Data Transmission and Computer Access

The *Picturephone*® System:

Wideband Data Service

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(Manuscript received October 9, 1970)

Use of the evolving Picturephone® *network to provide common-user, switched wideband data service is another step in the continuing effort to satisfy the growing need for moving information faster, in greater quantities, over longer distances, and at lower cost than is now possible. Full use is made of the planned network with but minor modifications to the basic face-to-face offering. Initial network capabilities permit synchronous data transmission at 460.8 kb/s; it is expected that data service at 1.344 Mb/s will become standard as network improvements are made.*

I. INTRODUCTION

The rapid growth of data transmission over the past several years has indicated a need for finding more efficient means of transmitting large amounts of data. At present, the majority of data transmission occurs at rates of a few kilobits per second over voicegrade facilities. Modern computer-associated equipment is capable of operating at rates several orders of magnitude greater than this with no significant economic penalty. For data service at such high speeds, wideband private-line facilities are available. Additionally, a common-user switched wideband service, called *Data-Phone 50,* is presently available to provide 50-kb/s transmission capability over a four-city experimental network. Data service using the planned nationwide network of *Picturephone* facilities will provide speed capability an order of magnitude greater than tbis.

Wideband data service over the *Picturephone* network begins with the offering of a switched 460.8-kb/s capability through use of the initial network of *Picturephone* facilities. Faster service at 1.344 Mb/s is anticipated as network improvements are made within the next few years. It is expected that provision of switcbed wideband data capability on the *Picturephone* network will be a significant step toward satisfying the growing need for higb-speed data communications. This common-user switched service sbould be most attractive to users whose community of interest includes many stations spread over a wide geographical area with traffic volume to individual stations not large enough to justify the use of wideband private-line facilities.

II. INITIAL SERVICE OBJECTIVES

A design objective for initial data service is to make full use of the network with but minor modification to the basic face-to-face service. This must be done while recognizing that although the face-to-face signal occupies a 1-MHz bandwidtb, various power, spectral distribution and processing constraints restrict the transmission of arbitrary 1-MHz signals. For data-type signals, these constraints are most severe at the interface between the analog and digital portions of the network.

The equipment used to provide tbis interface is called a codec.[1] The codec which will be used for initial *Picturephone* service was designed primarily for video service. To accommodate signals the analog interface is adaptively altered, but both data and video signals undergo tbe same basic encoding process. This process limits wideband data service to rates well below one megabit per second. As the network continues to evolve, an improved codec is expected to handle data rates up to 1.344 Mb/s by adaptively changing the encoding process as well as the analog interface.

Both initial 460.8-kb/s and future 1.344-Mb/s service can be obtained without extensive modification of tbe planned *Picturephone* network. Many plant items such as analog repeaters, central office switcbes and digital trunks will be sbared between video and data service. The few differences that will be found between the services will be in codec operation, station arrangements, and maintenance procedures.

III. LIMITATIONS ON DATA RATES

The wideband transmission patb in a typical *Picturephone* connection involving digital facilities will consist of an analog loop, switch, and trunk followed by a digital encoder, trunk, and decoder, and completed by the inverse analog trunk, switcb, and loop. Several factors limit the bit speeds that can be realized tbrough such a path at reasonable cost. These factors include tbe capacity of the digital trunks, technical and economic considerations in analog transmission, and the methods used to encode the analog signal into digital form.

3.1 *Digital Transmission*

Specifically, the transmission rate of the T2-format bit stream used in the *Picturephone* plant is 6.312 Mb/s.[2] A small percentage of the total bits transmitted must be reserved for control and synchronization of the digital system but the remainder are available to carry message information.

3.2 *Analog Transmission*

A fundamental restriction on maximum data rate in analog transmission is limited channel bandwidth. According to theory,[3] the maximum two-level PAM bit rate that can be attained in the 1-MHz video channel without intersymbol interference would be 2 Mb/s. Practically, imperfections in the *Picturephone* loop and trunk transmission characteristics reduce speeds that can be realized without unduly complex instrumentation to the vicinity of 1.5 Mb/s. Simple methods are available to encode data signals at rates up to that speed into the 6-Mb/s digital capacity of T2 bit streams.

