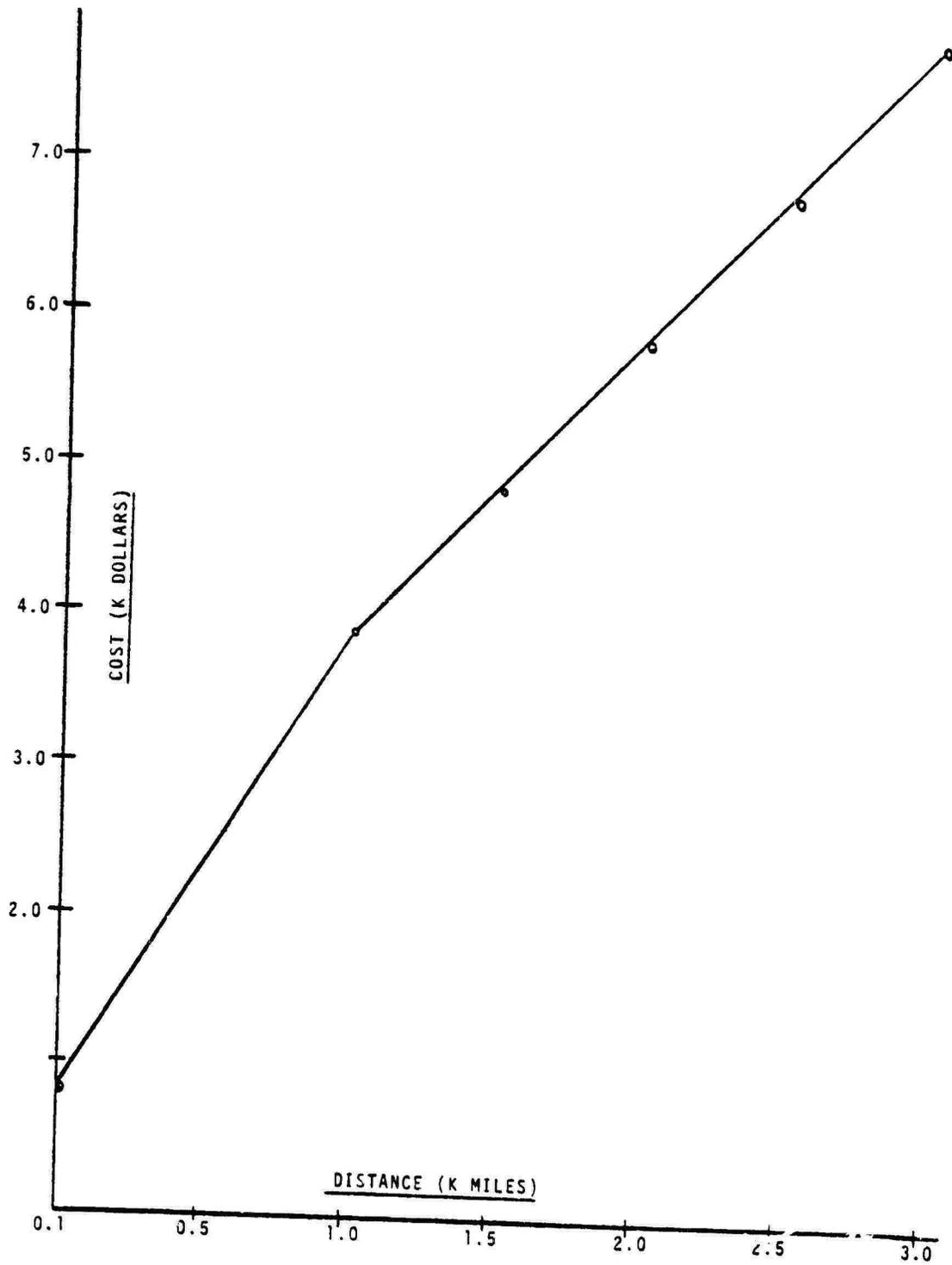


Figure 15 56 KBPS Digital Cost

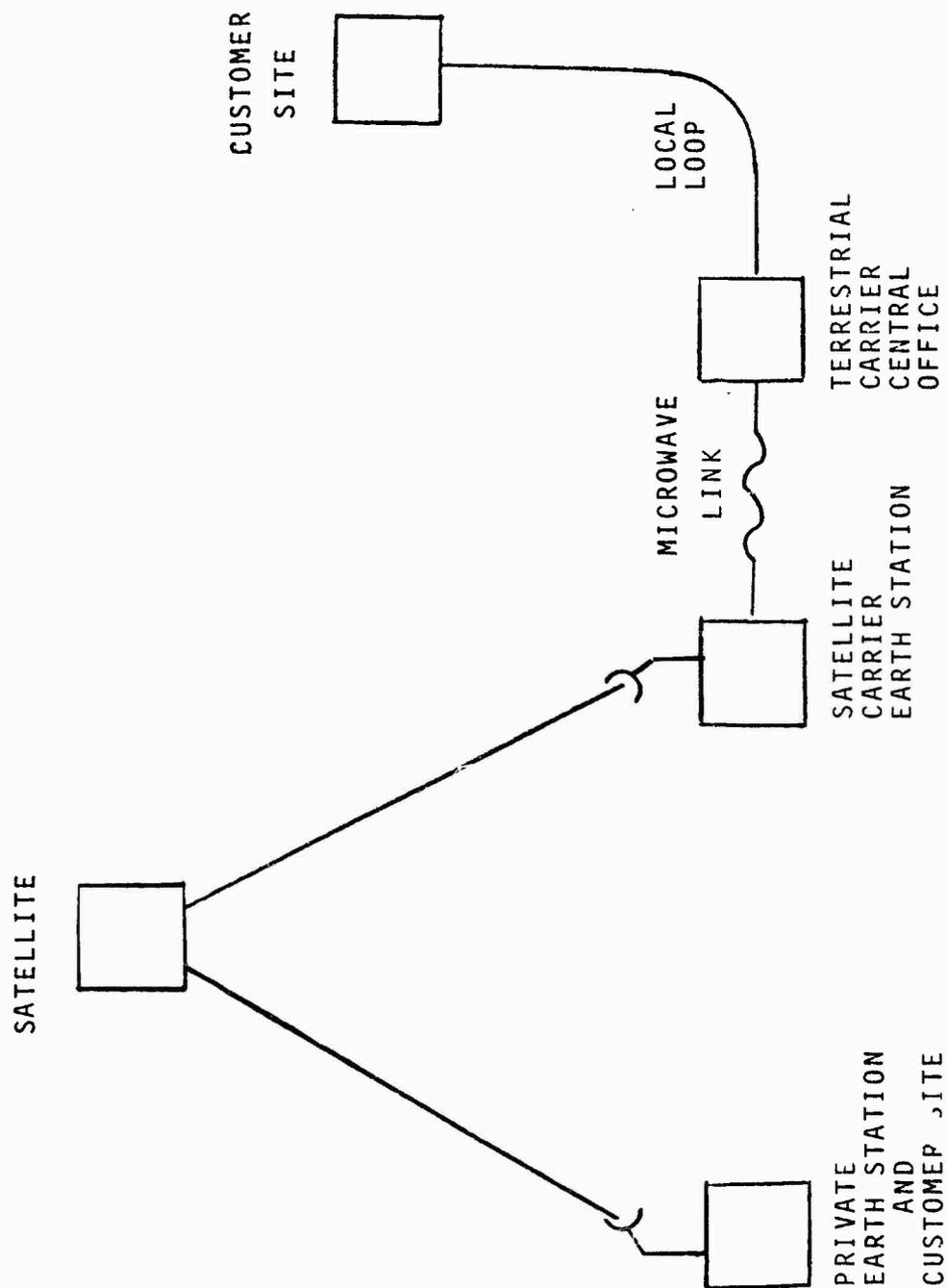


Figure 16 Satellite Access Concept

site and the in-town terrestrial carrier who then has a micro-wave link from his in-town office to the far-out site of the carrier's earth station. Reference 25 points out that when a user accesses a satellite via a terrestrial link, which most users will do in the near term, the problem of error control belongs to the user because only he can do anything about end-to-end error control.

The following data relative to the services provided by Western Union was taken directly from Reference 23. Western Union provides its Satellite Transmission Service between specified pairs of the following 24 satellite access cities:

Atlanta	Indianapolis
Baltimore	Kansas City MO
Boston	Los Angeles
Buffalo	Milwaukee
Chicago	New York
Cincinnati	Philadelphia
Cleveland	Pittsburgh
Columbus OH	St. Louis
Dallas/Ft. Worth	San Francisco
Dayton	Seattle
Detroit	Washington DC
Houston	Wilmington DE

Satellite Transmission Service rates for basic transponder (4 KHZ bandwidth) service are charged according to a zoning structure determined by groupings of specific city pairs. Rates for Zone 1 city pairs are \$1,000 per month; for Zone 2, \$900 per month; for Zone 3, \$750 per month; for Zone 4, \$700 per month; for Zone 5, \$600 per month; and for Zone 6, \$500 per month.

The Zone City pairs which are geographically close to San Antonio, TX and are therefore applicable to this study are noted in Table 10. San Antonio, TX is not part of a city pair.

Western Union offers a discount for multiple channel subscriptions. The following discount is based on the number of voice channels provided over the first five:

6-11	10%
12-23	20%
24-59	30%
60-239	35%
240 and over	45%

Therefore, if a 48 KHz bandwidth (12 voice channel) is provided between Dallas/Ft Worth and Washington, DC (Zone 3 City Pairs), the cost would be reduced by 20% to \$7,200 rather than \$9,000 (\$750.00 per channel x 12 channels). The Service Terminal charges are \$25.00 per month for each 4 KHz channel and \$425.00 per month for each 48 KHz channel.

Other Satellite Transmission Services offered by Western Union for Data Communications are:

1. Alternate Data/Voice
2. Remote Area Channels
3. Space TEL Channels
4. Synchronous Digital Service
5. Wideband Channels

Table 10 Satellite Zone City Pairs

Zone 3 city pairs are:

Dallas/Ft. Worth to	Baltimore
	Boston
	Buffalo
	Philadelphia
	Washington DC

Houston	Baltimore
	Boston
	Cleveland
	Columbus
	Dayton
	Detroit
	Philadelphia
	Pittsburgh
	Washington DC
	Wilmington DE

Zone 4 city paris are:

Dallas/Ft. Worth to	San Francisco
Houston to	Los Angeles
	New York
	San Francisco

Zone 5 city pairs are Dallas/Ft. Worth to Los Angeles and New York.

Zone 6 city pairs are:

Dallas/Ft. Worth to	Cincinnati
	Cleveland
	Columbus
	Dayton
	Detroit
	Indianapolis
	Milwaukee
	Pittsburgh
	St. Louis

Houston to	Cincinnati
	Indianapolis
	Milwaukee
	St. Louis

The Alternate Data/Voice Channel Service - This service is furnished on specific routes. The channel charge is based on providing a single voice band (4 KHz) channel capable of data rates up to 9600 BPS between specified cities in accordance with the same zoning pattern and zoning rates previously mentioned.

Remote Area Channel Service - This service is provided only to those customers who own and operate individual earth stations.

Space Tel Channel Service - This service combines satellite and terrestrial facilities to create communications paths between two customers. These routes are also zoned according to a pattern. The charges are based on the zones as noted in Table 11 and a minimum of 900 minutes of usage per calendar month. Overtime is billed on a per-additional-minute basis.

Synchronous Digital Service - Charges cover routes between Los Angeles and New York and provide both satellite and local channel facilities.

<u>CHANNEL CHARGE</u>	<u>INSTALLATION CHARGE</u>	<u>SPEED</u>
\$1,500	\$250.00	9,600 BPS
\$6,400	\$350.00	56,000 BPS

Table 11 Satellite Zone Charges

<u>ZONE</u>	<u>DISTANCE (MILES)</u>	<u>TERMINAL CHARGE (\$)</u>
1	0 - 1,075	\$325.00
2	1076 - 1875	\$350.00
3	1876 and over	\$375.00

The Zone City pairs applicable to this study are as noted below:

Zone 1 City Pairs are:

Dallas to	Cincinnati
	Cleveland
	Detroit
	Milwaukee
	Pittsburgh
	St. Louis

Zone 2 City Pairs are:

Dallas to	Los Angeles
	New York
	Philadelphia
	San Francisco
	Washington DC
Houston to	Los Angeles
	New York
	Philadelphia
	Washington DC

Wideband Channel Service - This service is provided only to other communications carriers.

With regards to Overseas transmission via satellite, of leased channels is relatively expensive. A single voice channel cost between \$7,000 and \$22,000 a month to most countries. In addition, the user must acquire domestic access facilities. Reference 30 (material on Western Union International Voice/Data Facilities) contains a table reflecting the rate schedule for service between New and European points. The table indicating both the Service Access Charge and Usage Charge is shown in Table 12. It can be observed from this table that the maximum speed of data transmission is 9.6 KBPS.

E. DATA SECURITY

The Data Security problem in large computer-based systems involves the protection of the data against accidental or unauthorized destruction, modification or disclosure. The protection of data during transmission presents a further security problem of which data encryption techniques is considered by most experts to be the most practical solution.

