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A NEW MAGNETIC RECORDING SYSTEM

by

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THE AVERAGE MODERN American is becoming spoiled. He has become accustomed to having things done with a minimum of effort. Magnetic tape is no exception. Under our present day standards, the inconvenience associated with the operation of tape machines is out-dated. One cannot expect the average person to thread tape over heads and pulleys, then fasten it onto a reel.

Magnetic tape fulfills the quality requirements of the most discriminating person. The frequency response and signal-to-noise are excellent. The ease with which good home recordings can be made is astounding, but the inconvenience and cost of the medium are detrimental. More than five years ago, we determined to correct this condition and modernize tape recording equipment.

THREE PROGRAMS INITIATED

Three programs were initiated to overcome these defects. One program was aimed primarily toward the improvement of frequency response so that the speed of the medium could be reduced. A second program was an investigation to find how narrow the tracks could be made without unduly sacrificing signal-to-noise. The third program was a thorough investigation of all possible methods of handling the tape without the present inconvenience of threading, and rewinding. This program included both the design of a new tape cartridge and the development of machines to operate it.

SLOWER TAPE SPEED

The first program revealed the fact that if a good head were constructed and if slightly less bias were used during recording, the present $7\frac{1}{2}''$ per second tape speed could be reduced by a factor of two and still maintain good frequency response. In order to do this, special heads were developed. These heads are constructed with a gap in the magnetic circuit of only 90 micro-inches.

Fig. 1 shows an uncompensated tape curve made with such a head. This curve was made by recording with constant current and reproducing with an uncompensated amplifier having high input impedance.

Fig. 2 shows a curve of the proposed E.I.A. (Electronics Industries Association) standard compensation for the reproducing amplifier.

Fig. 3 is a curve of the overall system operating at $3\frac{3}{4}''$ per second tape speed.

NARROW TRACKS

An investigation of narrower tracks was made in order to verify the available theoretical information with experimental data. The output level of recorded signals varies directly with the track width, but the output level of random noise varies with the square root of the track width. Therefore, the signal-to-noise ratio is decreased somewhat, but not directly with the track width. The azimuth angle error produces a decrease in the output of short wavelength signals. This reduction in output for any given angle error is increased very rapidly when the wavelength is shortened, but is decreased very rapidly when the track width is decreased.

loss in *db*

$$= 20 \log_{10} \left[\frac{\sin\left(\dfrac{\pi\ w \tan\ \infty}{\lambda}\right)}{\left(\dfrac{\pi\ w \tan\ \infty}{\lambda}\right)} \right]$$

w = width of sound track
∞ = angle of tilt
λ = wavelength of recorded signal

This formula reveals that if the track width were reduced in the same proportion as the physical wavelength for any given frequency, the losses from azimuth angle errors would remain the same.

The calculation of crosstalk between discretely separated tracks on the tape becomes rather involved. However, it is a function of recorded wavelength, track separation and track width.

TO THOSE WHO CONTRIBUTED

By
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The articles in this issue of the RCA ENGINEER, with respect to magnetic tape, touch upon a subject involving many facets of RCA Engineering. The authors and the editor acknowledge the contributions made by the various people in the RCA organization.

Currently, we are marketing a Tape Cartridge Instrument known as the SCP2 with others to follow. How did this come about, who solved the many problems, how long did it take, how much did it cost, and will it be successful are a few of the questions one could ask?

First of all, it came about as a result of a suggested program covered by a letter — "Establishment of Tape Cartridge Development Program" — dated April 5, 1954, which formalized the objective approach. Prior to this date, much technical background had been developed. In the creative minds of those involved, success seemed possible. Nor, can we neglect commercial pressure as a real force — since experience in threading tape "reel-to-reel" pointed the need for a better way.

The many problems were solved by many people. Those in Consumer Products, DEP, IEP, and the Laboratories who worked in the various activities involving magnetic tape contributed the narrow track and made possible the high resolution of information by means of a very small magnetic gap in the magnetic head. Those who worked in the amplifier field contributed to the accomplishment of high signal-to-noise ratio. There were many contributions from Staff personnel. Those in the New Products group arranged and actively pushed specific project programs.

Those who worked in the mechanical field resolved the Cartridge problem and the mechanism to operate the Cartridge. Those in Product Design concluded the final Cartridge, mechanism, heads, amplifier, the complete instrument, and Manufacturing successfully produced the product.

As a "consultant," Dr. Alfred N. Goldsmith, to mention one name, contributed to the resolution of the cartridge problem. Top Management and Operating Management were sympathetic to the many problems and offered encouragement when needed. This is truly an example of an all-RCA effort to make a major contribution, resulting in increased enjoyment of "tape" in the home.

It took a long time — five years, and it cost a great amount of money to say nothing of the wear and tear on dispositions of those involved.

Finally, will it be successful? This can only be answered in the market place. This accomplishment has a sound technical and commercial foundation. It has one other force — the dynamic power of a great corporation — The Radio Corporation of America — people like you.

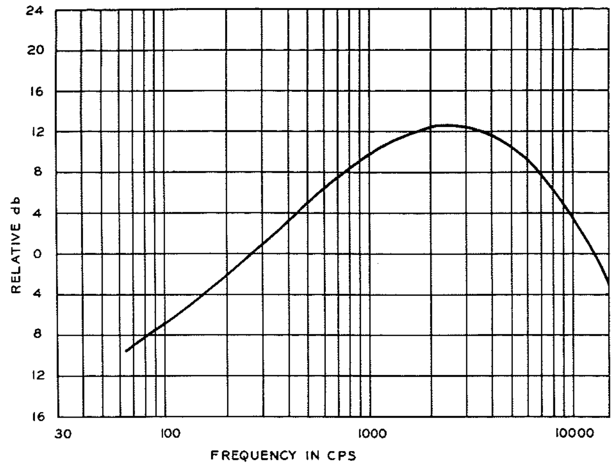


Fig. 1—Uncompensated tape curve made with a head having a 90 micro-inch gap in the magnetic circuit.

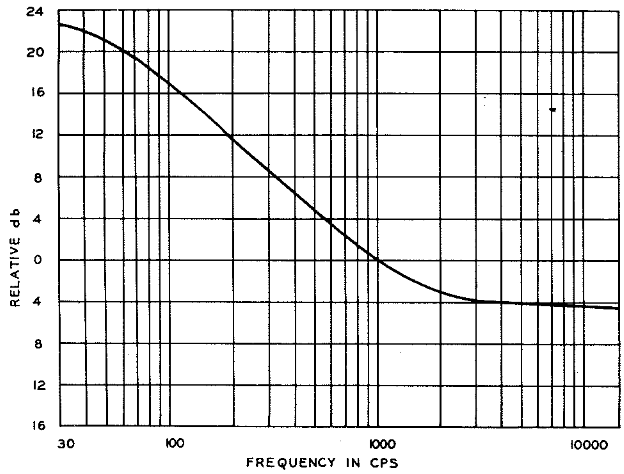


Fig. 2—Curve of the E.I.A. proposed standard compensation for reproducing amplifier.

