The *Picturephone*® System:

The Network

By IRWIN DORROS

(Manuscript received June 8, 1970)

A Picturephone® *network will take maximum advantage of existing telephone equipment. To provide service, a new videotelephone set will be added to a* Touch-Tone® *telephone installation. Video access lines (loops) to the serving central office will be provided using additional regular wire pairs, appropriately equalized. Arrangements are being provided for extending PBX and key telephone customer switching arrangements to have a* Picturephone *capability. Central office switching will be accomplished by auxiliary video switches under the control of ordinary switching machines. Short-haul trunks will be provided on ordinary trunk cables equipped with equalizers as for loops. Long-haul trunks will make use of existing and planned systems, with additional equipment needed only at the terminals.*

The network was designed primarily for face-to-face communications, but two additional services are being offered at the outset: data communications at 460.8 kb/s and interfacing arrangements for access to a customer's computer. Other new services are in the offing.

I. INTRODUCTION

Picturephone service adds a new dimension to telephone communication—that of sight. This face-to-face communication capability will be realized by taking maximum advantage of the existing nationwide telephone network.[1]

Although the advantage of more complete communication between people with *Picturephone* service is readily apparent, the switched *Picturephone* network will be useful in additional ways. (*i*) Simple graphic material, such as line drawings will be displayed and, if higher resolution is desired, slowly scanned images will be transmitted. (*ii*) The network will be used to communicate with a computer. High-speed data will be transmitted between business machines in the megabit-per-second range. (*iii*) Moreover, *Picturephone* service will be used to communicate among groups of people in conference rooms or by a number of individual persons at many different locations. (*iv*) It will even be used for surveillance of events at distant locations. Some of these additional uses will be possible at the outset of service; the rest will come later. There will surely be more applications, some yet to be thought of.

Important as these additional uses might become, the *Picturephone* network is expected to be used predominantly for face-to-face communication in much the same way as the telephone network is used predominantly for voice communication. Further, each of the additional uses, while important to a particular segment of the market, requires its own set of system parameters to match the system to the application best. There is no single system that will satisfy all applications of video communication, if cost-utility factors are considered. For these reasons, initial emphasis has been placed on designing the network for face-to-face performance. The other applications were kept in mind and those which did not seriously compromise the performance of the system for face-to-face communications have been accommodated.

The *Picturephone* network will complement the telephone network. That is, existing services will remain in place; telephones will continue to be used for setting up calls; card-dialers, speakerphones, and other extra telephone features will be retained; billing-recording procedures will not change; and customers will choose between a regular voice telephone call and a *Picturephone* call when they originate a call. This so-called vertical extension of existing services will take maximum advantage of existing equipment.

The first customers will be from the business community. This observation has affected the physical design of the *Picturephone* set, placed special emphasis on the use of customer switching equipment, and guided the design of the relatively short access lines (loops) which connect most business customers with the serving central office.

The articles in this issue cover the initial design of the systems of equipment that will provide *Picturephone* service. Innovations that will add to the initial service capability and reduce cost are already in the design stage and more are being studied. Future articles in this *Journal* and elsewhere will report on new improvements as they emerge.

This article presents an overview of the systems; the next article reports on system parameters and how they have come about. The remainder of the issue is organized by major communication system functions: stations, transmission, central office switching, customer switching, and finally, data and computer display equipment.

II. THE SERVICE, THE CUSTOMER, AND THE STATION

The most important advantage of *Picturephone* service is that the user will be able to *see* as well as *hear* the person with whom he is talking. Moreover, to simulate as closely as possible the naturalness of a face-to-face conversation, the customer's hands remain free as in a normal conversation. This feature is provided by the addition of a microphone and loudspeaker. However, a telephone handset can be used when audio privacy is desired.

The equipment required at the customer's location is packaged in four parts, three of which are shown in Fig. 1.[2] The picture *display unit* contains the camera, picture tube, loudspeaker, and complex electronics to drive them. A small *control pad* contains the user controls and the microphone. These and any standard *Touch-Tone* telephone are easily accessible in front of the user. A service unit, containing the power supply, logic and control circuits, and transmission equalizing circuits, is mounted out of sight in any location up to 85 feet away. Normal lighting is adequate.