The subject matter regarding data encryption is best discussed in an article written by Mr. David J. Sykes which appeared in the August 1976 issue of Datamation. This article is entitled "Protecting Data by Encryption," and it discusses various methods of applying encryption techniques such as

Table 12 IDDS Rate Schedule for Service
Between New York, NY and European Points

Service Access Charge (both sides):

Speed (bps)	Dollars (per month)
50	2,365
75	2,562
100	2,759
200	3,153
600	3,547
1,200	3,941
2,400	4,532
4,800	5,517
9,600	6,897

Usage Charge (for all speeds):

1st 10x10 ⁶ bits.....	\$100.00	per 10 ⁶ bits
next 25x10 ⁶ bits.....	\$ 32.00	per 10 ⁶ bits
next 50x10 ⁶ bits.....	\$ 16.00	per 10 ⁶ bits
next 100x10 ⁶ bits.....	\$ 8.00	per 10 ⁶ bits
next 250x10 ⁶ bits.....	\$ 3.20	per 10 ⁶ bits
next 500x10 ⁶ bits.....	\$ 1.60	per 10 ⁶ bits
next 1000x10 ⁶ bits.....	\$.80	per 10 ⁶ bits
next 2500x10 ⁶ bits.....	\$.32	per 10 ⁶ bits
additional bits.....	\$.16	per 10 ⁶ bits

- NOTE: (1) Bit usage rate is reduced to lowest level after transmission of $2.5R \times 10^6$ bits where R is the customer speed (e.g., at 50 bps = 125×10^6 bits).
- (2) Usage charge will be calculated on the total amount of bits transmitted and received at one side during the month.

communications link encryption, end-to-end encryption and media encryption. The author states that the encryption/decryption process is based on some form of transformation which is solely dependent on a key (a pattern of bits). He further states that key generation, distribution and protection is a critical issue since the whole principle is based on the security of the key. A summary of the requirements for an encryption capability and a discussion on distributing the key are also included in the article.

By March of 1975, the National Bureau of Standards (NBS) published a description of an encryption algorithm in the Federal Register. That algorithm has become the most widely used method of data encryption for purposes of security. Reference 4 reports that the NBS Standard was approved in January 1977 and became effective in July 1977. This reference further states that there are several commercial implementations of the LSI Chip Data Encryption Standard (DES). The prices range from a basic DES Chip costing \$28.00 to a complete cryptographic unit at \$3,500.00. The unit is placed between the terminal and the modem, and is available from IBM, Collins and Motorola.

The above mentioned article on Data Encryption also provides a valuable insight into the NBS Standard Encryption Algorithm. This article is considered to have significant tutorial value and as such has been included in its entirety as an Appendix to this report.

F. DATA REPRODUCTION

Compressed digital data is highly susceptible to the effects of line interference and other conditions which potentially can introduce errors. Error detection and correction techniques are therefore encoded in the data prior to transmission. When the data arrives at the receiver, error detection circuitry determines whether or not a transmission error has occurred requiring a retransmission. If the data is transmitted error-free, the data is made available to a de-compression module. This algorithm is the complement of the compression algorithm used prior to transmission, and is used to regenerate the original uncompressed data stream produced at the scanner.

As noted in a previous section, the digitized micro-image data received over the communications link may be reconstructed in a variety of forms. The output forms which may be selected based on the particular system needs may be categorized as follows:

1. Soft Copy (Direct view CRT Display)
2. Film Copy (Computer-Output-Microfilm)
 - a. Laser Beam Recorders
 - b. CRT Recorders
3. Hard Copy (Facsimile Printers)

The basic issue as to whether a suitable "soft" copy display terminal could be used to provide high quality legible displays of microimage documents was addressed by Reference 3. Recall that in the Data Conversion Section it was decided that approximately 2,100 scan lines along the image height were required in order to resolve six-point lower case type. It would then follow that any display device should have a similar resolution capability to provide a legible output. The interrelationships of all the parameters are shown in Figure 17. This figure was taken from Reference 3. The practical resolution of a Direct View CRT Display is generally accepted as 1,300 to 1,500 scan lines over the display height. It can be seen that with a resolution of 1,300 scan lines and using the 7 lines per character height criterion, the smallest resolvable character is 0.060 inches high. Therefore, in order to resolve a six-point character (0.045 inches high), approximately 1,800 lines (not including the effects of the Kell factor) are required. Since the scanned resolution exceeds the display resolution, the total information scanned provides the opportunity for a zoom capability to be incorporated at the output display. This capability would permit portions of the image to be magnified to the extent where the small characters become legible. During the presentation of the Telefiche System by PRC Image Data Systems at the NMA Conference, a 2:1 zoom capability was demonstrated on their CRT Display.

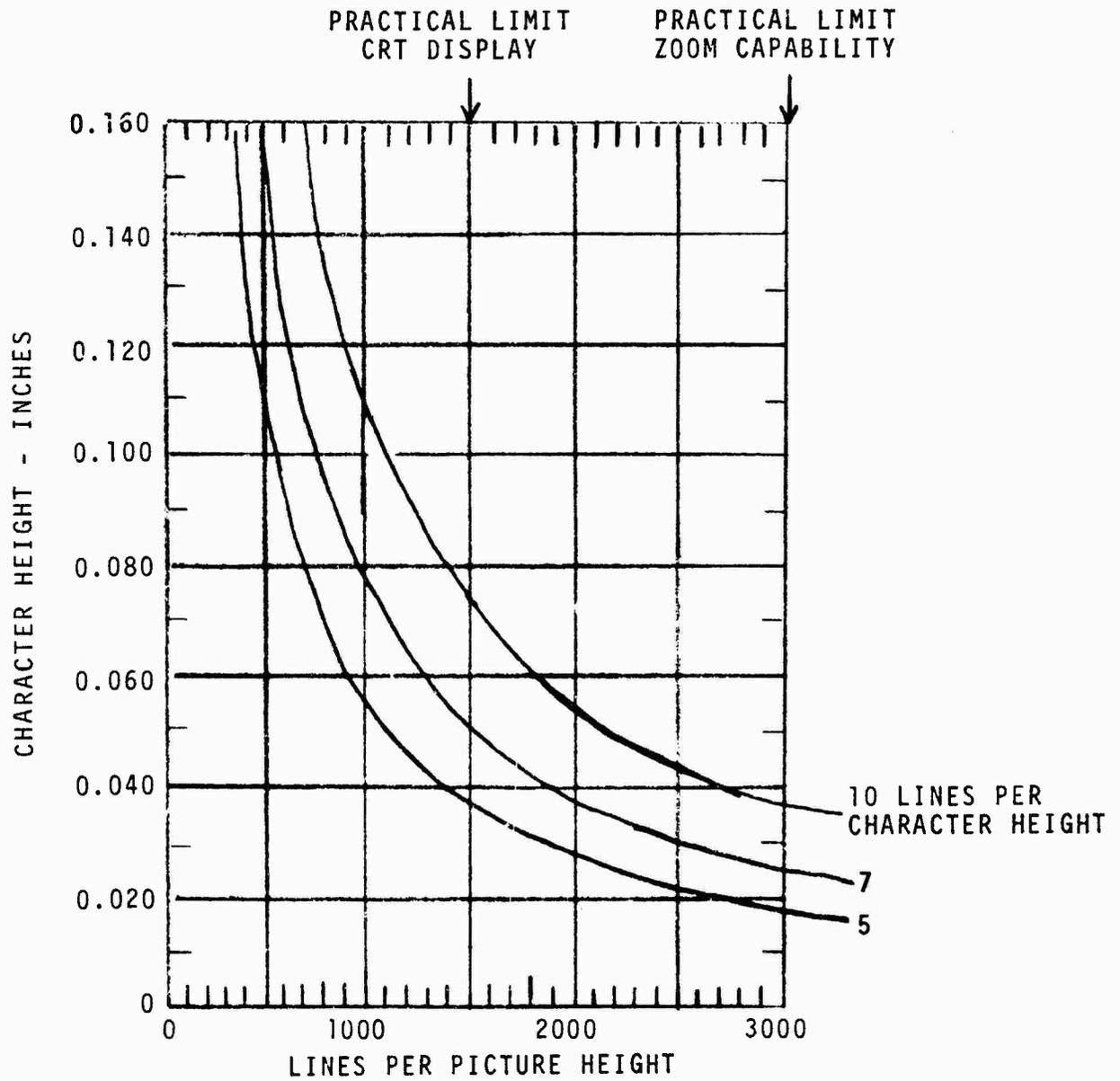


Figure 17 Scan Lines Versus Character Height

Film recording of electronically generated images is a very mature technology. A variety of computer-output-film (COM) devices are manufactured and sold commercially. These devices use both laser and CRT recording techniques. Although the characters are generated by the internal electronics in COM equipment as opposed to a line by line type of operation as is typical with facsimile, the technologies are otherwise similar. The demand for this type of output is quite small as compared to that for soft copy and hard copy. The technology is used primarily for outputting computer data onto microfilm rather than generating another microfiche electronically via a facsimile system. Although there is presently little demand for this type of output, the technology exists and is germane to this study.

The Modulation Transfer Function (MTF) concept has been used by many experts for many years as a quantitative measure of system performance. The function basically depicts a normalized curve showing the percent response of the system versus the spatial frequencies (the size and spacing of the lines) contained in the input image. A typical MTF curve is shown in Figure 18.

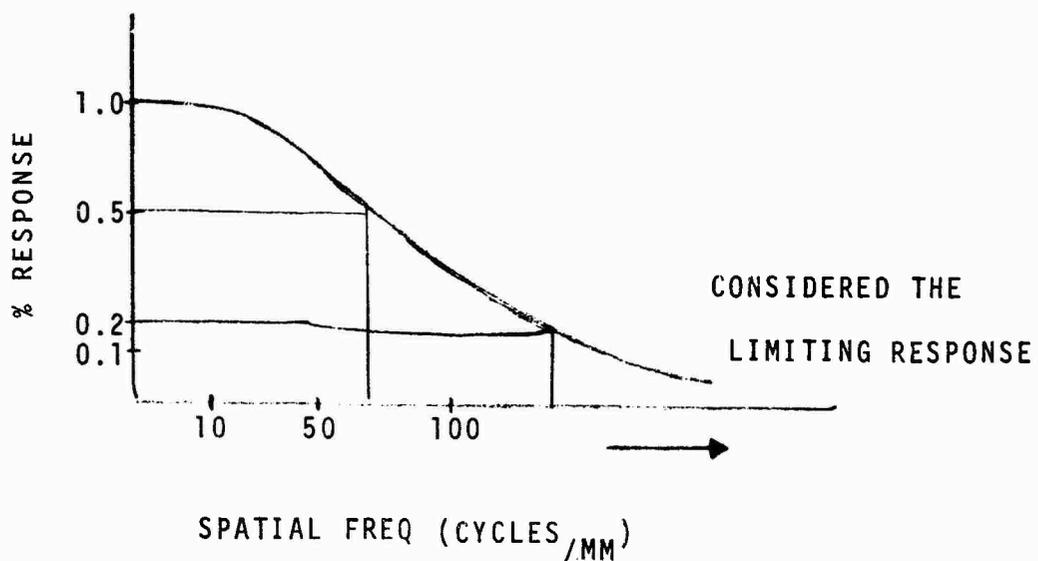


Figure 18 Typical Laser MTF Curve

A curve of this type is valuable for comparing the relative performance of scanner devices at various spatial frequencies. That performance is best typified by the signal strength output from the scanner equipment in comparison to the noise level. The % response value (also called the % modulation) is computed at selected spatial frequencies by taking the ratio of the

difference between the maximum and minimum signal values to the sum of those values.

Reference 19 suggests that image quality criteria for the evaluation of an image transmission system may be effectively reduced to three parameters; resolution, dynamic range and geometric fidelity. Since the amount of information that can be captured and reproduced in a single frame is proportional to the number of pixels per scan, resolution should be discussed in pixels per scan rather than line pairs per millimeter. The dynamic range which is the ability of the system to detect intermediate levels of contrasts (gray scale) should be stated at that resolution along with geometric fidelity (resultant image distortion). He states further that the three parameters relate to the MTF concept as follows: Resolution may be considered as the spatial frequency being analyzed and dynamic range as the distance between the response curve and the noise floor. Geometric distortion which cause pixel-overlap can reduce the response curve at high spatial frequencies.

Laser recording more so than CRT recording is a suitable technique for film recording of alphanumeric data in a facsimile mode of operation. This type of recording has been demonstrated by many agencies. Reference 19 indicates that the laser is capable of a recording density of over 3,000 pixels per inch at 0.5 MTF. Since in facsimile recording, the intermediate

levels of contrast is of no concern (only two levels are required), the usable recording density may be taken at an MTF as low as 0.20. Observe that in Figure 18 which was taken from Reference 19 and which demonstrates the recording density of laser recorders, the number of pixels per inch at an MTF of 0.2 is nearly twice that at an MTF of 0.5. This is of course more than adequate for facsimile film recording in a microimage format.

RADC's Intelligence and Reconnaissance Division recently concluded an effort to provide a means for secure transmission of images between DMA-Washington and DMA-St. Louis. The effort utilized as the basic equipment, the laserfax equipment manufactured by Harris Corporation of Melbourne, FL. Datalog (Litton Industries) concluded a development for the Naval Electronics Systems Command of a Tactical Digital Facsimile Unit which utilizes laser recording technology.

The hard copy output is perhaps the most desired output because of the fact that it can be carried away by the recipient, and can be read without the necessity of any specialized equipment. Facsimile printers are commercially available with resolution capabilities of 200 lines per inch in both the vertical and horizontal directions. At this resolution, a six-point lowercase character (0.045 inch high) subtends 9 lines and should be legible on a x 1 hard copy image (8.5 x 11 inches).

Unfortunately, as can be observed from Figure 19, the smaller characters do not have quite the legibility and clarity desired. Figure 19 is an output product obtained at the NMA convention. It was produced by a 200 line per inch facsimile hard copy printer. The original source document was a microimage which was scanned by a 1728 element solid state linear array scanner. Zoom capability works well with a soft copy display, and effectively increases the resolution when in the expanded mode. However, this capability does not augment the hard copy output product. Unfortunately, the required legibility must be contained in the X 1 image. No attempt is made here to determine where the weakness lies but to point out a marginal condition.