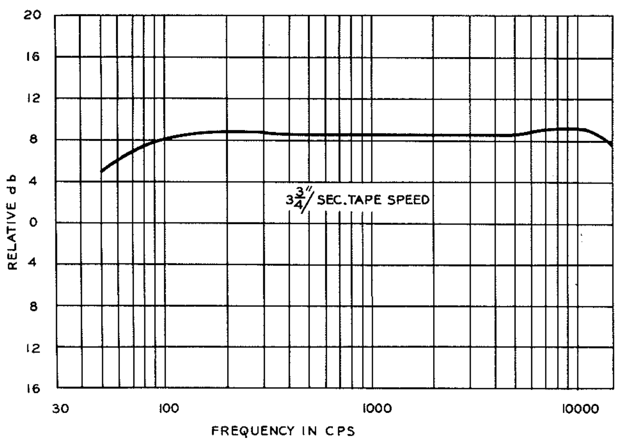


Fig. 3—Curve of overall frequency response for the system operating at a speed of 3¾ inches per second.

The tape speed was decreased to 3¾″/sec. which decreased the physical wavelength of any given frequency by a factor of 2. Therefore, the track width could be reduced by a factor of 2 without increasing the loss in output due to azimuth angle error or substantially increasing crosstalk between the tracks.

By selecting track widths of .043″ and separation between tracks of .025″, four tracks could be recorded on standard ¼″ tape. Fig. 4 shows the track placement. The tracks are recorded with the tape traveling in the direction shown by the arrows.

MAGAZINE LOADING CARTRIDGE

In order to find the most convenient method of handling magnetic tape, every conceivable means was investigated. Work which we had done several years previously was reviewed. This work included a self-threading tape machine, a coaxial spring loaded wire recorder cartridge, and coplanar film magazines for original sound-on-film recording. All available continuous-loop tape cartridges were tested. Additional work was also done to improve the performance of continuous-loop cartridges.

In all this work, the viewpoint of the consumer was kept in mind. Commercial advantages as well as technical details were considered in making decisions.

Self-threading tape machines are usually designed with a leader left in the machine permanently. Some sort of hook or latch is provided to snare the free end of the tape and pull it into operating position. Such a machine might be built which is practical, but most attempts have either been complicated or unreliable.

Spring loaded coaxial cartridges are usually made by using a clock spring between the two reels to maintain the tape tautly as it is unwound from a reel of one diameter onto a reel of another diameter. Such a cartridge is very difficult to repair and is inherently expensive.

Coplanar film magazines have been very successful over a period of years. Two hubs are used without flanges. In this manner, as one reel increases in diameter, the other decreases. In this way, the distance between hubs can be reduced substantially.

The continuous loop cartridge is operated by pulling the tape from the center of a spool and winding it on the outside of the same spool. This causes slippage between each two adjacent layers of tape. Special lubricants are sometimes used to reduce the friction caused by slippage. However, because of the inherent non-reversibility, the continuous-loop cartridge does not lend itself to home recording. It is also very difficult, if not impossible, to wind the tape initially so the free loop will not change length. The proper tension is usually approximated, then the length of the free loop is adjusted after a "run-in" period of time, all of which is quite costly for pre-recorded tape.

By the process of elimination, the coplanar tape cartridge was selected as the most logical, and was developed into a commercial product.

THE COPLANAR TAPE CARTRIDGE

Fig. 5 is a photo of a cartridge and its shipping box. The cartridge is approximately 7¼″ x 5″ x ½″. It is essentially rectangular in shape and will store in any average book shelf. Fig. 6 is a photo of the cartridge with the cover removed. Fig. 7 is a sketch of the various parts of the cartridge.

The polystyrene case is made in two parts. The tape is wound on two polystyrene hubs. A metal slide is moved by a spring to provide a brake on the hubs during shipping and storage. When the cartridge is placed on the machine, the brake is released. Two sheets of polyester film (Mylar) separate the tape from the walls of the case. These Mylar sheets perform several functions: the coefficient of friction between acetate tape and Mylar is very low; the melting point of Mylar is comparatively high, which reduces scoring; the sheets close the windows used for indicators and separate the brake and tape; and a film of air is trapped between the sheets and walls of the cartridge case, which reduces mechanical noises.

Pre-recorded tapes will be furnished in cartridges with holes in the back edge. An interlock switch may be provided on the machine which will interlock the recording amplifier if these holes are present. Blank tapes are furnished with knock-outs over these holes which may be removed for preserving tapes after recording, if desired.

Fig. 8 shows how the tape is fastened to the hub by a simple loop, spliced in the end of the tape, and hooked over a pin in the hub. The end of the tape is fastened to the hub to provide automatic stopping when the tension is increased. The tape passes over a trip pin on the mechanism as shown in Fig. 9 Before the end of the tape is reached, the tape and trip are in the position as shown by the dotted lines. A semicircular wall encloses the trip pin when in the tripped position. This prevents the tape from falling on the wrong side of the trip when the cartridge is placed on the machine.

SEMI-AUTOMATIC MECHANISM

Two different transport mechanisms were designed to operate the cart-

TRACK PLACEMENT

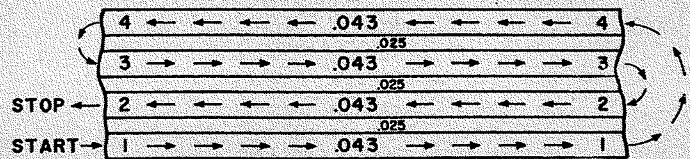
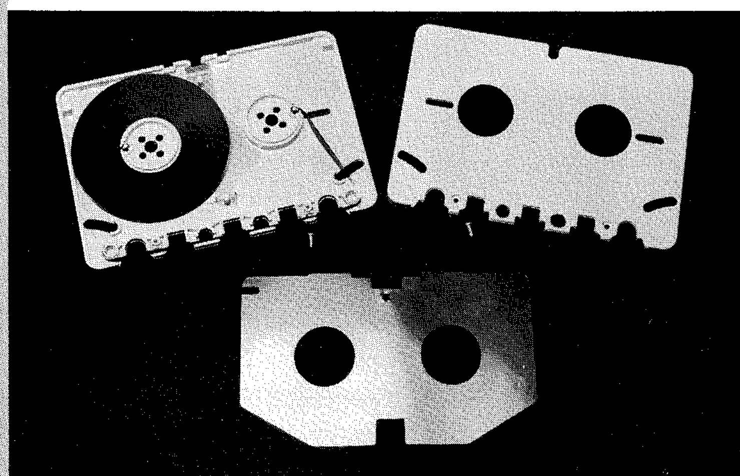


Fig. 4—Sketch of the arrangement for placing four tracks on standard ¼-inch tape.

Fig. 5—Photo of the cartridge in its shipping box.

Fig. 6—Photo of tape cartridge with cover removed.