The *Touch-Tone* telephone is used for *Picturephone* service because there are 12 symbols available rather than the 10 symbols provided by rotary dials. The 12th button, labeled #, in the lower right-hand corner of the *Touch-Tone* dial, is used to designate a *Picturephone* call. The customer simply depresses this button and then, in most cases, dials the number of the station he is calling. No new numbering plan is necessary, since the switching will recognize the symbol # and control the equipment to make the video connection.

In cases where telephone company operator assistance is required on a *Picturephone* call, the symbol # is depressed before the digits normally used to reach the operator. The operator responds on an audio-only basis. An appropriate fixed image, however, will appear on the customer's screen. Initially, the 3CL switchboard will be equipped for *Picturephone* operator service; the Traffic Service Position System (TSPS)[3] will be added later. Recorded announcements, such as "no such number" or "your call didn't go through," will also be provided on an audio-only basis.

Incoming *Picturephone* calls are identified by a distinctive ring created by a new tone ringer in the display unit. If the customer has a key telephone, the key corresponding to the called line lights red to identify a *Picturephone* call and white for a voice-only call. The call is normally answered in the hands-free mode by operating a switch on the control pad.

Normally, the *Picturephone* customer sits about three feet away from the display unit. He sees the other person on a 5 × 5½ inch (12.5 × 14.0 cm) screen. The images are displayed 30 times per second. Each display, or frame, consisting of 251 active scanning lines, is divided into two fields. The odd lines are first displayed in one field and then the even lines are interlaced in the succeeding field. This technique makes best use of the one-MHz transmission bandwidth, as is described in detail in the article on system standards.[4]

An additional provision permits the display of simple graphic material. A mirror, built into the display unit, is flipped out in front of the camera lens. Graphic material is placed beneath the mirror on the tabletop in front of the display unit and the camera focuses on the plane of the table.

Lines equipped for *Picturephone* service may also have voice-only extensions, such as a secretary's pickup. Although video calls can be

Fig. 1—The station installation, showing three of the four components: the existing *telephone,* a *display unit,* and a *control pad.* (The *service unit* is not shown.)

answered on such an extension, the caller would not see anyone until the call is picked up on a *Picturephone* set.

Full video service can be supplied to a PBX attendant if the customer wishes. As a further option, a fixed image, such as a company trademark, can be displayed to the caller while the attendant handles the call. In each of these situations, however, the communication system sets up a full two-way video circuit, and hence the customer will be charged at *Picturephone* rates.

Business communication services today range from simple direct lines to more complex PBX and Centrex arrangements. PBX service features include dial intercommunication and attendant service. In the case of Centrex, the service features include direct inward dialing to telephones and identified outward dialing. To assure continuation of the availability of these existing business services, new *Picturephone* key telephone units offering pickup, hold, and intercom service will be provided. Business customers who currently receive their telephone service from 701 and 757 PBXs, No. 101 ESS, or No. 5 crossbar systems, will be able to add *Picturephone* service and retain all of their major PBX and Centrex features. *Picturephone* service with other new PBX systems and with the No. 1 ESS system will be introduced at a later stage of the service.

III. LOCAL AND LONG-HAUL TRANSMISSION

The video signal leaving the *Picturephone* service unit of a station is a line-by-line electrical analog of the luminance of the scanned image interspersed with appropriate horizontal and vertical synchronizing pulses. The higher-frequency components of the luminance signal are pre-emphasized to approximately match the expected composite noise encountered in transmission. This technique improves the signal-to-noise ratio after de-emphasis at the distant station. The pre-emphasized time waveform is illustrated in Fig. 2.

Picturephone service requires no modification to the existing two-wire telephone loop; conventional calls and the voice portion of *Picturephone* calls use these wires. Two additional pairs of wires in standard telephone cables are assigned for the video signals—one pair for transmission in each direction. To compensate for the attenuation at video frequencies, equalizers are inserted at about one-mile intervals along the additional pairs. The ON-OFF switch-hook signals, *Touch-Tone* dialing signals and ringing signals, as well as the voice portion of *Picturephone* calls, are all transmitted over the voice pair.