Carpet & Rug Cleaners

AAA RUG & CARPET CLEANERS INC

**FAIRFAX - VIENNA
McLEAN - ALEX - ARL.
SPRINGFIELD
FALLS CHURCH**

**GET YOUR 2nd CLEANING FREE
WE CLEAN YOUR CARPETS TWICE
THE SAME DAY**

1st We Shampoo Your Carpets, Then
We Steam Clean Them

- Expert Carpet & Furniture Cleaning
- Disinfecting & Deodorizing
- Scotch-Guarding

Licensed - Insured
BankAmericard - Master Charge
Local References Supplied

■ See Our Display Adr. Page 263

569-4414

8204 BLAIRTON RD. SPRINGFIELD

AA ULTRA-CLEAN CARPET CO

Commercial - Residential
12-24 Month Written Stain Prevention
■ See Our Display Adr. Page 261
400 N WashSt FllsCh ----- 821-3225

A & W CARPET SERVICE INC

2817-M DorrAv Fairfax-560-4300

(See Advertisement Page 257)

APPROVED MAINTENANCE SERVICE INC

McLeanVa-336-3100

(See Advertisement Page 263)

ABACUS CORPORATION

3501Perry McLeanMd-277-8114

Home Office
2024M4Av

BaltMd-WashAreaTel No--621-1140

ABEY CARPET CO

6341-A ColumbiaPike FllsCh 256-0424

ABEY CARPET CO

7516RichmondHwy Alex-748-1300

(See Advertisement Page 260)

Abraham's Star Oriental

7704RichmondHwy Alex-360-9650

Abraham's Star Rug & Carpet Cleaners

2756Duke Alex-751-8070

ACTION CLEANING SVCS INC

2311 99thAv CheverlyMd-773-6696

Action Industrial Cleaning Associates

3801 N FairfaxDr Arl-522-1732

ACTION STEAMWAY

RESIDENTIAL & COMMERCIAL

**STEAM EXTRACTION
CARPET CLEANING**

Gentle, Sanitary, Economical
Best For Water & Smoke
Damage

Stays Clean Longer

Experienced Trained Personnel

**STEAMWAY... THE ULTIMATE
IN CARPET CLEANING**

534-3244

3010 Annandale Rd. Falls Church, Va.

Action Steamway

3016AnnandaleRd FllsCh 534-3244

Advanced Services 2800Junar Fairfax 560-8900

AETNA RUG & UPHOLSTERY CLEANING CO

2604PittmanDr SlSprMd 348-7060

AMMAD INTERNATIONAL ORIENTAL RUGS

7034W acAv Bethsd-654-2996

(See Advertisement Page 262)

Listings of This Classification

Carpet & Rug Cleaners

Are Continued on Next Page

**Man
KESHISI**

SUCCESSORS TO AND OF

**ARCADE-
SUNSHINE**

ORIENTAL & DO

RUG CLEAN

REPAIRING • APPRAISING • S

ALSO WALL TO WALL HO

340-66

RUG CLEANING PLANT: 626 ROCKY

"WE SERVICE WHA

ONE OF THE LARGEST
SELECTIONS OF
ORIENTAL RUGS IN
THE UNITED STATES

VISIT OUR ORIENTAL

6830 WISCONSIN AVE., BETH, MD 630

654-4044

Fladeed
PERSONALLY SUPERVISED
RUG CLEANING
ALL WORK DONE IN OUR
OWN MODERN PLANT



Wall To Wall A Speciality
QUALITY SERVICE

CLEANING • REPAIRING • MOVING & INSTALLATION OF CARPETS & RUGS

**CLEAN RUG
ORIENTAL RUGS**
CLEANED - REPAIRED - MOTH
Our Professional Ch

- REMOVES d
- SCRUBS a
- SAVES
- TEAR

**WALL TO
AND FUR**
FREE ESTIM

**LIKE
NEW
AGAIN**

3 DAY SERVICE **53**
Proper Storage - Insured Protection
CARPET SELLING - LAYING - FIN
WE BUY SELL & APPRAISE

Figure 19 Hard Copy Output

V. TRANSMISSION COST DATA:

The major cost in any microfacsimile or facsimile system is the monthly recurring cost of data transmission in addition to the fixed cost of equipment acquisition. As noted in the Data Transmission Section, the monthly cost consist of line (or channel) charges in addition to station terminal charges. The determination of recurring cost estimates must be accomplished for a specific systems concept. However, to accommodate a change or an expansion in concept, this section of the report presents generalized transmission cost data which will prove useful for future planning purposes in determining the most cost-effective mode of transmission, and in establishing future cost estimates for the specific system concepts discussed in the following section.

The approach used to present the generalized cost data was to compile a set of generalized curves whose parameters cover a range within which the AFMPC would probably operate. The parameters and the associated range considered are noted below:

Transmission Distance--100 to 3,000 miles

Transmission Speed-----9.6 to 230.4 KBPS

Transmission Volume----up to 8,800 images per day
per data link

Transmission Modes-----ground-line and satellite

The specific topics discussed pertain to the following:

- A. The relative monthly cost of different transmission links as a function of distance.
- B. The cost per bit for the different links.
- C. The break even line which determines when it is more cost effective to lease or to use the dial-up network.
- D. The volume of images which can be transmitted over a given link and during a specified time.
- E. The cost of utilizing the U. S. Postal Service.
- F. Relative cost of a ground-line and a comparable satellite channel.

The graph of Figure 20 depicts the relative cost in dollars per month for the lease of communications lines at the indicated speeds. The graphs were derived from data presented on the series 5000 (19.2, 50, and 230.4 KBPS) and series 3000 (9.6 KBPS) communication lines. The cost including monthly terminal fee at both points were determined as follows:

<u>CURVE</u> (KBPS)	<u>COST</u>
230.4	$C = \$1,406 + \33.00 per mile
50	$C = \$ 920 + \$ 6.60 \text{ per mile}$
19.2	$C = \$ 920 + \$ 3.30 \text{ per mile}$
9.6	$C = \$ 498 + (\text{cost data taken from Figure 11 at appropriate distances})$

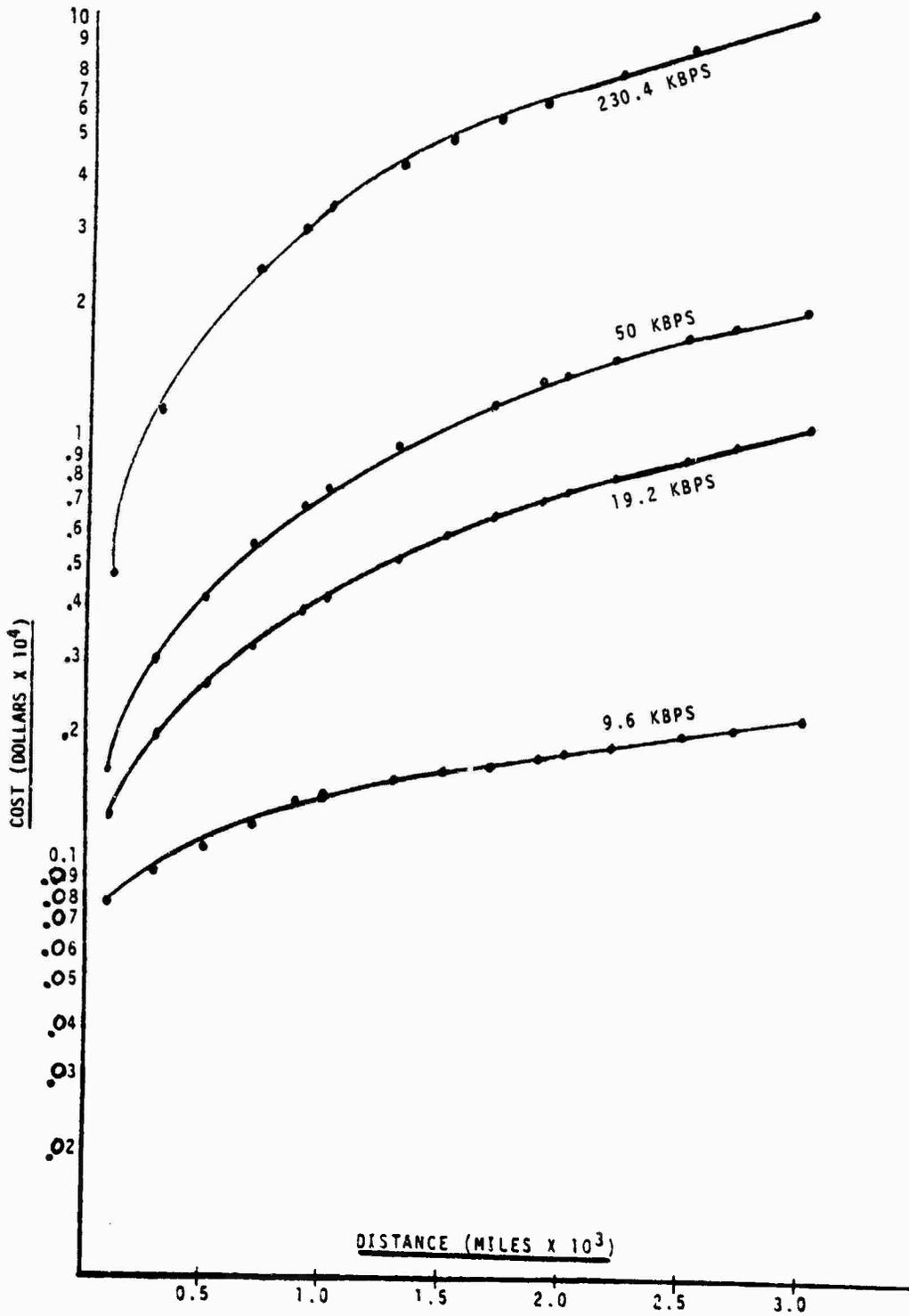


Figure 20 Monthly Cost of Leased Lines

Therefore, with a knowledge of the transmission speed required, a reasonable estimate of monthly cost at a given distance can be obtained from this graph.

The graph in Figure 21 depicts the cost per bit per second for the four transmission speeds presented in Figure 20. The cost per bit is usually but not necessarily less for a higher-speed line than for a lower-speed line. The graph of each curve was determined by dividing the monthly cost in Figure 20 by the "bits per second" speed for each transmission line for selected distances. As can be seen from the figure, the cost per bit for the highest speed line (230.4 KBPS) closely approximates the cost per bit of the 50 KBPS line, and is less than the cost of the 19.2 KBPS line. The graphs tend to support the above statement regarding the relative cost per bit for a higher-speed line versus a lower-speed line.

The graph in Figure 22 depicts the break-even line between using a leased or dedicated line versus using the dial-up or switched lines. The leased line used for comparison was the type 3002, and the day-rates (worst case) were used in connection with the switched lines. The break-even line was computed based on the transmission distances in the left column of Table 13.

