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Professional Group on Audio

A Group of Members of the I. R. E. devoted to the Advancement of Audio Technology

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The Institute of Radio Engineers

IRE PROFESSIONAL GROUP ON AUDIO

The Professional Group on Audio is an organization, within the framework of the IRE, of members with principal professional interest in Audio Technology. All members of the IRE are eligible for membership in the Group and will receive all Group publications upon payment of prescribed assessments.

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TRANSACTIONS of the I • R • E®
Professional Group on Audio

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Editorial Committee

SAN DIEGO CHAPTER ACTIVITIES

The San Diego Chapter of IRE-PGA has been conducting an active program of meetings for a year and a half. There were four meetings held before the formal approval of the chapter. The first meeting was held on April 29, 1952, where an interesting talk on microgroove recording was presented by Chester Boggs of Century Engineers Inc. A second meeting was held on July 29, 1952, when three short papers were presented on the subjects of disc recording, amplifiers and loudspeakers. Two of these papers were presented by members of the chapter and one was a PGA tapescript. The third meeting was held November 5, 1952, when Mr. Gales and Mr. Webster of the Navy Electronics Laboratory, Psychophysics Branch, gave a demonstration lecture on "Subjective Factors in Evaluating Audio Systems."

At a business meeting held in January it was decided to hold approximately four meetings in 1953. It was further decided to have a different member put in charge of each meeting. The first of these meetings was held on February 17 with Charles Miller as chairman. The subject of this discussion meeting was "Low Cost Instrumentation for the Evaluation of Audio Systems." The second 1953 meeting was held in July with Matt Brady as program chairman. A paper was given by J. P. Maxfield entitled "The Simulation of Spatial Distribution of Reproduced Sound." One week later the chapter met at the home of F. X. Byrnes for a business meeting. Up to this time no formal organization of the chapter existed. The ground work for the first meeting had been carried out by Stan Sessions, and at that meeting a working committee consisting of Stan Sessions, Matt Brady, Royal Burkhardt and Francis Byrnes had been formed with Mr. Byrnes as acting chairman. This informal organization was replaced when a regular slate of officers was elected, as follows:

David G. Bailey,	Naval Base, Chairman
Charles N. Miller,	NEL, Vice-Chairman
Cdr. William B. Bernard,	NEL, Secretary-Treasurer

On October 3 in a suite at the San Diego Hotel a demonstration meeting featuring high-fidelity audio equipment was held. The demonstration ran from 9 A.M. to 9 P.M. in order to permit everyone to have a chance to see and hear the equipment. The attendance, which was estimated at well over 500, was so large that during the afternoon and evening it was frequently difficult to see the equipment for the people. The meeting which was arranged by the chapter chairman, Dave Bailey, was very well publicized in the newspaper and on radio and television. The large attendance made it difficult for the PGA members to make a subjective evaluation of the equipment being demonstrated, as originally planned. Future demonstrations of this type should provide for a special session for members only, so that the principal purpose of the meeting can be fulfilled. The last chapter meeting of the year was a tour of the complete studio and transmitter facilities of radio station KSDO.

PHILADELPHIA CHAPTER EVENTS

1. At the first meeting on October 19, 1953, Mr. E. D. Nunn, President of Audiophile Records, presented a very interesting talk on "The Quest for High Fidelity – From a Hobbyist's Point of View." After a discussion of the early experiments, methods of approach and recording techniques and equipment, demonstrations of high quality equipment were made covering a frequency range in excess of nine octaves.
2. Dr. William L. Everitt of the University of Illinois gave a lecture with demonstrations on "A Method of Time Compression or Expansion of Speech" at the regular IRE section meeting on November 5, 1953. He explained how the ear is faster than the mouth; words can be understood more rapidly than they can be spoken. The device can produce speech either with the original frequency spectrum in a shorter time (speaker seems to be talking more rapidly) or the information can be transmitted in the same time over a narrower frequency band. Time or frequency expansion can also be obtained.
3. On February 18, 1954 the Audio Chapter will hear Dr. Daniel W. Martin, The Baldwin Company, discuss "The Enhancement of Music by Reverberation." He will use magnetic tape recordings to demonstrate the effects of natural reverberation upon organ and piano tones. A new loudspeaker with built-in reverberation will be demonstrated. The added reverberation improves the tone of an electronic organ installed in a small room.

Murlan S. Corrington, Chairman

SUMMARY OF AVAILABLE TAPESCRIPTS

Andrew B. Jacobsen
Phoenix Laboratory, Motorola, Inc.
Phoenix, Arizona

Tapescripts are recorded technical papers with slides, intended to extend the author's coverage to a larger audience. Ideally, we would like a personal presentation with slides, demonstrations and exhibits. The ideal can be approached through tapescripts by means of the author's recorded voice, continuous slide presentation and a duscussion leader who has previewed the paper, and studied the references.

Technical standards have been set for IRE-PGA tapescripts: sound recorded at 7½ inch per second on ¼ inch tape, full track on 7 inch reels; slides to be 2" x 2" cardboard mounts in black and white or color. A script and references, as well as an abstract, should be available.

Tapescripts are now available for loan, at no cost except for return postage, to any IRE-PGA group interested. They should be ordered ahead, so as to be available several days before use. This permits the discussion leader to preview the material. The Tapescripts Committee of the Professional Group on Audio has funds to provide copies and to ship the material. You may order one or more papers for preview at a program committee meeting.

The following papers are available from the PGA Tapescripts Committee Chairman, A. B. Jacobsen, 1802 North 47th Place, Phoenix, Arizona.

"Method for Time or Frequency Compression – Expansion of Speech", Grant Fairbanks, W. L. Everitt, and R. P. Jaeger, University of Illinois. Available February 1, 1954.

"Magnetic Recording", Marvin Camras, Armour Research Foundation of Illinois Institute of Technology. Discusses fundamentals of wire and tapes; heads; bias; circuits; equalization; present problems; and future developments. Thirty minutes.

"Phonograph Reproduction", B. B. Bauer, Shure Brothers, Inc. Present trends and discussion of design factors affecting record wear and quality of reproduction. One hour.

"Push Pull Single Ended Audio Amplifier", Arnold Peterson and D. B. Sinclair, General Radio Company. A convention paper presented by Dr. Peterson. Twenty-five minutes. 3¼ x 4 slides.

"Sound Survey Meter", Arnold Peterson, General Radio Company. A convention paper. Twenty minutes. 3¼ x 4 slides.

"Microphones for High Intensity and High Frequencies", John K. Hilliard, Altec Lansing Company. A convention paper. Twenty minutes. 3¼ x 4 slides.

"The Ideo-Synchronizer", J. M. Henry and E. R. Moore, Boston Bell. A humorous satire on technical writing, specifications, and engineering. Good for mixed audience. Twelve minutes.

Other tapescripts are available elsewhere, including the following:

"Germanium the Magic Metal". A technical paper on the preparation of Germanium, theory of diodes and transistors, and construction details. Seventy-eight color strip slides, sound on 16 inch, 33⅓ discs. Forty-five minutes. This may be obtained from J. H. Sweeney, General Electric Company, Electronics Park, Syracuse, N.Y.

The following Bell Laboratories Experimental Tapescripts may be obtained from W. H. Doherty, Bell Telephone Laboratories, Inc. Murray Hill, New Jersey.

Tapescript Number	Title	Author
1*	"Experiments with Linear Prediction in Television"	C. W. Harrison
2*	"Statistics of Television Signals"	E. R. Kretzmer
3*	"Efficient Coding"	B. M. Oliver
4	"The Physics of Music and Hearing"	W. E. Kock
5	"Transistors in Negative Impedance Circuits"	J. C. Linvill
6	"A Junction Transistor Tetrode for High Frequency Use"	R. L. Wallace, Jr.
7	"Some Circuit Properties of "Junction Transistors"	L. G. Schimpf
8	"Ferroelectric Storage Devices"	J. Reid Anderson

*These papers were published in the July 1952 issue of the Bell System Technical Journal.

PGA BRIEFS

A group of thirty-four members of the Cleveland Section of the IRE has petitioned for the formation of a Cleveland Chapter of the IRE Professional Group on Audio. The petition has been approved by the Executive Council of the Cleveland Section, and has been forwarded to IRE Headquarters.

Any IRE-PGA members planning to attend the International Meeting on Sound Recording, to be held in Paris April 5-10, and sponsored by The Société Des Radioélectriciens, 10 Avenue Pierre Larousse, Malakoff (Seine), can obtain further information from IRE Headquarters or from IRE-PGA. Early registration will be necessary for suitable arrangements to be made.

The program of the Chicago Chapter IRE-PGA has had several recent changes. The December 16 paper was changed to "The Design and Construction of Low Frequency Horns," Dan Plach and Karl Kramer, Jensen Mfg. Co. The January 15 paper was postponed. A paper entitled "High Fidelity", by John Clark of El-Rad Mfg. Co., has been scheduled for February 19.

Mr. Philip B. Williams, chairman of the Chicago Chapter IRE-PGA, has recently been promoted to the position of Chief Engineer of the Jensen Mfg. Co.

The Cincinnati Chapter IRE-PGA recently enjoyed hearing former Cincinnati resident Dr. W. E. Kock, Director of Acoustics Research, Bell Telephone Laboratories, give a paper, "The Physics of Music and Hearing," at a joint meeting of the IRE, AIEE, and the Engineering Society of Cincinnati.

An interesting program on "High-Fidelity" is being arranged for the 1954 IRE convention in March, under the chairmanship of Dr. W. E. Kock. The complete program of the convention, including 100-word abstracts of all papers, will be published in the March issue of Proceedings of the I.R.E. Make your plans to attend.

On November 17, 1953, Professor A. B. Bereskin of the University of Cincinnati, and an electronic consultant of The Baldwin Company, addressed the Cincinnati Section IRE on the subject, "A High Efficiency-High Quality Audio-Frequency Power Amplifier." The amplifier was demonstrated in a music reproduction system,. Following the section meeting the IRE-PGA chapter participated in a demonstration test prepared by officers of the chapter, entitled "How Much Distortion Can You Hear?" A special tape recording of signals containing various measured amounts of harmonic and intermodulation distortion was played over a low-distortion reproducing system in randomized paired comparisons. Attendance at the chapter meeting was at an all-time high. Results of the test were reported at the December IRE meeting, and will appear in a future issue of Transactions Of The IRE-PGA. The recording may be converted into a tape-script.

The latest news before this issue is printed concerns a petition from the Phoenix Section of IRE asking for the formation of a Phoenix Chapter of the Professional Group on Audio.

DEPARTMENT OF DEFENSE SYMPOSIUM ON MAGNETIC RECORDING

A symposium on magnetic recording was held on October 12 and 13, 1953, in the Department of Interior Auditorium, Washington, D. C., under the auspices of the Department of Defense. Attendance was open to all with a direct interest in development, manufacture or professional application of magnetic recording and playback. The sponsor of the meeting was the Department of the Navy, Bureau of Ships, as part of its allocation to provide coordination of Acoustics-in-Air research projects within the Department of Defense.

The program opened with an introduction, entitled "Purpose and Plan of the Symposium" by the session chairman, Dr. S. J. Begun, President of Clevite-Brush Development Company. Other session chairmen were: Mr. Marvin Camras, Armour Research Foundation, and chairman of the IRE Professional Group on Audio; Mr. Robert H. Carson, Sound Division, Naval Research Laboratory; Mr. Lynn C. Holmes, Research Department, Stromberg-Carlson Company; and Mr. Paul J. Weber, National Security Agency. The Institute of Radio Engineers was a co-sponsor of the symposium. The Washington IRE representative on the Papers Committee was Mr. Henry J. Meisinger, U.S. Recording Company. Some of the papers presented at the symposium appear in this issue of TRANSACTIONS of the IRE-PGA. Others are being solicited for future issues. The unclassified part of the program follows:

Paper No.	AUTHOR	TITLE
1	Dr. W. W. Wetzel	"Certain Advantages of Ferrite Over Mu-Metal Magnetic Recording Heads"
2	Dr. L. E. Loveridge	"A Vacuum Tube for an Electron Beam Magnetic Reproducing Head"
3	Mr. J. W. Gratian	"Core Structure for the Electron Beam Magnetic Reproducing Head"
4	Messrs. S. M. Rubens A. B. Bergh	"A Magnetostatic Reading Head"
5	Mr. W. R. Boenning	"Performance Characteristics of Magnetostatic Reproducing Equipment"
6	Mr. C. E. Williams	"Playback of Magnetic Recordings Through Transistor Amplifiers"
7	Dr. John G. Frayne	"Components and Mechanical Considerations for Magnetic Sound on 35 mm. Film"
8	Mr. O. C. Bixler	"Basic Mechanical Considerations for Tape Transport Systems"
9	Mr. J. E. Johnston	"Mechanical Factors Governing Tape Coatings, Backings"
10	Mr. G. L. Davies	"Magnetic Recorders for Data Recording Under Adverse Environments"
11	Mr. Walter T. Selsted	"Improved Performance of Magnetic Recording System for Precision Data"
12	Mr. E. W. Darcy	"Present Status of Measurement Techniques, Equalization Systems, and Calibrated Recordings in 16mm. Magnetic Recording"
13	Mr. Walter H. Erikson	"Tape Testing on a Comparison Basis"
14	Messrs. F. A. Comerci, S. Wilpon, and R. Schwartz	"Characteristics of Recent Commercial ¼" Magnetic Tapes"
15	Mr. Frank Radocy	"Some Notes on Problems Encountered in the Use of the Standard Reference Tape"
16	Messrs. F. Comerci, S. Wilpon, and R. Schwartz	"A Standard Magnetic Tape Recording for Standardizing the Characteristics of Navy-Recorder-Reproducers"
17	Mr. Frank G. Lennert	"Equalization of Magnetic" Tape Recorders, and General Recorder Performance Tests"
18	Mr. J. D. Bick	"Methods of Measuring Surface Induction of Magnetic Tape"

RCA RECORDS COLOR TELEVISION ON MAGNETIC TAPE

The recording of television pictures on magnetic tape in color and in black-and-white was publicly demonstrated for the first time on December 1, 1953 by RCA at its laboratories at Princeton, N.J. Although the video tape equipment is still in the development stage, it was estimated that it would be ready for commercial use in about two years.

This development is of particular interest to the Professional Group on Audio because it is an adaptation of audio equipment and techniques to the video field. The seven man team of research engineers responsible for the development of the equipment consisted of Dr. Harry F. Olson (a frequent contributor to TRANSACTIONS of the IRE-PGA) and William D. Houghton, who head the development program, and Maurice Artzt, J. T. Fischer, A. R. Morgan, J. G. Woodward and Joseph Zenel.

The demonstration featured a simultaneous side-by-side comparison of a live color television program fed directly to one receiver and at the same time recorded on tape and played back instantly to a second receiver. The program originated in NBC studios in New York City and was beamed by microwave radio across the 45-mile path to Princeton where it was received and recorded.

The equipment used in the demonstration utilized a single magnetic tape ½-inch wide on which five parallel channels were recorded, one for each of the three primary color signals, one for the synchronizing signal and one for the sound signal.

The four-minute program was recorded at a tape speed of 30 feet per second on a 17-inch reel. Work is now under way towards developing a reel 19 inches in diameter which will carry a 15-minute program.

Magnetic tape recording of television pictures offers several advantages over the present method of recording on film. Since a recorded tape requires no further processing, it may be played back immediately and eliminates the time and expense associated with developing and processing film. Moreover, unlimited number of magnetic tape recordings can be made quickly. In addition, recorded tapes can be demagnetized and used many times over.

Since the tape can be re-used it is estimated that recording a color television program on tape would cost one-twentieth as much as a film recording, and to record a black and white program would cost only one-fifth as much as the film recording.

AN ACOUSTIC LENS AS A DIRECTIONAL MICROPHONE*

Malcolm A. Clark
Bell Telephone Laboratories, Inc.
Murray Hill, N. J.

SUMMARY – An acoustic lens combined with a conical horn can be used to obtain a highly directional microphone without some of the disadvantages of the parabolic microphone. The directional characteristics can be calculated satisfactorily if one assumes that the horn provides uniform flooding of the lens aperture.