The basic local arrangement for direct lines is shown in Fig. 3.

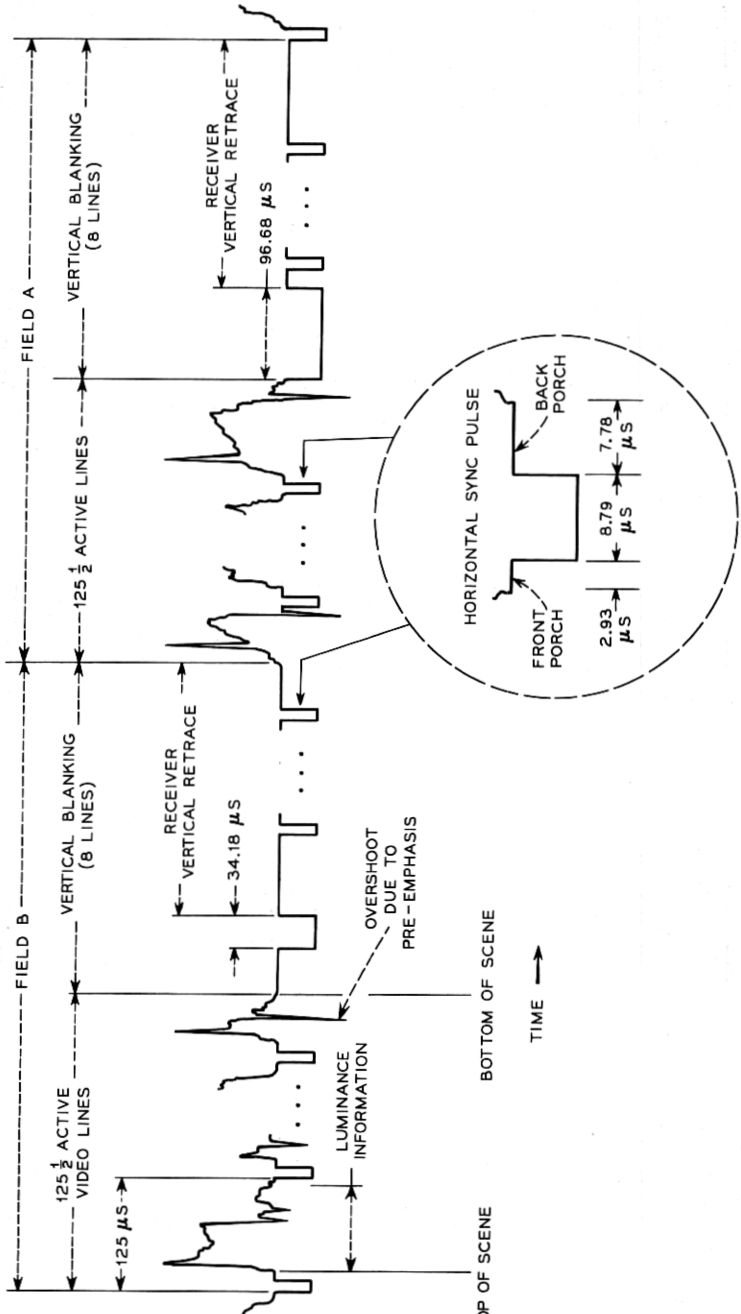


Fig. 2—Composite video signal. (Only video, not sync pulses, is pre-emphasized; line rate, 8 kHz; field rate, 59.93 Hz; video positive on top, as shown.)

More elaborate multistation arrangements on the customer's premises are served by similar loop arrangements. For PBXs, such six-wire loop arrangements serve as PBX trunks with the voice pair used exclusively for *Picturephone* calls.