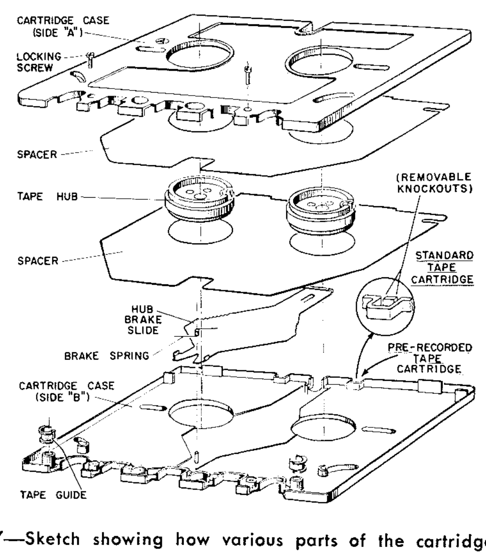


Fig. 7—Sketch showing how various parts of the cartridge fit together.

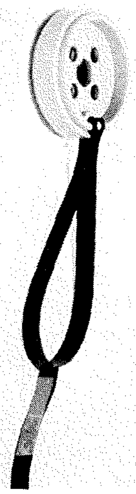


Fig. 8—Photo showing how tape is fastened to the hub.

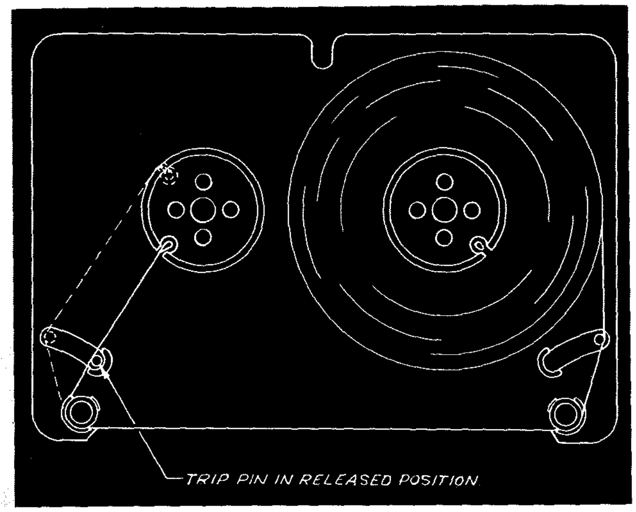


Fig. 9—Sketch showing how tape passes over a trip pin located on the mechanical assembly.

ridge. Both mechanisms may be used in either monaural or stereo instruments and both machines may be used as recorders as well as reproducers. One machine has been designed for the budget-minded customer and the other is a deluxe item.

Fig. 10 is a photo of the semi-automatic machine. The edge of the cartridge is placed in the guide bar at the back, and the front of the cartridge is merely pressed downward. The push-button on the left is depressed and the machine will operate up to one-half hour then automatically shut off. The cartridge is then turned over and restarted to play a different track on the tape. Four manual push-buttons are provided, having the following functions: Play/Record, Rewind, Fast Forward, and Stop.

When the tape reaches the end in either normal or fast speed, the increased tape tension is used to stop the machine. On first thought, it might seem impossible to stop a reel of tape during fast rewind without breaking. However, simple calculations as shown on Fig. 11 indicated that the stored energy in 600 feet of tape rotating at 500 RPM would produce a force at a tangent to the outer diameter of only slightly over 12 ounces. This nominal force, nonetheless, immediately challenges the ingenuity of the machine designer. When the problem is carefully considered, certain requirements become evident: the trip mechanism must operate in a minimum of time; all excessive inertia such as that developed by the motor and other mechanism parts, must be disconnected from the tape; and the take-up torque must be limited. A detent type of trip mechanism was chosen which would fulfill the first requirement. Clutches were chosen to fulfill the other two requirements.

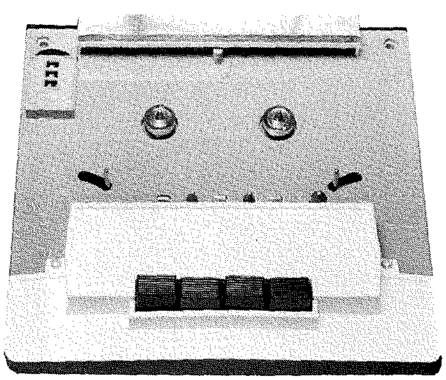


Fig. 10—View of the semi-automatic tape machine.

ANGULAR VELOCITY, $V = 500\ rpm = 8\tfrac{1}{3}\ rps$

RADIUS OF GYRATION, r_g

$$= \frac{\sqrt{r_1^2 - r_2^2}}{2} = \frac{\sqrt{2^2 - .75^2}}{2} = 1.31\ in.$$

LINEAR VELOCITY, $v = V 2\pi r_g = 8\tfrac{1}{3}\, 2\pi\, 1.31 = 68.5\ in./sec.$

$$E = \frac{Wr^2}{2g} = \frac{4(68.5)^2}{2(32.17)12} = 24.35\ in.\ oz.$$

$$F\ @\ r_1 = \frac{24.35}{2} = 12.175\ oz.$$

Fig. 11—Calculations showing that it is possible to stop a reel of tape during fast "rewind" without breaking.

FULLY-AUTOMATIC MECHANISM

The second mechanism, shown in Fig. 12, was designed to be fully automatic. After starting, it records or reproduces all four tracks on the tape, then shuts off at the point of beginning. To accomplish this, two capstans are rotated in opposite directions. The tape is propelled in one direction or the other by pinching the tape with a rubber pressure roller against one of the capstans. The control system is a combination electromechanical system. A programming motor is used to select the direction of tape travel, to connect the proper heads to the amplifiers and to stop the machine automatically.

The consumer is now offered a new system with all the former desirable features, plus new conveniences and economies.

DALLAS R. ANDREWS majored in Mathematics and Physics at Ball State Teachers College at Muncie, Ind. He later studied Radio Engineering at Purdue University Extension at Indianapolis. He has been engaged in development engineering at RCA in various phases of magnetic and disc recording for the past fifteen years. He is presently in the Record Changer Engineering Group of the Radio & "Victrola" section of the Home Instruments Department. He is a member of Audio Engineering Society, Institute of Radio Engineers, The Franklin Institute, and American Society of Inventors.

Fig. 12—View of the fully automatic tape mechanism.

TAPE RECORD DEVELOPMENT

By

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MAGNETIC TAPE AS a medium for recorded music in the home has been available for the past decade. Although there continues to be growing interest in this recording medium, it has not become sufficiently popular to "take over" the recorded music field because of two distinct disadvantages as compared to disc records. These are handling and cost. With this realization, RCA Victor set up a program to develop a new product which would provide for tape to be played as easily as a disc record and also be available to the public at somewhat comparable prices.