Although speed limitations have been discussed above in terms of bit rate, it is basically signaling rate that is limited by restricted bandwidth. Consequently higher bit rates are potentially achievable by transmitting more information per signal pulse; i.e., by using a multilevel signal format. In addition, more efficient use of the available band is possible if partial-response[4] signaling is used.

Unfortunately, both of these techniques for increasing bit rate will also increase the number of signal amplitudes that must be distinguished in order to recover the transmitted data. This, in turn, will reduce the error margin that the signal has against noise and crosstalk interference accumulated during transmission. The margin will be reduced even further by the distortions encountered on the analog facilities.

To overcome the loss of error margin incurred by multilevel signals, it might seem reasonable to increase the transmitted signal power to the point where the error rate is reduced to tolerable levels. However, it is necessary to consider the possibility that high-power data signals will crosstalk into other services. To protect these services (particularly face-to-face video), protective criteria that limit the allowable transmission power for data signals have been formulated.[5]

In Section 4.1, it is shown that the interference, distortions, and power limitations that are expected on *Picturephone* analog loops and trunks will limit economically feasible transmission to binary PAM with a maximum rate near 1.5 Mb/s.

3.3 *Digital Encoding and Decoding*

The objective of maximum alternate use of *Picturephone* facilities leads to the procedure of quantizing, sampling, and pulse-code modulating the analog data signal just as if it were a video signal. It will be shown that this procedure is the principal factor in the choice of 460.8 kb/s for the initial-service bit rate.

IV. DATA CAPABILITIES OF THE *Picturephone* NETWORK

To determine the exact capabilities for data transmission over the *Picturephone* network, the various components that form the network will be considered separately. In order of discussion, these components are analog loops and trunks, digital facilities, and analog switches.

4.1 *Analog Loops and Trunks*

The loops and trunks have been discussed in detail in a preceding paper;[6] only the pertinent aspects will be reiterated here when needed.

The major source of interference to data signals in the analog plant is impulse noise; both system allocations and actual transmission tests indicate substantial operating margin against thermal noise and crosstalk. Quantitatively, the maximum impulse noise level can be estimated from the objective[7] for face-to-face *Picturephone* service. Measured on the equalized facilities, this objective is that the probability of base-to-peak weighted noise exceeding 18 millivolts be less than or equal to 1.5×10^{-5} $[P(N > 18 \text{ mV}) \leq 1.5 \times 10^{-5}]$. For convenience, the voltage threshold of 18 mV can be translated to a dBV threshold of -35 dBV. Then, noting that the face-to-face objective is a weighted objective, a 6-dB modification to -29 dBV is made since data service is not affected by subjective weighting, and will not use pre- and de-emphasis. Impulse noise distributions found on *Picturephone* facilities are expected to display a slope of 10 to 12 dB per decade change in probability. Applying a 12-dB slope to the -29 dBV objective leads to the upper limit for system noise shown in Fig. 1.

To determine maximum allowable data powers, reference must be made to the protective criteria for interconnection.[5] One criterion concerning power present in narrow bands is met with ample margin by random data signals, but a second criterion for total power in specified wider bands places severe restrictions on signal power. Calculations for the maximum reasonable binary data rate of 1.5 Mb/s indicate allowable transmission levels of 2.5 dBm. In terms of peak voltage across the 100Ω line this level is -7.5 dBV.