Similarly, trunks to distant switching offices use six wires in much the same fashion. For the initial years of service, the equalizers in loops and trunks will be of the same design. Later, new trunk equalizers and loop equalizers, each with increased capabilities, will be available. The primary improvement in the later equalizers will be the capability to automatically compensate for cable transmission variations due to temperature changes. This will greatly increase the distance range of analog transmission in a local area. The mileage ranges are given in the article on the transmission plan.[5]

For transmission beyond the local area, which may initially be a business district but will later be an entire metropolitan area, the analog *Picturephone* signal will be encoded in digital form. This transformation involves sampling at the Nyquist rate of about 2 MHz and then encoding the amplitudes of the *differences* between successive samples into 3-bit binary codes. The bit rate is thus about six megabits per second. The equipment at one terminal that encodes in one direction and decodes in the other is called a *codec.*

Digital transmission is desirable because essentially all of the impairment in the process occurs due to quantization errors in the coding and the corresponding decoding (coding noise). Impairments can be controlled by an appropriate choice of the coding algorithm. Once encoded, the digital stream is transmitted, with regeneration at appropriate points in the path, in such a way that the received stream is

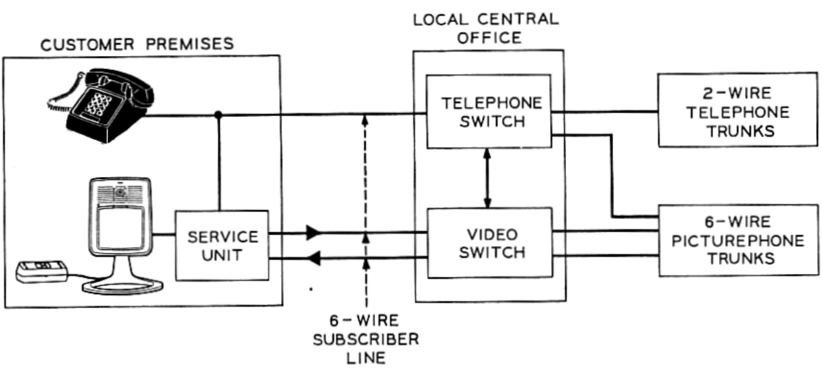


Fig. 3—Basic local arrangement.

nearly identical to the transmitted stream regardless of the distance transmitted.[6,7] The digit errors and the timing jitter introduced in transmission are controlled so as to have insignificant effect.

A switching and transmission plan has been devised which limits a signal in a complete connection to a single encoding and decoding to avoid an accumulation of coding noise. The signal stays in analog form in the local area. Once encoded for longer-haul transmission, it stays in digital form until it reaches the local area of the called station. Thus, the signals are switched in analog form in the local areas and in digital form in the long-haul plant.

In the initial years of *Picturephone* service, voice and signaling information will be transmitted on conventional carrier-derived voice-frequency channels. Later, as newly developed equipment enters the field, voice and signaling information will be converted to digital form and multiplexed together with the video signal into a composite bit stream.

The basic line rate for encoded *Picturephone* signals, with or without multiplexed voice and signaling, is 6.312 Mb/s.[8] The T2 digital transmission line, soon to be introduced, transmits at a 6.312-Mb/s rate and is, in fact, the reason for selecting this particular signal encoding rate. The T2 line will operate up to several hundred miles over wire pairs equipped with regenerative repeaters.

Digital transmission systems now being developed for a broad range of communications will ultimately take over the long-haul transmission of *Picturephone* signals. The first system to transmit digital bit streams for long-haul transmission will be the TD-2 microwave radio relay system. A pair of radio channels, one in each direction and each having a 20-MHz bandwidth, will be equipped to transmit 20.2-Mb/s streams carrying three coded *Picturephone* signals. Any or all of the ten pairs of radio channels on a TD-2 system may be so equipped.

The L-4 coaxial cable carrier system will also be equipped to transmit bit streams. In this case, a 13.29-Mb/s stream, carrying two 6.312-Mb/s signals, will be transmitted in place of one of the six mastergroups of voice channels (600 such channels per mastergroup) on a pair of coaxial units in a cable. Any or all of the six mastergroups on a pair of coaxials may be so equipped. Thus the TD-2 and L-4 systems, already in existence, will meet the long-haul needs of *Picturephone* channels for the first few years.

The TD-3 system, a solid-state successor to TD-2, will also be capable of carrying the 20.2-Mb/s pulse stream per radio channel. The L-5 system, now in development, will be equipped to handle 13.29-Mb/s pulse streams in place of a mastergroup, as in the L-4 system.