High-speed duplication and larger production tend to reduce the manufacturing cost of tape records. However, material costs of the tape and reels still far exceed the material costs of a phonograph record. It is apparent, then, that the cost of recorded tape could be decreased by reducing the amount of tape required to record a given amount of music. Two basic methods to achieve this are reducing the tape speed and reducing the width of the recorded track.

TAPE SPEED

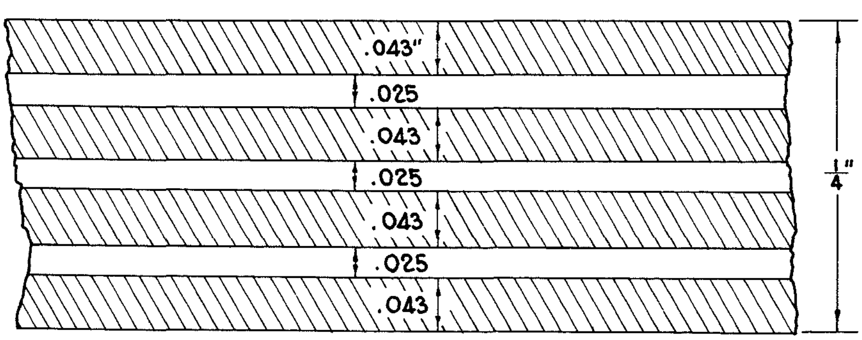
At one time, professional recordings were made at a tape speed of 30 ips and home equipment used a speed of 7½ ips. Since then, commercial tape and professional recorders have been improved so that satisfactory results are obtained at 15 and even 7½ ips. Today home recorders, which originally were limited to frequencies up to about 8 kc, give satisfactory frequency response to 15 kc at 7½ ips and, in general, this performance is required for reproduction of recorded music.

The tape speed of 3¾ ips which was chosen for the new system would result in a very poor frequency response using recording techniques existing at the time. This is due to shorter recorded wavelengths and is indicated by present day recorders, operating at 3¾ ips, having a limited recording and reproducing audio frequency range of from approximately 50 cps to 8,000 cps. However, one of the specifications and goals was to have full frequency range from 50 cps to 15,000 cps and with a performance which equals the quality of the 7½ ips recorded music tapes. To satisfy these requirements, heads with shorter gap widths than the conventional were necessary. This problem was undertaken as a design objective by Advanced Development of Defense Electronic Products. A playback head with 90 micro inch gap width was designed in order to permit faithful scanning of the high-frequency (shorter) wavelengths thereby maintaining full frequency range. A gap width of 120 microinches was chosen for the record head.

TRACK WIDTH

Two 0.090-inch wide tracks on a quarter-inch tape has been standard for home-type tape recorders in the past. Numerous measurements and investigations were necessary to determine how much the sound tracks could be reduced in width without causing deterioration of the quality of the system. With a reduction of track width, problems of guidance, tape-to-head contact, signal level and signal-to-noise ratio are inherently developed.

Fig. 1—Track arrangement for the 3¾ ips four track system.



Output voltage from a magnetic head is directly proportional to the number of lines of flux cutting the coil in the head. This means that if the track width is reduced by one-half, the output voltage from the head will be reduced by one-half. This in itself determines the additional amplifier gain required to obtain desired output signal level and with modern circuits it is not difficult to obtain gain to make up for the loss due to the reduced track width.

More important than the voltage output of the playback head is the resultant signal-to-noise ratio as a function of track width. In the analysis of background noise of tape, several sources determine the final signal-to-noise ratio. These are: "Tape Noise"—noise produced by irregularities in the random dispersion of the magnetic particles in the oxide coating. This noise tends to increase with any non-symmetry in the recording bias waveform; "Recorded Noise"—that noise recorded on the tape which originates from an original master and the electronics of the duplicating equipment; and "Amplifier Noise"—that inherent noise of the reproducing system including hum, thermal, and mechanical noises.

"Tape Noise" is found to be directly proportional to the square root of the track width. Since the waveform of this noise is random across the width of the track, the total contribution of all segments of the track will be

$$E_n = \sqrt{\sum_{i=1}^{n} e_{ni}^2} = \sqrt{n}\, e_n$$

where

$$e_{n1} = e_{n2} = \ldots\ldots e_{n_n} = e_n$$

and where E_n is the total noise voltage in the reproducer, e_{ni} is the RMS contribution from the i th segment of the track. It can be seen that tape noise level for varying track widths, as compared to the output from a standard track, would be

$$N_x = \sqrt{\frac{x}{s}}\, N_s$$

where x is the new width.

Therefore, the resulting ratio of signal-to-tape noise with bias in the record head can be expressed in db as

$$S/N = 20 \log_{10} \frac{E_s}{E_n} = 20 \log_{10} \sqrt{n}\ \frac{e_s}{e_n}$$

The relative change in this ratio with track width can now be derived. Let r be the ratio between the width of two tracks, with one track composed of n segments and one track composed of rn segments. For rn segments,

$$S/N = 20 \log_{10} \sqrt{rn}\, \frac{e_s}{e_n}$$

The relative change in the signal-to-tape noise ratio due to the difference in the track width is then

$$(S/N)_{rn} - (S/N)_n = 20 \log_{10} \sqrt{rn}\, \frac{e_s}{e_n} - 20 \log_{10} \sqrt{n}\, \frac{e_s}{e_n}$$

or relative $S/N = 20 \log_{10} \sqrt{r}$ where r is the ratio between the two track widths. Thus if the track width was reduced to one-half of the original width, the noise ratio will be decreased by $20 \log_{10} \sqrt{2} = 3$db

It should be noted, for this example, that the decibel reduction in "Tape Noise" ratio is only one-half the corresponding change in voltage output level. Also, it generally becomes the major noise source for slower tape speed systems. The analysis of "Recorded Noise" can be represented in a manner similar to "Tape Noise" and is found to vary directly with output level. The "Amplifier Noise" level for a given system is a constant and therefore is not a function of track width. However, the ratio of signal level to "Amplifier Noise" varies directly with track width. The use of "low noise" amplifiers tends to minimize this effect which is usually less than the "Tape Noise" for track widths greater than approximately .020 inches.

The final track width chosen was .043 inches, approximately one-half of the .090 inches which is the current standard for the two-track 7½ ips system. This was chosen on the basis of realizing a satisfactory signal-to-noise ratio, and providing an adequate width to minimize tape guidance and head contact difficulties for a proposed ¼ inch tape mechanism. The final design of the track placement on the recording medium is shown in Fig. 1.