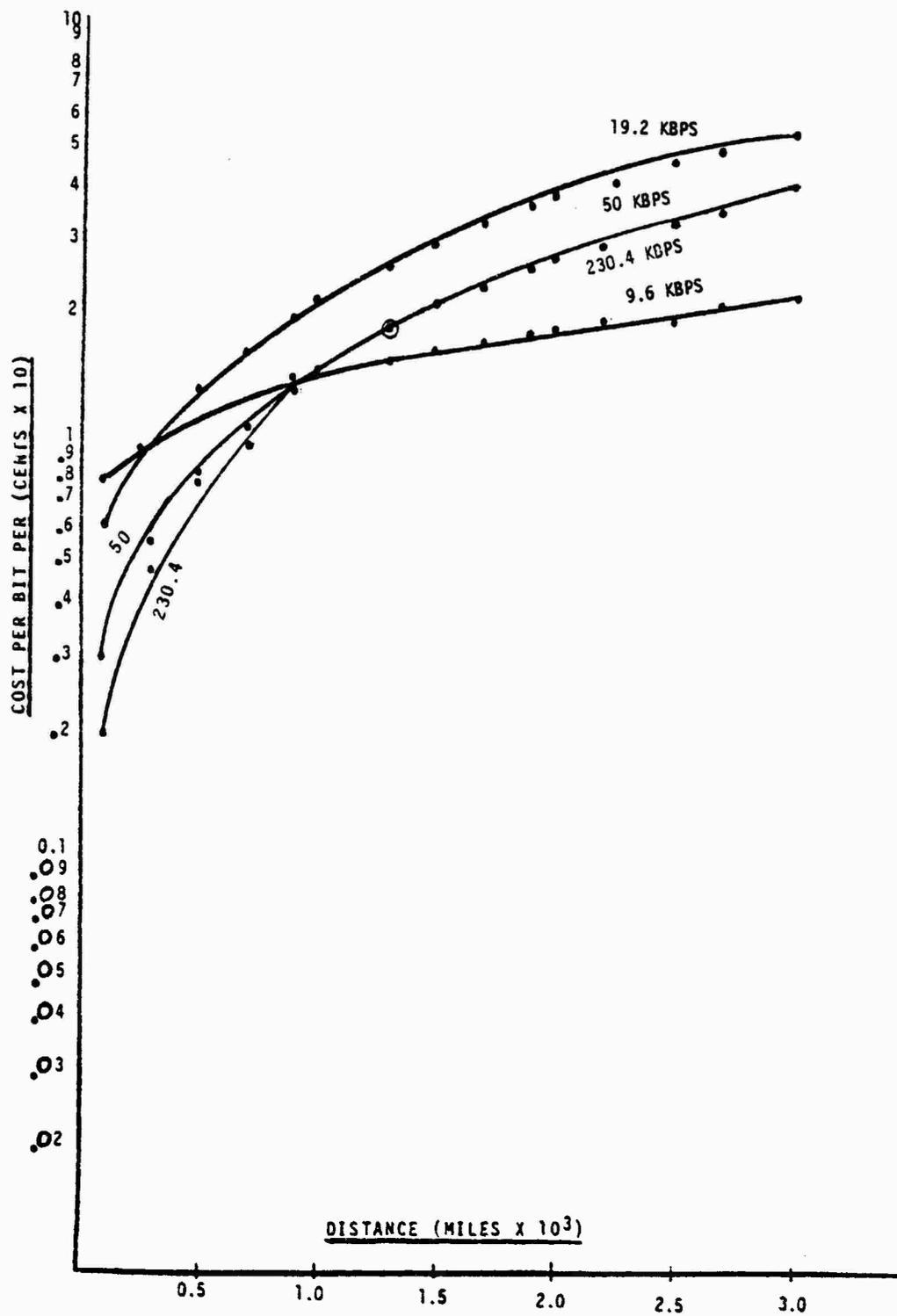


Figure 2i Cost Per Bit vs Distance

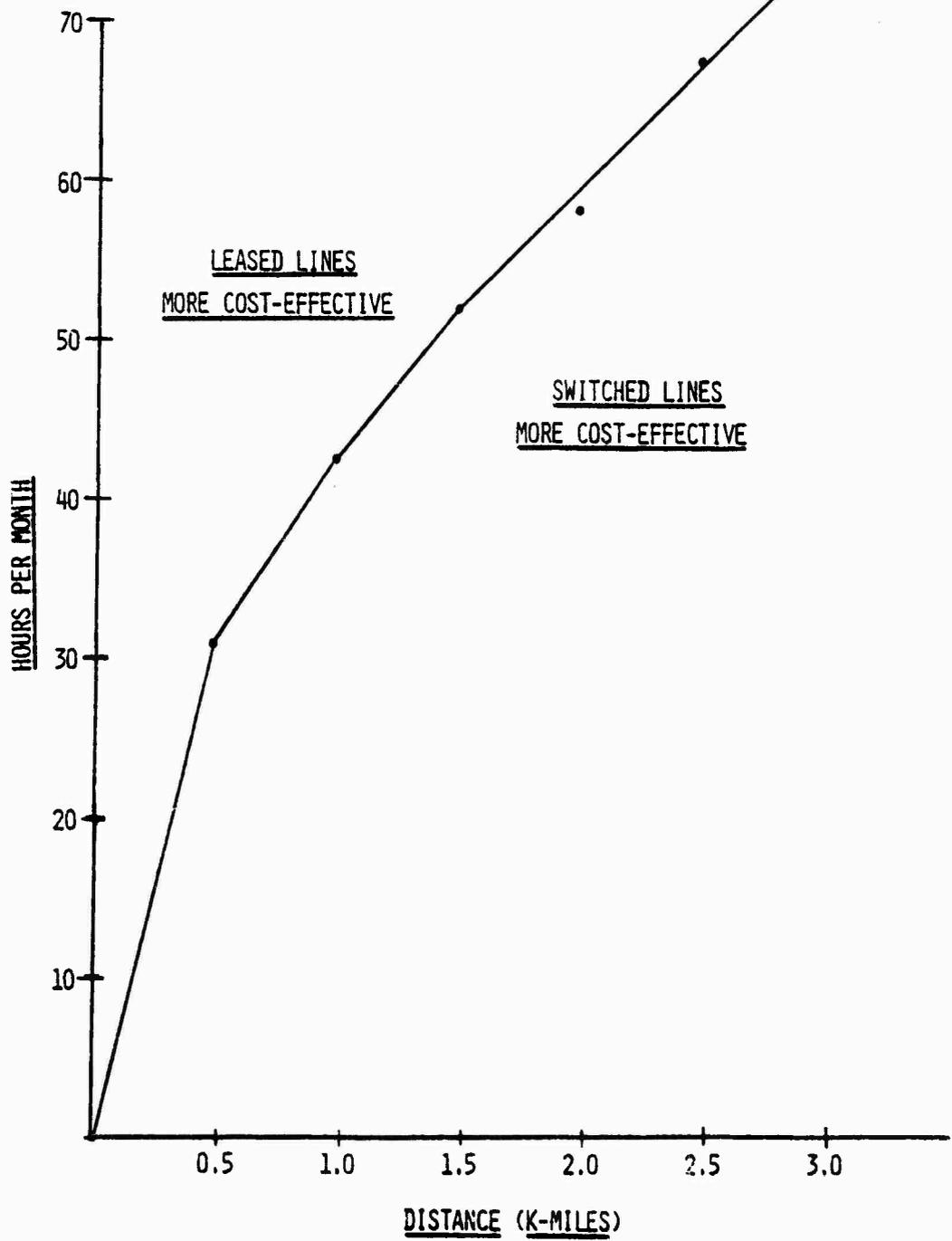


Figure 22 Break-Even Line (Switched vs Lease)

Table 13
Break-Even Time

DISTANCE (MILES)	LEASE COST/MO	COST/HR FOR DDD	BREAKEVEN TIME/HRS
100	\$ 300.00	\$17.50/hr	17.1
500	\$ 630.00	\$20.00/hr	31.5
1000	\$ 900.00	\$21.25/hr	42.3
1500	\$1,100.00	\$21.25/hr	51.8
2000	\$1,300.00	\$22.50/hr	57.8
2500	\$1,500.00	\$22.50/hr	66.7
3000	\$1,700.00	\$22.50/hr	75.6

For example, the lease cost for a type 3002 line (Schedule 3) at a distance of 100 miles is \$300.00 (obtained directly from Figure 14). The cost per hour for a direct distance dial (switched line) for 100 miles is \$17.50 (obtained from computing the slope of the "71-124" distance line on Figure 11). Therefore, the break-even time for this case is 17.1 hours ($\$300/\17.50). The other distances were determined in a like manner. Therefore for low volume applications, this curve

would prove valuable in deciding to use the switched network for data transmission or to lease a private line.

The graph in Figure 23 shows the relationship between transmission time and volume of images at different transmission speeds. The total bits per image used in the calculations was derived in the Data Conversion Section of this report. Other assumptions used in the calculations were a data compression ratio of 3 to 1, and approximately 15% of the total bits transmitted were attributed to overhead. Consequently, the total number of bits per image to be transmitted (3.35×10^6) was 1.117×10^6 bits after compression. Also, the effective transmission speed for each data link considering overhead was 8,160 BPS (9,600 BPS), 16,320 BPS (19,200 BPS), 42,500 BPS (50,000 BPS) and 195,840 BPS (230,400 BPS).

The graph in Figure 24 depicts the cost of U. S. Postal rates for first class mail. This graph is included for comparative purposes. It can be observed that the graph shows the cost of mail delivery of approximately 700 fiche. The U. S. Postal rates for first class mail are \$0.15 for the first ounce and \$0.13 for each additional ounce. (A diazo microfiche copy weighs 0.0148 pounds or 0.237 ounces). Therefore, the cost (in dollars) of postal service was computed from the relationship:

$$C = 0.15 + 0.13 (n-1) \text{ where } n = \text{the number of ounces.}$$

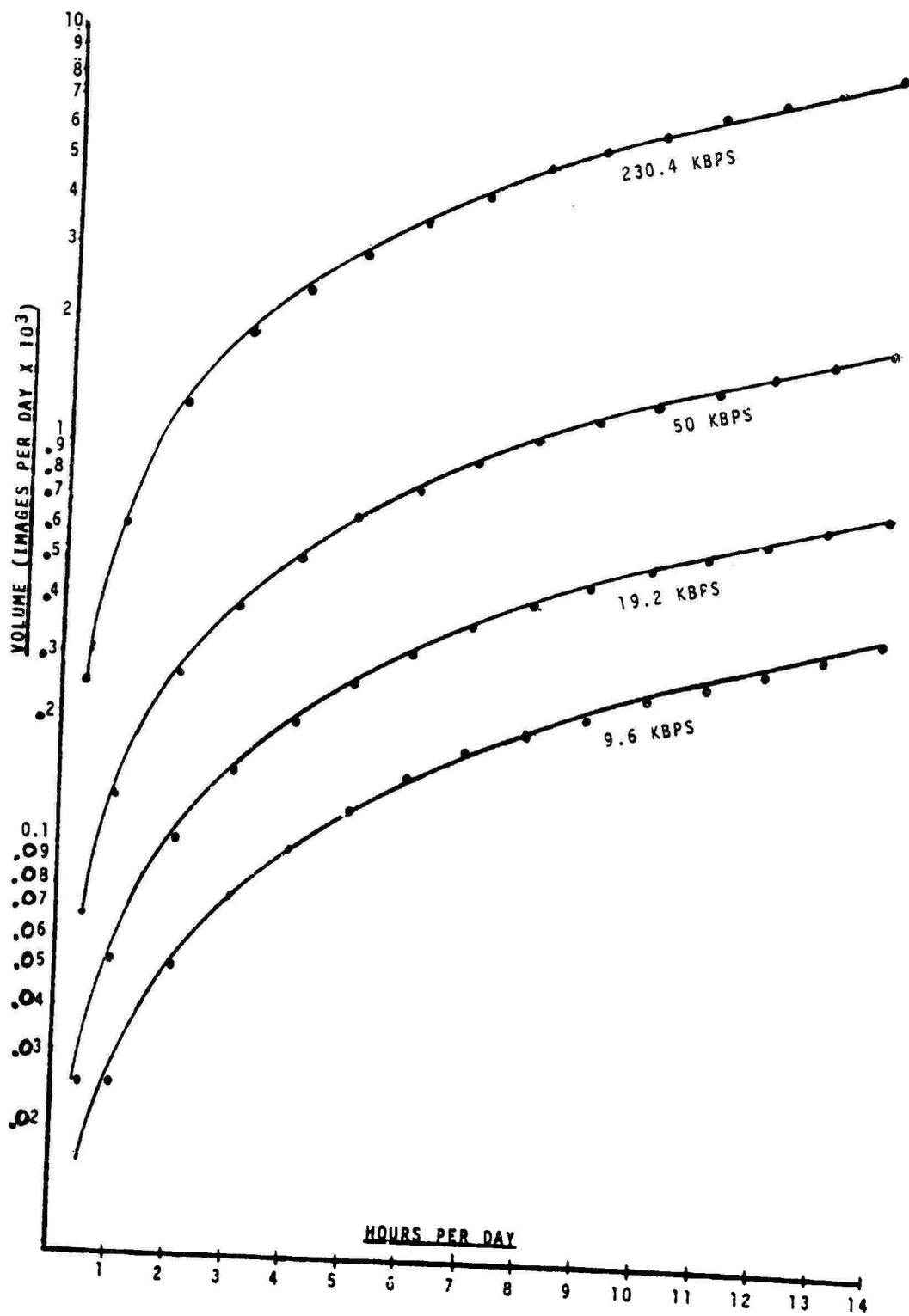


Figure 23 Volume vs Transmission Time

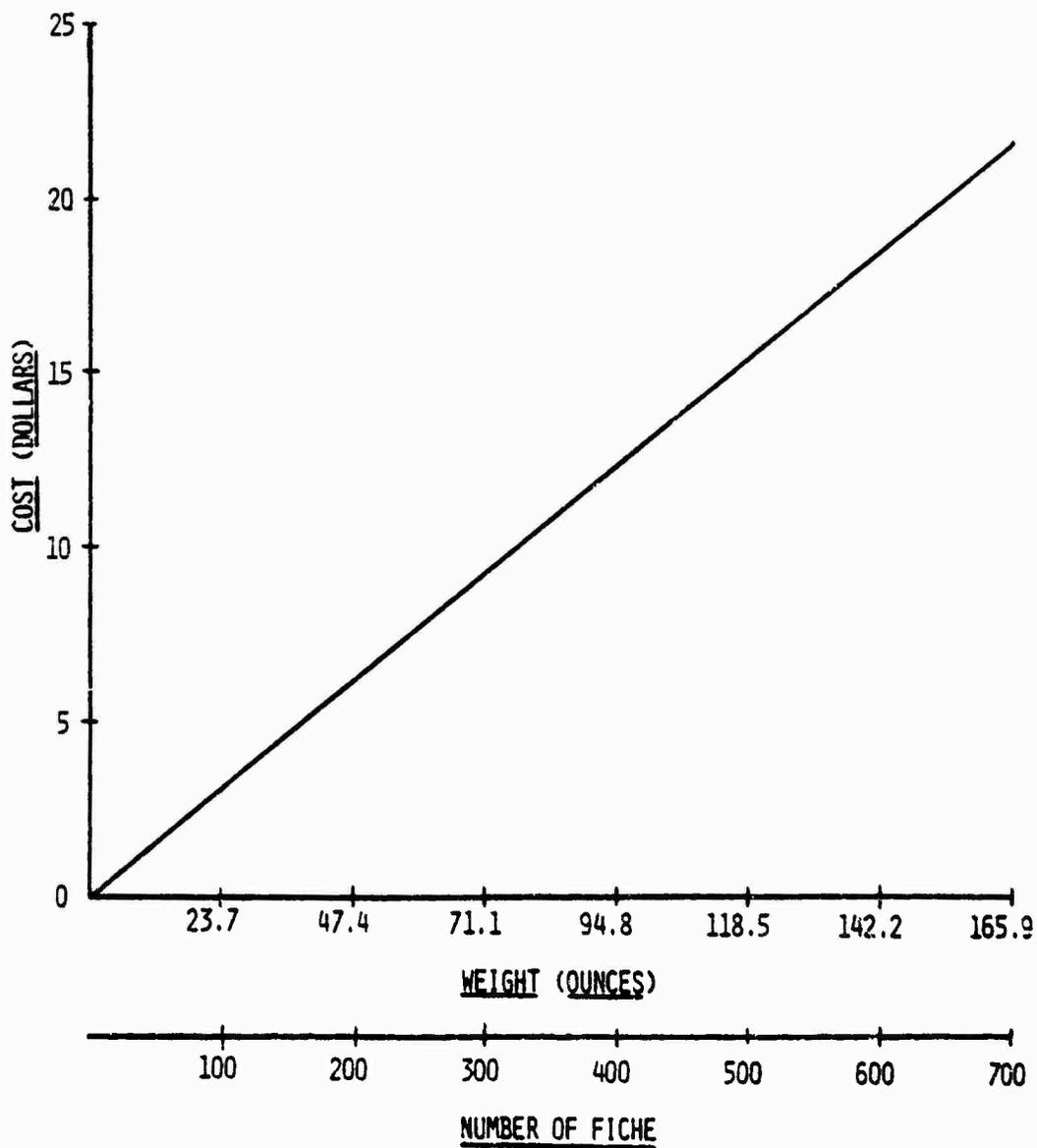


Figure 24 Postal Service Cost

The cost of providing satellite transmission service is not necessarily related to terrestrial distances involved. As noted in the previous section, satellite services are generally based on a predetermined zoning pattern. Consequently, satellite data link cost, unlike the cost of terrestrial links, is not easily presented in graph form. Nevertheless, a comparison will be made between the cost of transmitting data between Dallas/Ft. Worth, TX and Washington, DC (approximately 1,185 airline miles) via satellite and ground line systems. As noted in the Data Transmission Section, a single voice grade satellite channel operating between Dallas/Ft. Worth and Washington, DC cost \$750.00 per month. Therefore, the total monthly cost including terminal charges (\$25.00 a month per station for each voice grade channel) is \$800.00 per month. The cost of a comparable land line (9,600 BPS) as indicated in Figure 20 is approximately \$1,500 per month. Comparisons were made with other bandwidth data links operating between the same points and the results are shown in Table 14. The last comparison in the table involving the 240 KHz bandwidth satellite channel and the 230.4 KBPS line was included for comparison purposes only. Satellite channels of that bandwidth and higher are leased by Western Union only to other carriers rather than individual customers. These examples support the contention

by many experts that satellite transmission is more economical than transmission over land lines.