Higher bit rates, carrying more *Picturephone* signals in place of several mastergroups, are also contemplated on L-5 for greater efficiency. Still later in time, other coaxial systems and a new waveguide system will carry *Picturephone* signals with still greater efficiency.

Current research has shown good prospects for reducing the required bit rate from 6.312 Mb/s to significantly lower rates by taking advantage of the inherent frame-to-frame redundancy.[9] This is a future prospect, however, and will not be available in the initial system.

The picture that is finally viewed at a *Picturephone* station contains impairments introduced by each part of the built-up connection. The end-to-end impairments are controlled by holding each part of the connection within specified limits. Each of these has been assigned a numerical end-to-end maximum value with a specified portion allocated to stations, loops, trunks, etc.[5]

IV. CENTRAL OFFICE SWITCHING

At the local central office, the voice pair is connected to the existing telephone switch in the conventional way. The video pairs, however, are connected to a separate four-wire video switch which is under the control of the existing telephone switching machine.

As *Picturephone* service is first offered, No. 5 crossbar switching machines will be modified to switch video calls with up to a maximum of 3200 line appearances and 400 trunk appearances. The capability of providing *Picturephone* service will be added to No. 1 ESS later. *Picturephone* service for customers served from step-by-step, panel, or No. 1 crossbar offices will be routed to a nearby No. 5 crossbar or, later, to a No. 1 ESS office.

Whenever a customer dials a call, the common control equipment in the switching machine recognizes the digits and establishes a talking path between the lines and trunks. For voice-only calls, the existing two-wire telephone switch makes the connection. When the special prefix, #, is dialed, indicating a *Picturephone* call, the talking path is established through the two-wire telephone switch, and a path is established simultaneously through the four-wire video switch to the trunk side of the switching matrix. There, the audio and video paths form a composite six-wire appearance. For intra-office calls, the six-wire *Picturephone* signal returns through the switches to another line. For calls to a distant central office, however, the path is established over a six-wire *Picturephone* trunk. The audio portion of the six-wire trunk is dedicated to *Picturephone* traffic and is never used for voice-only telephone traffic.

What has been described above is the means for switching *Picturephone* signals in *analog* form. *Picturephone* signals will be switched in this way in the local serving central office. Initially, some of these same offices will also provide the toll switching function, also in analog form. The digital encoding and decoding are carried out within the interoffice trunks. Later, the bit streams will be switched at toll centers. Initially, No. 5 crossbar systems will function as the toll centers, and later, electronic toll switching machines will assume this function.

There are some cases where it will be economically attractive to add a switch remote from the serving central office. The large business customer having a number of *Picturephone* stations located a few miles from the serving central office is such an example. In this case, a wideband remote switch (WBRS) can be provided that acts as a concentrator to reduce the required number of video links between the customer and the serving central office. Only a portion of the control circuitry is at the WBRS. Control circuits in the central office direct the switch over regular telephone pairs, which serve as the control link.

Figure 4 illustrates the *Picturephone* switching hierarchy. Note that the toll center may switch either analog or digital signals. Actually, although not shown, a toll center or a primary center may be equipped to switch both analog and digital signals in separate switch matrices, with codecs in the interswitch paths. The choice is based on local trunking needs and economics. Figure 4 also illustrates a use of a WBRS and a wired-through connection at a local telephone end-office not equipped for *Picturephone* switching. Although not shown, trunks may exist between any pair of switching offices in the diagram (except that the WBRS connects only to its homing office).