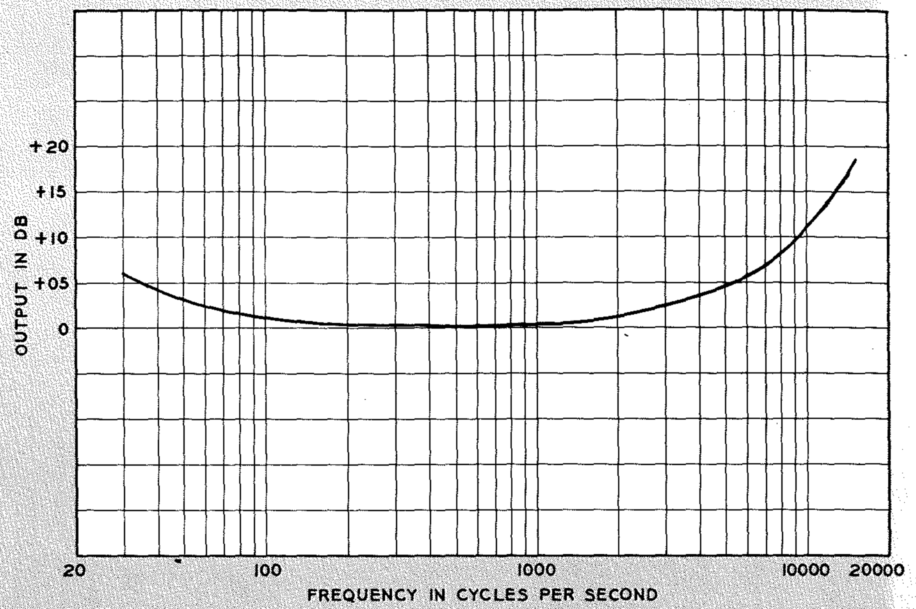


Fig. 2—Record characteristic for the 3¾ ips four-track system.

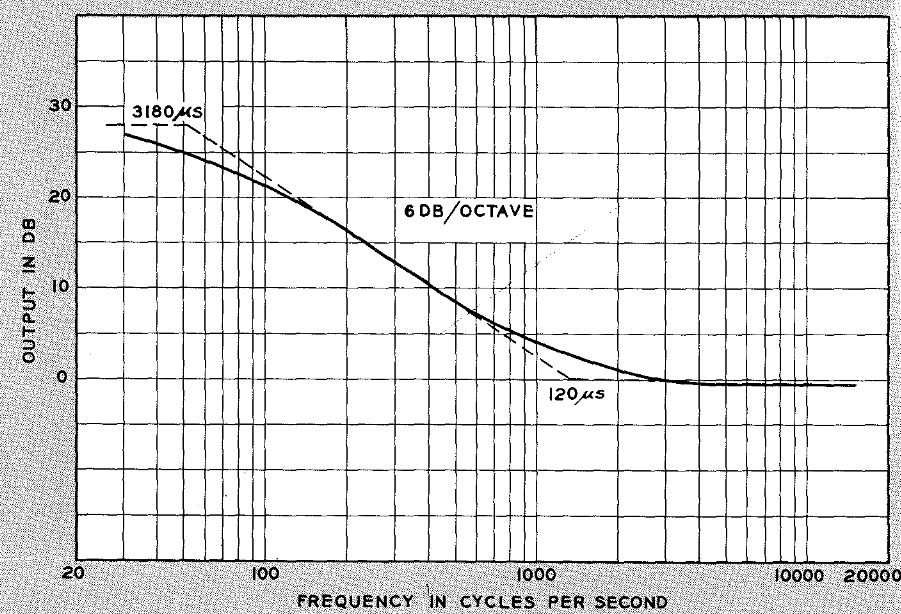


Fig. 3—Reproduce characteristic for the 3¾ ips four-track system.

CROSSTALK

For a four-track system with a recorded track width of .043 inches, the spacing between tracks becomes .025 inches. This is one-half of the .050 inch spacing used for the 7½ ips two-track system and results in increased crosstalk. In multitrack recording "crosstalk" is defined as the undesired signal picked up by the head from recorded signals on other tracks on the tape. In general, there are two types of crosstalk which may be bothersome. One is due to direct pickup by the head in use of the fringe flux lines from adjacent tracks. The separation that is necessary to prevent this type of crosstalk is a function of recorded signal wavelength. The longer the recorded wavelength, the greater the distance must be between the tracks in order to achieve a desired degree of freedom susceptibility. The two-to-one reduction in tape speed will reduce the wavelength by this same factor, and therefore crosstalk due to flux lines being reproduced from the adjacent tracks tends to be diminished to some extent. The other type is caused by direct coupling between two adjacent sections of a stacked head assembly. This crosstalk has been reduced to a sufficiently low level by the introduction of special shields between sections and by using interlaced tracks to provide increased section spacing. Investigation indicated that it was possible to reduce the distance between adjacent tracks to 0.025 inches with no increase in crosstalk.

OPERATING CONDITIONS

The general term "operating conditions" as used here actually covers a number of properties of the 3¾-ips four track system which are so interrelated that it is almost impossible to discuss them separately. This includes such things as the record and playback equalization, the high-frequency bias used in recording and the recording level. Each of these affects the quality of the over-all system and yet no one of them can be logically specified without specifying all the others.

The record and playback equalizations are the pre-emphasis and post-emphasis corrective circuits to compensate for losses in recording and reproducing and to make maximum use of the capabilities of the recording medium. If not enough pre-emphasis is used in the recording, the over-all system will suffer from poor signal-to-noise ratio; on the other hand, if too much pre-emphasis is used, certain frequencies will result in overload and cause distortion. Thus the choice of optimum record and playback equalization is very important; the determination of these characteristics is directly related to the energy spectrum of the signal to be recorded. Music as recorded today has no "typical" energy spectrum, and therefore can best be handled by experimental means. Different types of musical selections were recorded and checked by listening tests. Measurements were made of distortion and signal-to-noise ratio for a wide range of record and playback equalization curves until one gave the optimum results.

During the determination of the record and playback equalization, the high-frequency bias had to be considered. The undistorted output tends to vary directly with recording bias current changes. However, the relative frequency response tends to vary inversely with bias. Since these two properties are in direct opposition to each other, it is necessary that the bias current be accurately optimized for maximum undistorted output of low frequencies and minimum loss of high frequencies. Simultaneous determination of the various operating conditions provides optimum over-all quality. The record and reproduce equalization curves chosen to achieve the best results or performance are shown in Fig. 2 and Fig 3.

TAPE CARTRIDGE

The handling of reels of tape has always been a nuisance; the tape has to be threaded through the machine to the take-up reel prior to use and requires rewinding after it has been played. The net increase in playing time per unit length of tape as a result of the development of the slow-speed narrow-track system automatically suggested the packaging of this small roll of tape in such a way as to eliminate the direct tape handling.

The answer to the tape handling inconvenience was the design and development of a new product, the RCA Tape Cartridge and the Tape Cartridge Player. The cartridge is approximately 5 x 7 inches by ½ inch thick and permits a playing time of up to one hour of stereo or two hours of monophonic recording. It is only necessary to place the Tape Cartridge on the player and push the desired function switch to operate the player. It is unnecessary to handle the tape itself as is required with reel type machines.