Table 14
Satellite vs Land-Line Cost

DATA LINK	COST	
	SATELLITE	LAND-LINE
1 Voice-Grade Channel (4 KHz) 9.6 KBPS	\$ 800.00	\$ 1,500.00
5 Voice-Grade Channels (20 KHz) 19.2 KBPS	\$ 4,000.00	\$ 4,800.00
12 Voice-Grade Channels (48 KHz) 50 KBPS	\$ 8,050.00	\$ 8,500.00
60 Voice-Grade Channels (240 KHz) 230.4 KBPS	\$33,500.00	\$37,000.00

VI. SYSTEM CONCEPTS:

The systems concept discussed in the Operational Requirements Section involved the Major Commands (MAJCOMS). The average image traffic for each of the 26 MAJCOMS was estimated at 835 images per day. The distances of the MAJCOMS vary considerably from AFMPC. Table 15 is a listing of the majority of the commands and their respective distances from AFMPC. The average distance of a MAJCOM from AFMPC (with the exception of ATC and the USAF Security Service which are co-located in Texas; and USAFE, PACAF and Alaskan Air Command which are outside of CONUS and located in excess of 3,000 miles from AFMPC) is approximately 900 miles. A cost estimate for data transmission via land line will be established for a single MAJCOM based on the average traffic estimate and the average distance from AFMPC. The total cost can then be determined from the number of MAJCOMS involved.

The Operational Requirements Section indicates that better than 85% of the requests are multiple fiche requests as opposed to either single fiche or single document requests. These requests pertain mostly to a fiche family which consist of approximately 2.5 fiche. The following concept discussion will be based on each user requesting three fiche which contain an average of 20 images per fiche. Figure 25 illustrates the general concept involving the AFMPC and the major commands.

Table 15
Major Commands

<u>COMMANDS</u>	<u>LOCATION</u>	<u>DISTANCE FROM SAN ANTONIO TX (MILES)</u>
ADC	COLORADO	805
SAC	NEBRASKA	800 (Estimate)
AFSC	MARYLAND	1400
SOUTHERN COMMAND	PANAMA	500 (Estimate)
USAFE	GERMANY	
PACAF	HAWAII	
ATC	TEXAS	
AFLC	OHIO	1100
ALASKAN AIR COMMAND	ALASKA	
TAC AIR COMMAND	VIRGINIA	1200
MILITARY AIR LIFT COMMAND	ILLINOIS	790
AFCS	ILLINOIS	790
AF ACC'T & FINANCE	COLORADO	802
ARPC	COLORADO	802
NPRC	MISSOURI	792
US SECURITY SERVICE	TEXAS	

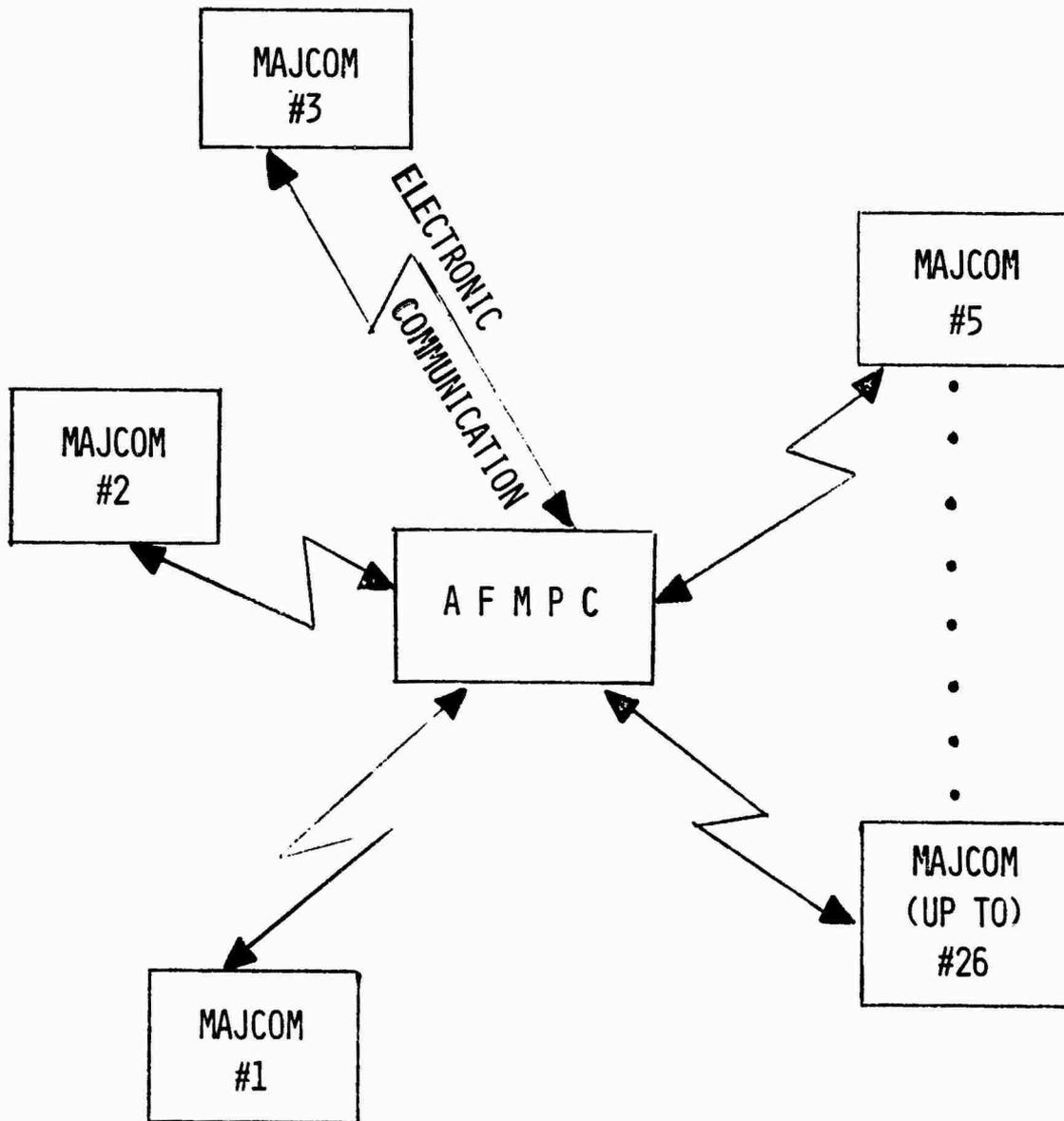


Figure 25 AFMPC/MAJCOM Concept

The communications discipline assumed between the AFMPC and the MAJCOMS allows the operator to retrieve either a single document or up to 20 document images per request.

Accurate cost estimates must be based on a detailed systems analysis. The thrust of this effort as described in the PMD was to make a technology assessment as opposed to making a detailed analysis of a specific systems concept. However, for comparative purposes, the following alternative system concepts using ground data links were examined:

1. An Electronic Transmission System using a 230.4 KBPS data link to each MAJCOM.
2. An Electronic Transmission System using a 50 KBPS data link to each MAJCOM.
3. A Hybrid Transmission System using a combination of electronic transmission on a 50 KBPS data link and Postal Delivery Service.
4. A Hybrid System using a combination of electronic transmission on a 19.2 KBPS data link and Postal Delivery Service.
5. A Hybrid System using a 9.6 KBPS data link in conjunction with postal delivery.

Preliminary cost estimates based on satellite transmission cannot be readily established since a knowledge of the cost between specific zone pair cities is required. Only the satellite carrier who provides the service is capable of providing a reasonably accurate estimate since ground loops and or additional terrestrial links may or may not be required to complete the transmission path to the respective MAJCOM.

Table 16 presents a summary of the concepts considered. One of the important system parameters which determined the extent to which these concepts were examined is the system response time. It is defined as the time interval between an operator request and the response of the system. The indicated range is commensurate with a request for a single image or up to 20 images. This time includes manual retrieval of the fiche from the file, loading and unloading of the scanner, scanning the fiche, and actual transmission to the MAJCOMS. The system response time for concepts four and five were considered too long to warrant any further discussion. The other is the mean waiting time in the user "Q" since operational considerations as well as technical considerations should determine the number of user stations required.

CONCEPT NO. 1:

This concept is an all-electronic data transmission system utilizing a 230.4 KBPS data link and in which all inquiries at each MAJCOM results in on-line traffic.

CONCEPTS	DATA LINK KBPS	TRANSMISSION MODE	NUMBER OF SHIFTS	TRANSMISSION TIME PER IMAGE (SEC)	SYSTEM RESPONSE TIME (MIN)	NUMBER USER STATIONS	MEAN WAIT TIME IN USER QUEUE (MIN)
1	230.4	ELECTRONIC	SINGLE	5.6	< 1-4	3	1.46
2	50	ELECTRONIC	DOUBLE	27	1.2 - 11	3	1.85
3	50	HYBRID	SINGLE	27	1.2 - 11	3	1.87
4	19.2	HYBRID	SINGLE	65	2 - 24		
5	9.6	HYBRID	DOUBLE	136	3 - 49		

Table 16
Alternative Concepts

Table 16 further indicates that the operation can take place during a single shift.

In order to establish the validity of a single shift operation, it must be shown that the total time required by the system to respond to all of the user request does not exceed the total time available in a single shift (480 minutes). The total time to respond to a user request is determined from the following estimates:

40 seconds to retrieve fiche (approximately 40 seconds are required to manually retrieve fiche from the file)

10 seconds to load/unload three fiche (estimate)

60 seconds-mechanical position for 60 images (estimate)

180 seconds to scan 60 images (3 seconds scan time per image reported in the literature)

336 seconds to transmit 60 images (based on 5.6 seconds per image)

626 seconds - total seconds to retrieve, load, scan and transmit per user request

Therefore, approximately 11 minutes are required by the system to service a single user request and 198 minutes to service 18 user requests. The 198 minutes are well within the time available in a single shift.

The time to transmit a single image is determined from Figure 23 (volume vs transmission). This figure provides an indication of the time required to transmit a contiguous block of up to nearly 9,000 images which have been scanned,

compressed and stored in a digital buffer and transmitted without interruption. For example, the estimated time from the graph to transmit a contiguous block of 900 images is 5,040 seconds. Therefore, a single image should require about 5.6 seconds.

The system response time as noted can vary from less than one minute to four minutes depending on the user request. This estimate was based on the following:

40.0 seconds to manually retrieve the fiche from the file.

3.0 seconds to load fiche in the scanner.

3.0 seconds to scan image.

5.6 seconds to transmit one image (determined from data in Figure 23).

SUBTOTAL 51.6 seconds total time to respond to a single-image request.

19.0 seconds-time to mechanically position to 19 other images.

57.0 seconds to scan 19 other images.

106.4 seconds to transmit 19 other images.

TOTAL 234.0 seconds-total time to retrieve, load, scan and transmit 20 images.

Figure 20 (Monthly Lease Cost) indicates that the lease cost for a 230.4 KBPS line for transmitting over a distance of 900 miles is approximately \$31,000 per month. Assuming

26 MAJCOMS comprise the network, the total monthly cost estimate for data transmission would be less than \$806,000.00 by about 15 to 20 percent. The \$806,000.00 figure is based on a worse case situation of having 26 separate lines originate from MPC and terminate at the respective MAJCOMS. Whereas the carrier uses a special algorithm to compute minimal path lengths based on the source and destination points of the data.

The number of user terminals (stations) required must be determined from both a technical and an operational point of view. From a technical point of view, the number of units required at each MAJCOM is determined from the total viewing time required and the total viewing time available. Exhibit IV of the Requirements Study indicates that the average viewing time per inquiry is approximately 17 minutes. Also, the average number of inquiries per day at each MAJCOM is 18. Therefore, the total viewing time required per day is 306 minutes. The total viewing time available must be determined from the difference between the total time available in a single shift and the total time required to service 18 users. The total time available in a single shift is 480 minutes. The total time to satisfy 18 user requests was determined to be 198 minutes. Therefore, the total viewing time available during a single shift is 282 minutes (480 minutes minus 198

minutes). Since the viewing time available is slightly less than that required, this situation might be considered as a borderline case for a system with a single user terminal.

As noted previously, operational factors must also be considered. Considering such factors as maintaining a minimum length queue of requests and providing adequate system availability, a single terminal system is less than desirable. A queuing analysis was conducted to determine the mean waiting time in the user "Q" for single and multiple user-station configuration. Infinite queue, poisson arrival distribution and exponential service were assumed. The following terms are defined:

λ = mean arrival rate per unit time. The MAJCOMS have 18 requests per day (single shift) or 2.25 requests per hour.

