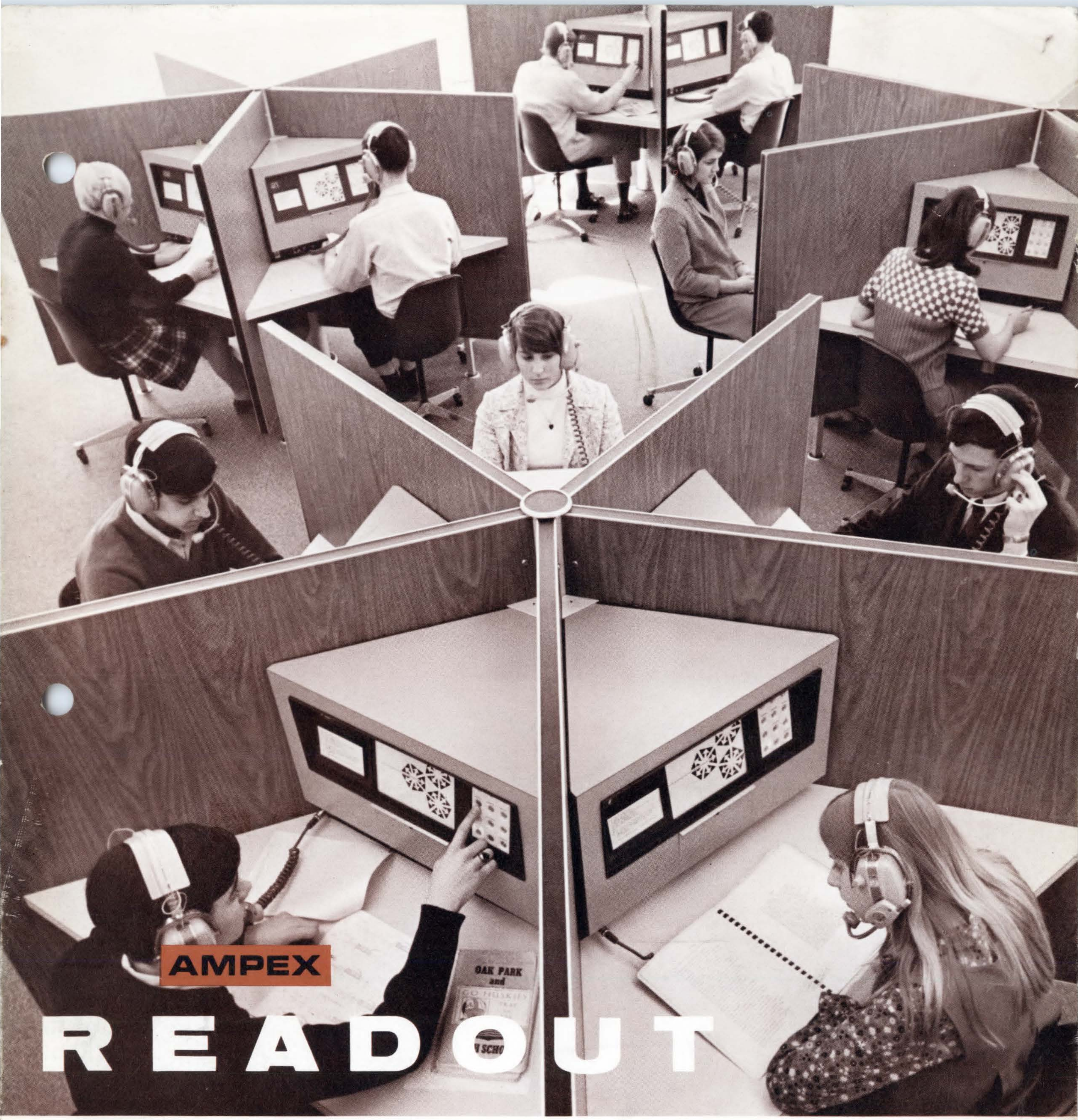

AMPEX READOUT

In this issue:

- Oak Park and River Forest Random Access
- French Space Program
- New York, Georgia and Delaware ETV
- Ampex Research and Engineering Articles

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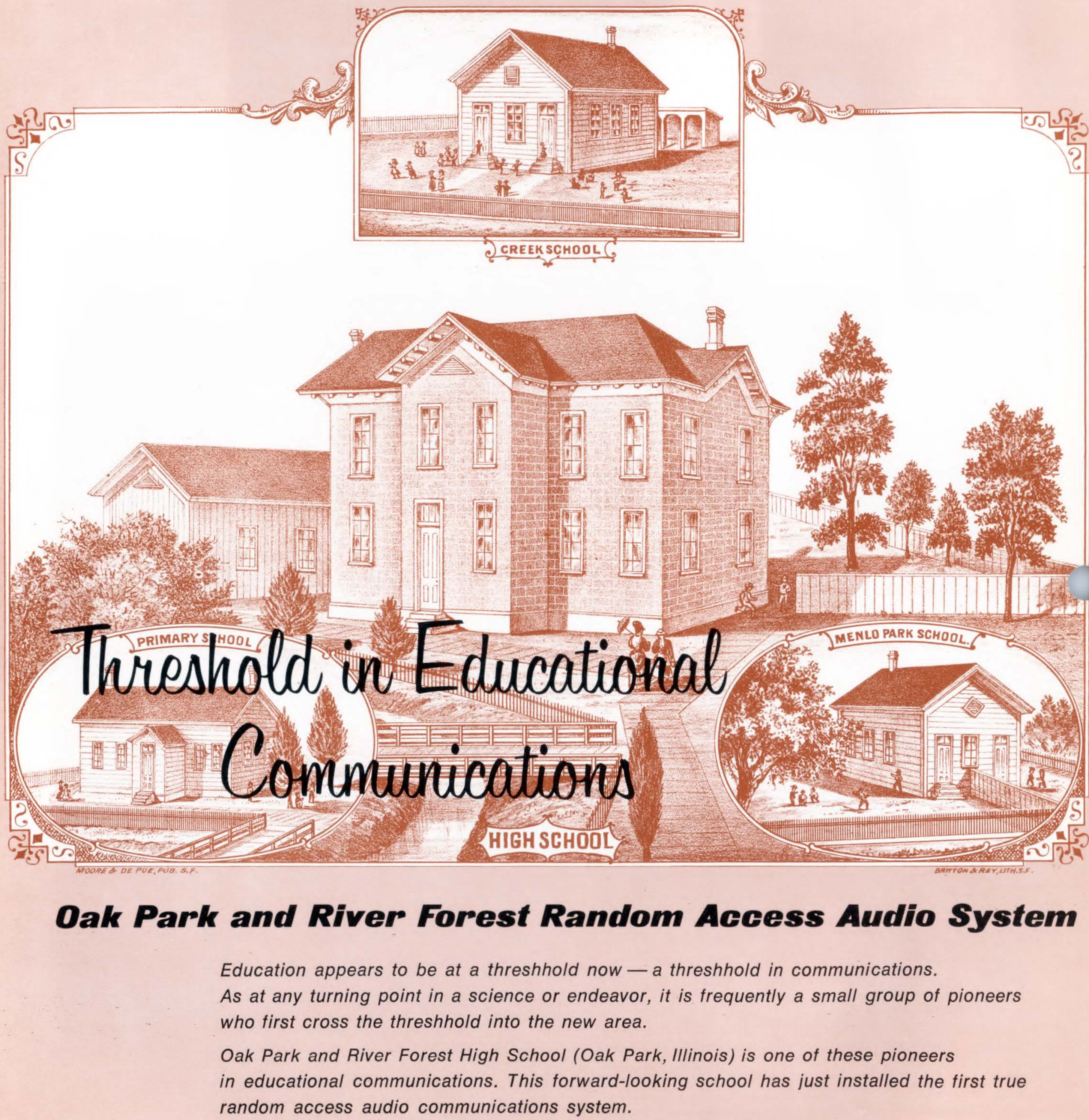


Threshold in Educational Communications

Oak Park and River Forest Random Access Audio System

Education appears to be at a threshhold now — a threshhold in communications. As at any turning point in a science or endeavor, it is frequently a small group of pioneers who first cross the threshhold into the new area.

Oak Park and River Forest High School (Oak Park, Illinois) is one of these pioneers in educational communications. This forward-looking school has just installed the first true random access audio communications system.

Its job is to do two important things: help students learn better, and help teachers teach better.

COVER: *Four of the five pentagon shaped carrels at Oak Park and River Forest High School, Oak Park, Illinois. System will be expanded later to 75 carrels, then to 200.*

AUTOMATED SYSTEMS: Freeing the Teacher to Work with the Students

Automated systems are sometimes looked on as impersonal methods of teaching. The truth is that automated learning actually works out to be more human than some traditional approaches. It creates more time for personal attention and teacher-student interplay. It frees the teacher to inspire and motivate, to bring out principles and uses of knowledge instead of dealing only with bare facts and routine techniques. It spreads out the efforts of those teachers who can present knowledge best by recording them so that many more students can benefit from their talents.

Most teachers want to have more time to spend with their students. However, they are quick to admit that they frequently end up spending a good deal of their time simply presenting knowledge.

The role of the new random-access system is to help the teacher shuck off some of the burdens of repetitive presentation. Unquestionably, many types of knowledge are best learned by repetitive presentation. The new system not only helps the teacher do this, but adds another dimension. It individualizes instruction by letting the student get what he wants when he needs it. Once received, he can proceed at his own pace and even repeat part of the lesson if he doesn't understand it. This isn't possible during a lecture and sometimes isn't possible or desirable even in a classroom.

To those who look at this as being a replacement for the teacher, we would draw attention to the invention of the printing press and the first mass produced books. The didacticists of that age were certain that if books were easily available they would degrade learning. The key to learning, they pointed out, was the dialogue between teacher and student, or next best, a small group in a Socratic dialogue. The book was seen as a threat to learning.

In point of fact, neither the book nor the many communications tools that came later are a threat to the teacher. They are simply tools that free the teacher to spend more time in individual contact with the student. They don't replace the teacher—they re-place him in a role more valuable to school and community.