INTRODUCTION

Many directional microphones,[1] of which the well-known "cardioid" is an example, have a medium directivity which does not vary appreciably with frequency over a wide band. More highly directional microphones include line microphones,[2,3] high-order gradient microphones,[4] and parabolic reflector microphones,[5,6,7] all of which are subject to variation of gain and directivity with frequency.

The development of convenient acoustic lenses[8,9] makes possible another highly directional microphone, similar to the parabolic one, in which the transducer is placed at or near the focal point of an acoustic lens and the intervening space enclosed by a conical horn.

PARABOLIC REFLECTOR vs. LENS-HORN

Parabolic-reflector and lens focussing have already been compared by Kock[10] in connection with microwave antennas. This comparison holds true in the acoustic case, since the behavior of the devices is essentially the same for sound waves as for microwaves, with the exception of polarization effects. The parabolic reflector microphone has the following disadvantages:

(a) The transducer, placed at the focus, blocks a portion of the beam (Fig. 1b).
(b) There is a finite sensitivity in the backward direction due to the diffraction of sound around the paraboloid into the transducer.
(c) There are strict requirements on the parabolic surface for good focussing.

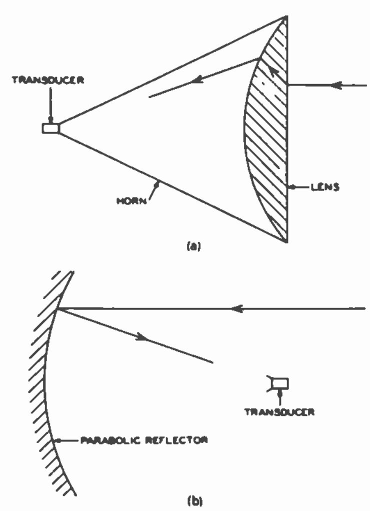

Fig. 1 – (a) The lens-horn microphone.
(b) The parabolic microphone.

*Manuscript received July 27, 1953. Also published in the November, 1953 *Jour. Acous. Soc. Amer.*

[1]For a comprehensive review of directional microphones see H. F. Olson, "Elements of Acoustical Engineering", D. Van Nostrand Company, Inc., New York.

[2]Olson, H. F., *Proc. I.R.E.*, vol. 27, 7, p. 438; 1939.

[3]Mason and Marshall, *Jour. Acous. Soc. Amer.*, vol. 10, 3, p. 206; 1939.

[4]Olson, H. F., *Jour. Acous. Soc. Amer.*, vol. 17, p. 192; 1946.

[5]Hanson, O. B., *Jour. Acous. Soc. Amer.*, vol. 3, 1, p. 81; 1931.

[6]Dreher, Carl, *Jour. Soc. of Mot. Pic. & Telev. Eng.*, vol. 16, 1, p. 29; 1932.

[7]Olson and Wolff, *Jour. Acous. Soc. Amer.*, vol. 1. 3, p. 410; 1930.

[8]Kock and Harvey, *Jour. Acous. Soc. Amer.*, vol. 21, p. 471; 1949.

[9]Kock and Harvey, *Bell Sys. Tech. Jour.*, vol. 30, p. 564; 1951.

[10]Kock, W. E., *Proc. I.R.E.*, vol. 34, p. 828; 1946.

The lens-horn microphone (Fig. 1a) is not subject to disadvantages (a) and (b), and since the arrangement of the lens elements is not very critical,[11] disadvantage (c) is practically eliminated. For acoustic applications, an additional disadvantage of the parabolic reflector derives from the need to cover a wide frequency range. The directional sensitivity of the transducer cannot be adjusted to flood the reflector aperture properly for a wide frequency range, and consequently appreciable "spillover" sidelobes are observed at the lower frequencies. In the lens-horn microphone this problem is avoided as the horn acts as an effective shield at all frequencies.

DIRECTIONAL CHARACTERISTICS OF A LENS-HORN

Fig. 2 shows a lens-horn combination using a slant-plate delay lens.[11] This lens has a 29-inch aperture and a 30-inch focal length. Directional patterns of this combination were taken, some examples of which are shown in Fig. 3. These patterns were taken with the lens-horn acting as a radiator, and, by the principle of reciprocity, are the same as would be obtained with the combination used as a microphone. The angular width of the beam at the half-power points has been calculated from diffraction theory,[12] assuming that the lens aperture is uniformly flooded by the horn. The result is

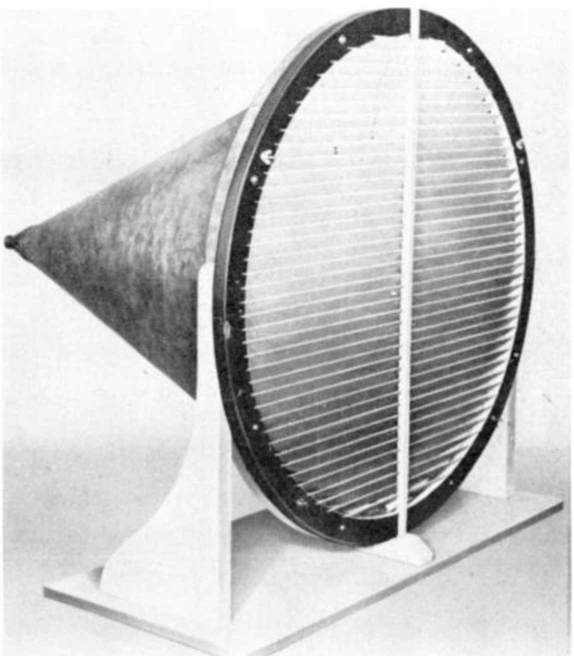

Fig. 2 – A lens-horn combination using a slant-plate lens.

$$\sin \frac{\theta_3 db}{2} = \frac{1.61}{\pi} \cdot \frac{\lambda}{D} \qquad (1)$$

where θ_{3db} is the angular width of the beam at the half power points,

λ is the wavelength of the sound waves,

D is the lens diameter.

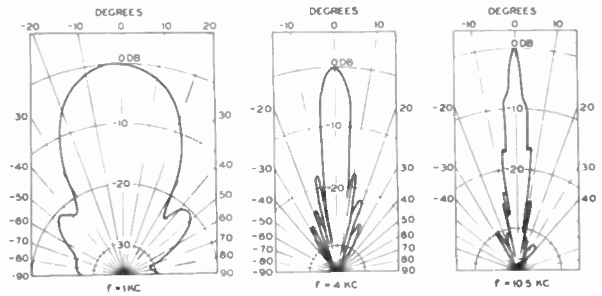

Fig. 3 – Directional characteristics of the lens-horn combination of Fig. 2.

For the lens-horn combination shown in Fig. 2, equation (1) is represented by the solid line in Fig. 4, which is to be compared with the experimental results shown by the vertical bars in the same figure. The lengths of the bars represent an estimate of the errors in measurement of the beam widths. The directional patterns were taken at a finite distance of 27 feet from the lens, and ought not to correspond exactly to the calculated characteristics, which refer to an infinite distance. The agreement between experimental and theoretical beamwidths shown in Fig. 4, however, indicates that at a typical distance at which such a microphone might be used the uniform-flooding assumption is fairly good.

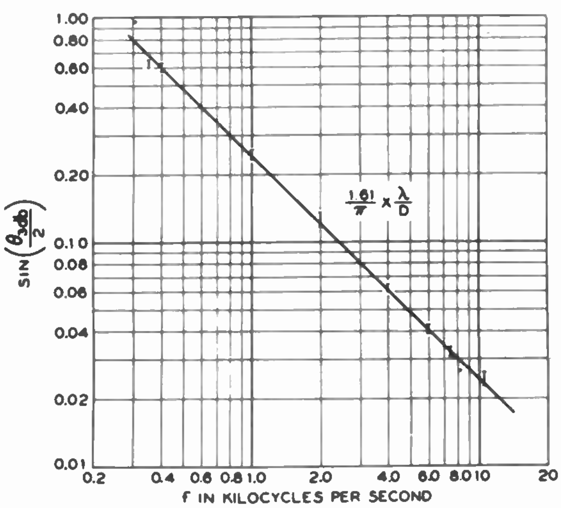

Fig. 4 – Theoretical and experimental beam widths for the lens-horn combination of Fig. 2.

[11] Kock, W. E., *Proc. I.R.E.*, vol. 37, p. 852; 1949.

[12] See, for example, P. M. Morse, "Vibration and Sound", McGraw-Hill Book Company, New York.

It has been pointed out[5,13] that the gain and directivity can be made less dependent on frequency by defocussing (i.e., moving the transducer away from the focal point of the lens or paraboloid). In particular, if one defocusses by moving the transducer closer to the lens, the resulting characteristic corresponds to a diverging beam. The width of the beam resulting from this divergence is independent of frequency, while that due to diffraction varies with frequency. Thus by sacrificing overall sharpness of the beam one can make its width less dependent on frequency. At the same time the gain of the device becomes less dependent on frequency as well.

[13]See reference in footnote [1], p. 213. (1st Edition.)

METHOD FOR TIME OR FREQUENCY COMPRESSION-EXPANSION OF SPEECH*

Grant Fairbanks, W. L. Everitt and R. P. Jaeger**
University of Illinois,
Urbana, Illinois

The purposes of this paper are to outline a method for compression and expansion of speech, to describe the device employed in the method, and to demonstrate by means of recordings the results of the method at this experimental stage.

Until comparatively recently we had not been aware of the fact that several approaches to the problem similar to ours had previously been made by other experimenters. We have now learned that our method, although developed independently, resembles in certain features of theory and details the earlier work of French and Zinn[1], Gabrilovitch[1], Haase[1], Gabor[2], Vilbig[3], and, perhaps, others.

Fundamentally, the process depends upon the fact that the duration of the average speech element or phoneme of live connected speech, such as *ah* or *s* or *r*, exceeds the minimum duration necessary for perception by a listener, or exceeds the minimum time necessary for sampling the essential phonemic qualities of the speech element in question. This minimum duration has been the object of a psychophysical study by Peterson[4] and of theoretical calculation by Gemelli and Pastori[5]. The excess duration may be referred to as *temporal redundancy*, which term we suggest as a useful specification at the experimental level when spoken language is in question.

The dimensions of the problem are clearly not only those of engineering, but also those of psychophysics. In this paper we confine ourselves to the method. A psychophysical program is in progress and its results will be reported separately.

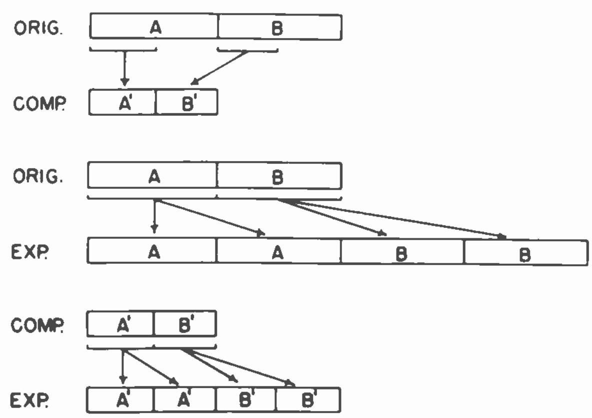

Fig. 1 — Theory of time compression and expansion by sampling.

For purposes of explanation assume two different phonemes, *A* and *B*, which are of equal duration and joined without interruption as shown (Fig. 1). Assume that *A'* and *B'* are valid samples of *A* and *B*, and that each is of adequate duration for perception. Assume that samples *A'* and *B'* are extracted from *A* and *B* and abutted in time as shown without discontinuity, and that *A - A'* and *B - B'* are discarded. If, now, *A'*,*B'* is reproduced, the time will be shorter than the original *A*,*B*, but the phonemes should be perceptible.

When this proposition was advanced several years ago by the first author it was validated for connected speech by cutting and splicing magnetic tape at arbitrary points, without regard to the phonemes. It was discovered

*Revised manuscript received October 30, 1953. This is the substantial equivalent of a paper presented at the 1953 National Convention of the I.R.E. in New York City, Reprinted with minor changes from the Convention Record, Part 8 — Information Theory, pp. 120 - 124. Because this paper included a demonstration, references to the latter have been retained in the published form.

**Now at Bell Telephone Laboratories.

[1]Cited in Gabor.

[2]Gabor, D., *Jour. Inst. Elec. Eng.*, vol. 93, Part III, pp 429-457; 1946; vol. 94, Part III, pp. 369-386; 1947; vol. 95, Part III, p. 39; 1948; vol. 95, Part III, pp. 411-412; 1948.

[3]Vilbig, F., *Jour. Acous. Soc. Amer.*, vol. 22, pp. 754-761; 1950; vol. 24, pp. 33-39; 1952.

[4]Peterson, G. E., PhD. Dissertation, Louisiana State University; 1939.

[5]Gemelli, A. and Pastori, G., "L'Analisi Elettroacustica del Linguaggio," Milan, Italy, pp. 149-162; 1934.

that substantially more than 50 per cent of the total time of connected speech could be discarded by this means without destroying intelligibility. That is, $A - A'$ could exceed A'. At about the same time, Garvey and Henneman independently used the same cutting-and-splicing method to compress isolated words and found similar results.

In the case of expansion, assume that phonemes A and B are caused to be repeated, as in the middle portion. If A,A,B,B is reproduced, the time will be longer and the auditory effect, given the above assumptions, should be that of prolongation of A and of B.

Finally, assume that A and B are first compressed to A' and B', and then expanded to A', A', B', B' as shown at the bottom. Here the original time for A and B has been restored. A and B have been reconstructed from A' and B'.

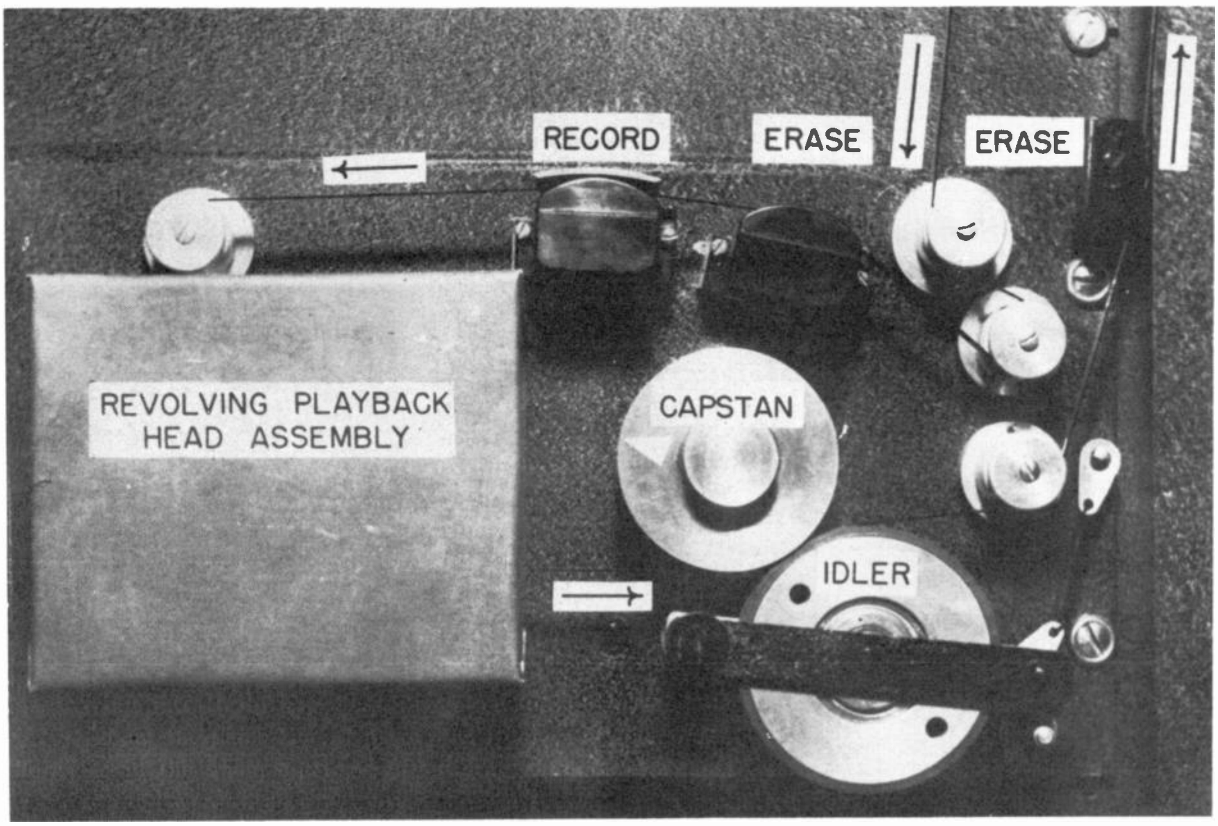

Fig. 2 – Apparatus.