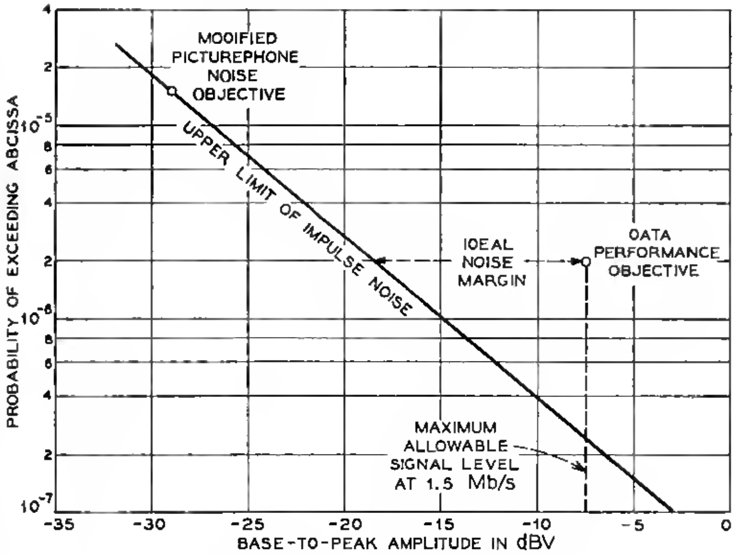


Fig. 1—Ideal data performance relative to impulse noise objective for analog loops and trunks.

The error performance of this signal can now he related to the impulse noise objective discussed previously. To meet the usual wideband data error rate ohjective of 10^{-6} for a peak signal level of -7.5 dBV, it is required that the prohahility of noise greater than -7.5 dB he less than or equal to $2 \times 10^{-6}[P(N > -7.5 \text{ dBV}) \leqq 2 \times 10^{-6}]$. The factor of two arises from the 50 percent prohahility that the noise and signal are of opposite polarity. As shown in Fig. 1, the data performance ohjective is met with 11 dB of margin.

So far the discussion has heen concerned with the effect of noise on ideal signals. In practice, however, even with the in-band gain well equalized, two significant sources of signal distortion remain. The first of these is deviation of the net phase characteristic from an ideal linear characteristic, and the second is deviation of transmission characteristics due to the lack of temperature regulation on the loops and trunks for initial service.

To investigate the effect of distortion on data signals, 1.344-Mb/s data signals were tested on simulated facilities. The results are illustrated by the "eye" patterns* of Fig. 2. The pattern of Fig. 2a was

* An "eye" pattern is a bit-synchronized superposition of possible data signals.

taken with the test data set connected back-to-back and is, therefore, the reference pattern. Expected worst-case phase distortion was simulated by 42 kft of 22 AWG cable maintained at constant temperature and gain-equalized by repeaters spaced at 6-kft intervals. The distorted "eye" is shown in Fig. 2b. A Bode Equalizer[8] was used to simulate worst-case distortion due to temperature variations. The equalizer shape was a compromise between the regulation characteristics of 20 kft of 24 and 16 kft of 26 AWG cable; both of these have +8 dB of gain at the 1-MHz band edge corresponding to a 50°F temperature differential. The result is pictured in Fig. 2c. Measurements of the "eye" patterns at the sampling points show an effective loss of margin against noise relative to an ideal undistorted signal of 0.6 dB, 1.5 dB, and 1.5 dB for back-to-back, phase distortion, and temperature distortion respectively. The phase and temperature distortion conditions used in these tests are extreme. It is not unreasonable, therefore, to allot 3 dB of margin for worst-case facility distortions and data set tolerances.

It is anticipated that second-generation cable equalizers will include both temperature regulation and improved phase control, but the extra margin derived therefrom will be allocated for the extension of loop and trunk length. Therefore, no appreciable improvement of analog transmission performance should be expected from second-generation facilities.