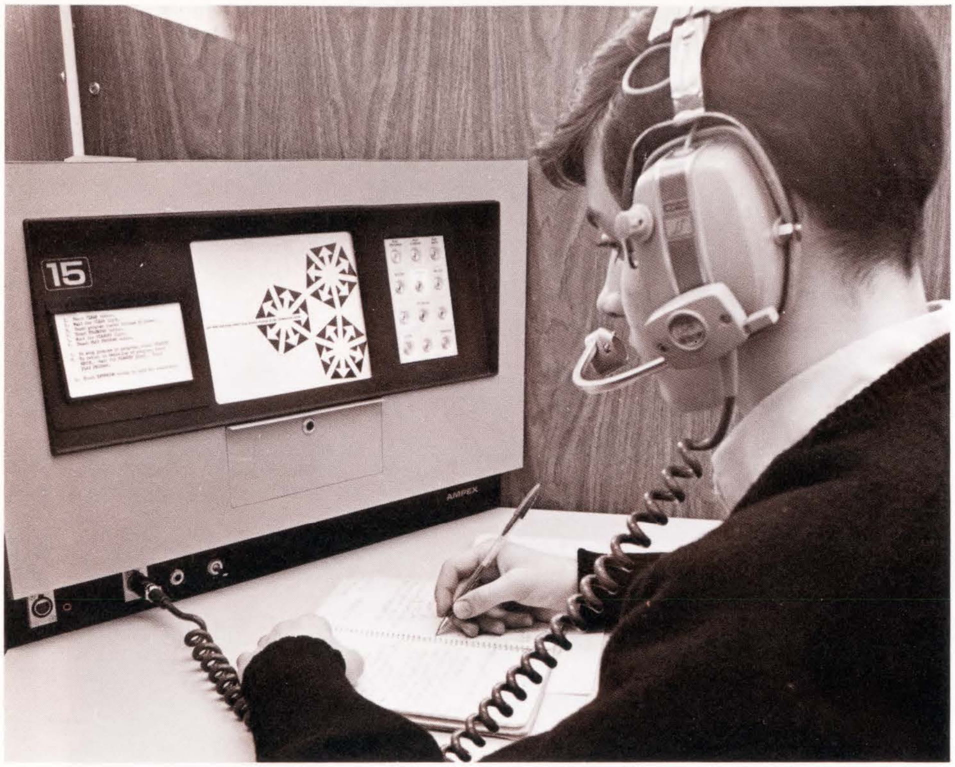
Subjects to be included initially in the system are vocational guidance, mathematics, science, driver education, languages, English, drama, music, and history. New material can be added at any time.

RANDOM ACCESS AUDIO SYSTEM: Heart of Instructional Resources Center

Random access is a method of storing programs and data by which any item can be brought forth immediately. The new audio system at Oak Park and River Forest High School is the first true random access audio information retrieval system in the United States. It can be called a true random access system because each student in 25 locations can select any one of 224 recorded programs and have it available for listening in his own earphones in less than 59 seconds. Program length can be up to 15 minutes long, which turns out to be about a maximum length for the average attention span when a student is learning by repetitive presentation.

Other systems permitting random selection of material are limited because a student may have to come into the middle of a program if another student has already requested it. With this new system, each student receives programs from the beginning.

Key to the Ampex system at Oak Park and River Forest are high speed duplication technology and new bin loop tape transports. These, in combination with a small high-speed computer, duplicate a 15-minute program in 30 seconds. This means that even if some other student has just requested a program, the maximum waiting time would be 59 seconds (that is, 29 seconds for the other student's material to be duplicated, plus 30 seconds for his). This is the maximum waiting time whether one student or all students request the same program.



Student with head set (earphones and microphone) listening to a program in a carrel. Desk allows student to take notes and refer to books or other course material. A second head set jack is provided so that two students can listen at the same time.

The student selects mode of operation (program number, play, stop, recue at beginning) by push buttons. System is immune to pranksters because the student doesn't operate the equipment directly. All commands are routed by a computer which controls the entire system.

The present installation is the first step of a scheduled three-phase instructional resource center recently engineered and installed by Ampex in the Oak Park and River Forest High School. Future phases will extend the system to 200 receiving locations and include random access video instructional material.

Students respond very favorably to this type of equipment. It's similar to the type of programmed descriptions found in science museums where a student can press a button and hear a presentation on what a particular demonstration means. Students of today's generation are used to receiving information via audio and video sources so that it seems very natural to them to be using modern communications tools in school.

REQUESTING A PROGRAM: Like a Library with Unlimited Copies of Each Title

In operation, the student selects the program he wants to hear on a twelve-button keyboard, similar to those used on the new TOUCH TONE® telephones. The computer routes his request to the master tape recorder which replays the selection at high speed (120 in/sec). A recorder connected to the student's own carrel receives the selection and duplicates it at high speed. A full 15-minute program is copied within 30 seconds. After the lesson has been copied the student can listen to it immediately, and the master recorder is free to duplicate it again for another student or duplicate any other lesson. Unlike a conventional library, no lesson is ever checked out when a student needs it.

Since the master program is stored in a reproducible form, unlimited copies can be made to take care of any number of students. Each student gets his own individual lesson to listen to. He can even plug-in his own recorder and copy the lesson for later use at home if he wishes.

SYSTEM COMPONENTS

Student Carrels. Students receive and listen to their material without bothering others in pentagon shaped carrels. In Phase One, there are five carrels, each with five student positions. This will soon be increased by ten additional carrels, for a total of 75 positions, then later to 200 positions. Illuminated push buttons select program material and control program replay, student record and play, standby, and recue. Program recording is controlled only by the computer, but an indicator light in the carrel shows when the system is in this mode. Each student has earphones, a microphone (for language instruction or intercom), an instruction card, and directory of programs.

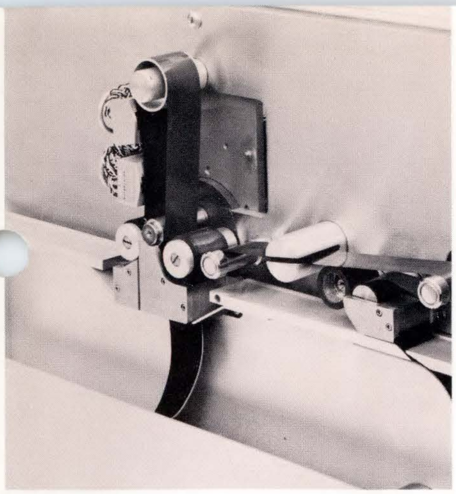
The system is quite immune to pranksters or improper operation because the student does not operate the equipment directly. All student requests go from the carrel keyboards to the computer which controls the entire system. The computer will reject an improper request or input. Because of this hands-off operation, students can't damage the system.

Keyboard control units can also be put in classrooms or auditoriums to connect into the system for group listening. Remote locations, including sick students at home or other schools, can connect into the system via five telephone interfaces. A TOUCH TONE® telephone is all that is required at a remote location to draw on the library of recorded material.

Supervisor Console. Unattended operation of the system is possible, since it is entirely automatic. For supervisory operation, the supervisor's console provides the most sophisticated control available. Audio for each student passes through the console and may be monitored. A complete intercom allows the supervisor to interrupt a program and talk with the student directly. For trouble shooting an auxiliary keyboard/display unit on the console allows the supervisor to take over control of any student buffer, share control with the student, or completely disable a given position. The computer teletype, located on the console, also logs out each requested program number with the position that requested it. This can be expanded to log out the student number, if desired.

Computer Control. The computer is the nerve center of the entire system. Its program has a log of audio program numbers and student carrel numbers. The student can also insert his own number into the system in order to identify himself for logging and testing.

The computer selects the proper program track and connects it via an audio switcher to the carrel recorder to duplicate the lesson at high speed. The computer can also test the condition of the entire system each day using basic diagnostic programs. One of the test programs cycles every program source in all student positions and logs out on the teletype any defective paths. This is important since nearly 6000 possible paths exist with the present 224 programs and 25 student carrels. Any defective paths or units located with the diagnostic program are identified on the computer teletype for action.



Tape bin in Master Reproducer has 250 feet of 1-inch tape with 32 tracks. Tape loops are made on a similar master recorder at 3 inch/second. Bin is then transferred to Master Reproducer for duplication at 120 inch/second onto student recorders connected to each carrel.

Technical supervisor at master control console, used when attended operation instead of the fully automatic control is desired. All student controls are duplicated here so that the supervisor can take over or share control. Teletype at left logs out program numbers and is used during diagnostic programs for readout.

Master Recorder. Master programs are recorded off-line on a master loop recorder which has 32 tracks on one-inch tape. This unit is manually controlled and records programs at 3 inch/sec from any regular input source such as a microphone, tape recorder, phonograph or radio. The tracks on the master recorder have separate erase and record heads so that each track is recorded independently of the other tracks and may be recorded, edited, or updated at any time.

For the highest quality in master recording, material will be recorded first on a standard professional recorder (Ampex AG-440 or the AG-500) at 7½ inch/sec and transferred onto the tape loop on the master recorder.

Master Reproducers. It is the seven master program reproducers that bring the high access speed and flexibility of the Oak Park River and Forest system. These are 32-track one-inch bin-loop units. After a tape is made on the master recorder, the bin is placed on the master reproducer. Here it is played at 120 inch/sec to duplicate material for the carrel units.

Since these are loop recorders, the tape doesn't have to be rewound before the next program can be duplicated. Programs are available from the beginning immediately after a transfer is done. No time is lost in reversing the tape as in a conventional reel to reel recorder. Each master reproducer can transfer a single program to a single carrel recorder, a single program to all carrel recorders, or all 32 programs simultaneously to all carrel recorders.