Fig. 2 shows a photograph of the essential part of an experimental model of a device for compression or expansion along the lines of such a theory. Basically, the device is a continuous loop magnetic tape recorder, mounted at the bottom of the rack containing the other components. The tape loop, approximately 12 feet long, rises along the right edge of the rack to a pulley under slight spring tension at the top. Its pathway is shown by arrows. Entering the device, the tape is directed by means of rollers over a Magnecord erase head, and then over a fixed Magnecord record head where the input is temporarily recorded. Passing over another roller, the tape then descends to a revolving playback head assembly enclosed in a mu-metal box, where signal recorded on the loop is scanned. Next the tape passes to the drive capstan, around a roller, and, finally, over a Brush permanent magnet erase head.

The revolving head assembly consists of a brass drum with four Brush playback heads equally spaced around its periphery. The output of the heads is taken off by means of a slipring-brush unit. The circumferences of both drum and capstan are 7.64". Drum and capstan are mounted on shafts supported in sleeve bearings at the back of the panel. Massive flywheels are also mounted on the shafts. The two units are driven by twin $^{1}/_{15}$ hp DC Bodine motors with independent speed controls by means of GR Variacs. Speeds are measured with a GR Strobotac.

The remaining components are conventional. An independent Magnecorder PT6-A is used for storage and playback. This has been modified for continuously variable speed reduction and furnished about a 15 to 1 range of tape velocities.

In Fig. 3 operation of the revolving head assembly is shown at the left. The four playback heads are identified by letters. The tape passes over the drum and is in contact with ¼ of its circumference, or a distance equal to

[*]Garvey, W. D. and Henneman, R. H., Air Force Tech. Rep. #5917; 1950.

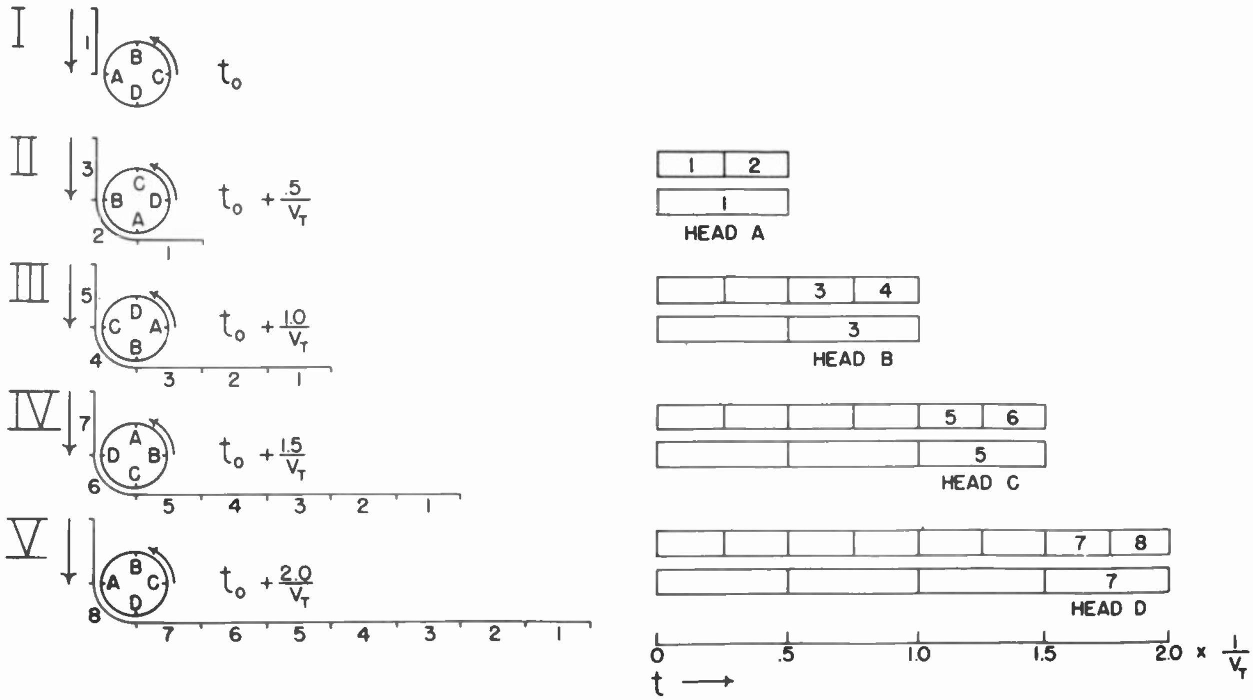

Fig. 3 — Compression process.

the peripheral distance between any two adjacent playback heads. The tape is retained by flanges around the drum periphery. Tape direction is constantly counter-clockwise. In the compression application the direction of drum rotation is also counter-clockwise. Under load the top tape velocity is approximately 190 in/sec. The top peripheral drum velocity is about 225 in/sec.

For purposes of explanation the tape is divided into hypothetical numbered segments, each equal to the distance between heads. The relative positions of tape and heads are shown at representative times. The diagram shows 50 per cent time compression as an example.

In Part I segment 1 is shown at t_0 when it first comes into contact with the drum. At this time it is intercepted by head *A*, which is moving in the same direction. If the drum were stationary, reproduction would be one-for-one. If its velocity were equal to the tape, no signal would be reproduced. Between times I and II, however, head *A* moves through ¼ of a revolution. During the same interval tape segments 1 and 2 pass the 9 o'clock point where head *A* was at t_O. As a result, head *A* reproduces segment 1 during that interval. The *effective* tape velocity is V_T - V_H. In the example diagrammed V_H equals $V_T/2$ which equals the effective velocity. Therefore, the frequencies of segment 1 as reproduced by head *A* are divided by 2.

At time II head *A* is at 6 o'clock and head *B* is at 9 o'clock, while segment 2 lies between them in contact with the drum. Head *A* is about to leave the drum, while head *B* is about to begin reproducing segment 3. Accordingly, although there is no discontinuity, segment 2 is not reproduced by any head. The remaining diagrams show how the process continues, the odd-numbered segments being reproduced at reduced frequency and the even-numbered segments being discarded. It is evident that various durations of either reproduced or discarded segments can be realized by varying the absolute and relative velocities of tape and head, and that a range of sampling frequencies and compression ratios can thus be produced.

The output of the device with respect to time is diagrammed at the right. Between times I and II, for example, segment 1 is reproduced by head *A* in the time necessary for both segments 1 and 2 to pass a point. Head *B* then reproduces segment 3, etc. The final yield is segments 1,3,5,7. When these segments are stored at a given speed and then reproduced at an appropriately higher speed, their original frequencies are restored and the elapsed time is shortened.

With respect to duration the odd-numbered segments are termed *sampling intervals;* the even-numbered segments *discard intervals.* The reciproval of their summed durations is the *sampling frequency.* One hundred times the discard interval divided by the sum of the two intervals will be termed the *compression percentage.* Since sampling is periodic the ratio applies also to the total message time, and describes the percentage by which that total time has been reduced.

Assuming that the process results in intelligible speech, it becomes evident that the processed message may be transmitted over a system with smaller bandwidth than originally necessary. The capacity of a conventional transmission link for handling simultaneous messages will be a function of the amount of compression, or frequency division.

Fig. 4 is a similar diagram for expansion. Here the drum bearing the playback head revolves in a direction opposite to that of the tape. The illustrative example shows the condition when these velocities are equal. The effective velocity is equal to their sum.

At t_O, shown at I, segment 1 is in contact with the drum between heads *A* and *D*. During the next interval head *D*, as it moves from 6 o'clock to 9 o'clock, will reproduce both segments 1 and 2 and then leave the tape. At that time it will be replaced by head C, which has moved to the 6 o'clock position to intercept the tape at the beginning of segment 2, and which will reproduce segments 2 and 3 during its sweep. The result, shown at the right, is that between times I and II, while segments 1 and 2 are passing the 6 o'clock point, segments 1,2,2,3 are reproduced. The rest of the figure shows how this process continues.

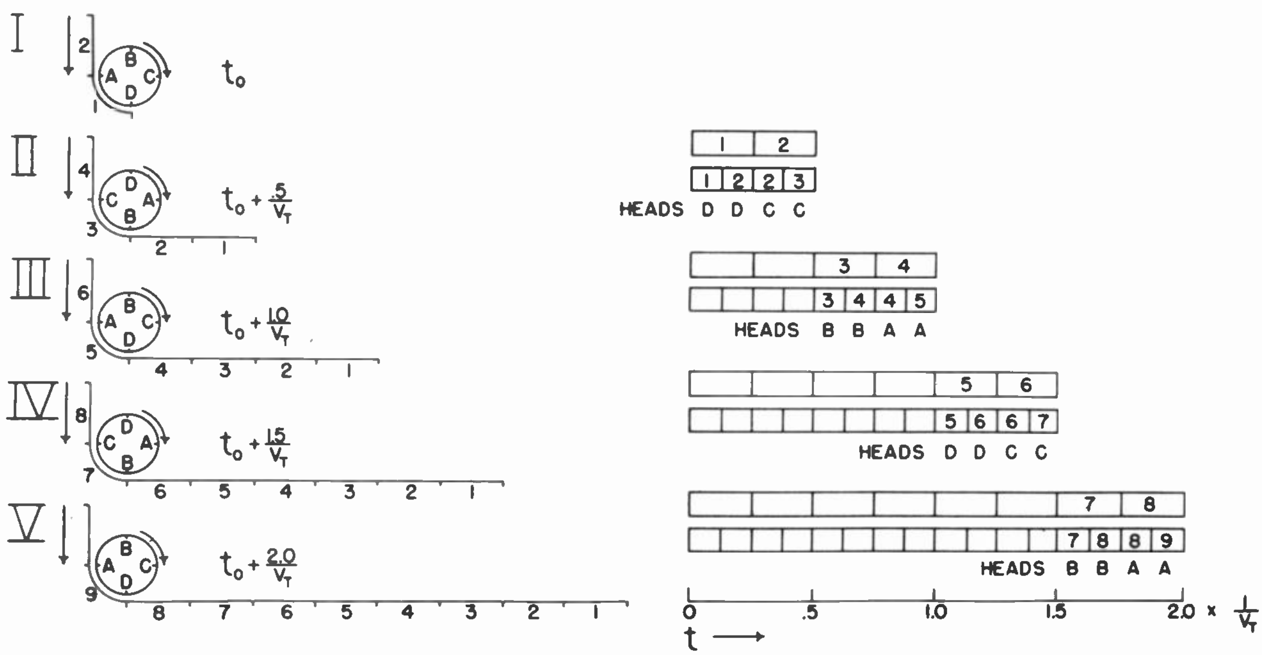

Fig. 4 – Expansion process.

Since the effective tape velocity has been increased by the opposite movement of head and tape, frequency multiplication has been incurred. The original frequencies are restored by reproducing the processed message in an appropriately longer time. One hundred times the amount of time thus added divided by the original time is the *expansion percentage*. In the diagram this equals 100 per cent.

Fig. 5 summarizes the various stages in compression. The comparative times and frequencies are indicated at the bottom. In an original time T_O and with original frequencies f_O, the input is recorded on the loop at the velocity V_T and scanned by the revolving head unit moving in a positive direction at $V_T R_C$. This yields the compressed frequency f_C shown at the bottom. Simultaneously the compressed signal is stored at a recording tape velocity which will be taken as V_R. This recording is reproduced at a later time at the higher tape velocity shown, in the relative time indicated, and with f_O restored. The following recordings will illustrate this.

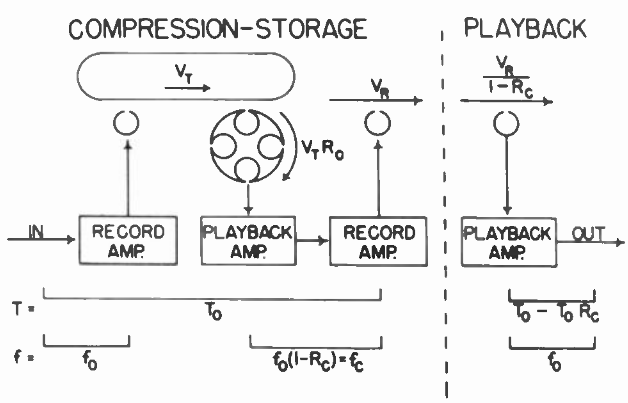

Fig. 5 – Method of time compression.

In this and the other recordings you will "hear" repetitions of a semi-nonsense test sentence which provides a rigorous test of the system. The sentence contains one and only one example of every American phoneme, with exception of the unstressed neutral vowel as in the first syllable of the word *away*, which occurs three times.

'Recording 1. Compression. Original message: We hasten the boy off my garage path to show which edge young owls could view. Frequency division 1.25. No time compression. Sampling frequency 10: (sentence). Time compression 20%: (sentence). Test out.'

Next you will "hear" the perceptual effects of various degrees of compression.

'Recording 2. Time compression series. Sampling frequency 10. Compression 10%: (sentence). Compression 30%: (sentence). Compression 50%: (sentence). Test out.'

'Recording 3. Time compression series. Sampling frequency 20. Compression 50%: (sentence). Compression 70%: (sentence). Compression 90%: (sentence). Test out.'

You will have noted that the smaller values of compression affect intelligibility and perceived speed of talking very little. Although both factors are perceptibly affected as compression is increased, you can observe that intelligibility persists with surprisingly large compression percentages.

sound. This occurs when the interval repeated exceeds the duration of one phoneme. This is a size limitation in our experimental model and not a limitation of the method.

Fig. 7 shows a system which involves the following: (1) compression, (2) transmission of the compressed message, (3) expansion of the compressed message. The steps are carried on simultaneously with two units. A transmission link, undiagrammed, is inserted between the two at the arrow. Velocities, times and frequencies are labeled.

The process is illustrated in the next recordings. First you will hear the original message. Then you will hear the transmitted message with frequency division. Finally you will hear the message as received after reconstruction by means of expansion and corresponding frequency multiplication. Eighty per cent of the message was discarded before transmission and the final message

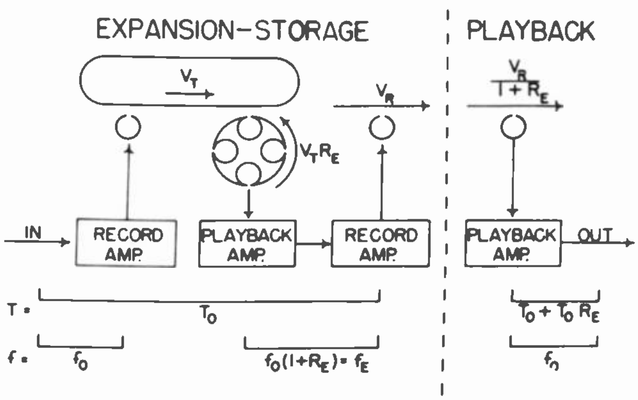

Fig. 6 – Method of time expansion.

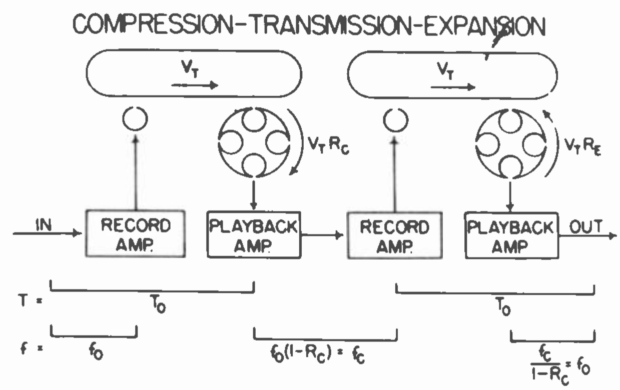

Fig. 7 – Method of frequency compression – transmission – expansion.