μ = mean service rate per unit time
2.13 requests per hour (determined from $1/\mu$.)

$1/\mu$ = mean service time. Approximately 11 minutes are required by the system to satisfy a request. Also, the average viewing time per request is 17 minutes. Therefore, the mean service time in this instance is taken as 28 minutes or 0.47 hrs per request.

$\rho = \lambda/\mu$ = traffic intensity.

L_q = mean number of requests in queue.

W_q = mean waiting time in queue.

CASE 1 - A single terminal (server) system.

$$\lambda = 2.25 \text{ requests per hour.}$$

$$\mu = 2.13 \text{ requests per hour.}$$

Since $\rho (\lambda/\mu)$ is greater than 1, the arrival rate exceeds the service rate and the queue is steadily building up. Therefore, a single terminal system is not satisfactory from an operational point of view.

CASE 2 - A two-terminal system.

$$Lq = \frac{\rho^3}{4-\rho^2} = 0.37$$

$$Wq = Lq/\lambda = 0.16 \text{ hours or } 9.6 \text{ minutes}$$

CASE 3 - A three-terminal system

$$Lq = \frac{\rho^4}{(3-\rho)(6+4\rho+\rho^2)} = 0.055$$

$$Wq = Lq/\lambda = 0.024 \text{ or } 1.46 \text{ minutes.}$$

Based on the above results, a two or three user terminal system at each MAJCOM should suffice. However, the follow-on discussion will center around a three-terminal system. Table 17 summarizes the mean waiting time in the queue for concepts 1, 2 and 3, using 1, 2 and 3 user stations.

Table 17
Mean Wait Time in User Queue

CONCEPT	NUMBER OF USER STATIONS	MEAN WAIT TIME IN USER Q (MIN)
1	1	00
	2	9.6
	3	1.46
2	1	743.4
	2	14.1
	3	1.87
3	1	134.0
	2	13.2
	3	1.85

The user terminal system consists of a Display Terminal supported by a buffer storage device with the necessary capability for user interaction. The Display Terminal portion is estimated to cost \$15,000 each. It must be a high resolution device (at least 1,000 line raster) capable of displaying a full page document. Therefore, the cost of the Display Terminal Equipment for the 26 MAJCOMS is \$1,170,000.

The Buffer Storage Unit should have sufficient capacity to store at least 60 images (20 images per user), and permit the operator to perform the paging function locally. One page consist of 3.35 million bits. Therefore, a 60 image buffer requires a storage capacity of 201 million bits or 25 million bytes. To estimate the cost of providing a multi-user system with buffer storage capacity for three users, the DEC System, SM-30HHA-LA, was used as a basis. The system consist of a Dual RK07 Cartridge Disk-Based PDP 1134A real time package. It includes the RSX-11M multi-user operating system, RK07 Disk Drive with a 28 megabyte storage capacity, serial line interface, real time clock, parity control, 64K bytes of MOS memory, hardware memory management programmer's console, extended instruction set and boot strap loader. In the July 1978 Price Listing, this system cost \$50,000. The cost for 26 MAJCOMS is \$1,323,400. This cost figure does not include the cost of creating the applications software.

Hardware maintenance cost for this system is \$441.00 per month. Software support for this and other DEC Systems is provided on a per-call basis (\$50 per hour, plus expenses), a weekly basis (\$1,800 per week, plus expenses), for a six month period (\$5,500 per month) and for a 12-month period (\$5,200 per month). A software support cost for four weeks will be included as part of the system costs (\$7,200).

Facsimile Printers (at the MAJCOMS) - A high resolution facsimile printer requires 90 to 120 seconds to generate a standard document. Exhibit III-9 of the Requirements Study indicates that 32 hard copy output documents are required at each MAJCOM per day. One printer is adequate for this function. Assuming a purchase price of \$10,000 (based on GSA data on the DACOM Printer), the printer cost for the 26 MAJCOMS is estimated at \$260,000.

Scanner Equipment (at AFMPC) - The average thruput rate for the scanner is estimated at ten seconds per image. This includes three seconds for actual scanning, and another seven seconds for loading, mechanical positioning to the next image and unloading. The combined MAJCOM requirement imposed on AFMPC would be 21,710 images per day (835 x 26). Therefore, a total of 217,100 seconds or 60 hours would be required by the scanner device to meet the daily demand. This time period extends beyond a single shift operation (8). Therefore, eight

scanner devices would be required. Although the technologies for a scanner device with a type of cassette load mechanism exist, it is felt that some engineering development remains to be done before a reliable device can be manufactured and sold commercially. An estimated development cost is \$250K and the cost of each additional unit is estimated at \$50K. Therefore, the cost of eight scanner units is estimated at \$600,000.

Manpower Impact (at AFMPC and the MAJCOMS) - In the current operational system at AFMPC, about 25 people perform the function of responding to user requests which equals about 24,026 requests per month. The combined MAJCOM requests of 9,580 per month represents 40 percent of current AFMPC workload. Therefore, eliminating the files at the MAJCOMS and requesting data directly from AFMPC would result in a 40 percent increase in the workload or a requirement at AFMPC for an additional 10 people. An average of three records maintenance people are assumed to be located at each MAJCOM in the current mode of operation. In all the alternative concepts, the three records maintenance people will not be required at each MAJCOM; however, one equipment maintenance person and one person to assist records users will be required at each MAJCOM. Therefore, 52 personnel will probably be required at the MAJCOMS along with the

10 additional people required at AFMPC. Table 17 reflects the manpower in the current and alternative concept systems.

Table 18
Manpower Impact

	CURRENT SYSTEM	CONCEPT SYSTEMS
MANPOWER		
MAJCOMS (26)	78	52
AFMPC	25	35
TOTALS	<u>103</u>	<u>87</u>

System Impact (at AFMPC) - The system impact resulting from the incorporation of this dissemination mode must be assessed by someone intimately familiar with the present load conditions in the system. A determination of whether additional hardware (excluding the scanner equipment) and software are required to handle the increased communications, or whether additional software alone on the existing system will suffice must result from a detail systems analysis.

CONCEPT NO. 2:

This concept is similar to Concept No. 1 with the exception that a 50 KBPS data link is used rather than a 230.4 KBPS line, and the operation requires a double rather than a single shift.

The requirement for a double shift operation is due to the fact that the total time required by the system to service all user requests exceeds the time available in a single shift (480 minutes). In this concept, 1,910 seconds or 32 minutes are required to retrieve, load, scan and transmit per user request. The additional 21 minutes over the previous concept is due to the increase in the time required to transmit 60 images on a 50 KBPS data link. Therefore, 576 minutes are required by the system to service all user requests.

The time to transmit a single image is likewise determined from the appropriate graph of Figure 23 (Volume vs Transmission). As noted in Table 16, 27 seconds are required to transmit a single image over a 50 KBPS link.

The system response can vary from 1.2 minutes to 11 minutes depending upon the complexity of the request.

Figure 20 (Monthly Lease Cost) indicates that the lease cost for a 50 KBPS line and transmitting over a distance of 900 miles is approximately \$6,600 per month. Assuming 26 MAJCOMS comprised the network, the total monthly cost estimate is \$171,600 per month for data transmission.

The number of user terminals required is determined as in the previous concept. The total time available in a double shift is 960 minutes, and the total time required by the system to service all requests is 576 minutes. Therefore, 387 minutes are available as viewing time. Since only 306 viewing minutes are required, a single terminal should suffice from a technical point of view. A similar queuing analysis was made on this concept using the following parameters:

$$\lambda = 1.125 \text{ requests per hour (18 requests over a 16-hour period).}$$

$$1/\mu = 0.82 \text{ hours per request.}$$

$$\mu = 1.22 \text{ requests per hour}$$

As noted in Table 17, based on the mean waiting time, a two or preferably a three-terminal configuration is desirable. The other areas with the exception of the scanner are the same as the previous concept. Since a double shift is used instead of a single shift, only four scanners as opposed to eight in the previous concept are required.

CONCEPT NO. 3:

This concept involves a combination of electronic transmission on a 50 KBPS data link as used in the previous concept and postal delivery service. As noted in the Requirements Section, 34.7% of the monthly inquiry volume is performed through on-line terminals. The remaining 65.3% represents off-line actions. It is assumed that on-line traffic for each

MAJCOM represents a requirement for which an immediate response is required. Whereas the remaining off-line traffic does not require an immediate response. The on-line traffic for each MAJCOM is approximately 290 images per day (835 x 34.7%). The off-line traffic is approximately 545 images per day. The on-line traffic corresponds to about seven requests per day. Therefore, at 32 minutes per request as previously calculated, 224 minutes would be required by the system to respond to seven requests. Thus, a single shift with 480 minutes available is adequate for this workload. The time to transmit an image and the system response time are the same as in the previous concept.

The number of user stations required is determined as in the previous concept. The total time available in a single shift is 480 minutes, and the total time required by the system to respond to seven requests is 224 minutes. Therefore, 256 (480-224) minutes are available as viewing time. Since only 119 minutes (17 x 7) are required, a single terminal should suffice from a technical point of view. However, the results of the queuing analysis, as noted in Table 16 and 17, indicate that a three-terminal system is preferable.

As noted in the previous concept, the total monthly cost estimate for a 26-MAJCOM Network using a 50 KBPS data link is \$171,600 per month for data transmission. The estimated

monthly postal service for the remaining off-line traffic (545 images per day) is \$987.00, making for a monthly total of \$172,587 to transmit the on-line and mail the off-line traffic for a 26 MAJCOM network. The basis for the Postal Service estimate is as follows:

The number of off-line requests per month for each MAJCOM is 241. Therefore:

241 (49.7%) = 120 Inquiries/mo	(Requiring access to all fiche in family.)
241 (21.0%) = 51 Inquiries/mo	(Requiring unrelated documents.)
241 (13.5%) = 33 Inquiries/mo	(Requiring single document.)
241 (15.8%) = 38 Inquiries/mo	(Requiring complete record.)
120 (2.5 fiche per inquiry)	= 300 Fiche/mo
51 (8 Doc/Inquiry x 1 Fiche/Doc)	= 408 Fiche/mo
33 (1 Doc/Inquiry x 1 Fiche/Doc)	= 33 Fiche/mo
38 (6 Fiche/Inquiry)	= 228 Fiche/mo
TOTAL	= 969 Fiche/mo
or	46 Fiche/day

According to Figure 24, the Postal Service cost for mailing 1,196 fiche per day, required for a 26-MAJCOM network, is approximately \$47.00 per day or \$987.00 per month.

Scanner Equipment (at AFMPC) - The combined MAJCOM requirement imposed on AFMPC in this concept would be 7,540 images (290 x 26). Based on an average scanner thruput of 10 seconds

per image, a total of 75,400 seconds or 21 hours would be required by the scanner device to meet the daily demand. Since the time required exceeds the time available (8 hours), three scanner devices would be required. As noted previously, three devices would cost \$350,000.

Microfiche Viewers (at the MAJCOMS) - The total viewing time required for 545 images or the equivalent of 11 requests is 187 minutes. The viewing time available during a single shift is 480 minutes; therefore, a single microfiche viewer at each MAJCOM will suffice. The cost of a good quality viewer is estimated at \$1,000.00. Therefore, the estimated cost for 26 MAJCOMS would be \$26,000. The other areas involving equipment and manpower is the same as in the previous concept.

In addition to the monthly recurring costs for equipment and data transmission, manpower is also a monthly recurring cost. In the current mode of operations, the monthly manpower cost was estimated at \$209,571. These costs were based on the need for 103 Air Force personnel (78 at the 26 MAJCOMS, 25 at Hq AFMPC), at an average GS-4 pay level (\$12,208 per year) and a 100% overhead rate. Monthly recurring costs for manpower in the concept systems was estimated at \$184,287. These costs were based on 26 maintenance personnel and 26 operators required for the 26 MAJCOMS, and the 35 personnel required for Hq AFMPC. An estimating factor of \$6.89 per hour (\$13,890 per year) for

technicians (estimating factor recommended by RADC procurement) and \$12,208 for the Hq AFMPC personnel plus 100% overhead were used in the calculations.

Table 19 is a summary of the various monthly costs for the current system and all the alternative-concept systems. All cost have been distributed over an assumed equipment lift span of 10 years in order to provide a common reference for purposes of comparison.

VII. CONCLUSIONS/RECOMMENDATIONS:

The long range electronic transmission of microimages is technically feasible. The scanner devices used to convert the source microimage from the film medium to a series of electrical pulses, and stated in the order of preference are the Solid State Scanner, the Laser Scanner and the CRT Flying Spot Scanner. The Laser and CRT type scanners are built and sold commercially. However, the Solid State Scanner is still in the developmental stages, and may require additional engineering and development before a device can be built and sold commercially. Data compression methods such as the run-length encoding scheme which is most widely used in facsimile type application can provide compression ratios in the range of 3 to 6:1. This reduces the total number of bits to be transmitted and the related cost. The output form provided from a Microfacsimile System can be in the form of a CRT soft copy

Table 19
Monthly Cost Comparison

ITEMS	CURRENT SYSTEM	CONCEPT NO. 1	CONCEPT NO. 2	CONCEPT NO. 3
MANPOWER	\$209,571	\$184,287	\$184,287	\$184,287
DATA TRANSMISSION EQUIPMENT		806,000	171,600	172,587
TERMINALS		9,750	9,750	9,750
MINICOMPUTER SYSTEM		11,028	11,028	11,028
H/W MAINTENANCE		11,466	11,466	11,466
S/W MAINTENANCE		1,560	1,560	1,560
PRINTERS		2,167	2,167	2,167
SCANNERS		5,000	3,333	2,917
MICROFICHE VIEWERS				217
TOTAL	\$209,571	\$1,031,258	\$395,191	\$395,979

display, another film microimage or a hard copy product. The quality of the hard copy output product is considered marginal due to the reduced legibility of the small characters. The legibility problem relating to the small characters is not serious as far as the soft copy output is concerned because the zoom capability may be used to effectively increase the resolution of the display to the point where the small characters become legible. Unfortunately, the zoom capability cannot come to the rescue of the hard copy printer. The technology of laser recording is sufficient to provide the capability of generating another microimage on film when operating in a facsimile type mode. The resolution of the film and laser is such that the quality and legibility should be good. Therefore, the marginal area of this technology appears to be in the generation of hard copy. The solution to this problem may have impact only in the printer area or in both the printer and scanner areas.