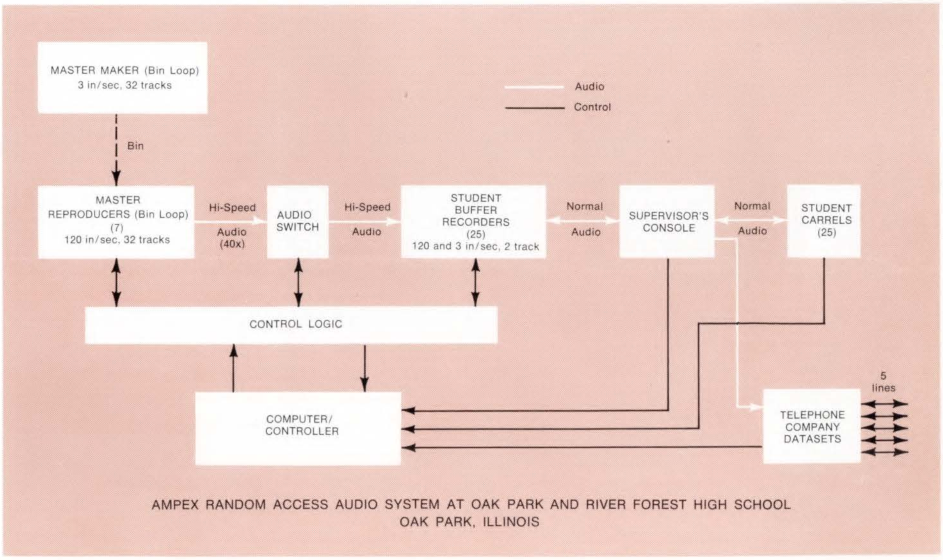
Carrel Recorders. The student recorder/reproducers connected to each carrel are identical mechanically to the master reproducers, except they are half-inch dual track. They operate at 120 inch/sec when receiving a program from the master recorder, then play it back to the student for listening at 3 inch/sec. Transfer time is 30 seconds for a 15-minute program. The student can listen to the program as many times as he wants or record it on his own personal tape recorder. Track one contains program material for playback. Track two is for recording the student's own voice.

PHASE TWO: Addition of Video

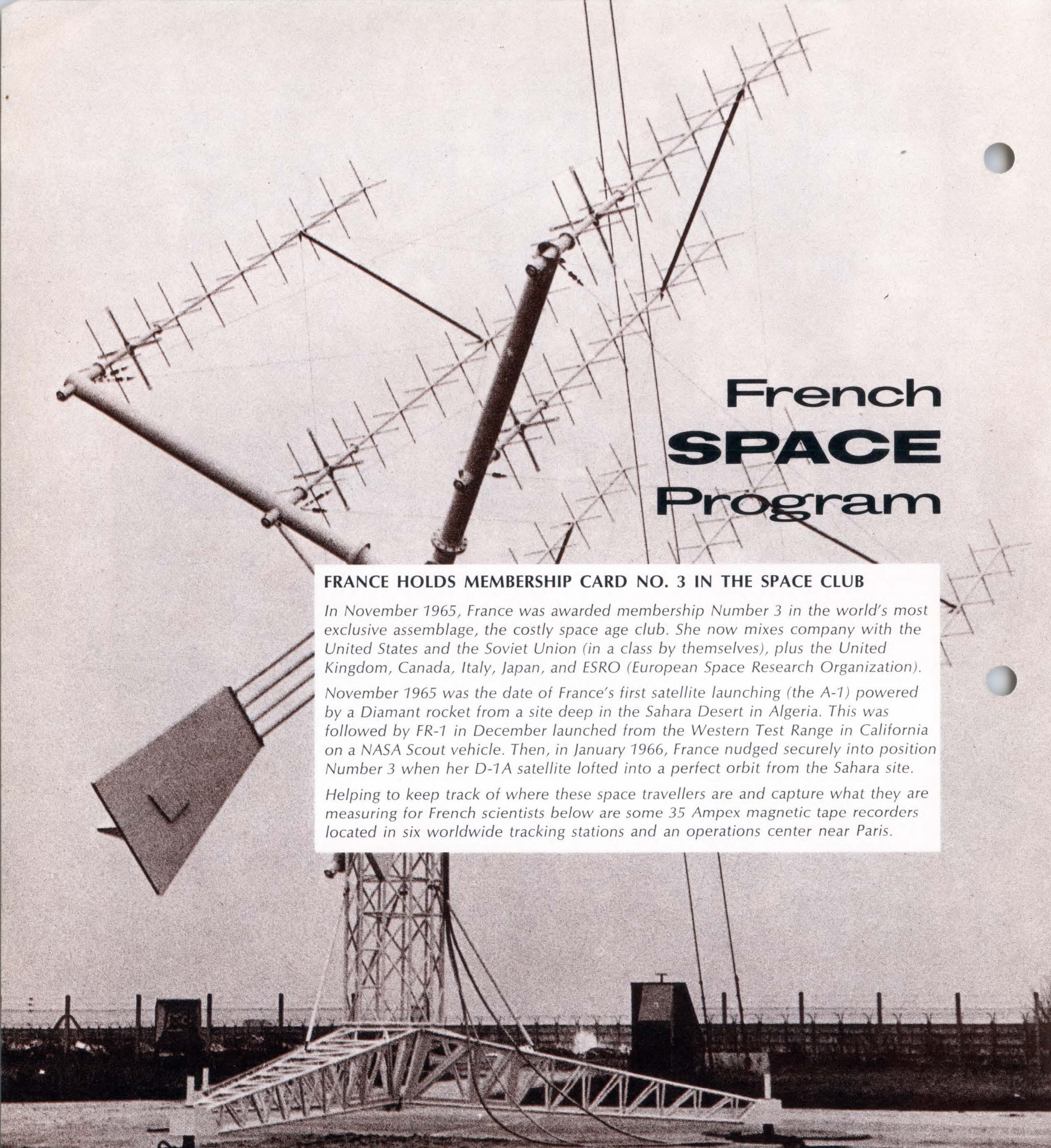
Phase Two of the system will provide video in conjunction with audio. The existing control logic and computer will switch video inputs from a television camera, one videotape recorder, and three film/slide chains. Television monitors can be added to the student carrels at any time in the space already provided. The present system is designed to accommodate random access video in the final phase. Equipment for this purpose is now under development at Ampex.

FUTURE PLANS: Automatic Student Testing

By adding a minor amount of computer programming, the system as it stands now can perform automated testing and scoring of students. The computer totals the score and prints out the required data. A tape punch may also be employed to create a tape with which the computer can later provide statistical data and class curves.



AMPEX RANDOM ACCESS AUDIO SYSTEM AT OAK PARK AND RIVER FOREST HIGH SCHOOL
OAK PARK, ILLINOIS



French SPACE Program

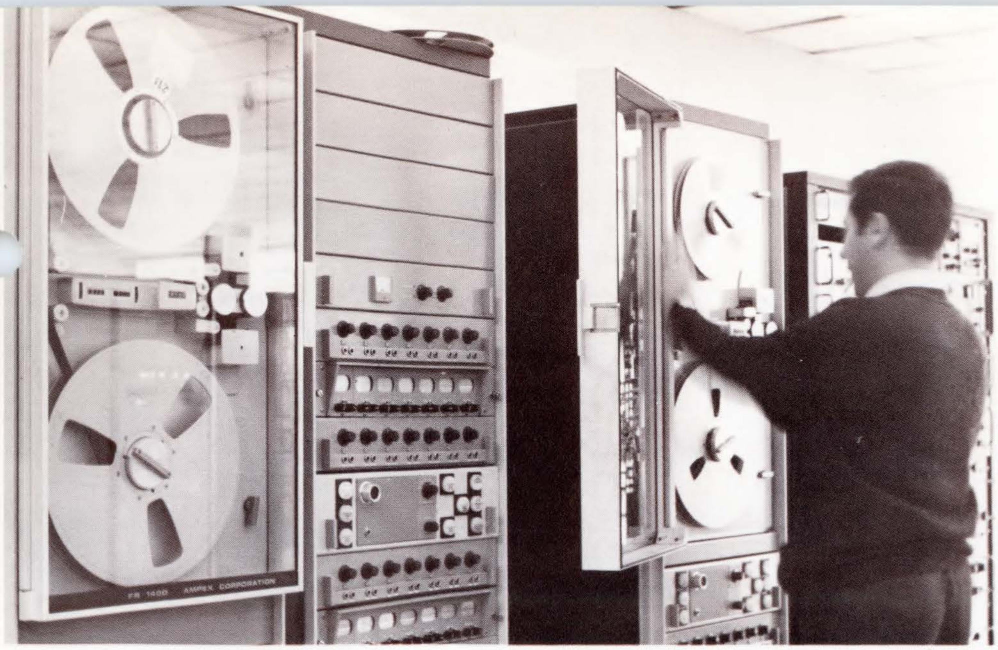
FRANCE HOLDS MEMBERSHIP CARD NO. 3 IN THE SPACE CLUB

In November 1965, France was awarded membership Number 3 in the world's most exclusive assemblage, the costly space age club. She now mixes company with the United States and the Soviet Union (in a class by themselves), plus the United Kingdom, Canada, Italy, Japan, and ESRO (European Space Research Organization).

November 1965 was the date of France's first satellite launching (the A-1) powered by a Diamant rocket from a site deep in the Sahara Desert in Algeria. This was followed by FR-1 in December launched from the Western Test Range in California on a NASA Scout vehicle. Then, in January 1966, France nudged securely into position Number 3 when her D-1A satellite lofted into a perfect orbit from the Sahara site.

Helping to keep track of where these space travellers are and capture what they are measuring for French scientists below are some 35 Ampex magnetic tape recorders located in six worldwide tracking stations and an operations center near Paris.

Telemetry and command antenna used by CNES receives signals in the 136-138 MHz band, and transmits commands in the 148-150 MHz band.



Data reduction center at Bretigny, where four FR-1400's are used to reproduce tapes from French telemetry stations.

Solid propellant Dragon sounding rocket on its launching pad. This is one of an extensive range of space probes launched by France.

FRENCH SPACE AGENCY: Oversees a Joint Government/Industry Effort

The main government agency responsible for France's space program is the National Center for Space Studies, or CNES, created in 1962. The CNES has three basic jobs: to develop and guide scientific aerospace and research; to prepare programs and insure their execution, either in its own facilities or through research contracts with industrial firms; and to coordinate international cooperation in space programs in conjunction with the Ministry of Foreign Affairs. CNES also works with French universities to develop training programs and promote interest in space sciences and technology.

France's space program is modest by comparison with programs in the United States and Soviet Union. Currently, France spends only about 1% of the U.S. expenditure and plans no manned space project. Its budget rose from $18 million in 1961 to nearly $120 million in 1968.

FRENCH NATIONAL PROGRAMS: Launch Vehicles, Probes, Satellites and Balloons

Launch Vehicles. The Diamant (diamond) launchers are the latest in a series of rockets named after precious stones. Continuing the success of Diamant 1 and 2, numbers 3 and 4 placed the D-1C and D-1D satellites into orbit in February 1967. Diamant B, next in the series, has a bi-liquid propulsion stage that will develop 35 tons of thrust. Diamant B has been selected for the Vempa test vehicle by ELDO, European Launcher Development Organization, for its Europa II rocket. The first of four scheduled launchings will be made from France's Space Center in Guyan during 1969.