Fig. 6 is a similar diagram for speech expansion. Head movement is negative with respect to the tape, and equals $V_T R_E$. In the original time the original frequencies are multiplied by 1 plus R_E, yielding f_E as stored. The message is then reproduced at the lower velocity shown, f_O being restored with the time expansion. The next recording illustrates the three stages.

'Recording 4. Expansion. Original message: (sentence). Frequency multiplication 1.2. No time expansion. Sampling frequency 10: (sentence). Time expansion 20%: (sentence). Test out.'

We will now illustrate the perceptual effects of expansion. The expansion percentage will be progressively increased.

'Recording 5. Expansion series. Sampling frequency 10. Expansion 10%: (sentence). Expansion 30%: (sentence). Expansion 50%: (sentence). Test out.'

'Recording 6. Expansion series. Sampling frequency 33.3. Expansion 50%: (sentence). Expansion 70%: (sentence). Expansion 90%: (sentence). Test out.'

Note that small percentages did not affect the perceived speed of talking very much, and that the details of speech became more readily heard as expansion increased. Toward the end you may have heard an echo-like

as you hear it was reconstructed from the 20 per cent fragment that remained. To help you appreciate the last point we will also "play" at the end a recording in which the original frequencies are restored by accelerated playback without time expansion.

We present this next recording with some hesitation and we hope you will not be disappointed. It was made on an experimental model of the device. Its main purpose is to validate the theory and demonstrate potential feasibility. (You will "hear" considerable noise and distortion. Some of this can be eliminated fairly readily, but part of it is inherent in the method and will need to be counteracted.)

The important thing, however, is that the final output is intelligible at all when bandwidth reduction is by a factor of 5 and compression is 80 per cent.

'Recording 7. Compression – transmission – expansion. Original message: (sentence). Transmitted message. Original time. Frequency division 5. Sampling frequency 60: (sentence). Restored message. Original time. Frequency multiplication 5. Sampling frequency 16: (sentence). Time compression 80%: (sentence). Test out.'

Apart from its theoretical interest, the method appears to have several practical applications. For one thing, the smaller compression and expansion ratios should be useful in the programming of rebroadcast speeches in radio, since they furnish 'tailormade' time without the audience's knowledge. A saving of 10 minutes per hour is completely realistic. Conversely, and we advance this suggestion with diffidence, thinking of commercials, more intelligence can be communicated to an audience in a given amount of time.

Straightforward compression by larger amounts should be useful wherever high-speed communication is crucial, as in certain military situations. Expansion should facilitate branches of study such as experimental phonetics and linguistics where auditory analysis is important.

Finally, of course, the method gives promise as an approach to the long-standing problem of bandwidth reduction.

In conclusion we should like to "play" two more recordings. The first of these is self-explanatory.

> 'Recording 8. In order to demonstrate that the method is inherently practical, the recorded explanatory materials in connection with the recordings that you have heard today, as well as these words that you are hearing now, were all compressed by 10%. Test out.'

We are frequently asked if the method applies to women's voices, fast articulation, or music. The next recording illustrates its use with all three.

> 'Recording 9. Vocal music. Rosemary Clooney. *Come On-a My House.* Columbia record Number 39467. 78 rpm, shellac. Compression series. No time compression: (music). Compression 30%. Sampling frequency 20: (music). Compression 60%. Sampling frequency 40: (music).'

The final recording shows the effect upon music which has already been processed to make it ultra-fast. In the first section you will hear a portion of the original. The second section demonstrates 30 per cent compression.

> 'Recording 10. Compression series. Les Paul. *Lover*, by Rodgers and Hart. From Capitol LP record Number H226, *The New Sound.* No time compression: (music). Compression 30%. Sampling frequency 20: (music). Test out.'

A DEVICE FOR TIME EXPANSION USED IN SOUND RECORDING*

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In volume three, 1948, of *Funk and Ton* there was described a device for finding certain recorded sound elements on recorded tape. To do that, the tape was usually standing still and the playback head was rotating. Gunka and Lippert have mentioned that this kind of device could be used not only for editing but also for sound analysis. Actually an article was found in American technical literature where a similar device was used for a tape recorder which was very similar to the German "Magnetophon".

The magnetic tape recorder "Magnetophon-Special" produced by AEG used rotating heads. That recorder was developed at the beginning of the last war and manufactured on a large scale. In that recorder, the time expansion device was called a "Zeitdehner". The basic principles will be discussed further in this article.

Modulated recording mediums for different sound recording systems, such as disc, film or tape, never hold the recorded frequency by themselves. By measuring the distance between two maximum groove amplitudes, or maximum opaque for film, or maximum magnetization on tape, we can determine the wave length λ For the frequency, we have to know the velocity for the recording medium

$$f = v/\lambda \qquad (1)$$

Usually the velocity for recording medium remains the same in the recording and playback processes. Any unwanted change in velocity, caused by speed variations will cause variations in the reproduced sound pitch.

By increasing the speed of recording medium carrying a recorded message, we can transmit the message more cheaply, because the time is reduced to use cable line and the charge will be less. Furthermore, there will be a need to slow down recorded dictation for the typist. By slowing down the speed in the usual fashion, the intelligibility will be changed and it would result in a complete misunderstanding.

The velocity v in (1) represents the relative velocity between recording medium and recording or playback head element. Usually, the recording or playback head will not

EDITORIAL NOTE. – Because of the widespread interest in the preceding paper by Fairbanks, Everitt and Jaeger, and related work in this country, a translation has been made of a German paper by Dr. H. Schiesser which appeared in *Funk Und Ton*, vol. 3, no. 5; 1949. This translation is published with the permission of *Funk Und Ton.* The illustrations have been reproduced from photostatic copies *of the original publication.*

be in motion. Gunka and Lippert described a device where the recording medium stands still, and the playback head element moves.

In general, it could be arranged that the recorded medium and the playback head element both are in motion. Velocity for the recorded medium is v_t and for playback element v_a. Recording done by a relative velocity v will give us the same pitch in playback at *two* different velocities for the recording medium, depending on the relative direction of motion between medium and playback head element.

$$v_t = v \pm v_a \tag{2}$$

As long as the pitch in playback is determined by the relative velocity between recording medium and playback head, the tempo by which the recorded information can be reproduced is determined by the velocity of the playback gap moving along the recording medium.

From a design standpoint, the playback gap striking area on tape is determined and the tempo for reproduction depends upon the speed of the recording medium.

Expanded playback requires diminishing the velocity of recording medium v_t with respect to velocity that was used in the recording process. To simplify the problem, a stationary head was used in the recording process, and in that case the velocity for recording medium is equal to the relative velocity between medium and recording device.

The expansion factor will be

$$d = v/v_t \tag{3}$$

The above-mentioned relation represents the ratio between the time for recording and reproduction.

For d smaller than 1, it appears as a time compression. Fig. 1 curves, where, by a chosen certain amount of compression or expression d, there can be found the corresponding velocity for recording medium in playback and the two velocities $\dot{v}_a$ for the playback head rotational motion, to get the same pitch as it was recorded.

The resulting velocities will be multiples of the recording velocity V. Only in one special case $d = 1$, the motional velocity for the gap along the medium will be the same as the relative velocity between medium and playback device. And only in that case is it possible to have uninterrupted continuity in playback. It can be seen that a time compression in playback by keeping the original pitch, could be done only by partially sampling the recorded information from the tape. For time expansion we have partly to overlap the recorded information by our playback gap striking area or by introductory interruptions. By introducing interruptions or by repeated (overlapped) reproduction, the samples of the separate recorded signal elements and the interruptions should be short so as to avoid introducing too much discontinuity so as to be out of range where human hearing system distinguishes sound separations. That principle used here is similar to human optical inertial that is encountered in moving pictures.

The interrupted "take off" procedure is done periodically by using a rotating or oscillating scanning device. The disc recording is rather difficult, but it is easier in magnetic or photoelectric recording.

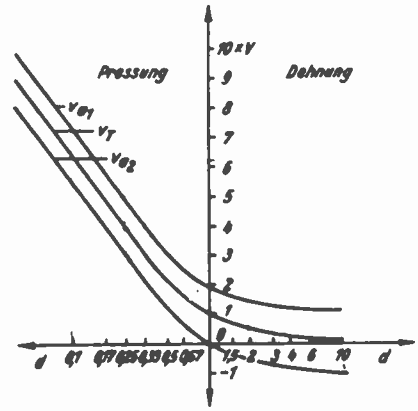

Fig. 1 – Velocity for recording medium v_t and the playback device v_a as a multiple of velocity used by recording vs. compression expansion factor (d).

The gap must move periodically along the recording medium at a velocity v_a and displacement h. At the end of determined displacement h, the gap must jump back to starting point and repeat the same procedure. By photoelectric recording, that motion can be reached by using a rotating spiral opening in the path of the light beam.

For magnetic tape recording, it is more convenient to use a rotating device with many gaps distributed around a rotating drum.

The wrap angle for tape around the playback head with n number of gaps, must be wider than $2\pi/n$ and there must be provisions that allow only one effective gap in contact with the tape in this sector.

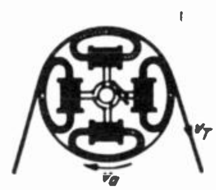

Fig. 2 – The basic principles of a rotating device, using four heads 90° apart and electric current commutator.

Fig. 2 represents the rotating head arrangement for AEG tape recorder. There are four independent heads mounted on a base. Every one is a closed ring head by Schuller with a proper gap and core made of high permeability material. Magnetic potential developed in the gap creates an EMF in the coil. The lead ends from coil are going to a collector lamination, and then from collector to the input of playback amplifier. By this collector arrangement, after 90° rotational displacement of the gap, the point of pickup returns to the beginning of the sector. The very low current through collector causes some troubles, and that is why a "magnetic switching" arrangement will be better. (The induced voltage into the coil is around 1 mv).

Fig. 3 represents this so-called "magnetic switching" device basically. This in rotational motion is only a cylinder made of hi-μ material. The cylinder or drum has four gaps distributed evenly around this surface. The magnetic flux lines come from the effective gap through a part of the drum, and then by the shortest path through a wide overlapped gap into the pole piece with the coil.

The playback effective gap displacement h will be the distance between two gaps. For one playback element

Fig. 3 – The basic principles of rotating playback head by using four playback gaps 90° apart and magnetic commutator.

the distance that the effective gap strikes the medium is L. L is different from h, because the tape is in motion.

$$L = hv/v_a \qquad (4)$$

The sequence for separate "picking ups" for the two corresponding spots on the tape will be e.

$$l = hv/v_a d \qquad (d = \text{compression-expansion factor})$$

For $d = 1$, $L = l$, indicating that the distance between two corresponding spots contacted by two sequentially following "picking-ups" will be the length of the partial element on tape. The playback will follow with an uninterrupted continuity. For d smaller than 1, (meaning time compression) there will be introduced dead spots between two played back elements. For d larger than 1, (meaning time expansion) there will be overlaps of played back elements; every separate spot on tape gets reproduced d-times.

Fig. 4 represents time-displacement diagram. The horizontal axis represents the displacement of the playback gap on the recorded medium. An example will be for $d = 4$, and $d = 0.5$, the playback head is rotating in one direction for one diagram and in the opposite direction for the other diagram. The gap displacement h is in both cases the same. The projection of arrows on horizontal direction will represent the length L by which the playback gap strikes the tape. The distance between the arrow points will represent 1. The slope of the arrows is reversed proportional to the velocity v_a of the playback device. The slope of the center line of arrows is revised proportional to the velocity v_t of the recording medium. As it can be seen from examples on b and d, the separate elements get played back reversed since the motion of medium and playback device are in the same direction. That way we get larger amounts of separate short elements; by using an opposite motion for the head and tape, there will be less separate elements, but longer.

The number of elements will be greater when d is smaller. To get a better continuity for listening, the separate elements should be many and small, and that is why for time compression it is necessary to have the same motional directions for both the medium and the playback device. In that case, the separate elements get reproduced backwards, but that doesn't matter since the elements are small enough.

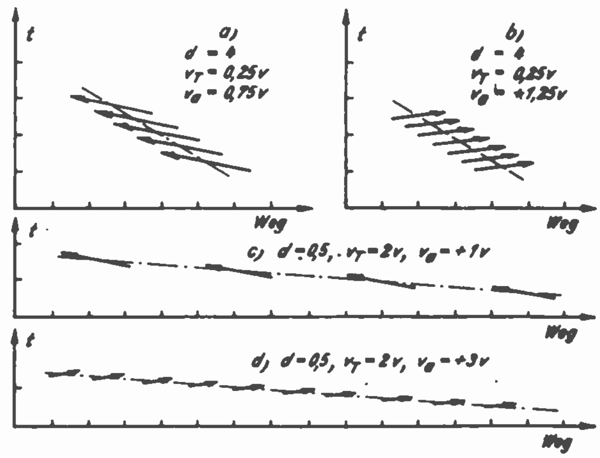

Fig. 4 – Time-displacement diagram for interrupted playback for $d = 4$ (expansion) and $d = 0.5$ (compression) for both velocities v_a for the playback device.

A tape recorder with rotating head assembly for the most unfavorable condition in playback which was represented in Fig. 4, diagram b, and uses a gap displacement $h = 2.5$ cm and recording tape speed of 75 cm/sec. The separate element length in playback is $L = 2$ cm. That corresponds to a 26.6 millisecond recording or it will be ⅛ syllable.

That length of the separate element is short enough to give us a sufficient continuity in playback and the elements could be played back backwards without introducing noticeable distortions.

By the above discussed example, 38 elements per sec. were played back with the listener having the impression of discontinuity. It is supposed that much greater expansion would not be necessary in general use. For special occasions where we have to use a much greater expansion, the tape speed has to be increased in recording.

CONCLUSIONS

The previously discussed article should explain the problems in using an expansion or compression for sound recording. This process is possible in the present recording systems used for magnetic or photoelectric recordings. The time expansion or compression is used for dictating machines, for more economical use of cable lines in communication and for scientific purposes especially for phonetic research.

MECHANICAL COMPONENTS FOR HANDLING MAGNETIC RECORDING TAPE*

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GENERAL DESIGN OBJECTIVES

The object of this paper is to discuss all the component elements in the tape path which contribute to the tape handling and to the characteristics of the recording which are dependent, to a great extent, upon the mechanical tape transport unit.

The objective of the design of a mechanical tape transport is to provide means of storage for magnetic recording tape both before and after recording and to translate the tape uniformly at a controlled and even speed past a point where the tape may be erased, recorded or reproduced. An additional design objective is to provide such flexibility of mechanical design as to allow fully automatic control when desired, and to incorporate safety features and means for remote control. The result of the mechanical design should yield safe mechanical and environmental conditions for the magnetic recording medium.

GENERAL MECHANICAL CONFIGURATIONS

One of the usual tape transport configurations is shown in Fig. 1 as a bare panel view, and in Fig. 2 as a completed unit. The tape pays off from one reel, passes over a non-rotating alignment guide which is combined with a spring loaded compliance arm, then passes over a tape stabilizer roller before being fed to the head assembly where the erasing, recording and reproducing are done; following the head assembly, the tape is pulled and its motion metered by passing between the capstan driven at a constant speed and a pressure roller with a rubber rim; following the capstan tape puller, the tape is fed over another non-rotating tape guide combined with a compliance arm and fed to the take-up reel.

In some tape machines, the capstan is placed at the input to the head assembly. Either arrangement may be used except that it is believed some inherent advantages accrue in having the capstan beyond the head assembly as follows: 1) Should the tape break beyond the capstan or should the tape take-up reeling mechanism fail, the recording may be safely made even though the tape piles up on the floor. A floor pile-up of tape may be readily cleared by reeling the tape up carefully without disturbing the pile. 2) A faster start is possible with a tape puller. The pressure roller may be engaged with the continuously moving capstan, thereby bringing the tape from standstill up to its normal speed in less than a tenth of a second.