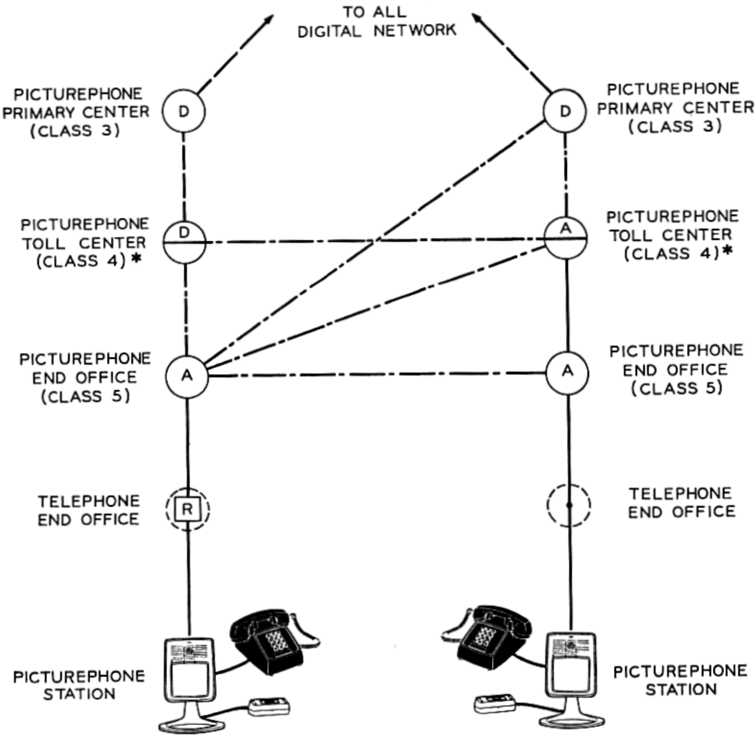
An illustrative local area configuration is shown in Fig. 5. Analog loops and trunks are shown with local and toll analog switching. Also shown is how they interface with digital trunks and bit stream switching.

V. OTHER SERVICES

Picturephone service will provide a one-MHz switched network, which will be capable of providing more than "see-as-you-talk" communications. Two obvious and important additional capabilities are being implemented from the start: digital data transmission and interaction with a computer.

For initial service, the *Picturephone* network will transmit and receive synchronous digital data through a data set at the station, much like *Data-Phone*® data communications service on the voice network. Initially, transmission of digital data is limited to a rate of 460.8 kb/s by the coding processes in the trunks, but improvements are planned to extend the maximum bit rate to 1.344 Mb/s.

The capability of interacting with a computer from a *Picturephone* set is provided by means of a special display data set, which appears to the computer as a voice-frequency time-sharing access line and to the switched network as a regular *Picturephone* set. The special display data set communicates with the computer in the format of a voiceband data set, such as those currently used in time-shared sys-



* The toll center may be either A or D. The two cases shown are illustrative.

Fig. 4—*Picturephone* switching hierarchy. [R wideband remote switch (WBRS); —·—·— analog or digital transmission; ——— analog only; - - - - - digital only; D = digital switch; A = analog switch.]