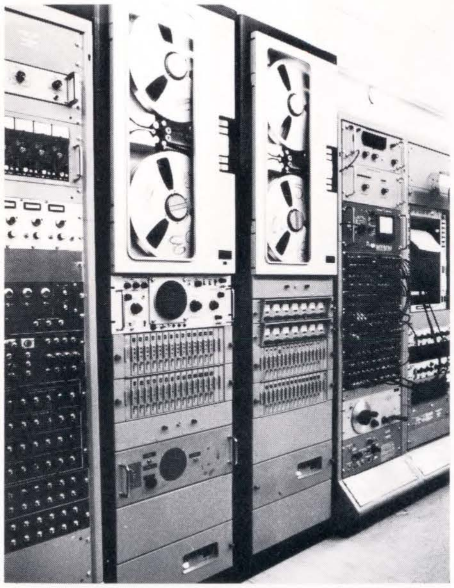
Sounding Rockets. France has launched an extensive range of sounding rockets for scientific teams, both French and foreign. They have gathered valuable information in particle and cosmic ray physics, astrophysics, and ionospheric physics. Launchings have been made with the solid propellant rockets Belier, Centaure, Dragon, and Rubis. Two other solid propelled rockets are being developed, Dauphin and Eridan. Liquid propellant rockets include Veronique A.G.I., Veronique 61, and Vesta.

The last three rocket firings were in Norway in October 1966 (particles in the aurora borealis zone and the electric field), Argentina in November 1966 (spectral analysis in the ultraviolet band during total solar eclipse), and Terre Adelie (four Dragon launchings for geophysical phenomena).

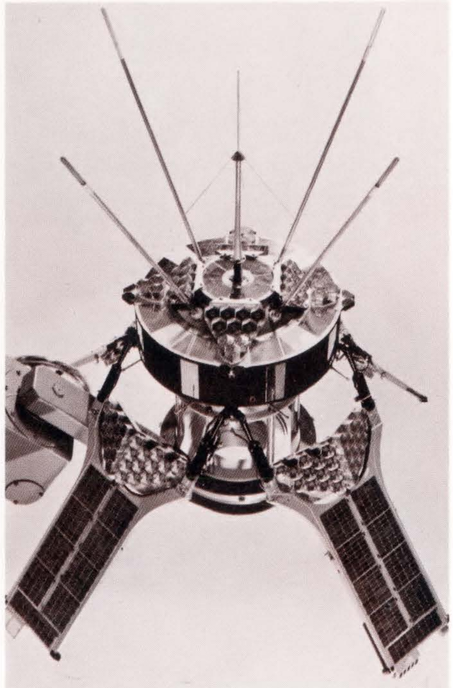
Satellites. France's first satellite, the A-1, lifted off from the Hammaguir Firing Range in the Sahara in November 1965. This was an 88 pound experimental capsule made of fibreglass. It remained aloft for about two weeks in an elliptical east/west orbit with an apogee of 1,121 miles and a perigee of 83 miles. Its primary mission was to test the three-stage Diamant vehicle. Although the launch was successful, the A-1's radio transmission malfunctioned.

France's second satellite, the FR-1, was launched by a NASA Scout rocket from the Western Test Range in California on December 6, 1965. This is a French-built scientific satellite developed under a cooperative agreement with the United States. It studied the propogation of very low frequency radio waves in various regions of the ionosphere, plus the earth's magnetosphere and electron densities. It weighed 160 pounds, including the 23-pound separation stage. It was placed in a circular polar orbit at an altitude of 490 miles. Planned life was three months, but it operated for a much longer period.

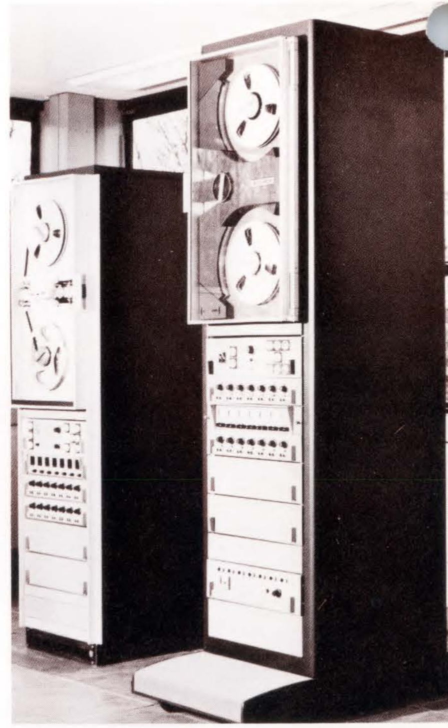
The D-1A, nicknamed Diapason, was the third French satellite, and the first of the D-1 series of scientific satellites. It was placed in orbit by a Diamant launcher from the Hammaguir base on February 17, 1966. It was suc-



Testing laboratory at CNES Space Center at Bretigny where two of its seven Ampex FR-1200 recorders are used for vibration tests of satellite and space probe components.



The Diademe I (D-1C), a geodetic satellite that was launched along with Diademe II in February 1967. Purpose of these satellites is trajectory measurement and high-precision geodesy from three laser stations in France, North Africa and Greece.



Telemetry station at Bretigny with an Ampex FR-1800L and FR-1400 data recorders. Other stations in the French ground network also use FR-1400 recorders.

cessful in all respects. It weighs 42 pounds and is orbiting the earth every 118 minutes on an elliptical path with an apogee of 1696 miles and a perigee of 312 miles. Diapason helped develop orbit computing methods and made preliminary studies on navigation and geodetic satellites. The geodetic satellites Diademe I (D-1C) and Diademe II (D-1D), launched in February 1967 from Hammaguir, are adding to the data already gathered. France has been active since 1964 in geodetic studies, when it made photographic observations from five points in a homogeneous geodetic system (linking France and North Africa) of Echo I.

Balloons. Free balloons, the simplest of space vehicles, give astrophysicists a vast field of research without requiring costly rockets or satellites. CNES produces and launches hydrogen-inflated polyethylene balloons with volumes ranging from 1,000 to 100,000 cubic meters. The largest carry a load of 125 kg (275 lbs) to nearly 40 km (25 miles).

PENDING PROGRAMS: D-2, Eole, Symphonie, and Roseau

Design for France's second series of scientific satellites, the D-2, was begun in 1965. Launching is planned for 1969. The first will carry five experiments, primarily concerned with solar physics. Orbit will be elliptical at 450 to 900 km, inclined 45° with respect to the equator. Data will be transmitted in real time and also stored on board for transmission on command from the ground network.

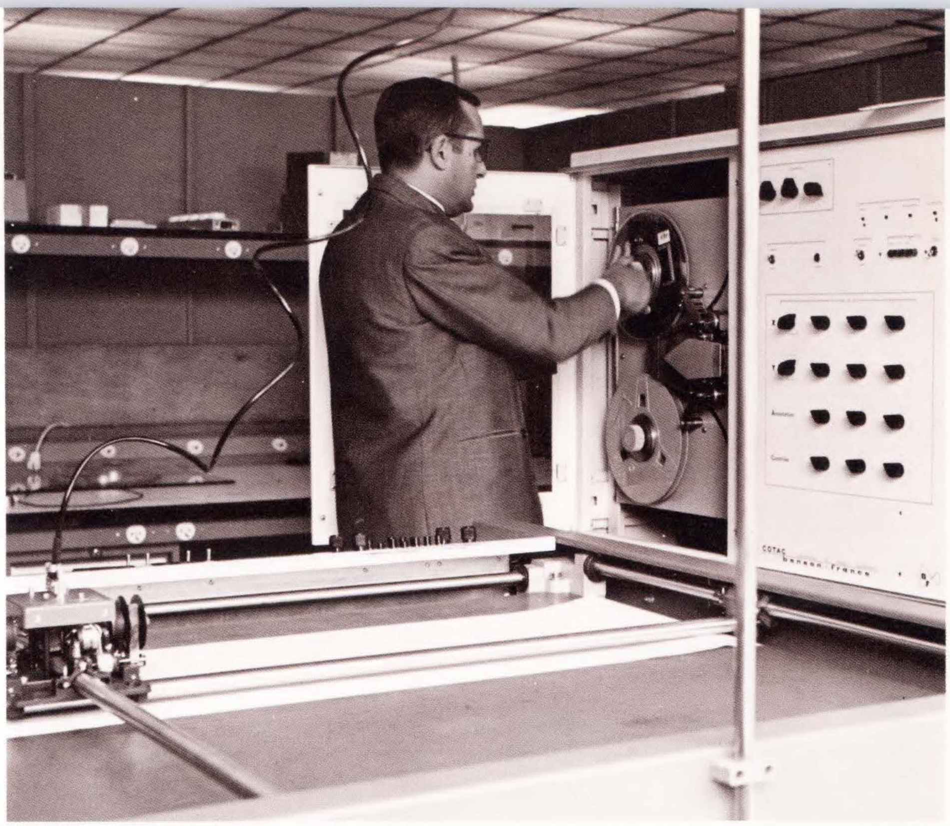
Another program called project Eole combines a satellite and a fleet of 500 balloons to study wind systems and design a model simulating atmospheric currents. The satellite collects data and locates the positions of the balloons, stores this information in an onboard memory, and then retransmits it to the ground stations on command. Balloons will be launched in the southern hemisphere betweeen the equator and the 55th parallel. The satellite will be placed in a circular orbit at 800 km (500 miles), with a 50° inclination. Besides the scientific data, Project Eole will develop operational data on locating balloons by the satellite, gravity gradient stabilization, onboard memories (150 k bits), balloon pontoons, and real time data processing. The program will be carried out in cooperation with the United States National Aeronautics and Space Administration.

Two other satellite programs are under development, the Symphonie satellite with the Federal Republic of Germany, and the Roseau satellite with the Soviet Union. Symphonie is a telecommunications satellite handling sound and television broadcasting, telephone links, and data transmission. It is planned for launch using a Europa II rocket from the Guyan Space Center in 1971. Roseau includes two phases, a lunar satellite and an earth satellite, to be launched by Soviet rockets. The lunar satellite will study lunar surface and atmosphere, the earth satellite will scan the magnetosphere and its boundaries. A follow-on project, agreed to in 1967, will investigate solar plasma, the magnetosphere and the plasmasphere.