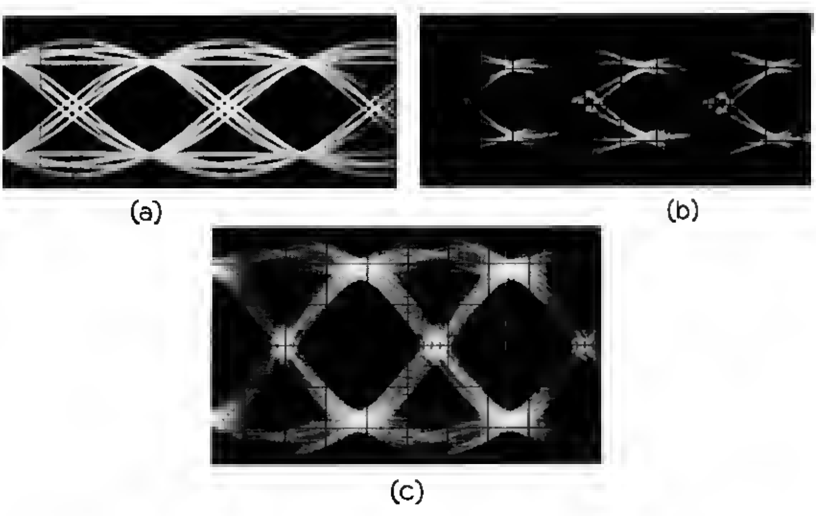


Fig. 2—Eye patterns for a 1.344-Mb/s data signal transmitted: (a) back-to-back, (b) through a phase distorted channel, and (c) through a temperature distorted channel.

The effect of distortion can be related to the performance curve of Fig. 1. The ideal signal has an 11-dB margin against impulse noise. If 3 dB of this is allotted to facility and data set distortions, 8 dB of margin remains to be distributed between gain misalignment, thermal noise, and crosstalk interference.

From the preceding considerations, it can be concluded that data transmission at rates up to 1.5 Mb/s is feasible on the *Picturephone* analog loops and trunks. The transmission levels will cause neither excessive interference into other services nor excessive susceptibility to impulse noise. However, margins are so small that transmission at higher bit rates appears unlikely without appreciable increase in data set complexity.

Before closing this section, two additional points should be considered. First, it will be shown in the following section that the initial-service codec will not support data rates much greater than 500 kb/s and signals encountering digital trunks will be subject to codec jitter and quantizing noise. Furthermore, network protection criteria impose more severe power limitations on signals in this speed range because their energy is concentrated in the region of the transmission band where the risk of crosstalk interference to other services is greatest. Fortunately, cable equalization tends to concentrate interference at the high end of the band; the amplification needed to offset cable rolloff enhances the high-frequency components of noise and crosstalk. This tends to make the signal and interference spectra disjoint; the net result is expected to be performance at least as good as that at 1.5 Mb/s. The expectation has been borne out by preliminary testing on *Picturephone* trial facilities.

The second point concerns low-frequency transmission characteristics. To allow for dc potential differences between repeaters, the transmission path must be ac-coupled. The cutoff is in the vicinity of 1 Hz; the associated time constant is on the order of 160 ms. With the 20-stage scrambler/descrambler normally included in wideband data sets,[9] the probability that more than 20 consecutive symbols of the same polarity will be transmitted is negligible. At a 500 kb/s rate, this corresponds to only 40 μs without a signal transition. It is clear, therefore, that low-frequency cutoff will have no appreciable effect on *Picturephone* data transmission.

4.2 *Digital Facilities*

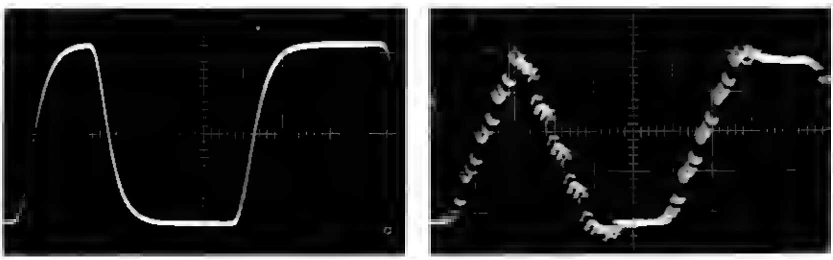
As mentioned in companion articles,[7, 10] digital facilities will carry the bulk of *Picturephone* toll transmission. The basic building block of the digital facilities is the 6.312 Mb/s differential pulse code modulated (DPCM) signal derived from the A/D operation in the codec. This bit stream may be transmitted by itself over T2 facilities or multiplexed with other bit streams for transmission over radio or coaxial carrier systems.[11, 12]