The compliance arm following the tape puller is used to take up the momentary starting slack until the take-up reeling mechanism has a chance to get started. Some machines use a transient surge of power in order to overcome the reel starting inertia and to prevent throwing a tape loop during the starting period.

TAPE STORAGE MECHANISMS

The most generally used form of tape storage is that of a simple reel. Other means of storing tapes are: 1) by passing the tape over a number of spools which may be distributed about a panel, or 2) by feeding the tape into a tape tank just wide enough to receive the tape and within which tank the tape makes a number of folds back and forth upon itself. The tape is usually fed from the top and pulled out from either the side or bottom of the tank. 3) by using a spiral endless loop device where each layer of tape slides on the adjacent layer. These devices are utilized in endless loop service wherein it is not required to store the length of tape required in the usual recording operations. Their application is limited to tape lengths of several hundred feet.

TAPE REELING MECHANISMS

The storage of tape on reels is the usual mode of operation in most recorders. Nationally, we have standardized upon 7", 10½", and 14" diameter spools. It is to be

*Manuscript received November 26, 1953. This paper was delivered at the Department of Defense Symposium on Magnetic Recording, October 12-13, 1953, Washington, D.C.

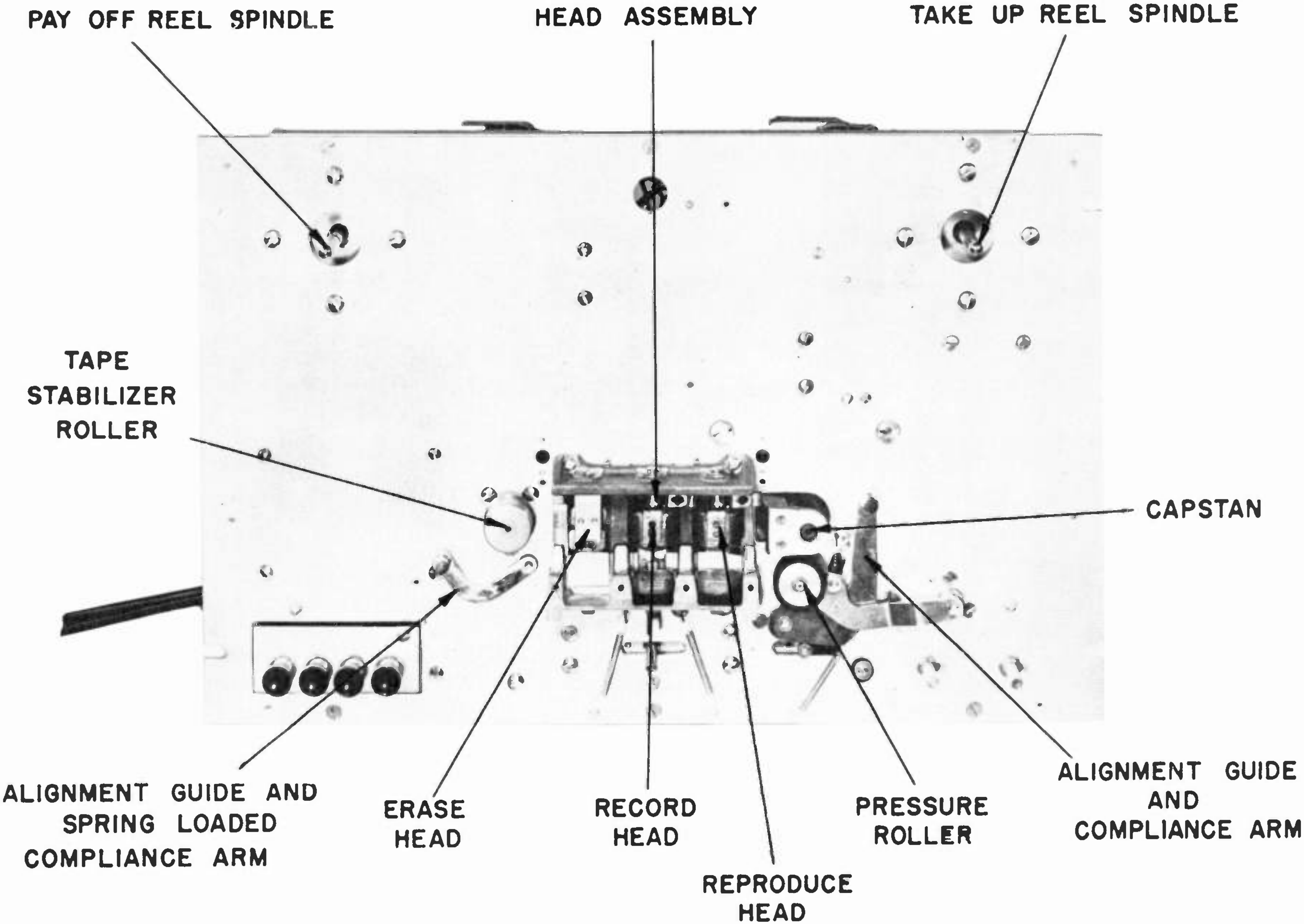


Fig. 1 – Tape transport – bare panel view.

noted that the position of the drive slots in the reels have been the subject of tacit national standardization in order to obtain reels which are interchangeable between tape machines. The most common tape width is, of course, ¼" at the present time.

In the usual design of tape handling mechanisms a spindle is provided with a fixed flange onto which the tape reel can be slipped. The reel spindle is usually mounted on some sort of bearing assembly behind the front panel of the recorder and may be attached directly to a torque motor shaft to save the cost of extra bearings. The spindle shaft is controlled in one of several ways in order to put either back or forward tension upon the tape for pay-off and take-up reels respectively. This holds the tape taut with from 2 to 8 ounce tape tension so that it does not flop loosely over the recording heads.

There are three basic reeling control means in use at the present time. 1) Friction disc clutches which are adjustable in order to control the spindle drag and consequently the tape back tension. The usual felt-to-brass clutch is designed from the formula

$$T = FN \frac{(r_1 + r_2)}{2} \mu .$$

where T = torque
F = axial force
N = number of clutch surfaces
μ = coefficient of friction = .3 for felt against brass
r_1 and r_2 = the inner and outer clutch radii

2) Torque motors, (Fig. 3), operating at full voltage during high speed reeling and at reduced voltage during normal forward operation of the machine in order to provide both back torque and forward take-up torque; motor braking for the pay-off reel may also be applied by means of energizing with dc the windings of an ac motor.

3) Servo-controls which operate through servo motors or magnetic clutches. These latter are the more elaborate and costly systems, and operate through sensing tape tension and correcting the reel torque accordingly.

Fig. 2 – Tape transport completed – panel view.

These schemes have been used to obtain essentially constant tape tension. It is to be noted that in the first two of the three control modes mentioned above, constant torque rather than constant tape tension is obtained. It should also be noted that the true design objective is to obtain constant tape tension over the magnetic record/reproduce heads, and thus maintain a minimum disturbance to the capstan pull so that minimum flutter or wow result. The tape tension force F is related to the torque, of course, by the simple formula:

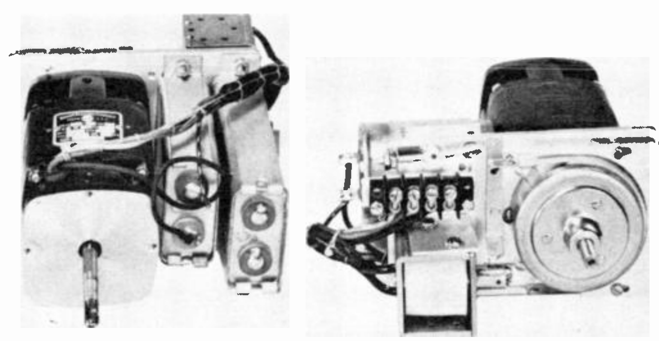


Fig. 3 – Bi-directional torque motors with condensers and band brake assemblies.

$$F = \frac{\text{Torque}}{\text{Radius of tape pay-off}}$$

Since the torque is essentially constant with either torque motors or any other good constant torque device, it will be seen that the tape back tension varies as the ratio of the outer reel to the tape hub diameter. The tape back tension desired is usually in the neighborhood of 2 to 8 ounces and the tape take-up tension about 6 to 20 ounces. Typical torque motor curves are shown in Fig. 4.

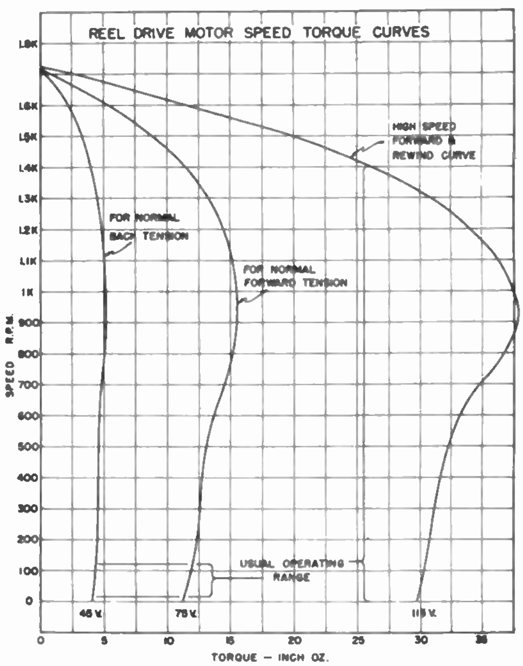


Fig. 4 – Typical torque motor speed-torque curves.

In most commercial tape reels today, an effort has been made to minimize this diameter variation. Maximum to minimum tape pay-off ratios are now usually held to approximately two to three, although a few years back this ratio was as high as five. (See Fig. 5.) To date, no really satisfactory simple automatic mechanical device has been devised to compensate for this diameter change. In the motion picture industry, where large diameter ratios and heavier, wider "tapes" are used; tape follower arms have been installed which continuously measure the diameter of the reel and adjust the reel torque accordingly to obtain essentially constant tape tension. When ¼" wide tape is used, mechanical clearances are such that this device is tricky to use. The fragile nature of the ¼" wide tape, only .002 thick, also militates generally against the use of the mechanical follower arm. Devices depending on the weight of the tape to determine tape tension have also been used, but for only vertical operation of the machine.

High quality professional machines may use any of the three reeling control methods listed above, but it is felt that the simplest and most dependable method of reel control is through a torque motor.

NOMINAL REEL SIZE	LATEST REEL DIMENSIONS			ACTUAL PLASTIC TAPE LENGTH	PLAYING TIME	
	TAPE I.D.	TAPE O.D.	O.D./I.D. RATIO		7.5"/SEC.	15"/SEC.
7" O.D.	2 3/4"	6 7/8"	2.5	1250 FT.	30 MIN	15 MIN
10½" O.D.	5"	10"	2	2500 FT.	60 MIN	30 MIN
14" O.D.	5"	13 3/4"	2.75	5400 FT.	120 MIN	60 MIN

Fig. 5 – Present day reel pay-off ratios and playing time.

When a motor is used, the torque characteristics through every degree of rotation of the motor are important since it is desired to maintain constant tape tension independent of the angular position of the reel. Some problems have been encountered in this respect since it has been found that motors may be built for "constant" running torque, but that during slow speed operation (15 to 60 RPM) within one revolution the torque may vary as much as 25% in extreme cases. In one investigation of a quantity of torque motors, it was found that variations in the air gap and in the electrical properties of the rotor caused motor torque variations within one revolution as shown in Fig. 6, Curve A. In a cooperative program with a motor manufacturer, this torque variation was reduced to that shown in

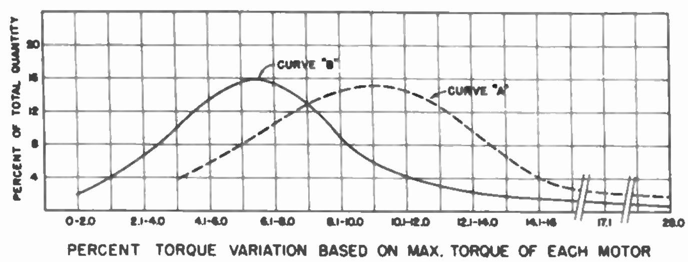


Fig. 6 – Torque motor torque variation within one revolution before (A) and after (B) quality improvement.

Fig. 6, Curve B. The effect of the high torque variation was to insert a flutter rate, which is to say, a tape speed variation rate in the order of one or two cycles per second. Reduction of the torque variation was sufficient to improve recorder performance appreciably and to allow other tape handling elements to further improve the constancy of tape speed.

TAPE STABILIZATION AND MOTION FILTERING

The tape stabilizers located on either side of the head assembly form a portion of the filter system which prevents any reeling or reel mechanism irregularities from affecting the smoothness and straightness of tape travel over the heads in order to hold flutter and signal drop-outs to a minimum while maintaining adequate tape wrap around the head gap magnetic structure to obtain good low frequency response. These stabilizers take the form of flywheel loaded pulleys over which the tape passes. The tape wrap around these pulleys must be made sufficient so that, with the tape to pulley surface coefficient of friction, no slippage can occur in normal operation. Further, one of these inertia or flywheel loaded pulleys (preferably the one following the heads) is utilized as the main tape drive element and is therefore designated as the capstan which is motor driven either directly or through some speed reducing means. Both the stabilizer roller and the drive-motor-stabilizer assembly require close tolerance precision honed-oilite (±.00015 dia. tolerance) or precision ball bearings. It becomes of importance to remove heavy flywheels during shipping in order to avoid Brinelling of the bearing races or bending of the flywheel shafts, which could cause flutter later.

Typical tolerances on a capstan with a nominal diameter of .2367" moving at 600 rpm to achieve 7½" per second tape motion are as follows: diameter tolerance ±.0002; run-out tolerance ±.00005. Such accuracies assure 7½" per second tape speed flutter below 0.15 per cent and tape timing with an accuracy of ± 3 seconds in one-half hour of recording. The other flywheel loaded pulley is driven by the tape itself.

If A~C~ torque reeling motors are used, it is the usual thing to expect a certain amount of 60 cycle and 120 cycle hum to appear in the tape tension. The stretch or compliance of the tape between the tape reel and the spring loaded compliance arm acts with the tape stabilizer inertias to absorb this 60 cycle and 120 cycle variation in tape tension, and to completely eliminate this effect from reaching the head recording area.

Examining the tape, the tape compliance arm and both stabilizers as a filter, it may be said that we have a low pass filter. It is desirable to push the filter cut off down to as low a frequency as is practicable, considering the physical size of the flywheel used in the stabilizer. This is desirably below one cycle and in practice can be easily held to about ¼ to ½ cps. An illustrative calculation follows:

Considering the pay-off reeling mechanism, both stabilizers and the first compliance arm for a practical case, we then have:

$$F_R = \frac{1}{2\pi\sqrt{IC}} \text{ and } C = \frac{\theta}{F}$$

where

F_R = low pass filter resonance (near cut off) frequency in c p s

I_1 = tape driven stabilizer rotary inertia

$= \frac{wt}{2}(R^2 + r^2)$

$= 2.47 \times 10^{-4}$ slug ft²

I_2 = motor driven stabilizer inertia

$= 2.25 \times 10^{-3}$ slug ft²

C = equivalent arm compliance

ϕ = arm deflection in radians = .75 radians

F = arm deflection torque $= \frac{1}{192}$ lb ft.

Then for the tape driven stabilizer:

$C = .75 \times 192 = 144$ radians per lb ft

$$FR_1 = \frac{1}{2\pi\sqrt{.000247 \times 144}} = 0.85 \text{ cps}$$

This cut-off frequency filters out the 60 cps and 120 cps flutter components. The tape couples the motor drive stabilizer to the driven stabilizer so that even lower frequencies are filtered out by the combination of both stabilizers:

$$F_R(1+2) = \frac{1}{2\pi\sqrt{.000247 + .00225) \times 144}}$$

$$F_R(1+2) = 0.267 \text{ cps}$$

This last value is very satisfactory. The actual mechanical arrangement and simplified electrical analogue is shown in Fig. 7.