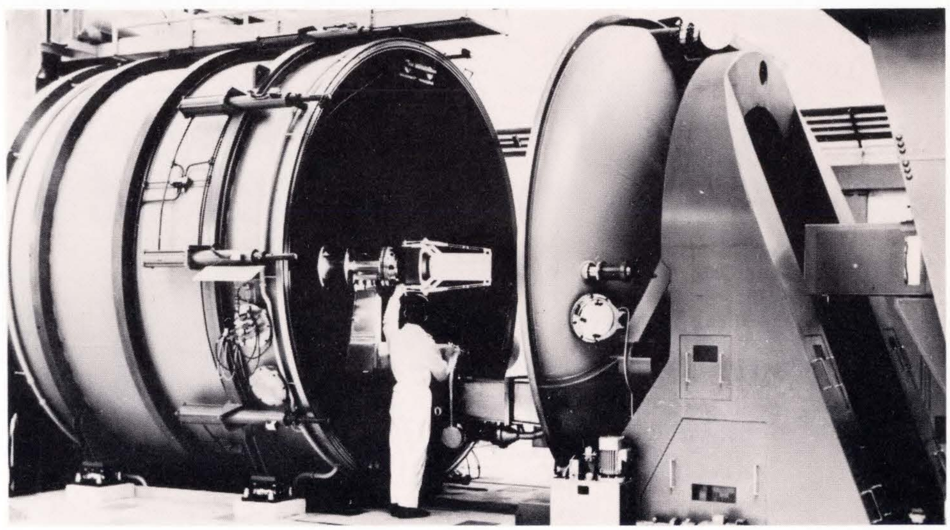
INTERNATIONAL PROGRAMS: Multinational and Bilateral

France cooperates actively in both of the multi-national European space programs, ELDO and ESRO. ELDO, the European Launcher Development Organization, was created by seven nations in 1962 to build a three-stage launcher (Europa I), able to place an 800-kg (1750 lbs) satellite in a low orbit. Europa II is now under development. France supplies the second stage, the Coralie. It is also preparing a launch installation in Guyan and is in charge of the suborbital in-flight tests of the perigee and apogee motors (the PAS system).

ESRO, the European Space Research Organization is a nine nation group. Cooperation is carried on through a technology center in the Netherlands, a data center in Germany, a



A Benson-France X-Y plotter in operation at the Bretigny center uses an Ampex TM-4 digital tape transport.



Diapason (D-1A) satellite in a simulation chamber at the Space Center in Bretigny.

launching range in Sweden and a research laboratory in Italy. Satellite programs include ESRO I and II, Heos, TD-1 and TD-2. ESRO II, an astronomy satellite, was fired from the Western Test Range in California by a NASA Scout rocket, but failed to orbit. French industry, based on the experience gained from France's national programs, has been granted more than 40% of the contracts awarded by ESRO.

CNES also represents France in the European Conference on Telecommunications Satellites (CETS), the yearly meeting of the European Space Conference, the World Committee for Space Research (COSPAR) and the International Telecommunications Satellite Committee (INTELSAT).

Bilateral cooperation includes projects with Greece, Mexico, the Soviet Union, Germany, Argentina, Canada, Spain, Great Britain, India, Iceland, Norway, and Pakistan. France has always maintained a close working relationship with the United States. NASA launched the French FR satellite. CNES's agreement with NASA also provides training for French personnel in the United States. Future cooperation is planned through an agreement with CNES for the Eole meteorological satellite.

GROUND STATIONS AND CONTROL CENTER: Africa, Canary Islands, Guyan, and France

In 1965, France set up a network of tracking (Diane), and telemetry/telecommand stations (Iris). Three telemetry and telecommand stations are located in Africa: Pretoria (South Africa), Brazaville (Congo), and Ouagadougou (Upper Volta). Recently, a telemetry and telecommand station was added in the Canary Islands. The new space center in Guyan also has a tracking station. The network operated during the 1966 launch of the Diapason satellite and has proved its successful operation on several missions since then. All stations are linked to the Bretigny Space Center. Tapes from the stations are processed here, then digital data analysis is done to calculate satellite trajectory and the scientific experiments. Much of the equipment used for calculation is of French manufacture.

Working to record location and scientific data in each of these tracking stations are two Ampex FR-1400 instrumentation recorders. One is a one-inch 14-channel version, and the other a half-inch seven-channel version. Fourteen-track versions are used to record data from space probes. The seven-track machines are used for data from satellites.

Data formats for the probes are normally FM/FM, PAM/FM, and PDM/FM which are multiplexed for transmission to the stations. The satellite format is normally FM/FM, PAM/FM, and PFM or pulse frequency modulation. The more recent satellites and most of the future ones will use PCM with the word format depending on the type of experiment to be run.

At the CNES operations control center located in Bretigny near Paris, some 24 additional Ampex instrumentation recorders help with the reduction of telemetered data and also in the development of satellite and instrumentation packages. These recorders include an FR-1600, an FR-1800, seven FR-1400's, six FR-1200's, and one each CP-100, FL-300 and FR-600. In addition an Ampex TM-4 is used with a Benson-France X-Y plotter.

At the space operations center, the data reduction section uses four of the FR-1400's to reduce telemetry from the tracking stations. Two of the recorders are half-inch 7-track, the other two are one-inch 14-track. Two of these machines (one seven and one 14-track) are used to take a quick look at the data with a simple graphic recorder. The other two feed into a complex demodulator system set up with the various types of electronics to match the telemetry formats used for the data. At the output of this demodulator system an analog-to-digital converter arranges the data in digital format for final reduction on the center's IBM 360/65 computer.

HEAD-TO-TAPE INTERFACE

By M. Wildmann, Ampex Corporation

INTRODUCTION. Sliding contact between magnetic heads and tape is present in all tape recorders in existence today. This sliding contact is probably the one feature which has least changed since the introduction of tape recorders. It is also probably the area which gives the most concern to tape recorder designers and manufacturers, and the most difficulty to tape recorder users.

MECHANICAL CONSIDERATIONS. A bearing can be defined as an interface between two surfaces in relative motion. If we accept such a definition of a bearing, the head-to-tape interface in a recorder is obviously a bearing. In order to reduce wear and friction in bearings, two methods are employed: 1) provide low shear strength material between the two surfaces, such as oil in an oil bearing, or 2) replace the sliding contact by a rolling contact, such as is done with ball bearings.

Unfortunately, neither of these solutions is directly applicable to the head-to-tape interface. The introduction of a lubricant between the head and tape will result in separation between them. The resulting spacing losses can not usually be tolerated, particularly if the recorded wavelength is short. The recording process itself requires relative motion between the fixed field in the head and the magnetic surface of the tape. Rolling contact between the two is therefore obviously out of the question. The head-to-tape interface is thus a particular interface in which intimate contact between the two surfaces, and relative motion between them have to exist at the same time.

To get a better understanding of how the interface under consideration really behaves, it is useful to refer to Figure 1, which shows a head drawn to scale in the vicinity of the head gap with the tape in contact. From this figure it is apparent (when drawn to scale) that the tape does not appear to be a very flexible membrane. Four major parameters describing this interface will now be examined.

Pressure Between Head and Tape. The average pressure between head and tape can be determined by examining the tape itself as a free body and by neglecting bending stiffness effects in the tape. The bending stiffness effects are usually small. A free body diagram is presented in Figure 2, showing the tape with a total wrap angle Θ, and average gauge pressure p. The radius of curvature is R, the tension per unit width is T. In order to balance forces in the vertical direction, the integral of the vertical component of the pressure over the tape must be equal to the vertical component of the tension, or:

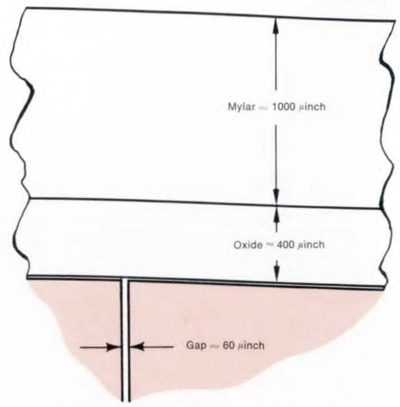


FIGURE 1. Head and Tape in Vicinity of Head Gap

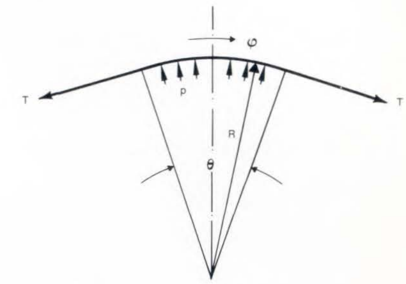


FIGURE 2. Tape with Constant Pressure p

$$\int_{\Theta/2}^{\Theta/2} p\, R \cos \Phi \, d\Phi = 2T \sin \Theta/2$$

$$\therefore p = T/R$$

We thus arrive at the well known result that the pressure between the tape and the head is equal to the tension per unit width divided by the radius of curvature. It should be noted that this pressure is independent of the wrap angle.

Surface Asperities. The pressure between the head and tape just determined is the average pressure between the two surfaces. However, when two solid surfaces are in contact, this ideal pressure can never be reached. Because of surface roughness on both members, only some points on the surfaces will be in contact, and the entire load between the two will be borne by these asperities. The high points of the asperities will thus deform until an actual area in contact will be sufficient to carry the load. This actual area is a function of both the geometry of the surface asperities and the ultimate strength of the material in contact.

In the head-to-tape interface, it is important to keep the surface asperities small. This will distribute the load among as many surface asperities as possible and, even more important, not introduce undue head-to-tape separation.

Fluid Lubricant Between Head and Tape. If the fluid film between the two surfaces is thick enough so that none or only a few of the asperities actually touch each other, the pressure in the fluid is given by the expression derived above. A lubricant which is almost always present between the head and the tape is the ambient air in which the tape recorder is operating. Air is not usually considered a lubricant. However, the main characteristic of any lubricant is viscosity. Air, though much less viscous than liquid lubricants, still has sufficient viscosity to act as a lubricant when the separation between the two surfaces to be lubricated is small.

Such is the case in the head-to-tape interface. The radius of the head, the speed of the tape, the tension of the tape are determined. If we assume that the transport is operating in air, then the air dragged into the interface will give a separation of:

$$h = 4.1 \times 10^{-6} R \, (U/T)^{2/3}$$

where h is the separation in inches, T the tape tension in pounds per inch of width, U the tape velocity in inches per second, and R the head radius in inches. Very few heads are actually cylindrical in shape, but in many heads a sharp corner is provided at the edges of the head. In this case the head-tape separation provided by the air film can be approximated by

$$h = 4.1 \times 10^{-6} \, r^{1/3} R^{2/3} \, (U/T)^{2/3}$$

where r is the radius at the edge of the head, and R is the average radius between the tape and the head. Both geometries are shown in Figure 3.