4.2.1 *Codec Operation*

The interface between the digital and analog facilities is provided by the codec which uses differential encoding to transform the nominal 1-MHz analog signal to a 6.312 Mb/s PCM signal.[1] Because of basic format differences between video and data signals, it is necessary that the codec be able to operate in two distinct modes. This is achieved by sensing the presence or absence of video sync signals to determine whether the input signal is video or data.

For data signals the codec operates as a simple nonsynchronous differential encoder. The input signal is brought to a nominal level, 0.72 volts peak-to-peak, by a ±6 dB AGC which compensates for all but catastrophic gain misalignment in the analog plant. This signal is then sampled at a 2.016 MHz rate with each sample differentially encoded into one of eight signal levels (±12, ±36, ±84, ±180 millivolts relative to the input signal level). The resultant levels are then 3-bit encoded; framing, stuffing and signaling bits are added; and a 6.312-Mb/s PCM signal is delivered to the digital facility. At the far end, the opposite procedure is used to recover a nominal-level analog signal to be sent to the appropriate end section. This is illustrated in Fig. 3 which compares a typical data signal as seen at the input of the near-end codec, Fig. 3a, to the resulting signal at the output of the far-end codec, Fig. 3b.

From Fig. 3 one can observe the distortion caused by three types of impairment introduced by the codec: jitter, slope overload, and quantizing noise. Jitter is introduced into the signal by the nonsynchro-



(a) (b)

Fig. 3—A typical 460.8-kb/s data signal as found: (a) at the input to a near-end codec, and (b) at the output of a far-end codec.

nous method of sampling used in the A/D conversion. The amount of peak-to-peak jitter, equal to the reciprocal of the sampling rate, is approximately 0.5 μs. It is usually desirable to keep the total range of jitter in a data signal less than 50 percent of a bit period to ensure detection of the signal near its peak. Therefore, codec jitter can be thought of as imposing an upper limit of one half the sampling rate, or 1.008 Mb/s, on binary data transmission.

Slope overload considerations also limit data signals in the following manner. The use of differential encoding with a maximum step size of ±180 millivolts means that the codec output signal cannot rise at a rate faster than 180 × 2.016 or about 360 mV per μs. Thus, for high-level or high-speed signals, the output will not be able to track the input accurately. For a rectangular pulse at the input, the point at which the output signal can no longer rise to the peak of the input signal in one pulse interval is referred to as the overload point. This is illustrated in Fig. 4 where it is seen that the output, bottom trace, cannot rise to the peak value in a single bit interval. However, if the input remains constant over several bit intervals, the output can attain the peak amplitude of the input. Figure 4 then illustrates operation beyond or above the overload point. Operation below the overload point requires the number of samples per bit interval to be greater than the signal voltage divided by 180 mV. For the planned 0.72-volt data signal, four samples are required per bit interval, thus placing an upper limit of 504 kb/s on the data speed.

In addition to jitter and slope overload impairments, the codec, through the process of A/D conversion, introduces distortion known as quantizing noise. For worst-case bit combinations at the input, codec operation is just below the overload point such that maximum quantizing steps are used continuously. Since the signal is simultaneously undergoing jitter, argument can be made that the worst-case quantizing noise found on data signals is 180 mV or 25 percent of the peak data signal. This analysis must, of course, be tempered by far-end loop and data set considerations. The analog loop will add noise to the signal and the data set will contain a low-pass receive filter with the result that the quantization noise will become hidden in other impairments.

From the above discussion, it is apparent that data transmission above one megabit through initial codecs suffers from a large amount of jitter and a low overload point. Since transmission should be satisfactory at rates below 500 kb/s, initial service will be offered at 460.8 kb/s, a rate that is compatible with present private line offerings.