CONCLUSION

A system for tape recording has been developed which for all practical purposes equals the quality of standard 7½-ips tape and does this at a tape speed of 3¾ ips and with a recorded track width of only one-half that of the 7½-ips system. The development of the Tape Cartridge was a big step toward making magnetic tapes a desirable medium for recorded music in the home. A new design of the record and playback heads, a set of record and playback characteristic curves designed for minimum over-loading and maximum signal-to-noise ratio and determination of optimum operating conditions each contributed toward the improvement of the system. Any one of these changes in itself would not have represented a worthwhile improvement. However, with each component part being optimized for this particular application, a noteworthy advancement resulted in the field of magnetic recording.

ARNOLD J. VIERE received his BS degree in Electrical Engineering from the University of Illinois in 1951. After graduation he joined RCA at Indianapolis in the Record Engineering Laboratory as a Development Engineer. He has worked on phonograph record and magnetic tape recording development since he joined RCA Victor. Mr. Viere is a member of the Institute of Radio Engineers.

ARTHUR G. EVANS was graduated from the University of Illinois in 1947 with a BS degree in Electrical Engineering. After graduation he joined RCA at Indianapolis in the Record Engineering Laboratory as a Development Engineer. His work has been in the field of disc and magnetic tape recording, both in the development of new products and specialized electronic equipment.

He is a member of the Institute of Radio Engineers, and Audio Engineering Society and Eta Kappa Nu honorary society. He is currently Central Vice-President for the Audio Enginering Society.

A HIGH-RESOLUTION FOUR-TRACK STEREO HEAD

By

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During 1955 several studies, within RCA, were made concerning the feasibility of narrow track, slow-speed tape recording. These studies proved conclusively that it was possible to record and play back frequencies as high as 15,000 cps at a tape speed of 3¾ ips. It was also found that the track width could be reduced one-half its nominal value and still satisfactorily maintain a signal-to-noise ratio for high-quality reproduction. Although the track spacing was reduced by one-half, measured crosstalk was minus 50 db or greater at one-thousand cycles.

When, in the summer of 1956, it was decided to engage actively in the development of a tape cartridge transport, a production design was started on a dual-track, in-line stereo head for this application. Up to this time, heads used for the above studies were handmade in RCA laboratories and, of course, were too costly a design for commercial application.

PRODUCTION DESIGN CRITERIA

Early investigations into all phases of the cartridge concept provided the necessary information from which design specifications could be developed. In most cases these were common or closely related to other components of the system. The performance considerations such as equalized frequency response and constant current record-playback characteristics were to be equivalent to high-quality heads operating at 7½ ips tape speed. Also the signal to noise ratio and crosstalk factor requirements were 50 db or better. These, you will note, are system requirements. The head, with "multiple-track" tape, and associated amplifiers are dependent on each other in producing the required results. Other specific criteria such as low head-impedance for driving a low-noise transistor pre-amplifier, controlled pickup of stray magnetic fields, and mechanical considerations of compatibility with the narrow tape tracks and cartridge were also dependent on individual components. Probably one of the most important goals was to achieve a design that would lend itself to large quantity production with a basic cost equivalent to the average unit presently available for high-quality recorders.

PRODUCTION DESIGN

The four-track stereo tape system dictates that the head must be an in-line stereo type. First consideration was given to the material to be used in the manufacture of the case half. Thermo plastic, thermosetting plastic and epoxy type case halves were reviewed. However, bearing in mind the degree of flatness needed on the case face and also the critical track spacing and tolerances required on a

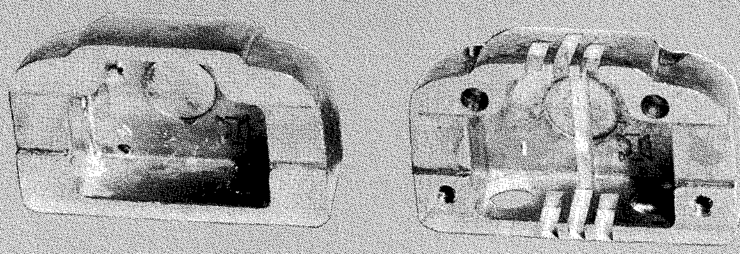


Fig. 1—Stereo case head before and after machining operations.

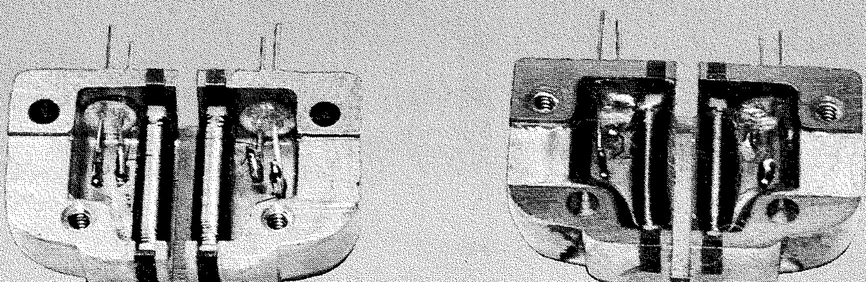


Fig. 2—Stereo case head before (left) and after epoxy resin filling and lapping.

Fig. 3—Finished stereo head in shielded case.

four track system, all of the above materials were found to be unsatisfactory. Dimensional stability with temperature and humidity variations was also a factor in rejecting these materials. Because of the above stated requirements, it was finally decided to use a cast aluminum case with precision milling and drilling operations. The case half before and after machining operations is shown in Fig. 1.

The thickness of the lamination material was next to be considered. Tests were made on both photo etched two-mil laminations and stamped six-mil laminations. After building a head from each type of lamination, an evaluation of the electromagnetic efficiency of each was made. A perfect head tested under these conditions would produce a 6-db per-octave curve. Both units showed excellent results. The greatest deviation from the 6 db per-octave curve was one decibel at 15 kc on the 6 mil lamination head. As this investigation showed very little difference between results obtained from either 2-mil or 6-mil laminations and also because of economic reasons, 6-mil punched laminations were used in production units. Balanced windings, which will cancel external fields, are used in order to reduce hum pickup from associated circuits.

After laminations and coil assemblies are placed in the case halves and the soldering operations on leads are completed, the unit is internally potted with epoxy resin. A precision lapping operation is then performed on the case half. This area has been undercut in order to achieve a high degree of flatness. Fig. 2 shows the case half ready for epoxy resin and also shows this same unit after pouring and lapping.

A 45-micro inch quartz spacer is then evaporated on each pole tip area, and the two mating halves are fastened together with four screws to form a working tape head. Fig. 3 shows the finished head in a shielded case and the front face polished.

The constant-current record-and-playback curve taken at 3¾ ips is shown in Fig. 4. The dotted curve is a typical one taken on a popular head designed for and operating at 7½ ips.

The head impedance is approximately 1000 ohms at 3000 cps. Its output is fed directly into an equalized transistor preamplifier. The signal-to-noise ratio measured at 1000 cycles from a one-percent third harmonic distortion signal is 54 db.

The equalized record and playback curve is shown in Fig. 5. This curve is flat within 1.5 db from 100 to 15,000 cps and rolls off 3 db from 100 to 50 cps. This response was taken 20 db below the one-percent third harmonic distortion point.