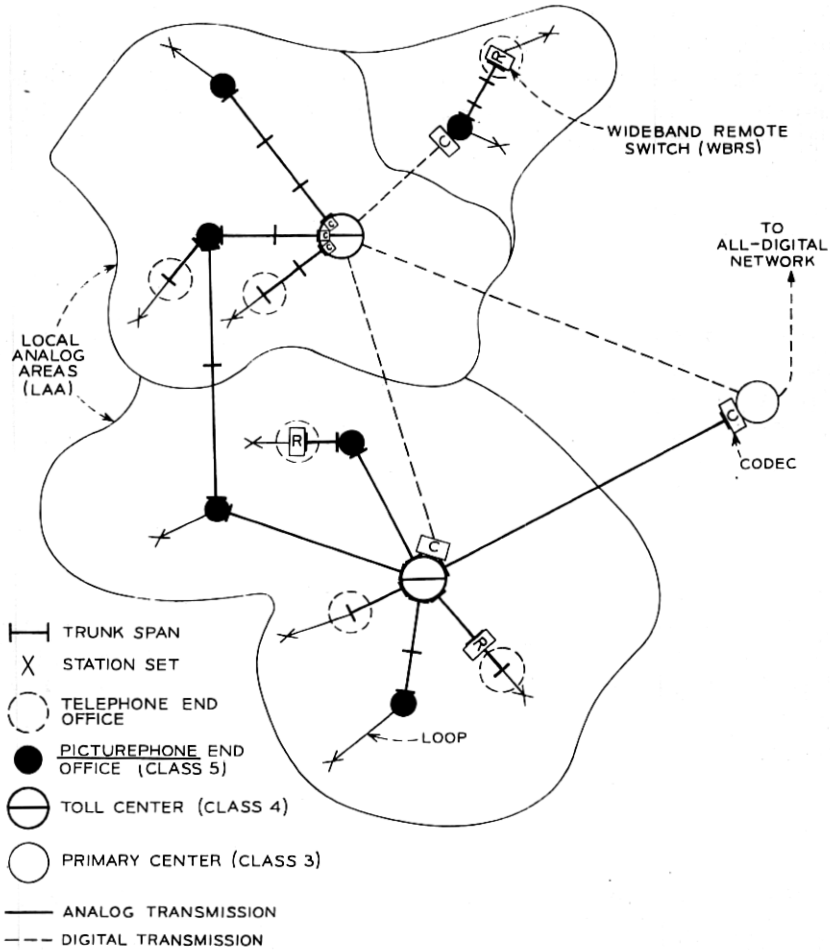


Fig. 5—Illustrative local area configurations.

tems. The data set generates an analog video signal from ASCII-coded* computer information for display on the *Picturephone* set. The data set also converts the tone signals from the *Touch-Tone* telephone to ASCII code to interrogate the computer. Thus, a user can dial a regular *Picturephone* number, reach a customer's computer, and interact using the user's display tube and the *Touch-Tone* dial with no additional

* American National Standards Code for Information Interchange (ANS × 3.4—1968).

equipment at the station location. An optional extension of this capability, using an ASCII keyboard, is under way.

Other uses will come in time, many by customers interconnecting their own station arrangements. It should be made clear that although the *Picturephone* signal occupies a nominal one-MHz bandwidth, the switched network cannot be used to transmit arbitrary one-MHz signals because of power constraints, spectral distribution constraints, and signal processing constraints in the digital coding. The connecting arrangements for customer owned equipment are described in an available technical reference.[10]

One other service that should be mentioned here is multipoint conferencing, involving many conferees, each at a different location. A Voice Operated Video Conference System (VOVCOS) is planned for introduction a few years after the initial service offering. In this system, a voice-actuated switch causes the picture of the person talking to be seen by all other conferees whose sets are connected to the special VOVCOS conference bridge. Such a system is necessary to extend the voice conferencing services now offered, to the *Picturephone* network, where the new question of who sees whom arises.

Two more obvious extensions of the service are still in the active research stage: full color service and a high-resolution graphics capability. In the latter, high resolution will be obtained within the same bandwidth by sacrificing response to animation. It is expected that in time, these service capabilities will be added.

REFERENCES

1. Bell Laboratories RECORD, Special Issue on *Picturephone®* Service, *47,* No. 5 (May/June 1969).
2. Cagle, W. B., Stokes, R. R., and Wright, B. A., "The *Picturephone®* System: 2C Video Telephone Station Set," B.S.T.J., this issue, pp. 271–312.
3. "Traffic Service Position System," special issue of the B.S.T.J., *49,* No. 10 (December 1970), pp. 2417–2734.
4. Crater, T. V., "The *Picturephone®* System: Service Standards," B.S.T.J., this issue, pp. 235–269.
5. Brown, H. E., "The *Picturephone®* System: Transmission Plan," B.S.T.J., this issue, pp. 351–394.
6. Oliver, B. M., Pierce, J. R., and Shannon, C. E., "The Philosophy of PCM," Proc. IRE, *36* (November 1948), pp. 1324–1331.
7. Kelley, R. A., and Andrews, F. T., "Challenge in Transmission," Science & Technology, No. 76 (April 1968), pp. 55–62.
8. Davis, J. H., "A 6.3 Megabit Digital Repeated Line," 1969 International Communications Conference, Boulder, Colorado, Convention Record, p. 34.9.
9. Mounts, F. W., "Conditional Replenishment: A Promising Technique for Video Transmission," Bell Laboratories Record, *48,* No. 4 (April 1970), pp. 110–115.
10. Bell System Technical Reference, "*Picturephone®* Connecting Arrangement-PVF, Interface Specifications," September 1970.