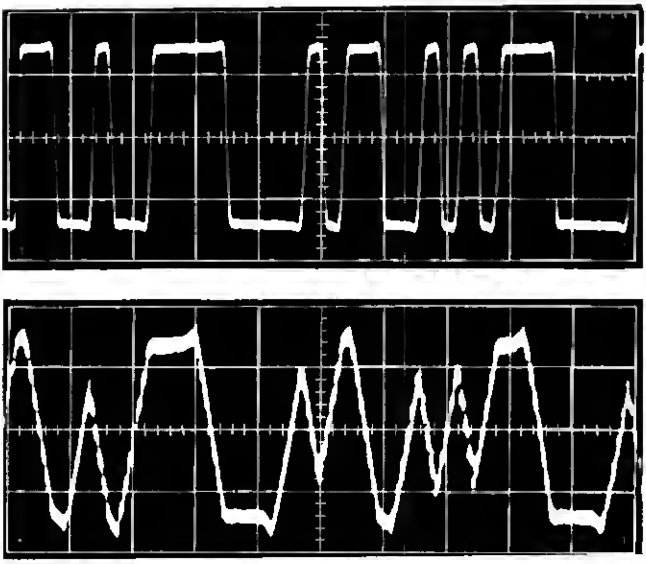


Fig. 4—A 460.8-kb/s data signal operating beyond the overload point of the codec. Top trace is a high-level input which produces the overloaded output seen in the bottom trace.

4.2.2 *Transmission Facilities*

Having been transformed by a codec into a 6.312 Mb/s DPCM bit stream, a data signal is indistinguishable from a similarly encoded video signal. In either case, the DPCM signal can be transmitted to the far-end codec via any one or any combination of digital transmission facilities. The DPCM signal can occupy a complete T2 line or be multiplexed through a M2R onto the digital channels carried on TD-2 radio.[11]

L-Mastergroup Digital terminal equipment (LMD) multiplexes two 6.312-Mb/s bit streams onto mastergroups on L-4 coaxial systems.[12] Future higber capacity digital and analog systems will also include the necessary multiplexers to enable compatibility with the T2 format. Whatever the facility, the digital bit stream is expected to contribute less than 10 percent of the overall data error rate, so that, for most practical cases, the codecs may be thought of as being back-to-back. That is, any distortion introduced into a data signal by a digital facility will in all likelihood arise within the codec and be independent of distance.[13]

4.3 *Analog Switches*

As has been described in a preceding paper,[14] wideband video switching on the *Picturephone* network will be realized by four-wire video switches slaved to the associated voice-pair No. 5 crossbar switches. Questions on the capability of these switches for handling wideband data services in the megabit range are: (*i*) what effect in terms of crosstalk would wideband data services have on video-telephone services sharing the same switch, (*ii*) to what extent are wideband data signals impaired by switch characteristics, e.g., reflections from stub multiples, mismatch, etc., and (*iii*) what is the effect of office switching noise on data?

To answer the first two equations, data transmission tests were conducted on a laboratory model No. 5 crossbar *Picturephone* switch. Crosstalk investigations included measurement of near-end crosstalk (NEXT), far-end crosstalk (FEXT), and measurements in which both types of coupling paths contributed. The transmission performance of the switch was determined by "eye" pattern observations of a 1.344 Mb/s data signal for one passage through the switch from wideband-line link frame (WBLL) to wideband-trunk link frame (WBTL), as well as for a loopback connection on the WBTL side of the switch. The question of impulse noise could not be answered by direct measurement; the model switch is not in a real central office environment and field installations were not available at the time of the tests.

Based on the measurements made on the laboratory switch model, it appears that dual use of the *Picturephone* switching plant for wideband data will present no difficulties either in terms of data interference into video, or in the quality of transmission through the switch. With crosstalk power weighted by the *Picturephone* noise weighting and de-emphasis curves, the worst-case crosstalk interference from a data disturber was found to be −83 dBV (RMS). This is well below the mean random noise objective of −75 dBV.[7] Observations of the data signal "eye" revealed no significant transmission impairment.