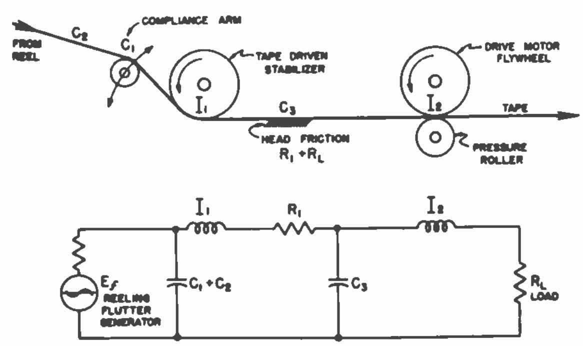


Fig. 7 – Tape transport simplified mechanical-electrical analog schematic. Hi-frequency flutter source at heads neglected.

Present day professional tape recorders are capable of maintaining flutter between 0.05 and 0.3 per cent. The weather may actually enter into the flutter performance of the tape recorder, since stickiness of the tape affects its travel over the heads and other elements in the tape path. Tape is both thermoplastic and humidity plastic. Sticky tape may cause chatter, which is to say variable speed or flutter.

TAPE DRIVES

Over the years that recordings have been made on a moving medium, various driving methods have been used. The modern tape recorder draws from all previous experience and knowledge and has used many various drives and speed reducers. Since for speeds below 600 rpm, overly large motors are necessary, it is desirable to have the drive motor running at 600 rpm or some speed in excess of 600 rpm. A speed reducing scheme is then normally used in order to obtain adequate capstan torque and the low speed from a small drive motor. Standard motor speeds used have been 600, 900, 1200, 1800 and 3600 rpm. General practice has established about 5 pounds available capstan pull to do a satisfactory tape driving job. The actual average pull on the tape is much less than this, about 6 to 8 ounces.

For a professional or industrial type recorder, it is usual to select a synchronous drive motor in order to minimize actual tape speed errors. Since tape has no sprocket holes to eliminate slippage, the design philosophy is to make all other parts of the drive mechanism as accurate as possible, thus making the major speed error that of the actual physical tape slippage itself. In the smaller fractional horsepower ratings a straight synchronous motor is not too efficient insofar as physical size, starting torque, and running torque are concerned. Therefore, the trend has been toward the use of hysteresis synchronous motors in designing these mechanisms. Hysteresis synchronous motors have the drawback of running hottest when lightly loaded, thus making heat dissipation a problem.

Speed reduction methods that have been used (see Fig. 8) are:

(a) Gear reductions with their usual complications of gear tooth modulation and worm irregularity modulation. These effects can be minimized in design by the use of helical gears and by using multiple thread worms. Gears and worms are difficult to handle, insofar as flutter elimination is concerned, because they generate low frequency flutter which most easily passes through the low pass filters discussed previously under TAPE STABILIZATION and MOTION FILTERING.

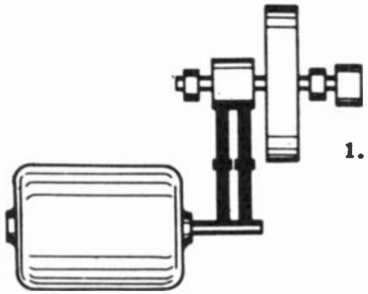
(b) Puck speed reducing systems, where a rubber rimmed puck reduces the speed between the motor shaft and a driven hub, which in turn directly drives the capstan and reduces the motor speed in the ratio of approximately the drive motor shaft diameter to the drive hub diameter. This puck reduction in speed must be corrected for an error which is the result of the difference of indentations in the rubber puck by the drive motor shaft, and the larger driven hub shaft. The puck is maintained at the normal puck optimum wedge angle of 114°. This angle is that which is sub-tended by the driven hub and motor shaft with the puck hub considered as the apex of the angle. Absolute looseness of the puck support is essential in order to assure self-centering action with its resultant uniform drive. Some recorders use two parallel pucks in order to assure uniformity of drive. A special form of puck may be used which is essentially a rim drive. The puck effect is obtained by putting a rubber rim around the driven hub and resting the drive motor shaft against this rim. An alternate system is to place a small rubber drive tire around the motor shaft, which in turn rests against a solid driven wheel. This latter configuration is not as satisfactory as the others because the speed error is greater in this case due to the rubber indentation in the small motor roller causing a greater error than a similar size indentation in a larger driven hub.

(c) A toothed compliance belt, which is an efficient and accurate speed reducing means, but which produces flutter within itself at both the belt rotation rate and the belt tooth rate. It is then necessary to utilize a mechanical filtering system beyond the driven hob to eliminate these two flutter rates. This system is somewhat more complex and more difficult of deriving satisfactory results than those previously mentioned.

(d) An endless woven flat belt. Due to the compliance of such a belt, this method is ideal insofar as it eliminates flutter components which might come from the motor. However, because of the vagaries of woven materials and because of belt slippage, the belt drive average speed control is not as precise as some of those previously mentioned. In the usual professional machine wherein high accuracy of tape timing is desired, it is then necessary to evolve a more complicated drive speed control system wherein servo elements are used to control or meter the tape. This is usually handled through recording of a standard control frequency on the tape so that when it is played back, the reproducer can be controlled to play with exactly the original timing. This standard recorded control signal has taken the form of superimposed 60 cycle modulation, a high frequency carrier 60 cycle modulated, and printed patterns on the reverse side of the tape from the oxide surface.

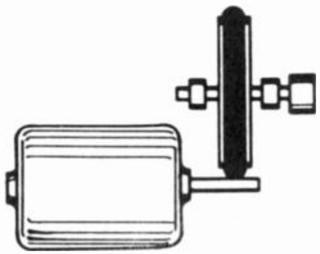
(e) A direct drive system wherein the tape is driven directly by an accurately ground area located on a shaft extension of the motor. This is perhaps the simplest accurate drive system possible, but requires careful design in order to reduce the flutter effects caused by shaft run out, bearing and housings tolerances, and vibration due to being directly coupled to the motor. This design is capable of good results if as low a speed motor as is practicable is used to prevent reducing the tape drive diameter of the capstan to too small a physical size. Experience has shown that diameters below approximately 0.2 inch should not be used. Too small a drive diameter is not only physically weak and subject to bending to

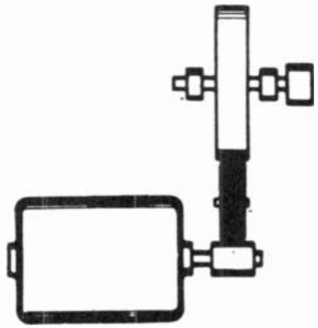
RUBBER INTERMEDIATE IDLER ROLLER OR PUCK REDUCERS



1. **CAPSTAN HUB SHAFT DRIVE (Used in Magnecorder PT6-A)**

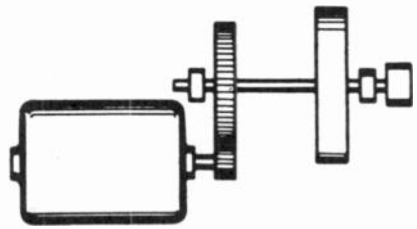
Two independent pucks drive hub on capstan shaft . . . permit full flywheel action to minimize flutter. Provides constant contact and least possible slippage.

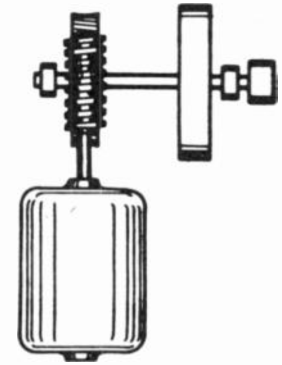




2. RUBBER TIRE FLYWHEEL DRIVE **3. FLYWHEEL RIM DRIVE**

GEAR REDUCERS

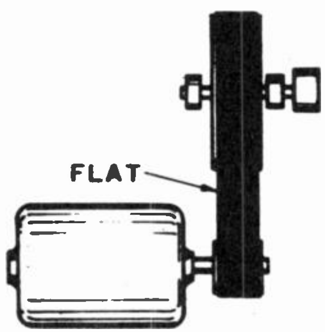


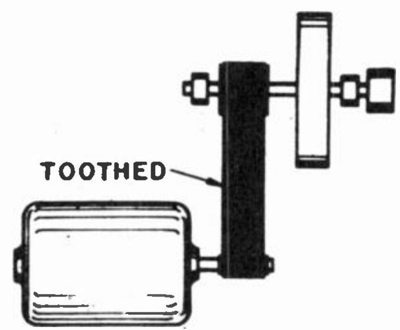


SPUR, HERRINGBONE OR HELICAL GEAR DRIVE

WORM AND WORM GEAR DRIVE

BELT REDUCERS





1. FLYWHEEL RIM DRIVE (BELT) **2. CAPSTAN SHAFT HUB DRIVE (BELT)**

Fig. 8 – Speed Reducer Systems.

cause flutter, but should any oxide deposits from the tape build up on the capstan, their effect in speed deviation (once per capstan revolution) is greatly exaggerated.

TAPE GUIDANCE

Proper tape guidance first assures uniform wind on both take-up and rewind reels. Secondly, it assures the tape of a uniformly straight linear motion with no snaking or side to side motion over the heads. Since ¼" tape is normally held to slitting width tolerances of +0 -.002 inches, it is seen that the slot or guides which control the tape movement from side to side may be fairly accurate. Too much control, that is to say, too tight a pressure on either side of the tape will result in tape buckling so that an added means of flutter could be induced in a machine or poor tape contact with the heads might be obtained.

It is usual to establish the compliance arm tape guides to control reel winding and in addition to use some means in the head area to achieve control over the tape movement from side to side. Tape slither or skating from side to side causes the tape transverse axis to be no longer parallel to the longitudinal axis through the head area (to which the head gaps are aligned at 90° during the so-called azimuth alignment). This, of course, results in momentary head to tape misalignment so that high frequencies are not reproduced at normal amplitudes. In some cases where tape is not properly controlled, the high frequency output near the upper limit of the tape recorder may vary as much as 20 or 30 db. This amplitude variation should be held to one or two db at the most. Surface and contour squareness of recording heads, pulleys, guides, etc., are critical in order to minimize tape skating.

CONTROL FEATURES AND MISCELLANEOUS

The control features of a recorder are aimed at making all conditions of tape travel as automatic as possible so that they are completely controlled by the transport with a minimum of control effort expenditure by the operator. Thus, after loading the machine with tape, the operations of normal forward, high speed forward and high speed rewind, should be available to the operator at the touch of a button. This requires mechanical linkages, relays, solenoids, etc., in order to provide for fail-safe operation and safe handling of the tape under all conditions without tape breakage.

Some means of keeping the tape under constant tension between the reels must be built into the machine not only in normal and high speed operations, but under braking conditions from high speed to stop as well. This requires that torque differences for all conditions of operation be established between the take-up and pay-off reels and particularly during the stopping conditions from high speed operation. This latter problem may be solved either by dynamic braking or mechanical braking of the pay-off reel at a slightly higher rate than the take-up reel.

The mechanical braking can be achieved by making use of the differential braking of a band brake. One end of the band is fixed while the other end is moved by either a mechanical or electrical device to apply braking. A fail-safe method is to operate the brake with a spring arrangement and to release it with a solenoid. This provides safe braking of the machine should the power fail, as well as providing for normal operation. (Fig. 3) A 180° band, felt lined, ½" wide brake of 2¾ inch diameter can provide a direction differential of 4 in. oz. with 7 in. oz. and 11 in. oz. total braking torque in the two directions of rotation respectively.

Another essential control feature of a tape transport is to lift the tape clear of the heads during high speed forward or rewind operation in order to save wear on the heads and tape. This may be accomplished by either solenoid or mechanical linkage operation inter-locked with the forward and high speed control functions. There are two design possibilities; one is to lift the tape from the heads, during high speed operation; the other is to physically wrap the tape around the heads during normal operation and to allow it to fall away during high speed conditions. Either function is quite satisfactory.

When full solenoid control is designed into a tape transport, it is relatively easy to provide for remote control with remote lights indicating the operating state of the mechanism. Since a large amount of tape can be spoiled because of tape breakage during high speed operation and because a remote operator usually does not have direct view of the reels during normal operation, it is standard to install a "tape break" switch in conjunction with one of the moving compliance arms in order to bring the machine rapidly to a stop should the tape break. With a tape puller capstan the tape break switch is installed between the pay-off reel and the capstan; this insures continuity of program should the tape fail beyond the capstan.

Mechanical and electrical interlock functions must be provided to assure operational safety so that an operator will be forced to go through the "stop" condition from "high speed" conditions. This is necessary since if the tape is moving fast when the pressure roller grips the tape against the positive metering capstan, the tape is usually broken.

An important feature which is too often not considered is the desirability of building into a precision tape mechanism adequate cooling. A blower will dissipate to the surrounding atmosphere the heat of the torque motor, drive motors, and other electrical elements. Over an extended operating time, the operating temperatures of the front panel and tape handling parts may come excessively close to the nominal 105°F upper tape limit which is set to minimize the tape stickiness unless cooling provision is included.

CONCLUSION

The overall design of a tape transport for a professional tape recording system is very complex, full of many compromises and special problems, involving not only design, but the physics of machine shop practice in order to turn out a device which may be manufactured readily with uniformly good operating characteristics.

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2. Olson, Harry F., "Dynamical Analogies", D. Van Nostrand Company, New York.

ELECTRON BEAM REPRODUCING HEAD FOR MAGNETIC TAPE RECORDING*

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and

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INTRODUCTION

Since the time of Poulson's invention[1] of magnetic recording over 50 years ago only one principle of reproduction has been employed. This is the generation of a varying electric current in a coil by the variations of magnetic flux from the tape. The flux has usually been guided from the tape into the coils by elements of magnetic material although a simple coil has been used with the recording wire or tape passing through it.

A disadvantage of this kind of reproduction lies in the fact that the output signal is proportional to the *rate of change* of the flux in the tape rather than to the instantaneous values. This gives a frequency characteristic that increases from zero linearly until limited by the gap size.[2] And since in recording, the flux is directly proportional to the input signal the output from a conventional head is not a true reproduction of what was recorded. As is well known, equalizing networks must be incorporated in the reproducing circuits to restore the balance between low and high frequencies so that the reproduction will sound like the recorded signal.

In the new pickup head,[3] described herein, the magnetic flux in the tape is guided by a magnetic structure into a tiny cathode ray tube where it deflects the electron

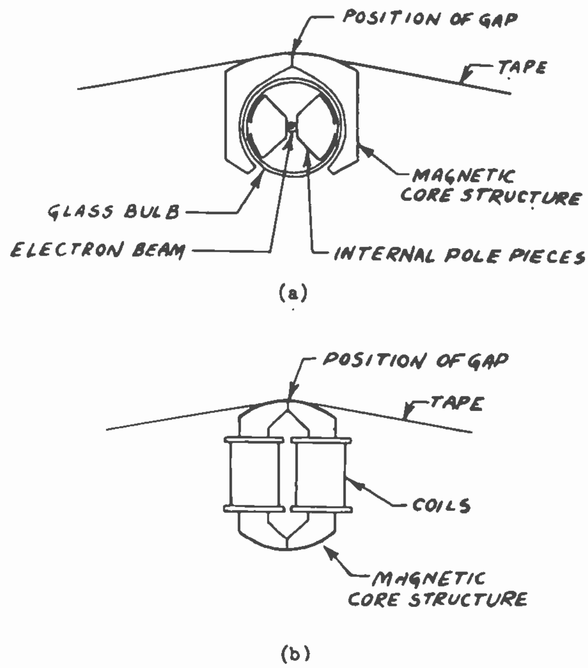

Fig. 1 – (a) Section through new head.
(b) Old head.

beam in proportion to the instantaneous magnitude of the flux. Thus, unlike in present equipment, the magnitude of the output signal is independent of the recorded fre-

*This paper was presented at the Meeting of the Institute of Radio Engineers on February 7, 1953 at San Antonio, Texas. Reprinted from *Electronics*, October 1953, with permission.

[1] V. Poulson, Patent No. 661,619, November 13, 1900.

[2] S. J. Begun, "Magnetic Recording," Murray Hill Books, Inc., New York, p. 81; 1949.