As wavelength is equal to tape speed divided by frequency, in order to reproduce a 15-kc signal at 3¾ ips, the head must resolve a wavelength of 250 micro inches. The effective gap width of the tape head to resolve this wavelength must be 125 micro inches or less. The capability of the RCA high resolution head to perform this task is shown in the overall frequency response in Fig. 5.

CONCLUSION

Current production has yielded a high-quality, uniform, low-cost tape head. Essentially flat response from 50 to 15,000 cps at a tape speed of 3¾ ips is achieved by this high-resolution head when proper record and playback equalization is employed.

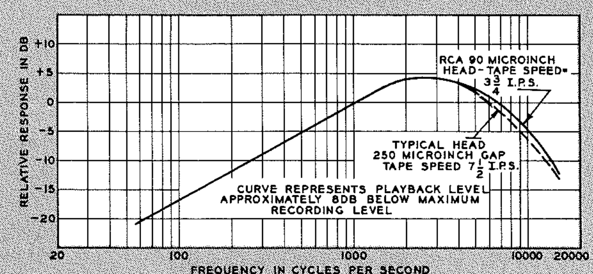


Fig. 4—Constant-current record and playback curve taken at 3¾ ips.

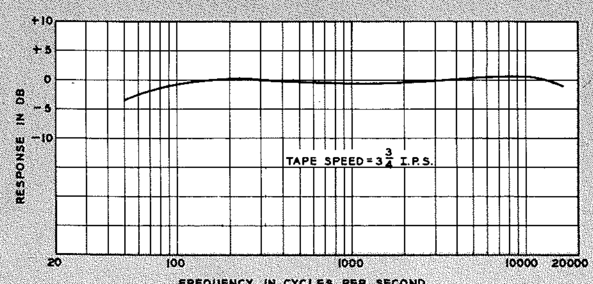


Fig. 5—Equalized record and playback curve.

ANTHONY A. SARITI joined RCA in 1941 as a troubleshooter in Special Apparatus. He attended Drexel Institute of Technology Evening School and graduated with a Diploma in Electrical Engineering in 1951. Mr. Sariti was then employed as an Acoustical Engineer in Component Parts until being transferred to the Radio and "Victrola" Division in 1957. He became Leader and then Manager of Transducer Engineering in 1959.

An active radio amateur, Mr. Sariti's call letters are W2RVV.

ENGINEERING DEVELOPMENT OF PRE-RECORDED TAPE IN A CARTRIDGE

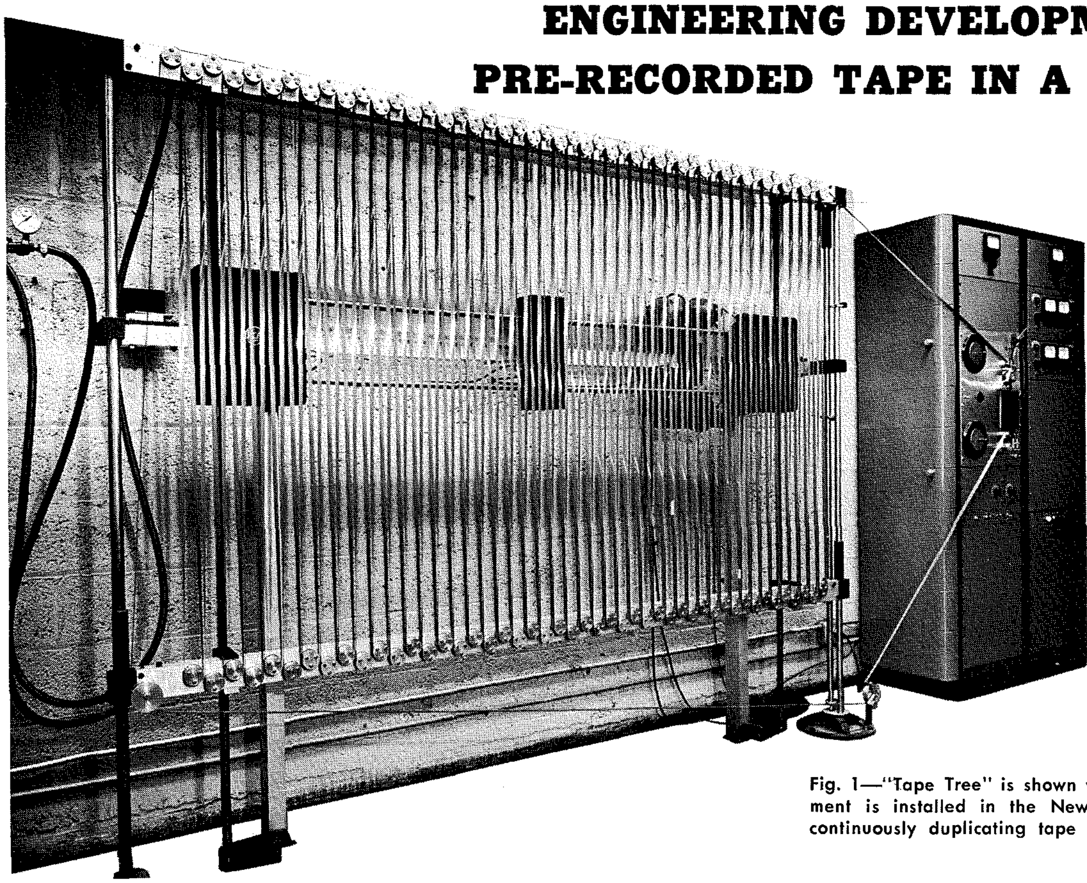


Fig. 1—"Tape Tree" is shown with its transport. This equipment is installed in the New York recording studios for continuously duplicating tape records from a master tape.

by

S. W. Liddle

Record Engineering

RCA Victor Record Division

Indianapolis, Ind.

THE INTRODUCTION of recorded magnetic tape in cartridge form is a major advancement in the home entertainment field. The cartridge makes a compact, self-contained package of music. Combined with the player, it eliminates threading of the tape, and in convenience and ease of handling, approaches the phonograph record. To play the tape, it is only necessary to place the cartridge onto the transport and push a button; it is no longer necessary to thread tape through magnetic heads and connect the free end to a reel. One hour of high-fidelity stereophonic music is available.

The original development work on the tape cartridge was carried out by the Radio and "Victrola" Division at Cherry Hill, in conjunction with their development of the transport mechanism. On completion of the initial design in the latter part of 1958, all future responsibility for the tape cartridge was assigned to the Record Division. This was a logical move since this division markets the cartridge with pre-recorded tape, and thus becomes the greatest user of cartridges.

It is the object of this paper to discuss the problems of recording and loading the tape into the cartridge. To accomplish this, new manufacturing techniques were developed to minimize both time and labor.