It is obvious from the two formulas above that a small radius at the edge of the head will result in a small separation between the head and the tape. This is the main reason that a sharp corner is provided in the so-called apex heads. Examination of the formulas also shows that head-to-tape separation increases with speed. This the the well known increase in spacing loss encountered in tape transports at high speeds.

Elastic Deformation of the Tape. The effects examined so far have assumed that, except

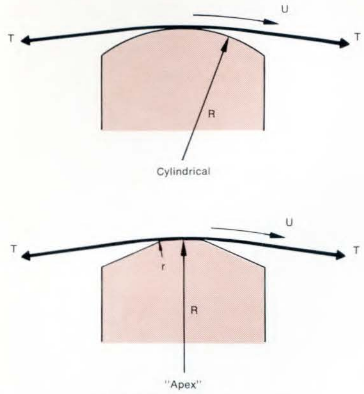


FIGURE 3. Cylindrical and "Apex" Heads

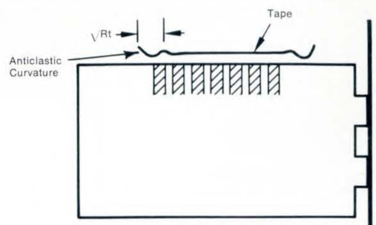


FIGURE 4. Section Across Tape Showing Anticlastic Curvature

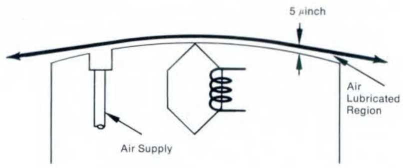


FIGURE 5. Noncontact Head

for small surface asperities, the tape conforms exactly to the shape of the head. However, tape is initially flat and has to be deformed in order to conform to the curvature of the head. If a flat plate—and from an elasticity point of view, tape is a plate under tension in one direction—is bent, deformations normal to the direction of bending occur. This, usually referred to as anticlastic curvature, is shown schematically in Figure 4.

This curvature results in a bending of the tape away from the head at the edge of the tape and of a forcing of the tape into contact with the head on each side of the tape, slightly inward from the edge. This area of maximum contact pressure occurs at a distance approximately equal to $\sqrt{Rt}$ from the edge of the tape (t is the thickness of the tape, R the head radius). For a tape thickness of 1.4 mils and a head radius of 0.3 inch, this distance is about 0.020 inch. Most of the head and tape wear will thus occur in this region, and the usually encountered head wear, near but not right at the edge of the tape, is due to this effect.

The four items examined in detail should give the reader an understanding of some of the mechanical considerations to be taken into account in head-tape interface study. However, the effects can not usually be separated because they interact in various proportions in most heads. Thus, the entire load between the head and the tape may not be carried by the surface asperities since a certain amount of air lubrication is always present. At the same time, due to the anticlastic effects occurring at the edge, a major part of the load may be carried by the edges, so that the pressure under the tape is not exactly the same derived above.

MATERIAL CONSIDERATIONS. It is important to understand the mechanical aspects of the head-to-tape interface so that the forces acting between the two surfaces can be determined and the effect of ambient air be ascertained. However, a major part of the interface is the interaction of the materials coming into contact. This is similar to the problem of two surfaces sliding in contact without lubricant. Unfortunately, this does not lend itself to analysis as do the mechanical aspects of the interface. Again, this is similar to the behavior of two solid surfaces sliding in contact, where after several centuries of studies in this field, no complete understanding of two simple materials in contact has yet been obtained. Study of this interface is therefore reduced to an empirical study of the behavior of materials in contact, and the presently used heads and tapes have been designed on the basis of continuously accumulating empirical data. Such accumulation is, of course, helped by data on surfaces in contact gained in other areas where friction and wear studies have been conducted.

A program presently in progress at Ampex measures the wear rate of head materials under closely controlled environmental conditions, i.e., controlled temperature and humidity, as well as controlled operating conditions such as tape tension and speed. Data thus obtained has shown that the wear rate of most materials is: 1) a linear function of speed provided no air lubrication effect is present; 2) a function of tension and of temperature which depends on the type of tape and head material; and, 3) a very strong function of humidity. High humidity always results in high wear rates. At low humidity the wear rate may be low but, instead of abrading of the surfaces, smearing tends to occur. This results in the so-called gap smear, in which the head becomes inoperative due to shorting of the magnetic gap.

The results described apply to closely controlled laboratory conditions with presently available commercial tape. With different tapes, and if oxide is allowed to accumulate, conditions can be drastically changed. It should be remembered that iron oxide particles are very hard and therefore very abrasive. A commonly used lapping compound, known as "jeweler's rouge," is nothing but iron oxide.

Most tapes presently in use contain a lubricant within the binder. The effectiveness of this lubricant probably arises from the fact that it provides a low shear strength material between the asperities of the two surfaces in contact. Removal of this low strength material will thus occur before the asperities on the head or tape are deformed. After removal of this lubricant, the normal wear process continues until some more lubricant is exposed. This effect reduces wear but does not completely eliminate head wear and depends on some tape wear to supply lubricant.

NON-CONTACT HEADS. Some wear will always occur when two surfaces are in contact. One way of eliminating this contact and wear is to purposely introduce lubricating air between the head and the tape. Heads, where this is done with externally pressurized air, have been fabricated and are shown schematically in Figure 5.

Head-to-tape separation could also be obtained without externally supplied air by use of the effect previously described. Such separation would, however, be a function of the tape speed and tension. With an external supply, the supply pressure can be adjusted to make the separation independent of speed and tension.

With the configuration shown in Figure 5, it has been possible to provide separations of as little as 5 microinches between head and tape with no measurable wear. Such separations are intolerable for extremely short wavelengths. However, with more efficient head design and higher output tapes possibly available in the future, such separations may be tolerable and still result in an acceptable signal-to-noise ratio. In other applications where the long wearing characteristics of such a head are of prime importance, such an approach may be ideally suited.

CONCLUSION. Head-to-tape interface present in all tape recorders is fairly well understood from a mechanical point of view. The materials problems associated with this interface are presently amenable only to empirical study, but with programs now in progress sufficient data may be available to at least predict what the effects of environmental changes will be. For some special applications where head wear is a major consideration, a non-contact head approach may be acceptable.

In our April 1967 issue, we described how Nebraska had set up a far reaching educational television network. Since then, we have learned about three other states that have chosen to bring similar statewide organization to their ETV efforts: New York, Georgia, and Delaware.

Statewide ETV Improves Education

WHY STATEWIDE ETV: Better Education for Everyone

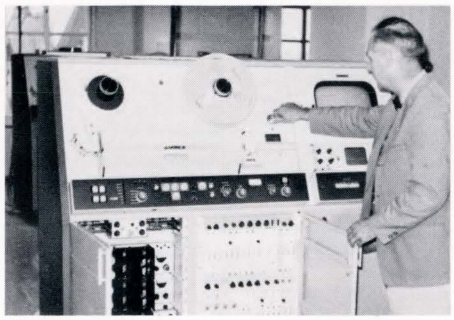
Each state network has followed a slightly different path in adapting television to its needs. But the ultimate goal is the same: to bring the best possible education to all citizens in the state. Programs are broadcast for all levels of school and college education, plus in-service training for teachers, the business community, and public service agencies.

Successful educational television is made up of two basic ingredients: good teaching materials and a flexible means of getting these materials to all schools so they can use them when they need them. Videotape recording has helped fill both these basic needs.

For the highest quality master recording, all the networks have chosen broadcast quality (quadruplex head) Ampex VR-2000, VR-1200, or VR-1000 videotape recorders to produce their lesson materials. For distribution, these recorders play back the material with the highest fidelity for direct broadcast over the air or duplication onto closed circuit videotape recorders (helical scan) for local replay.

Videotape recording simplifies production of lesson material. It allows scenes to be replayed and corrected immediately to be sure the material has the right blend of good teaching and good presentation. Editing electronically further simplifies production allowing segments from many different sources (slides, film, still pictures) to be put together into a unified whole. Updating either picture or sound can be done easily, so that material is always current.

Once captured in recorded form (whether locally produced or selected from outside sources), programming can be broadcast repeatedly during the week to match the differing class schedules in schools throughout the state. An added degree of flexibility is the ease with which individual schools can use their own lower cost videotape recorders to record a program from the state network and replay it to meet their needs. This is especially true in high schools, where schedules are more complex and each class may have several sections. Schools also produce their own locally oriented programming, benefitting from some of the same production capabilities now built into the low cost helical scan recorders that the networks have in the studio machines.



One of four Ampex VR-2000 videotape recorders used for monochrome and color transmissions at the Network Operations Center in Albany, New York.

One of the two Ampex VR-1100 recorders (plus a VR-1200) duplicates tapes at the State Department of Education in New York.

QUALITY AND PROFESSIONALISM: Need for Broadcast Quality Standards

The need for professionalism and high quality is recognized by all state networks. Georgia's state superintendent of education, Jack P. Nix, sums it up this way: "Today's children have television as commonplace at home; they enjoy it; they believe what it presents. In the same manner that they learn to sing commercial jingles, they can be educated if the TV presentation is as good or better than commercial programming."

NEW YORK NETWORK: Potential Audience of 14.3 Million

The Empire State's educational network is the nation's largest system to connect independently owned and operated community television stations. It broadcasts on two channels simultaneously, giving each station a choice of three programs: two from the net, or a third of its own. The network is programmed entirely by the stations, but is administered and operated technically by the State University of New York. It was developed by the University and the NYS Office of General Services both working closely with the State Education Department and the stations. The broadcasts originate mainly from a Network Operations Center in Albany, although any station can originate programs for the other stations.

The network began its operation in October 1967. It links stations in Buffalo, Schenectady, Syracuse, Rochester, and New York. Binghamton and Watertown will be added soon. An eighth station in Nassau County will be developed later. The present five station network has a potential audience of 14.3 million people and serves more than 80% of the state's population.