[3] A. M. Skellett, Patent No. 2,165,307.

quency and of the speed of the tape. In fact if the tape is moved very slowly or even stopped altogether the amplitude of the output signal is not decreased. Furthermore, the tube acts as a deflection type of amplifier, and as a result the output voltages are many times those from conventional heads.

Fig. 1 (a) shows a sectional view of the new type of reproducing head for comparison with the old type shown in Fig. 1 (b). It contains the conventional gap in contact with the tape from which the flux is guided by the magnetic core structure through the glass walls of the tube. The internal magnetic pole pieces carry it into the deflecting region where it produces a magnetic field that deflects the electron beam.

THE TUBE

The tube not only has to provide the electron beam and associated elements but also its design must be optimized for best performance of the complete head. The design of the internal pole pieces for example is dictated as much by the relation to the external structure as by the deflection requirements of the beam.

Fig. 2 shows a cut-away view of the tube. The miniaturized electron gun at the left sends a beam of electrons between the pole pieces toward the split target. The deflection of the electrons is at right angles to the flux and hence parallel to the pole piece faces. This property of magnetic deflection is advantageous in increasing the sensitivity since the pole pieces never get in the way of the deflected beam. The pole pieces are made of thin moly permalloy because of its suitable magnetic properties. The other metal parts of the tube are non-magnetic stainless steel.

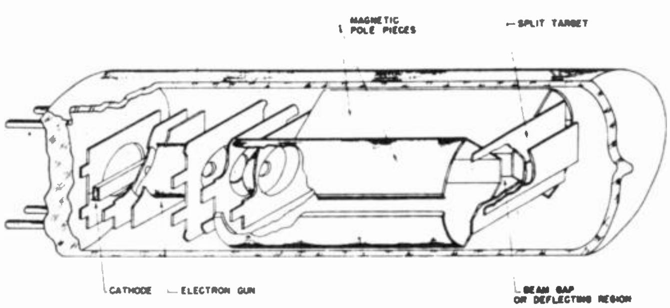

Fig. 2 – Cut-away view of tube.

Fig. 3 shows the basic circuit connections. The small plate located just behind the slit between the target plates is grounded to repel those electrons that pass through the slit. It repels them equally to the two plates and thus reduces the effective slit width. For zero flux and hence zero deflection the beam is equally split between the output plates of the target and hence the output voltage across the load resistors shown in Fig. 3 is zero. In operation the beam swings back and forth between the two plates. When the flux is negative it swings in one direction and when positive in the other. When the beam is deflected the target currents are no longer equal and hence a net output voltage is developed across the two load resistors.

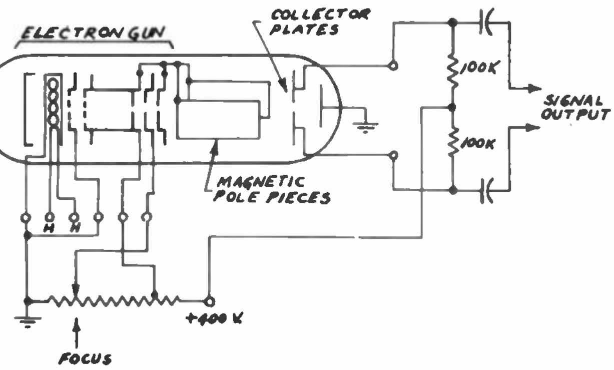

Fig. 3 – Circuit for tube.

Fig. 4 is an output characteristic. It is the output voltage measured across the output plates for different values of flux in the beam-gap. Load resistors of 100,000 ohms were used in series with each plate as shown in Fig. 3. Note that it is linear over a range of plus or minus one gauss. This range is about 50 times greater than the maximum flux variation from standard ¼-inch magnetic tape when used with the complete head under typical operating conditions.

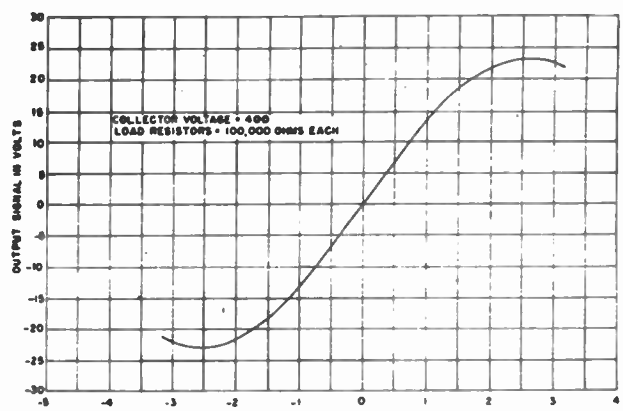

Fig. 4 – Beam-gap flux in gausses.

Fig. 5 shows the internal structure of the tube and Fig. 6 is a photograph of the finished tube in its present form. The tube is made in a T5½ miniature bulb with a standard jumbo miniature stem so that it can be used in a standard 9 pin tube socket.

THE MAGNETIC STRUCTURE

While the primary function of the magnetic structure is the guidance of the flux from the tape into the tube

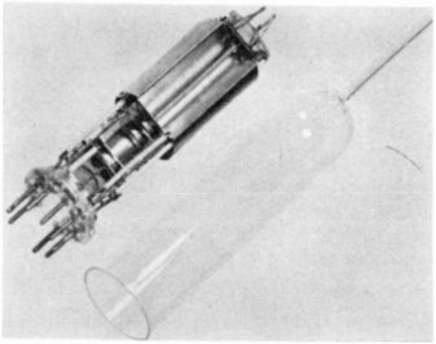

Fig. 5 – Tube structure and bulb before sealing.

many other considerations must be taken into account in order to arrive at the most efficient design. The design shown in Fig. 1 (a) while representing a practical design was abandoned early in the work. The following considerations led to the adoption of the strip-type structure shown in Fig. 7.

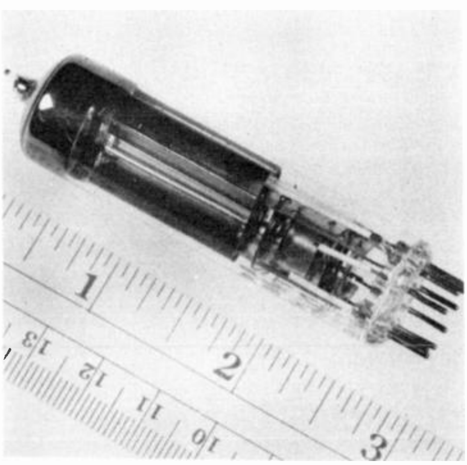

Fig. 6 – Finished tube.

Contrary to the conditions of the conventional pickup which has a very low reluctance path, the magnetic gap caused by the deflecting region in the tube introduces a very high reluctance. In consequence, the reluctance of the elements in the magnetic circuit becomes negligible in comparison with the beam gap reluctance and the magnetic elements may therefore be reduced to the smallest practical dimensions without appreciable loss of flux. A single lamination of Mu metal 0.014 inch thick proves to be adequate.

For experimental work it became easy to fabricate this strip-type structure by using hysol thermo setting casting resin which had good adhesion to the metal and which was very easy to handle. A molybdenum spacer .0003 inch thick was used at the pickup gap.

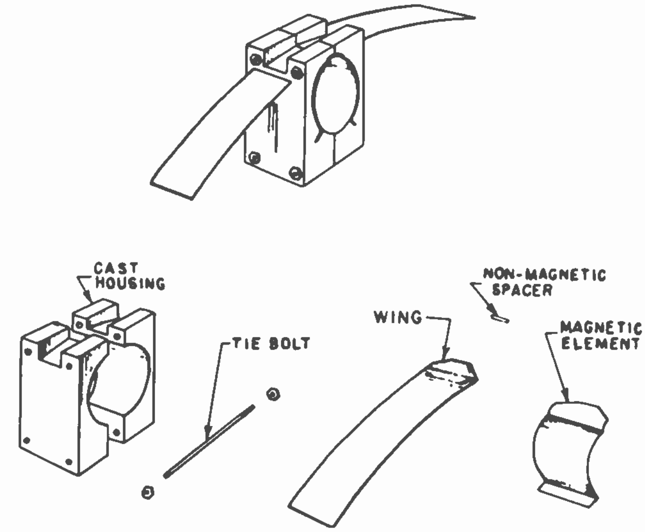

Fig. 7 – Assembly and exploded view of typical experimental winged core model.

Fig. 8 is a photograph of the completed head. The wings, which extend out in the direction of the tape and increase the effective length of the magnetic core, act to extend and flatten the low-frequency response of the pickup.

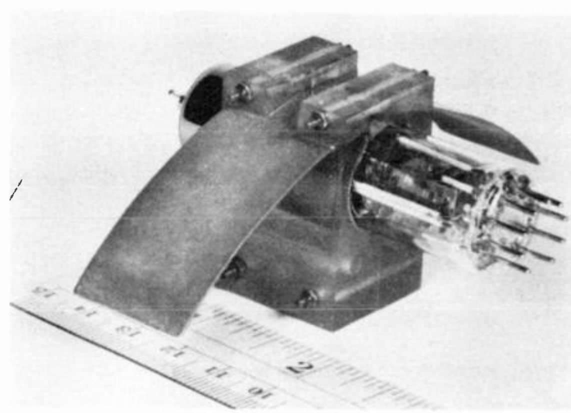

Fig. 8 – Complete head.

SENSITIVITY

No simple method was available to determine the flux density at the electron beam. A method was developed in which a calibrated vibrating probe was used to measure the flux density in the gap between a pair of dummy pole pieces mounted in proper relation to the external magnetic structure. With a saturated tape recording, it was found that a field intensity of approximately 0.04 gauss was available for deflection of the electron beam. (Reluctances and leakage factors of the various portions of the magnetic circuit were determined by additional measurements and calculations. Using these values, it was shown that the total flux in the beam gap should approximate 8% of that available from the recording. The cross-section area of the magnetic tape coating was approximately 1/1200 that of the beam gap. Thus it was shown that a saturated recording on a typical tape having a retentivity of 600 gauses should provide a beam-gap flux density of 600 x 0.08 x 1/1200 = 0.04 gauss, which is in agreement with the earlier measurements.)

Tube sensitivity was determined by measuring the tube voltage output with a known applied magneto-motive force. The beam-gap flux density was calculated from the known mmf and previously determined magnetic circuit parameters, thus permitting the tube sensitivity to be expressed in terms of tube voltage output per gauss of beam-gap flux density. With the sensitivity of the tube equal to 15 volts per gauss and a beam-gap flux density of 0.04 gauss, a maximum output voltage of 0.6 peak plate-to-plate was expected. Tests with recordings on tape confirmed these figures within experimental error.

These figures indicate the high sensitivity of the cathode ray tube. It will give satisfactory output voltages on field strengths from one-tenth to one-hundredth the strength of the earth's magnetic field.

FREQUENCY CHARACTERISTICS

Curve A of Fig. 9 gives the frequency response of the new head without any equalization. Curve B, shown for comparison, is the frequency characteristic of a conventional pickup head also without equalization. It should be noted that the scales are quite different for

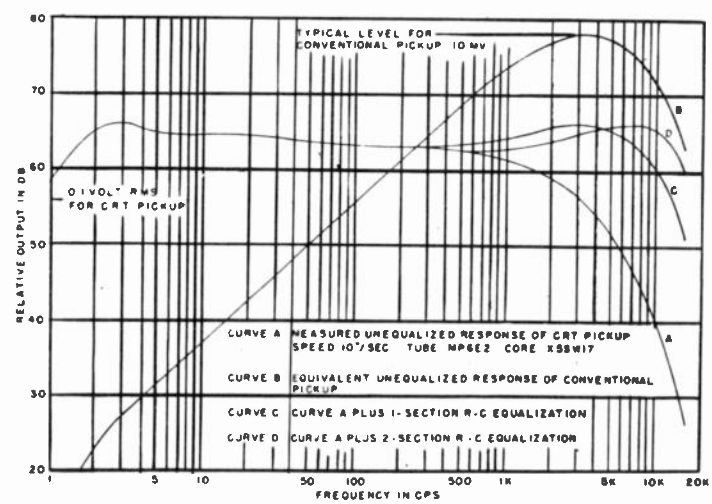

Fig. 9 – Comparison of crt and conventional pickups.

Curves A and B. For example, the maximum output obtained by the conventional head is only 10 millivolts whereas the level of most of the frequency range of the new head is about two-tenths of a volt. These curves were taken with conventional longitudinal recordings and demonstrate the superior low frequency performance of the new head.

At the upper frequency end of the curves the deterioration in output is caused by the so-called "gap effect" which comes about because the gap itself is comparable in length with the wavelength of the recorded pattern. The curves show that this effect is more serious with the new type of head. The reason is that the steeply ascending curve of the conventional head partly compensates for this gap effect whereas the flat characteristic of the new head has no compensating feature.

Calculation indicates that a very simple, single section R-C equalizing network used in conjunction with the new head will modify the characteristic to Curve C. A two section R-C filter will give an even better effect as shown by Curve D.

PATTERN OF MAGNETIZATION OF THE TAPE

All of the discussion given above was based upon conventional longitudinal recording on the tape. Yet for very low frequencies, i.e., for long wavelengths in the tape this is not the optimum type of recording pattern. For the long wavelength the gap has access only to the leakage flux near the center of the elementary magnet and therefore as the head is moved slowly over a long recording, of a square wave for example, the response will be a maximum at the ends and a minimum at the center of the square pulse.

Either perpendicular or transverse magnetization would be more suitable, but both of these suffer at the high frequency end. The work to date has been restricted pretty well to longitudinal recording since the over all response was more important than the very low frequency end of the spectrum.

Work is being carried on, however, on perpendicular recording, i.e., magnetization through the tape and indications are that this may be made to give much superior results at the low frequency end without too great a loss at the high frequency end of the spectrum.

APPLICATIONS

This new type of head offers advantages over conventional heads in a number of uses. In spite of the excellent results obtained with well equalized conventional recording of music, it is believed that ultimately the quality obtained with the new head will surpass that possible with conventional types.

There are certain commercial and military applications where it is desirable to record very low frequencies, dc levels or pulses without distortion and for these the new head is ideally suited whereas the old type will not perform adequately without considerable complexity of the apparatus, e.g., the dithering head, frequency modulation for dc recording, etc.

The inherent amplification of the tube and the cheaper equalization circuits required by the new head gives rise to the hope that a simpler, cheaper magnetic tape recorder may be possible. This, of course, because of the economic advantages, would further popularize and widen the field of magnetic tape recording.

ACKNOWLEDGMENT

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INVESTIGATION OF CORE STRUCTURES FOR THE ELECTRON-BEAM REPRODUCING HEAD IN MAGNETIC RECORDING*

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SUMMARY – The relative advantages of perpendicular versus longitudinal recording have been re-evaluated in terms of the electron-beam pickup. It is shown that dc response can be obtained only with perpendicular or transverse recording, but because of other considerations longitudinal recording appears to be more generally practicable, even though the resulting low-frequency response limit depends upon the extent to which the physical dimensions of the core may be increased and the speed of the recording medium may be reduced. Measurement techniques have been devised to permit study of the magnetic circuit parameters which influence over-all pickup sensitivity; associated studies show the advantages of a core structure having unconventional configuration and physical dimensions. Procedures recently presented by other writers for the investigation of factors contributing to high-frequency loss in conventional heads have been tested with the electron-beam pickup; tape-coating thickness appears to be responsible for a decibel loss approximately equal to the total contributed by all other factors. Relatively simple strip-type core structures for use with the electron-beam tube have been developed – over-all performance data under typical recording conditions show an output of the order of 0.2 volt and an equalized response range of approximately one to 15,000 cycles per second, plus or minus three decibels, at a tape speed of 10 inches per second.

INTRODUCTION

The electron-beam magnetic reproducing head described in a recent paper[1] represents a radical departure from the conventional pickup. Its potential outstanding characteristics are wide-range frequency response and high sensitivity. Realization of wide-range response and high sensitivity is dependent to a large extent upon the configuration of that portion of the core structure which is external to the pickup tube itself. Objectives in the investigation of this core structure have been:

(1) To obtain as high an upper limit of frequency response as is practicable at a given tape speed.
(2) To obtain as low a lower limit of frequency response as is practicable without impairing the upper limit and without resorting to very large core structures.
(3) To obtain as smooth a response as is practicable between the lower and upper limits.
(4) To obtain as high sensitivity as possible without serious sacrifice in high-frequency response.