Although a microfacsimile system is technically feasible, preliminary cost estimates indicate that it will be a more costly system to operate than the current system. This can be observed from the results of the data on monthly cost comparisons presented in Table 18. Concept 2, an Electronic Transmission System which operated over a double shift, was the most economical of the three concepts presented.

It appears that even this concept will result in a significant increase in the monthly recurring cost over that of current system. Concept 3, which has approximately the same recurring cost as Concept 2, is operated over a single shift. However, it is a hybrid system which involves a combination of electronic transmission and postal delivery service. As noted previously, the cost of the hardware and/or software engineering to incorporate this dissemination mode at AFMPC could not be assessed. Therefore, these additional costs are not reflected in Table 18. Nevertheless, many experts feel that the cost of electronic transmission systems is going down and will continue to do so with the growth of satellite communications along with competing ground systems.

A thorough systems analysis should be performed to establish a more definitive system operational concept. This would provide a sound basis for obtaining a more accurate cost estimate of the complete system. In conjunction with the above mentioned analysis, a reassessment of the operational benefits to be gained by implementing an electronic transmission system should be made to determine whether or not the increased cost is justified.

Reprinted with Permission of DATAMATION® magazine,
©Copyright by TECHNICAL PUBLISHING COMPANY,
A Division of DUN-DONNELLEY PUBLISHING CORPORATION,
A DUN & BRADSTREET COMPANY, 1978-all rights reserved.

APPENDIX A

Protecting Data by Encryption

by David J. Sykes

Data communications presents new security problems for computer systems. Encryption is the only practical means of providing protection.

Since there is no way of making data communications links physically secure, particularly if some form of radio transmission is involved, encryption is the only practical method of protecting data outside the computer room. Military and diplomatic circles have used encryption techniques for centuries, and most of their current methods are very sophisticated and highly classified. In the commercial world and nonmilitary parts of government, there is a growing need for encryption, but it cannot be as expensive and as shrouded in secrecy as that used by the military.

This need for encryption is not just to satisfy the legal requirements for privacy, but also to protect systems from criminal activities. Used in conjunction with adequate physical security, both at the computer site and at terminal locations, encryption can be a powerful method of combatting several threats. These threats include the monitoring, misrouting, substitution, modification, and injection of messages. Data files can also be safeguarded by encryption techniques.

Presented here are various methods of applying encryption and a summary of requirements for an encryption capability. A specific examination of the proposed NBS standard, its properties and implementation possibilities are also discussed. (See page 82.)

Communications link encryption

The original data known as *plaintext* (or *cleartext*) is converted into *ciphertext* by *encryption* and back to plaintext by *decryption*. (*Encipherment* can be used synonymously with encryption.) The encryption/decryption process is based on some form of transformation which is solely dependent on a *key* (a pattern of bits). A viable encryption system will have a large number of keys and only if a recipient of the ciphertext has the correct key, can he obtain the original cleartext message.

As opposed to encryption devices, *scramblers* are relatively simple devices which give protection only against casual eavesdropping and will not hinder a determined individual. (The term *code* is often used in the encryption field, but since the word also applies generally to any prearranged relationship of characters, words, phrases, etc. it will not be used here.)

By placing encryption devices at the modem interfaces, all data on the link will be encrypted and decrypted in a manner which is essentially transparent to the sending and receiving stations. The clear bit stream entering the encryptor is reproduced at the exit from the decryptor. Thus, all synchronizing, delimiting, and control characters can be recognized by the receiving station as usual. If a transmission error occurs which modifies the ciphertext, the resulting cleartext will contain an error. The error detection mechanism will thus operate as it would without the encryption devices.

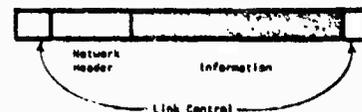
Link encryption is adequate for protecting against wiretapping, but in a network it does not guard against misrouting. In a network which contains a routing (switching) function, this switch handles cleartext, and if a message sent from A to B is misrouted by the switch to C, the message is as intelligible to the user at C because it has been reencrypted using the key that deciphers the encryption at that station. The misrouting could be due to an error, but it could also be brought about deliberately by a penetrator.

End to end encryption

By encrypting at the source only, and not decrypting until the communication reaches its ultimate destination, the information content of the message is only usable by recipients who possess the appropriate key. With this approach, it is of little consequence if misrouting of the message occurs. The message can be sent via networks of any type, private or public, employing

circuit switching, message switching, or packet switching. All users can share a network with confidence if their messages take the appropriate form and the keys are properly assigned, distributed, and controlled.

The message header, which contains routing, priority and other information used by the network itself, cannot be encrypted. The messages at the interface to the network will take the following form, the shaded area representing encrypted data.



Link error detection is performed on the total combination of encrypted information, clear header and link control characters. If it is thought that monitoring the header could reveal frequency of communication between certain users or other facts, this can be countered by superimposing link encryption onto an end to end encryption scheme.

One major threat to a system with remote terminals is that of someone falsely claiming to be an authorized user. This can take place either at actual system terminals, or by intercepting the communication link. The second case includes the injection of previously recorded authentic messages into the system.

This threat can be effectively combatted by a combination of encryption, passwords, and time/date stamping of messages. The basic principle is based on end to end encryption. The user initiates the dialog by transmitting a request in the clear identifying himself and the terminal (the terminal ID may be automatically performed by the terminal). The computer then looks up the current key for that terminal and sends an encrypted response contain-

(Continued on page 84)

**FELIX FC 16/64
ELECTRONIC BILLING
ACCOUNTING MACHINE**



of advanced logical design implemented by microminiature technology. It employs integrated circuits which greatly reduce the need for discrete components, providing advanced equipment reliability :

- Data-16/64 registers of 15 digits each + sign
- Work - 3 stack registers + 1 supplementary register of 15 digits each + sign
- International decimal keyboard with several function keys as well as 3 manual selector keys.
- One digit display for program hexadecimal number.

FELIX FC 64 type optionally can be provided with a tape reader for program and data for processing, printing and punching.



**Specialized Foreign
Trade Company
BUCHAREST-ROMANIA
2, Gabriel Peri st.
POB 105 tel.151609
telex:114c6;11547;
11584**

ENCRYPTION

ing the date and time. On receipt of this response at the terminal, the date/time is decrypted, the user password (pw) entered, and the combined date/time/password encrypted and sent to the computer where they are verified. Allowances are made for a few seconds difference due to response time. The dialog can only proceed beyond this point if this verification is positive. Subsequent messages in this dialog can be tied to this validation by including the date/time as part of the encrypted text.

There are several variations of this principle such as the key being made user dependent rather than terminal dependent. In such an implementation, the user would enter the key into the terminal by means of a magnetic card reader, or by a similar method.

Distributing the key

The subject of key generation, distribution, and protection is a critical issue since the whole principle is based on the security of the key. Keys themselves should be generated with no predictable relationship between them. They should be changed as frequently as can be achieved, or whenever a compromise is suspected, and distributed by courier or registered mail. For special situations it could be arranged that two or more keys held by different persons would be necessary to validate a "user." These multiple keys would be entered sequentially, their sum being the effective key.

If the encryption device is terminal rather than user oriented, it is possible to down line load the new key encrypted with the current key. If this is the only long term method, down line loading has the problem that if a key becomes known to a penetrator, he can easily obtain each subsequent key. On the other hand, the keys never become physically recorded on media which can be lost or stolen. Perhaps some combination would be the best solution, but careful planning should be performed by the system implementors to achieve the most appropriate method.

Media encryption

The encryption principles described for communications are equally applicable to encryption for storing data on removable (or fixed) media. To avoid any performance degradation, however, the device controllers must contain high speed encryption hardware. For fast disc/tape applications, bit rates up to 10 Mbps must be handled, which are several orders of magnitude higher than required for most data communications.

The encryption/decryption would take place in the controller using a key entered by the application program. With media encryption, the secrecy of the key must be maintained as long as the data is valuable or sensitive, compared to communications applications where the key can be changed frequently.

Media encryption not only combats media theft but guards against the effects of misaddressing where one user gets another user's data. It also allows media to be reused without extensive degaussing or erasing.

Requirements for encryption

In nonmilitary applications, the techniques used for encryption should have the following characteristics:

1. Security must depend solely on the current key. It should be assumed the adversary has complete knowledge of the encryption algorithm, its implementation, and its application.
2. Without the knowledge of the particular key, deciphering is not feasible in a reasonable period of time. This implies a nonlinear algorithm and a large number of possible keys.
3. It should be suitable for high volume production, thus yielding low unit cost.
4. It should not adversely impact system performance.
5. It should be difficult to modify the encryption process.

Need for a federal standard

Because the federal government intends to procure a significant amount of data communications and terminal equipment with encryption built in, it is obviously to the government's advantage to deal with only one standard. Furthermore, this standard can be thoroughly understood and tested so that a known confidence level can be established. It is the consensus among manufacturers of data processing equipment that this algorithm is adequately secure and that, because of its nonlinear nature, it would take resources beyond the reach of individual organizations to break the cipher within a reasonable time.

The most significant advantage of a standard will be the cost savings due to high volume production of the devices. Another advantage of such a standard would be the relative ease of communicating between equipment built by different manufacturers. Finally, since all requests to export equipment containing cryptographic devices have to be approved by the government, this procedure may be simplified by having a federal standard.

Conclusion

Encryption, properly implemented, is an essential ingredient of data communications security. Adequate physical security at computer/terminal sites, security features in computer hardware and operating systems, and sound auditing methods, however, are still vital to overall system security.

The proposed NBS standard encryption algorithm, if adopted, will benefit both users and manufacturers. The proposed algorithm has more than adequate security for most nonmilitary applications, and having a standard would not preclude the use of other algorithms in special cases where the expense can be justified.

The problems of voice and facsimile should not be overlooked either. It is possible to purchase scramblers for voice and facsimile today, but the eventual solution will be by digitizing the analog signal at the source (40.8 Kbps is more than adequate for a voice channel), and using encryption to protect this digital information in a manner similar to that described for data communications.

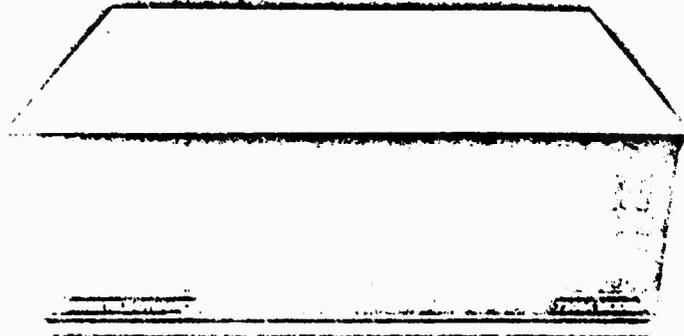
Data communications and remote terminals introduced new threats to the security of computer systems. Encryption can be effectively used to counter these threats and reduce the problem to the common denominator of reliance on certain trusted people. The entire encryption scheme, including key generation and distribution, must be very carefully planned. If a casual approach is taken, the situation could be worse than having no encryption at all.



Mr. Sykes' present position is as manager of communications system design for Honeywell Information Systems in Phoenix. His responsibilities include the system level design and specification of data communication processors and associated software for front-end and remote applications. Prior to this he was responsible for mini-computer system design.

Before joining Honeywell, he was with RCA Defense Electronic Products in Princeton, engaged in the design of equipment for data communications associated with spacecraft.

**Our NEW
7208A Modem
gives you full Bell 208A
compatibility plus a few
extras you can't get
from Bell**



The 7208A is our new 4800-bps modem for private lines. It's directly and completely compatible with the Bell 208A. And it gives you all of the line features of the 208A.

But that's not all!

The 7208A also gives you some innovations not available with Bell. Innovations such as our exclusive all-digital adaptive equalizer with automatic retrain. This circuit provides maximum convergence and prevents drifts and other analog errors—even with marginal unconditioned lines.

Then the 7208A gives you both common carrier and terminal loopback provisions for system trouble shooting. You can't get that in the 208A either. Then there's a special connector for remote test access. And a separate carrier strip that lets you connect your telephone lines with only a screwdriver.

All of these features together with a surprisingly low cost make the 7208A the most cost-effective modem of its kind. And our purchase plan will save you money month after month after month.

Write or call today for additional information.

TELE-DYNAMICS
DIVISION OF AMBAC

515 VIRGINIA DRIVE FORT WASHINGTON, PA 19034 215-643-3900 TWX 510-661-3964

The proposed NBS standard

In March 1975, the National Bureau of Standards published a description of an encryption algorithm in the *Federal Register*. This algorithm was selected from responses solicited earlier by NBS from the manufacturers of data processing equipment. There is only space here to describe this algorithm very briefly, but full details can be obtained by writing to the Systems and Software Div., Inst. for Computer Sciences Technology, Bldg. 225, Room A-265, National Bureau of Standards, Washington, D.C. 20234.

The algorithm is based on a recirculating block product cipher, where a block of data bits is enciphered all at once (as opposed to a bit stream cipher where the plain text is encrypted bit by bit). The NBS proposed block size is 64 bits of input and output data with a 64 bit key, although only 56 of these key bits are active—and which ones are to be active can be varied independently. The other eight bits are for key parity.