Programming Policies. A program committee of seven representatives (one for each station, plus two non-voting members from the university and education department) selects all programming for the network. Each station retains the option to broadcast any program or not, or record it for a future broadcast. Besides its weekday daytime schedule, the network broadcasts University of the Air courses on Saturday, and programs from N.E.T. and the Eastern Educational Network each evening including weekends. Some live programming connecting several stations in town meeting style is also planned.

Program Sources. A major source of educational material is the stations themselves and the State Department of Education, through its Bureau of Mass Communications under the direction of Dr. Bernarr Cooper. One of the Bureau's most important jobs is to supply copies of tapes to the network and to the 177 school systems, reaching an estimated 1.6 million public school students. Duplication is

Demonstrating a test run on one of its two Ampex VR-2000's is Georgia Network Control Supervisor George Kirkley for Network Director of Engineering Harvey J. Aderhold. Two other Ampex machines, VR-1000C, at Network Control may be seen in the background.

Authentic settings for an upper grade music series are used by telecourse teacher Barbara Rustin in Georgia's "Our Musical World."

in New York, Georgia and Delaware

Part of the nine VR-7000 and six VR-660's used to duplicate tapes at the Education Department in New York.

Ampex Model 3200 duplicator makes copies of audio tapes for New York schools.

Listening to the audio on a music telecourse is Georgia ETV Network Director, Lee E. Franks (right). Recorder is one of the Ampex VR-7000 recorders used for duplicating programs to one-inch format.

supplied for the Ampex VR-660 and VR-7000 videotape recorders located in the schools. Most of these schools have received financial assistance for their recorders and closed circuit systems from a matching-funds program administered by the Bureau under Raymond W. Graf.

Tape copies (averaging 100 per week) are made from a library of more than 1500 programs, including many complete courses. The Bureau also makes available duplicates of some 8500 titles from its audio tape library on request and for the minimum cost of the audio tape raw stock. Duplicating of video tapes is done by replaying them on a quadruplex recorder, an Ampex VR-1200, or two Ampex VR-1100's for recording on nine helical scan VR-7000's and six VR-660's. Audio duplication uses an Ampex Model 3200 duplicator with two slave units. New York State's experience seems to indicate clearly that the availability of software in the form of usable content materials makes possible the systems approach to more learning opportunity.

Network Operation Center. New York's Operation Center in Albany uses the most modern transmission and studio equipment available. Videotape recording and playback is done on four high-band VR-2000 recorders, equipped for monochrome and color. In addition, four VR-660 and four VR-7000 helical scan recorders duplicate material for use by university campuses. For audio material, the network center has an Ampex PD-10 audio tape duplicator with three slave units. The two-channel color compatible microwave system connecting the stations allows origination from any station or from Albany.

On-Campus Systems. At the university level, television will be playing an even larger role in the future. Ten of the four-year colleges, four university centers, and one two-year college are now planning extensive closed circuit television facilities. Presently, five of the colleges each have two Ampex VR-1200 recorders for local production, recording, and playback. A number of the colleges are also equipped with VR-660 and VR-7000 helical scan recorders.

GEORGIA NETWORK: Ten Interconnected Stations

In a short two years of operation, Georgia's ETV network has become the largest interconnected system in the country, with ten stations located througrout the state. In addition to the stations owned and operated by the Georgia Department of Education, the network includes a station from the University of Georgia (WGTV) and the Atlanta City Schools (WETV). As in Nebraska, this means educational television in Georgia has the state education department, a university, and a public school system all providing professional quality daily lesson material to every level of education. Georgia's system reaches some 920,000 students, 98% of the state's total.

Videotape recording has been of great importance in Georgia. With the exception of programming between 7 and 11 p.m. (which may be tape, film or live), everything on the network originates on video tape from network control in Atlanta. In total there are 17 videotape recorders of many models led by two Ampex VR-2000's in Atlanta. For remote work, the network has a mobile van with cameras and an Ampex VR-1000 recorder.

Source of Programming. Georgia's Department of Education is responsible for about 80% of the material broadcast on the net. Teleproduction is done in the network studios in Atlanta, using the high band VR-2000 videotape recorders. Lee Franks, Executive Director of Television Services states: "We believe that all in-school and teacher courses should be flawless. For this reason we have chosen to produce all of our materials on video tape, where we can see the results immediately and make any portion over if needed."

Quality of the network programming is reflected by Georgia's rapid climb to one of the five leading producers of telecourse material in the United States. Four of its series are now under contract for national distribu-

Technician adjusts monitoring oscilloscope on one of the six VR-1000C recorders used by the Delaware ETV Network.

Teleproduction of a program in the series Youth Forum, produced by the Delaware ETV Network.

tion by the National Center for School and College Television in Bloomington, Indiana.

Describing Georgia's teleproduction methods, Mr. Franks states: "It often takes us a year or more to prepare an extensive series for use throughout the country. I believe this is justified since each telecourse is broadcast several times a week and is likely to be repeated over the years. Videotape recording allows us to achieve the highest quality. We regularly develop program segments which are later assembled with electronic editing."

Atlanta Control Center. Network headquarters is at the Control Center in Atlanta which will soon move into its own $2-million building. Included in the new building are two studios with full teleproduction capability in color. All network transmission equipment is adapted to pass color.

To service the helical scan recorders in several of the school districts (VR-7000), the Control Center duplicates material in this format. In its new building, it will set up a regular library and duplication facility in anticipation of increased demand. To assist the many Georgia public school systems interested in establishing their own systems, the network provides free engineering consultation.

Teacher Aids and Training. To get the most from its programming, Georgia broadcasts daily after school video tape communiques for classroom teachers, These show how to prepare the students, give an overview of the objectives and content, and suggest how to correlate the telecourses with classroom followup activities. Printed course guides are also supplied for all courses. Some are 320 pages in length. Georgia is very active in in-service training for teachers as well as several professional groups. Teacher to teacher content courses include foreign languages, English, music, reading and science. These range from 4 to 25 lessons, usually 30 minutes each. Other daytime programming includes current events, management procedures, and medical self help, and a weekly report directly to public school administrators by the State Superintendent of Education.

DELAWARE: Three-Channel System Reaches All Classrooms

Delaware began its statewide ETV broadcasting in 1965 on a three-channel microwave and cable network that reaches every public school classroom in the state. More than 110 thousand students in 5600 classrooms receive television in all 207 Delaware schools.

Its primary goal is to bring the highest quality of education to all Delaware students. Delaware differs from New York, Georgia, and Nebraska in that it is basically an instructional televison network, linked together by microwave and cable. Operating from a new resources center at Delaware State College in Dover, the network transmitted some 10,000 program units during its 32-week school term in 1966/67. The schedule in 1967/68 includes 62 separate series, including five in-service series for teachers. The network works closely with the State Deparment of Education. It was financed entirely from state funds.

The network operates three channels simultaneously, sending out an average of 55 instructional units each day. Expansion to six channels and transmission in color are planned for the future. As in the other networks, the local schools can elect to receive the materials or not depending on their own scheduling and curriculum requirements. Some programs are repeated as many as 15 times each week to insure that all schools have been covered. About 70% of the program material is for grade schools, about 20% for high schools, and 10% for the colleges. However, the number of broadcast hours for high schools is much greater (about 65 to 80% of the total) because high school scheduling is far more complex and requires more repeats.

Nearly all transmissions in Delaware are done in recorded form. William C. Lewis, Technical Service Director states: "We could not begin to match the complexities of grade and high school scheduling without the ability to repeat materials on demand for our 48 school districts."

In addition to graded instructional material, the network has an extensive program of in-service training programs for teachers.

Program Sources. Programming philosophy in Delaware dictates that the best material will be used from either outside sources or its own studio productions. Principle outside sources are the National Center for School and College Television in Bloomington, Indiana, and the Great Plains Library in Nebraska. Delaware uses tapes from these sources in a quadruplex format playing them back on three of their six VR-1000C recorders.

For production of its own materials, Delaware has two studios, a sizeable number of backgrounds and props, six VR-1000C recorders, and four image orthicon cameras. Production plans for 1967/68 include series in English composition, plane geometry, literature, and map reading, plus consumer banking and a special on income tax filing.

Local Use of Videotape Recording. Districts in the state are increasingly using helical scan recorders (Ampex VR-7000) to replay local programs on a delayed basis. An unusual use for recorders has been found at the Alexis I. duPont school district in Wilmington. Here two VR-7500's record selected high school lectures and enrichment materials given during the day. Students then come to the educational resources center to replay the lectures at a time when their class schedule permits.

A parochial school in Wilmington makes extensive use of videotape recording (VR-660B and VR-1500). It has tied team teaching and television together in an award winning program of advanced instruction. The golf coach at this school has used recording extensively in training his players and leading them to a recent championship. He attributes his success to the instant replay of his recorder which enables him to show his players their strokes and putting during practice sessions.

SIGNAL TIME COINCIDENCE IN AN INSTRUMENTATION TAPE RECORDER

By Ron Young, Ampex Corporation

A multichannel instrumentation tape recorder exhibits some predictable time differences between its various data channels. These may or may not be a problem in a given application depending on how accurately you need to correlate time between events recorded on different channels. Interchannel timing errors can be attributed to three main factors: 1) Static delays (skew) caused by head manufacturing tolerances and any guiding misalignment of the tape path relative to the heads; 2) Dynamic delays (also commonly called skew) caused by the tape transport and the flexibility of the tape; 3) Static and dynamic delays caused by the electronics.

STATIC TIME ERRORS

The major cause of static timing errors in a multichannel recorder is the manufacturing tolerances of the heads. To illustrate, take as an example the specifications of the Inter Range Instrumentation Group (IRIG) for head design which furnish the standards adhered to by most tape recorder manufacturers (IRIG 106-66, Section 6).

Gap Scatter	100 microinches
Stack Spacing	1.500 ±0.001 inch
Head Tilt	±1 minute of arc

Gap Scatter. A multiple track instrumentation head stack has a number of individual heads (typically 7 for a 1-inch staggered head stack), incorporated in the stack. It is mechanically impossible to exactly align these gaps, so the term gap scatter refers to the actual tolerance of alignment of each of these tracks in relation to a line through the mean position of all gaps in the stack. The positional tolerance of these head gaps within a given stack is a band 100 microinches in width. The worst case condition of timing between two tracks would be when the gaps in question on the record head stack were at one limit of the tolerance while those at the reproduce stack were at the opposite end of the tolerance band. This gives a worst case error of 200 microinches between two tracks allowing 100 microinches in the record and 100 microinches in the opposite direction on the reproduce head. As a final note it should be stated that this error is somewhat random in occurence within a stack, and heads with the widest spacing or error may occur adjacent to each other or at the opposite ends of the stack.