Without suitable test facilities, the effect of impulse noise can be estimated only on the basis of allocation. Since the switching office allocation is included in the overall impulse noise objective, it has already been taken into account in the discussion of analog loops and trunks (Section 4.1).

V. INITIAL SERVICE

In the preceding section, it has been shown that the initial network of *Picturephone* facilities will not support data speeds greater than 500 kb/s. Therefore, an initial offering of 460.8-kb/s service was chosen for compatibility with private line services presently being offered through use of T1 carrier facilities. Other possible speeds may arise from customer provided data sets that comply with network protection criteria.

Modifications of the analog video plant are not necessary to provide data service. A loop conditioned for video transmission can be used by either service. This applies even when the customer uses the network for data transmission without subscribing to *Picturephone* face-to-face service.

The terminal equipment that currently provides short-haul 460.8 kb/s service on T1 lines is the Data Station 303 that includes a Data Set 303J25, a T1 Wideband Modem, and a T1 Line Terminating Unit. For initial *Picturephone* service, a new version of this data station has been developed. The changes that have been made include the replacing of tbe T1-oriented equipment by a 114A Interconnecting Unit and modifying the data set (recoded as tbe 303J26) as required for interconnection witb the 114A. In addition, the telephone bandset associated with a video station is replaced by an 804 Data Auxiliary Set (DAS) that provides data-oriented line control functions as well as handset and dial. The complete data station for *Picturephone* network application is pictured in Fig. 5.

Call set-up for data will proceed in the same manner as for video. The call will be originated from the 804 DAS by dialing the desired number preceded by the # prefix to indicate that a wideband cbannel is required. As the call progresses, maintenance-loopback testing and removal will take place in normal fashion. When tbe connection is completed, either by manual or automatic answer at the called end, the wideband circuit is ready to accept tbe data signal.

In addition to the line-continuity testing by the *Picturephone* Maintenance Loopback feature, the data station will have the capability for both remote and local data testing. As in existing data services, this capability will be provided by the line and test unit 806 DAS operating in conjunction with the 804 DAS. The specific tests involved permit isolation of troubles to the transmission facility, the data station, or the customer's equipment by looping the signal at interface points and monitoring transmission quality. The tests are originated and monitored remotely from a Data Test Bay in a serving central office.

VI. SUMMARY AND CONCLUSIONS

It has been recognized that the system of *Picturephone* facilities

Fig. 5—Typical Data Station 303 used for 460.8-kb/s data transmission on the *Picturephone* network. Lower shelves provide space for the VLTU (shown in position), and optional equipment such as an automatic calling unit.

provides a high-capacity, common-user switched network which can help satisfy the growing demand for wideband data transmission. Because of the objective that network facilities be used without alteration wherever possible, data transmission over the network is now limited to rates below 500 kb/s. A rate of 460.8 kb/s, compatible with service now being provided over T1 carrier facilities, has therefore been chosen for the initial data offering on the *Picturephone* network.

The upper bound on data speed is largely a result of limitations arising from the particular encoding process used to transform the local analog signal to digital form for long-haul transmission. However, as the network evolves, it is anticipated that alternate use codecs will enable data transmission at rates above 1 Mb/s. Since investigation has sbown that the analog portion of the network could support rates up to 1.5 Mb/s, it is expected that the next generation of wideband data service over tbe *Picturephone* network will be at the rate of 1.344 Mb/s consistent with service now being introduced for use on T1 facilities. This expectation is contingent on possible video bandwidth compression techniques that may place additional limitations on attainable data rates.

VII. ACKNOWLEDGMENTS

The authors wisb to acknowledge the technical assistance and suggestions contributed by many of their colleagues in both the data transmission and *Picturephone* service areas. Particular thanks go to R. S. Libenschek, who played a major role in studies leading to the offering of data service on the *Picturephone* network.

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