The big advantage of block encryption over bit stream encryption is that the one-to-one correspondence between input bits and output bits is avoided. Each bit of the input block can potentially affect all 64 output bits, thus making analysis of the output extremely difficult.

The term "recirculating block product cipher" means that encipherment is achieved by alternately performing linear permutations (using wire crossings) and non-linear substitutions (based on table look-up).

Fig. 1 illustrates how the recirculating block product cipher works. The data input is subjected to an initial permutation (accomplished, in practice, by wire crossings) and then entered into a key dependent cipher computation. Only 48 of the 56 bits of the key are used at this time. The output of this process is fed back to the input and a similar computation performed, but with a different 48 bits selected from the key. This recirculation process is repeated until a total of 16 iterations have been performed. Finally, the output of the last iteration is subjected to a permutation, the inverse of the initial permutation. (The initial permutation, and its reversal, actually provide no additional security, but they are part of the proposal.)

One iteration of the algorithm is shown in Fig. 2. If L_n and R_n are the leftmost 32 bits of the input and output, L_{n+1} and R_{n+1} the rightmost, then

$$\begin{aligned} L_{n+1} &= R_n \\ R_{n+1} &= L_n + f(K_n, R_n) \end{aligned}$$

where f is the cipher function containing the non-linear substitution and K_n represents the key selected for that iteration. All 16 iterations are similar except the last one in which the R and L crossover does not take place.

The cipher function $f(K,R)$ is

computed as shown in Fig. 3. The 32 bits from the leftmost or rightmost part of the input are expanded to 48 bits according to a table and modulo 2 added to the 48 key bits, K_n , selected for that particular iteration. The resulting 48 bits are handled as 8 groups of 6 bits and entered into 8 substitution (S) boxes. Each S box is represented by a different table mapping input to output, and the output of each box is only 4 bits (making the mapping irreversible). The 32 bit output is then subjected to a 32 bit

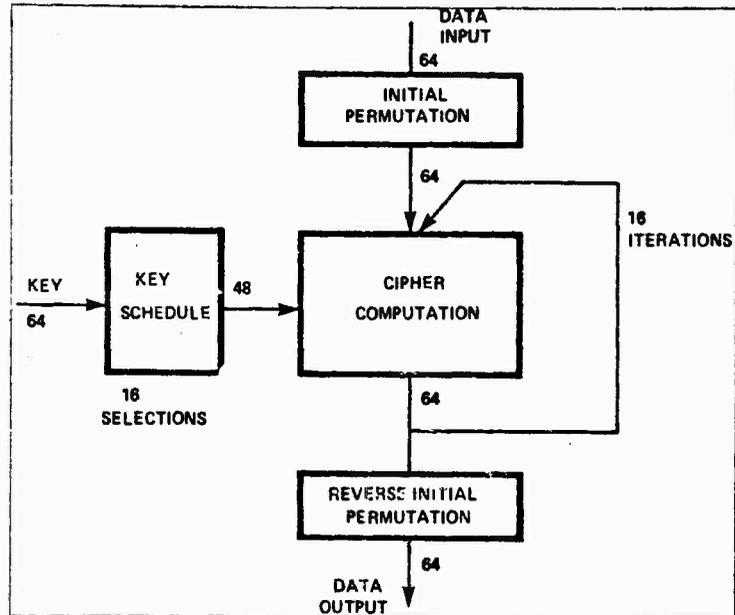


Fig. 1. Recirculating block cipher

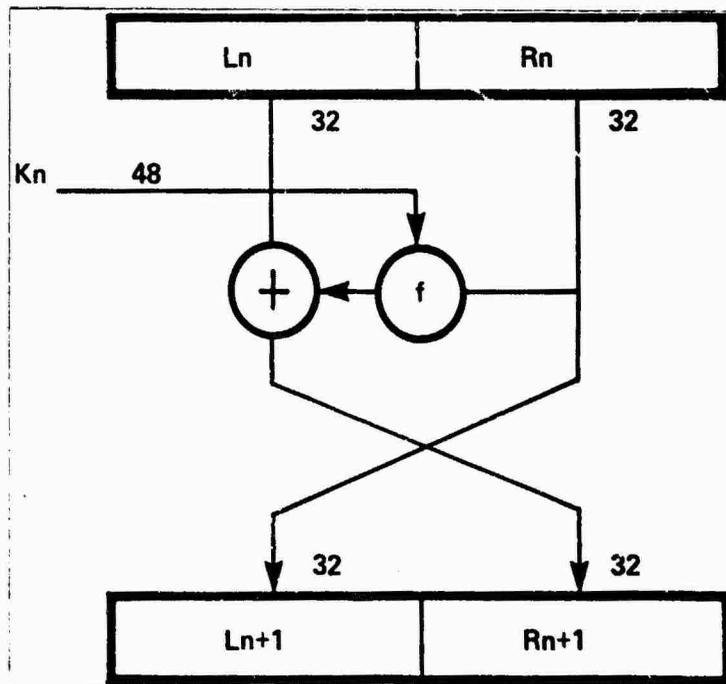


Fig. 2. One iteration of the enciphering function

permutation to yield the $f(K,R)$.

At each iteration, the 48 key bits are selected according to a "schedule" which itself involves permutations and rotations of the key bits.

Decryption is accomplished by performing the same process as the encryption but with the selected key bits in reverse sequence, i.e., the 48 bit key pattern used in the 16th round of encryption is used in the 1st round of decryption, and so forth.

Properties of the Standard

It can be assumed that an adversary would fully understand the algorithm, including its particular implementation. Also, he would possess reasonable quantities of clear and matching cipher text, but would not know the key in use. To break the cipher, two approaches could be taken:

- determine the key by trial and error of the cipher text.
- analyze the cipher text statistically.

Trial and error would need an aver-

age number of attempts equal to half the number of possible keys. With a 56 bit key ($2^{56} = 7.2 \times 10^{16}$) if each trial took one microsecond (which is not really possible today), it would take over 1,000 years to find the key. If one tried to speed things up by multiple simultaneous trial and error tests using expensive five microsecond devices to obtain the key, 4 million devices would be required to guarantee finding the key in 24 hours. Such resources would not be available in any organization outside of the government.

The statistical approach would need a great deal of expertise in cryptography and a large amount of computing resources. The NBS proposed algorithm has been designed to be highly resistant to statistical attack by careful choice of the various permutation and substitution tables involved. It is not possible to quantify this resistance, but the consensus of experts across the industry believes it to be adequate. Nevertheless, it is not out of the question that a government

organization could find quicker ways to break the cipher if the need were great enough.

Other properties worth noting are that super encryption with the same key does not produce plain text, and that the encryption/decryption process can be interchanged (i.e., decrypt plain text to yield cipher text and then vice versa).

Implementing the Algorithm

Although it is possible to implement the algorithm in software, this would not be a practical solution for encryption on a continuous basis. Table 1 compares the estimated time using typical implementations of the NBS algorithm to encrypt or decrypt a block of 64 bits. The large computer is much faster than the minicomputer, not just due to the word length but also because the large memory enables the permutation and substitution tables to be implemented more effectively.

Hardware solutions are immensely more efficient than software because the permutations are achieved by wire crossings and the substitution tables are in read-only memories. The T²L hardware would take a "large board" full of logic and would cost approximately 10 times as much as the LSI chip. The LSI chip approach is relatively slow (due to lower power and limited pin connections) but is still perfectly adequate for most data communications applications. Only the T²L circuitry would be fast enough for encryption of media or high speed disc and tape drives, the serial bit rate of which are already in the region of 10 Mbps.

Status and schedule

NBS has a goal of getting the standard finally approved by September 1976. There has been some opposition from a few individuals in the academic community on the grounds that the key is not long enough. However, none of the major computer and terminal manufacturers has raised any formal objection to the proposed standard. As a result, several manufacturers are known to be already developing semiconductor devices which implement the algorithm as currently defined. Such components are expected to be available in late 1976 or early 1977 at a price in the region of \$100 each. With higher volumes in later years, the price could drop to around \$20. Terminals and communications processing equipment which incorporate these encryption devices, can be expected to appear in the marketplace toward the end of 1977.

Implementation	Time to Encrypt (64 bits)	Data Rate (bits/sec)
Software		
Large computer	100 usec	640×10^3
Minicomputer	50 msec	1.3×10^3
Hardware		
T ² L	5.0 usec	1.3×10^7
LSI chip	50 usec	1.3×10^6

Table 1. Estimates for encryption using NBS proposal

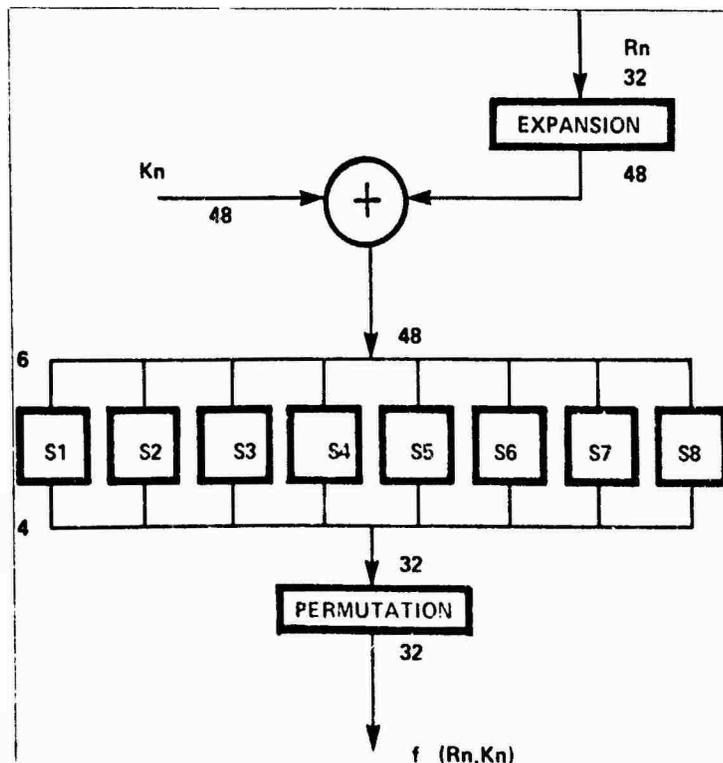


Fig. 3. Computation of the cipher function

REFERENCES

- (1) D. Endicott, D. Solarek and K. Drake, "The Bureau of Naval Personnel's Microfiche Image Transmission System (MITS): A State-of-the-Art Microfacsimile System," TP-529, Dec 76.
- (2) J.F. Reintjes and D. R. Knudson, "Design Study of Text-Access Facilities for the Library of Congress," Final Report ESL-FR-705, Dec 76.
- (3) R. A. Botticelli, D. J. Walker and G. N. Wallmark, "Microfiche Scanner and Remote Display System Study," RADC-TR-76-150, May 76. (B012994L)
- (4) D. J. Solarek, D. L. Endicott, J. L. Sutton and B. A. Saltzer, "A Catalog of State-of-the-Art Components and Techniques For the Advanced Records Technologies and Systems (ARTS) Project TN 495," Sep 78.
- (5) D. M. Costigan, "Microfacsimile: A Status Report," Journal of Micrographics, Vol. 4, No. 4, May 71.
- (6) J. L. Tregay, "Microform Facsimile Transmission," Proc. National Microfilm Association, 1973.
- (7) L. L. Dobrin, "State-of-the-Art: Microfacsimile and Remote Transmission," Proc. National Micrographics Association, 1975.
- (8) PRC Image Data Systems Company, "Long Range Image Transfer System Requirements Study-Detailed Analysis," May 78.
- (9) D. A. Shurtleff, "Legibility Research," Proc. of the SID, Vol. 15-2, Second Quarter 1974.
- (10) A. Gordon, "Legibility and Resolution Criteria For The Bureau of Naval Personnel's Microfiche Image Transmission System," NOSC, Sep 76.
- (11) Air Force Manual (AFM) 9-1, "Functions of a Forms Management Office."
- (12) D.M. Costigan, "Resolution Considerations Affecting the Electrical Transmission of Technical Documents by Scanning Processes," Journal of Micrographics, Vol. 1, No. 3, Spring 68.

REFERENCES (CONTINUED)

- (13) NMA Standard MS3-1972, "Facsimile Transmission of Micro-Filmed Documents."
- (14) D. Erdicott, "Review of Microfiche Scanners for the Microfiche Image Transmission System," TN-1732, NOSC, Sep 76.
- (15) Harris Corporation, "Terminal Analysis Study," RADC-TR-76-185, Jun 76. (B012785L)
- (16) NOSC, "Advanced Mail Systems Scanner Technology," NELC/1965, Oct 75; NELC/2020, Oct 76; NOSC/TR170, Oct 77.
- (17) William M. Sillers, "Redundant Area Coding Study," RADC-TR-71-192, Sep 71. (888625)
- (18) Fairchild Semiconductor Data Sheet, CCD121H, 1728-Element Linear Image Sensor.
- (19) C.R. Horton and L.W. Dobbins, "Image Data Transmission- An Assessment of Practical Systems."
- (20) A.E. LaBonte, and C.J. McCallum, "Image Compression Techniques," RADC-TR-77-405, Dec 77. (A050679)
- (21) Dishon, Yitzhak, "Data Compaction in Computer Systems," Computer Design, Apr 77.
- (22) S.D. Bradley, "Data Compression for Image Storage and Transmission," PROC. of the S.I.D., Vol. 11/4, Fourth Quarter 1970.
- (23) Auerbach Computer Technology Reports
- (24) "Inter City Services Handbook," AT&T Long Lines, Mar 78.
- (25) Basics of Data Communication, McGraw-Hill.
- (26) D.J. Sykes, "Protecting Data by Encryption," Datamation, Aug 76 (included as an Appendix to the Report).



MISSION
of
Rome Air Development Center

RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control Communications and Intelligence (C³I) activities. Technical and engineering support within areas of technical competence is provided to ESD Program Offices (POs) and other ESD elements. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.