Head Stack Spacing. In order to achieve the normal recording density of 14 tracks for 1-inch tape (or 7 tracks for ½-inch tape), it is necessary to place half the heads, the odd numbered tracks, in one stack and the even numbered tracks in a second stack. This allows sufficient shielding to be provided between tracks in the head stack to minimize undesirable signal coupling and crosstalk. The normal spacing difference between the odd and even head stacks is 1.500 inches with a tolerance of ±0.001 inch. This means that under worst case conditions (record stacks spaced at one limit of this tolerance and reproduce stacks at the other limit), adjacent odd and even tape tracks could be displaced from each other by a possible 0.002 inch (2000 microinches).

Head Tilt. This measurement and specification refers to the difference between the mean gap azimuth of a given head stack and a line perpendicular to the edge of the tape. In practice this may be caused either by lack of perpendicularity between the head stack and base plate, or the misalignment of the tape path of the transport relative to the head. These effects are difficult to separate and are usually tested as one measuurement. No attempt will be made here to separate them. The value permissible under IRIG specifications is ±1 minute of arc or a distance approximately 280 microinches across a 1-inch tape width. Again this is an additive specification. Thus in a worst case condition this figure could be doubled between record and reproduce head stacks.

Time Dimensional Changes. Additional effects are caused by the inherent characteristics of the magnetic tape which are not a function of head manufacturing tolerances. The backing of tape is an elastic material. As such, the distance between any two points on the tape depends on the tape tension to some extent. This shows up primarily as a change in the 1.5-inch gap-to-gap dimension. Large temperature changes between the time of recording and reproducing and uncontrolled long term tape storage conditions can have the same effect. This tape tension effect is not as significant as other head spacing tolerances as its value is approximately 240 microinches change across the 1.5-inch head spacing with a 1-ounce tension change between the record and reproduce process on ½-inch tape (1 mil backing thickness). A more significant change is observed if the temperature is varied between the record and reproduce process. For a 50°F difference, the 1.5-inch spacing will change 750 microinches.

An even more interesting change is observed if the relative humidity of the air around the tape is varied over its full range between record and reproduce. In this case, a relative humidity change from zero to 100% would vary the 1.5-inch head spacing by 1650 microinches, more than all other effects put together. These phenomena, although seldom considered, result from the physical properties of polyester base materials of magnetic tape.

DYNAMIC CHANGES

Dynamic skew and dynamic registry changes between channels are caused by runout of the tape transport, which is always present to some degree, as well as tape guiding eccentricities, tape slitting errors, and tape damage. While static skew can be allowed for and ignored to some extent in the data, dynamic skew is a time variable phenomenon and thus is much more difficult to eliminate. The only known method for minimization of this is control of the record and reproduce transport guiding. Typical values of dynamic skew on a state of the art basis are 250 microinches from record to reproduce across the full width of a 1-inch tape. Typical tape transports of the instrumentation variety have a normal value of 500 microinches. (The zero loop design of the Ampex FR-1800 and FR-1900 capstan reduces the dynamic skew to 225 microinches.)

ELECTRONIC DELAYS

The delay variation between channels caused by the signal record and reproduce electronics are normally inconsequential compared to the mechanical delays shown above. For instance, the time delay from a FM system would be primarily a function of the reproduce filter. The typical delay of such a filter for a 10-kHz bandpass (60 ips) would be 62 microseconds with a delay variation of only 1 to 2 microseconds between filters. This would correspond to only 120 microinches at 60 ips, well below the values for mechanical errors.

MEASUREMENT CONVERSION

In the previous discussion, dimensional changes caused by heads and tape are expressed in two different units: linear measurement in microinches and time measurement in microseconds. The conversion between units can be easily made if you remember that a tape recorder running at 120 inches per second moves tape 120 microinches per microsecond. This would mean a linear error of 240 microinches would occupy 2 microseconds of time at 120 ips, 4 microseconds at 60 ips, etc.

WORST CASE CONDITIONS

Figure 1 is a compilation of the various skew contributions in an absolute worst case condition. It is divided into 1) errors caused by the tape dimensional change, 2) errors caused by transport and head static errors, and 3) errors caused by transport dynamics. It should be noted that the contribution of the tape back material (polyester) due to extreme environmental changes is approximately as great as all other manufacturing tolerances on the head assembly. The majority of these contributions are of largest effect on the stack-to-stack spacing of 1.5 inches, and this is the real cause of misregistry problems.

In-Line Heads. The minimization of these errors by the use of an in-line head assembly can be illustrated by Figure 2. This is the same data as Figure 1 with the exception that the errors caused by the 1.5-inch spacing, the tolerances on it and changes to it, are eliminated by the expedient of manufacturing a head with all tracks in a single stack. However, manufacturing a single in-line head stack with the same number of tracks as two staggered head stacks creates two main problems. First, it requires that the amount of intertrack shielding be reduced. This increases the crosstalk between data channels. Second, the track width must be reduced which cuts the signal-to-noise ratio, since it is impossible to make a full width track because there is only a 20-mil space between them. Little or no room remains for shielding, mounting, or wirewinding. FM recording is desirable when using in-line heads because its inherent signal limiting characteristics help compensate for the increased crosstalk and reduced signal-to-noise ratio. Bandwidth will be reduced with FM as compared to Direct, so the trade off with dynamic range must be weighed against this. An alternative to special in-line heads is to put all data needing precise time correlation in the same head stack.

Significance to User. What does this mean to the user of instrumentation recorders? In real terms if he is recording vibration data on different tracks of a recorder, the correlation available between heads on different head stacks may limit the usable correlation frequency to below 1 kHz at 60 ips. Two ways to get around this are to use in-line heads (with an FM recording technique, depending on bandwidth and dynamic range requirements) or a method of multiplexing such as constant bandwidth FM which places many data channels on the same tape track. On 1.5-MHz channels, for instance, constant bandwidth recording may allow at least 7 tracks of 20-kHz data with approximately 40-dB signal-to-noise ratio to be put on the same data track, or up to 49 channels in the same 1-inch, 7-track head stack.

While the values presented in the table are worst case values, they do illustrate the extent of the problem. Even if it were possible to significantly reduce all the mechanical contributions of the transport to the time misregistry of the data, the environmental problems related to the tape could still cause large amounts of trouble with a staggered head arrangement. It would appear that the only solution for the user who must have the ultimate in registry between data channels lies in the use of in-line head assemblies with their inherent drawbacks, in-line recording on the same head stack of critical time related data, or a method of multiplexing which preserves the data registry of all channels within the same track. Other methods of electronic registry are possible, but the cost is extremely high.

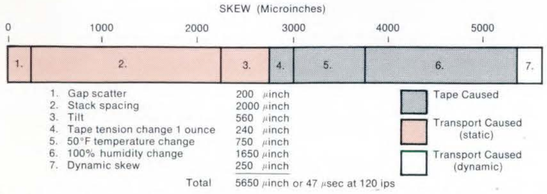


FIGURE 1. Worst case skew for a staggered head assembly. Most errors are caused by the tolerances related to the 1.5-inch stack-to-stack spacing.

FIGURE 2. Worst case skew for an in-line head assembly. Although it eliminates the major source of errors (stack-to-stack tolerances and dynamics) an in-line head has two drawbacks: 1) crosstalk increases beyond an acceptable level, 2) narrow (non-standard) track spacing is required, which reduces the signal-to-noise ratio, and makes the tape non-interchangeable. Recording all time-related data in the same staggered head stack is a commonly used alternative.

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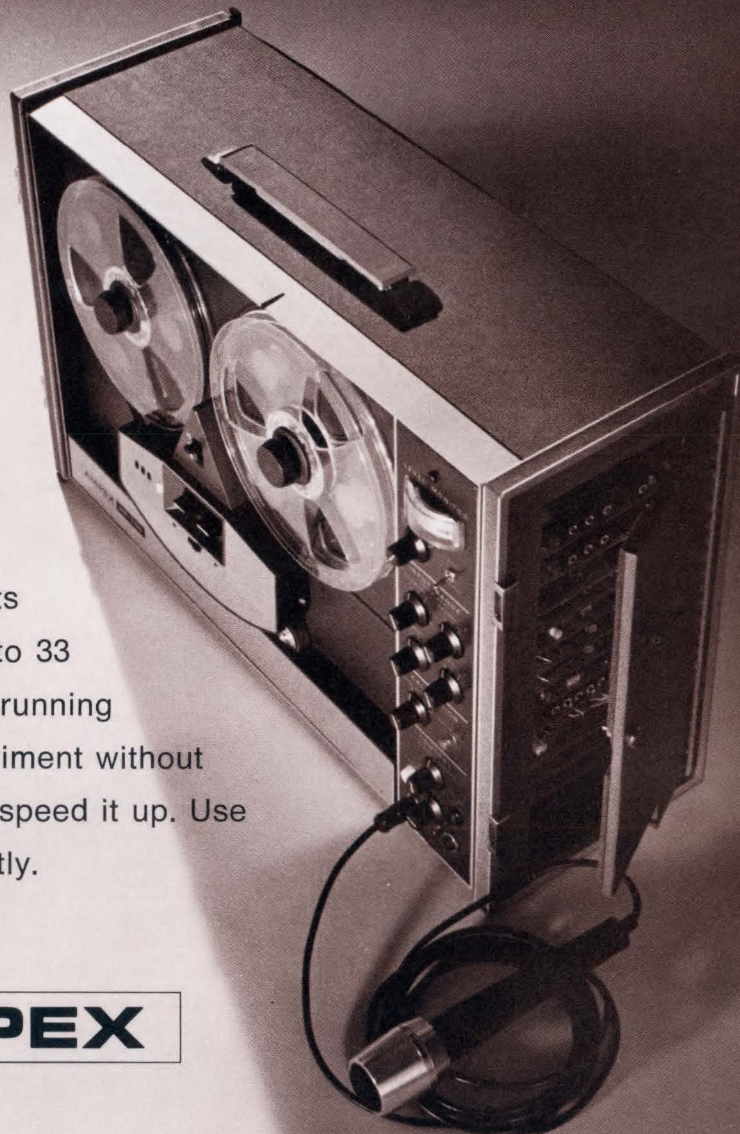

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