TAPE TREE

The tape used in the cartridge is one-mil base thickness by one-quarter inch wide. The music is recorded onto the tape on four separate tracks for reproduction at a tape speed of 3¾ inches-per-second. In the case of a stereophonic selection, two tracks are played in one direction and two tracks in the reverse direction. To compare this with two-track tape on a conventional reel operating at 7½ inches-per-second the cartridge will require one-fourth as much tape (for a given musical selection length). The reduction in the amount of tape needed (per musical selection) permitted new production techniques.

The shorter tape length, coupled with the requirement of minimum periods of silence during reversal of direction of tape travel, make it desirable to duplicate tapes from a continuously running master in order to reduce tape wastage. The continuously running master developed for this application is shown in Fig. 1 and is called a "tape tree." Basically the "tree" replaces the supply reel of the master transport unit, also shown in Fig. 1, in that it provides a "moving storage place" for the master tape. This enables the master tape to be played continuously with no rewinding.

The unique feature of this "tree" is that the tape is supported by an air film as it passes over the idlers (an idea conceived due to the work by DEP in air bearings). These air idlers make it possible to obtain the low tape tension needed using small idlers—a space saving feature permitting the "tree" to be erected in a small space.

To illustrate the operation of the "tree," let us assume a pre-recorded tape or tape record of approximately 400 feet in length is to be copied. A master tape, from which exact copies are to be made, has been carefully prepared. This tape with its four tracks recorded on one-half inch tape at 7½ inches-per-second is placed on the "tree" by weaving it up and down as can be seen in Fig. 1. The ends are spliced together at the transport with a 36-inch length of tape. This forms a continuous loop, and since the master was recorded at two times speed, the length of this master tape is 800 feet. The beams of the "tree" containing the air idlers are raised or lowered by motors to accommodate the exact length of master and maintain proper running tension.

The music on the master tape is now electrically transferred from the master transport to 4 slave units, each of which is supplied with a 7200-foot reel of blank tape. After 96 minutes of continuous operation, we have four 7200-foot recorded reels of tape, each containing 18 tape records. These are now ready to be separated or broken down into the individual tape record and placed in cartridges.

BREAK-DOWN MACHINE

Another piece of equipment used in the production of the recorded tape cartridge is shown in Fig. 2, which was designed and developed by DEP in accordance with recommendations by W. H. Miltenburg. This machine is called a break-down machine since its function is to separate or break-down the 7200-foot recorded reels of tape into the tape record length. As the tape record is wound from the recorded reel onto the plastic hub of the cartridge, an actuating signal stops the tape and starts a mechanical sequence which automatically cuts the tape at the exact separation point of the adjoining records, and forms two end loops. One end loop is the end of one record while the other is the beginning of the next record. Both loops provide the connecting link between the tape and the cartridge hub. The tape record, on its hubs, is now ready for insertion into the cartridge.

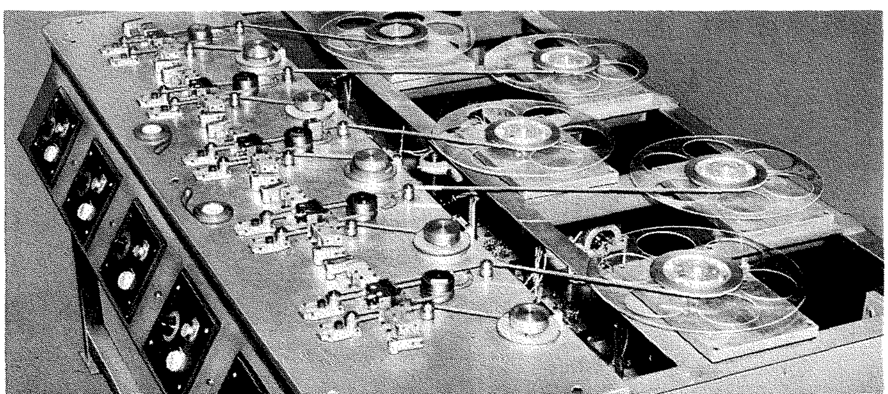
INDUSTRY EVALUATION OF CARTRIDGE

To test and evaluate the cartridge as to possible difficulties that might be encountered with transports of other manufacturers, an industry test was set up. Cartridges with known case designs, length of end loop, type of splice to make the end loop, and types of tape, were sent to ten transport manufacturers. The transports they used were in various stages of development, so actually the cartridges also defined for these manufacturers some definite requirements for their transports. Of the ten manufacturers to whom cartridges were sent, six were active and presented data by returning the cartridge unopened, after a failure had occurred, for our examination. In general, information of this nature, since the test sources were limited in number and since the transports were development models, merely indicated potential sources of trouble as opposed to hard, concrete facts that could only be obtained from customers.

Results of the variables represented by the test cartridges sent out indicated the following:

1. Case Design—Two case designs were included in the test. These cases were different in that internal ribbing was added to later designs to give the cartridge greater stiffness. Both designs gave satisfactory operation,
2. Length of End Loop—End loops of three different lengths were tested. Loops of one inch length were found unsatisfactory by one manufacturer. Longer loop lengths of $2\frac{3}{4}$ and $3\frac{1}{2}$ inches performed satisfactorily.
3. Type of Splice to Make the End Loop — Heat seal and taped splices were used to form the end loop of the tapes. Both type connections were satisfactory.
4. Type of Tape—Cartridges containing "mylar" and acetate type tape were tested. "Mylar" type tape was satisfactory in that no tape breakage occurred.

Fig. 2—"Break-down Machine" pictured below is used to separate the recorded reels into tape records.



S. W. LIDDLE received his B.S. degree in M.E. from Rose Polytechnic Institute in 1945. He joined RCA in 1946 as an engineer in Engineering Development of the RCA Victor Record Division, where he is currently employed. His activities have been chiefly concentrated on the design and development of tools and equipment for record manufacturing.

Mr. Liddle is a registered professional engineer in the state of Indiana and is currently doing graduate work at Purdue University.

Cartridges containing acetate tapes indicated that tape breakage might occur in two different regions. Five of the six transport manufacturers had breakage occur in fast wind where the end loop connects to the hub. It can be demonstrated that this breakage can be practically eliminated by proper radiusing of the hub slot. This in effect relieves the stressing point of the tape. Three of the six manufacturers had breakage occur along the "head-line" of the cartridge. This breakage is caused from either improper handling of the cartridge or damage occurring to the tape during insertion onto the transport. This damage usually does nothing more than tear or nick the tape edge ever so slightly, so that further strain breaks the tape. The breakage is very difficult to control or evaluate, as it is directly related to the handling of the cartridge.

The seriousness of the breakage is of course reflected by the number of plays and fast winds the tape is expected to survive. Based on experience with phonograph records, we use 100 plays or fast winds as the survival point. While applying the radius to the hub slot has increased the survival point of acetate tape to well over 100 plays, there is still the accidental breakage of the tape due to handling which at this time can not be evaluated. Based on results of the industry test and the breakage in the handling of acetate tape by inexperienced users, we selected "mylar" tape for our cartridges.