The purpose of this paper is to present a comprehensive discussion of those factors which affect the performance of the core structure in combination with the electron-beam tube. Experimental data concerning the separation of losses in response at short wavelengths will be presented as well as data showing the effects of shielding and variation in the parameters of the magnetic circuit of the pickup. Magnetic-recording phenomena associated with signals of long recorded wavelengths and the relative advantages of perpendicular versus longitudinal recording will be discussed. Curves will be presented to illustrate the extent to which the objectives have been met in a practical design.

INITIAL CONSIDERATIONS

A typical circuit for the electron-beam tube is shown in Fig. 1. In operation, a beam of electrons is

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[1]Skellet, A. M., Loveridge, L. E., and Gratian, J. W., "Electron beam reproducing head for magnetic tape recording," presented at IRE Meeting, San Antonio, Texas, Feb. 7, 1953; published in *Electronics*, vol. 26, No. 10, pp. 168-171; Oct. 1953; and elsewhere in this issue.

projected from a miniaturized electron gun through the gap between a pair of magnetic pole pieces to a pair of collector plates. The electron beam is deflected toward one or the other of the two collector plates depending upon the direction of the flux through the beam gap. A push-pull output voltage is thus provided across the two load resistors.

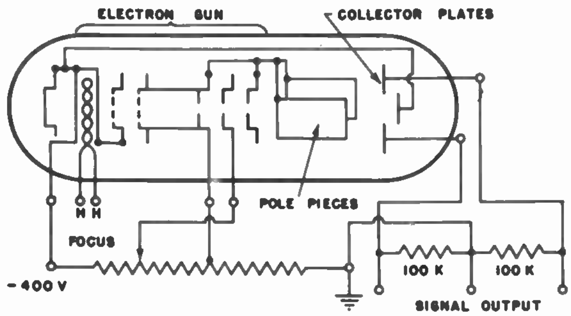


Fig. 1 – Electrical circuit for electron-beam tube.

When used in a reproducing head for magnetic recording the tube is fitted with an external core structure which may be of the form indicated in Fig. 2. The complete magnetic circuit in this case is similar to that of a ring-type head. However, practical design requires that special consideration be given to the high reluctance of the beam gap and the space occupied by the tube envelope, which is between the external core and the tube pole pieces. Assuming the recorded tape to act substantially as a source of constant flux, it is seen that the available signal flux after entering the pickup core divides between two primary paths. The portion of the flux which is conducted to the beam gap within the tube is used to deflect the electron beam; the portion of the flux which is shunted through the front gap of the core is wasted. An extremely short front-gap length is necessary since the high-frequency response of the pickup is limited by the ability of the front gap to resolve signals having a wave-length of a fraction of a mil. However, to provide maximum over-all pickup sensitivity, the reluctance of the front gap must be large compared with the reluctance through the useful flux path which includes the beam gap.

The electron-beam tube provides a voltage output which is proportional to the flux through the tube, in contrast to the conventional pickup for which the voltage output is proportional to the time rate of change in flux through the core. Consequently, if the flux induced in the electron-beam pickup were independent of the wave-length of recorded signals, the frequency response would be flat to zero cycles per second. As is generally known, however, the response of conventional longitudinal-type pick-ups falls at a rate exceeding six decibels per octave as the recorded wavelength becomes increasingly larger than the physical dimensions of the pickup. Previous work by other writers[2,3] has shown theoretically that the response should approach a slope of 18 db per octave for signals of very long recorded wavelength. Since no published experimental verification was known, the curve of Fig. 3 was obtained through the use of high tape

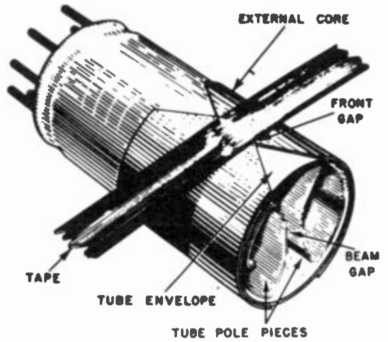


Fig. 2 – Cut-away view showing magnetic elements.

speed, an amplifier having a very low noise level and a ring-type reproducing head having an over-all length of approximately ⅜ inch. Fig. 3 confirms the 18 db per octave slope for a conventional longitudinal-type pickup;

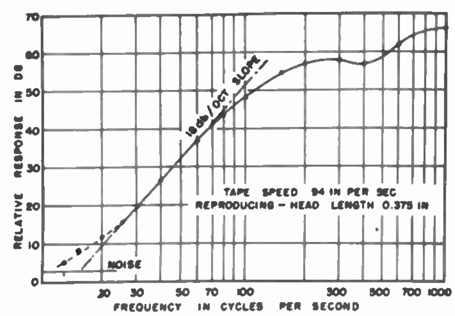


Fig. 3 – Low-frequency response for a conventional reproducing head.

[2] Otto Kornei, "Frequency response of magnetic recording." *Electronics*, vol. 20; August, 1947.

[3] Donald L. Clark and Lynn L. Merrill, "Field measurements on magnetic recording heads," *Proc. I.R.E.*, vol. 35, no. 12; December, 1947. (In subsequent unpublished work the authors found that (8) of the published paper could be expanded in series form to predict that response should vary at a rate of 18 db per octave when the recorded wavelength is much greater than that of the over-all core length.)

the electron-beam tube in combination with a longitudinal-type core structure should therefore produce a response which reaches a falling rate of 12 db per octave at recorded wavelengths which are much greater than the physical length of the core.

In contrast to the characteristics of the longitudinal pickup as outlined above, the flux induced in a perpendicular-type pickup is independent of recorded wavelength for recorded signals of very long wavelength.

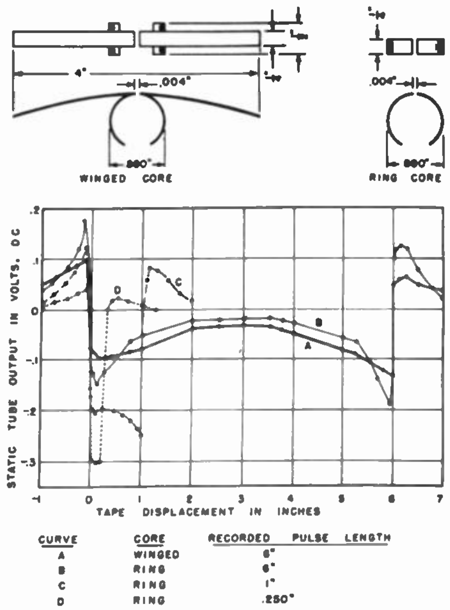


Fig. 4 – Pulse response of longitudinal type core.

For comparison there is shown in Fig. 4 the pulse response of two longitudinal pickups and in Fig. 5 the pulse response of a perpendicular pickup. In all three cases, a unipolarity rectangular pulse was recorded and the reproduced output was read, point-by-point, on a dc meter as the recorded tape was drawn slowly over a pickup comprised of the indicated core and an electron-beam tube. Curves B, C, and D of Fig. 4 show the response for pulses of three different lengths when reproduced with the aid of a ring core having an outside diameter of approximately 0.88 inch. Curve A shows the improvement in response which results from the use of a winged core which has an over-all length of four inches. The superior long-wavelength response of a perpendicular core, as shown in Fig. 5, is evident.

Although the perpendicular core in combination with the electron-beam tube is seen to offer possibilities which deserve further study, especially for applications in which dc response is required, further development of the longitudinal core was undertaken first for the following reasons:

(a) Existing equipment can be adapted to accommodate the longitudinal electron-beam pickup with no fundamental change in the recording portion of the equipment.

(b) The effective gap of the longitudinal pickup can be made several times shorter than that of the perpendicular pickup, thus providing maximum high-frequency response at minimum tape speed.

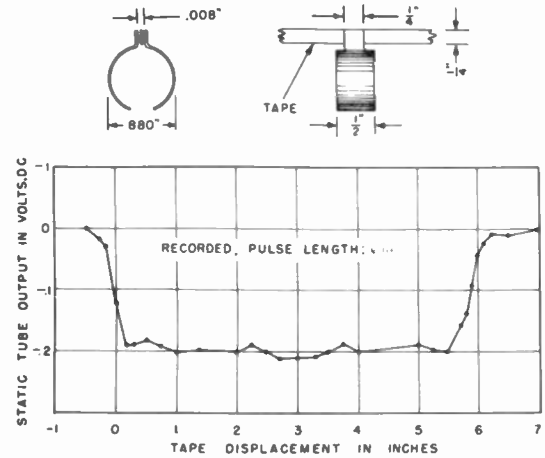


Fig. 5 – Pulse response of perpendicular type core.

(c) The longitudinal core places a limit only on maximum recorded wavelength, not on minimum frequency. The inherent ability of the tube to respond to static fields is not impaired.

(d) A low-frequency response limit of the order of one cycle per second can be provided using conventional tape speeds and practicable pickup dimensions.

(e) The low-frequency response limit can be lowered as far as desired with no loss in output by reducing tape speed.

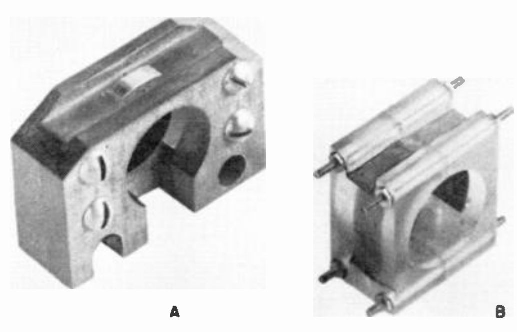


Fig 6 – Experimental ring-type core models.

EXPERIMENTAL RING CORES

The photograph of Fig. 6 shows two core models which were particularly useful in initial studies. The magnetic core of model A consists of two C-shaped half sections built up of eight-mil thick laminations to an over-all core width of 0.128 inch. The pole faces are undercut as in conventional pickups to provide a front-gap pole-face height of approximately 30 mils. In contrast, each half section of the magnetic core of model B is composed of a pair of eight-mil thick by ¼ inch wide strip-type laminations concentric with the axis of the tube to provide a total strip thickness of 16 mils. The inner laminations are set back 0.015 inch from the edges of the front gap, leaving an effective front gap pole-face height of eight mils as determined by the thickness of the outer lamination alone. The magnetic core is cast in a thermo-setting resin to complete the structure.

Fig. 7 shows response curves as a function of wavelength for core model A in combination with a tube model having ½ inch long pole pieces. Curves A, B and C for front-gap lengths of 4.8, 0.72 and 0.24 mils, respectively, show the manner in which sensitivity decreases and relative high-frequency response improves as gap length is reduced.

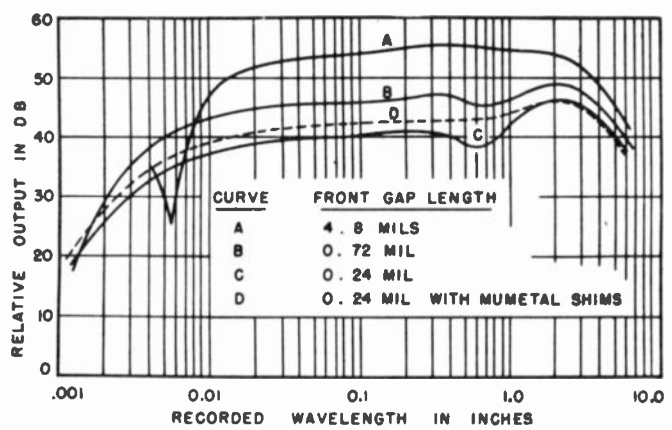


Fig. 7 — Wavelength response curves for core model A.

The cause of the hump in the response at two inches recorded wavelength is believed to be associated with the fact that the length of the tube pole pieces is appreciably greater than the external core width. Recorded signals having a wavelength which is several times that of the spacing between the recording medium and the pole pieces act to induce an appreciable component of flux in the tube pole pieces with no assistance from the external core of the pickup. (Experimental evidence confirming this is shown in Curve C of Fig. 8.) The external field for signals of shorter recorded wavelength, however, is concentrated nearer the tape and must be conducted to the tube pole pieces by the external core of the pickup. In effect, the front gap is more closely coupled to the flux source for signals of short recorded wavelength than for signals of longer wavelength. Increasing the shunt effect of the front gap therefore tends to reduce pickup sensitivity more for signals of short and moderate wavelengths than for signals of long wavelength.

For Curve D of Fig. 7, conditions were identical to those for Curve C except that eight-mil thick Mumetal shims having a width several times that of the core were inserted in the clearance space between the tube and the external core. The increase in sensitivity at short wavelengths is due to the decrease in core-to-pole-piece reluctance which permits a larger percentage of the available input flux to be conducted to the beam gap. The small change in sensitivity at long recorded wavelengths results from the tendency of the shims to shield the pole pieces from the direct influence of signal fields of long recorded wavelength. With the addition of the shims which become an effective part of the external core, the total flux induced in the core by long wavelength signals may be greater than that induced without the shims. However, all components of flux which enter the core, regardless of their point of entry as determined by the signal wavelength, are then attenuated approximately equally by the effects of the shunt front-gap reluctance and series core-to-pole-piece reluctance before reaching the beam gap; hence, a flatter response curve results.

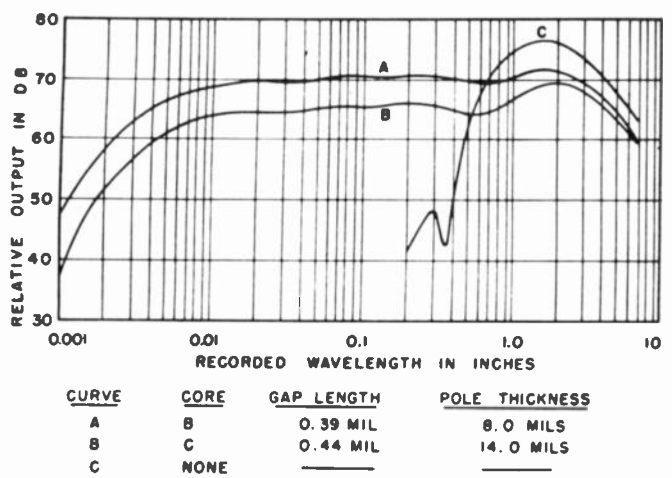


Fig. 8 — Wavelength response curves for electron-beam tube with two different cores and for tube alone.

Considerations which made a strip-type core as represented by model B seem especially well suited for use with the electron-beam tube are the following:

(a) The necessity of providing an aperture for passage of the electron beam in the tube precludes the provision of a very low-reluctance path for useful flux as is possible in the conventional pickup. Since thin strips of high-permeability alloy provide reluctances which are negligible in comparison with the beam-gap reluctance, a heavier cross-section is of no advantage.

(b) The strip may be made sufficiently thin to restrict eddy-current loss to a tolerable value.

(c) With the availability of casting resins which have good adhesion to metal, it is possible to provide satisfactory support for the critical edges of the front gap.

(d) Cores of unconventional size and configuration may be more readily produced in strip form.

Curves A and B of Fig. 8 show the response of two strip-type cores with a given tube model. Core model C is similar in construction to the previously described model B except that the core is formed of non-laminated strip having a thickness of 14 mils and the measured gap length is 0.44 mil versus 0.39 mil for B. Curve A for model B shows higher sensitivity and more uniform response. The higher sensitivity is due primarily to a smaller front-gap pole face area. The improved high-frequency response is due partially to a shorter front gap and partially to reduced eddy-current loss. The flatter low-frequency response is associated with the more favorable ratio of front-gap reluctance to beam-gap reluctance plus core-to-pole-piece reluctance.

Curve C of Fig. 8 shows the response of the electron-beam tube with no external core. As may be seen by comparing Curves A, B and C, the tube pole pieces, which are one inch long for this tube model, determine the shape of the over-all response curve at long wavelengths. The primary consideration which led to the use of relatively long-pole pieces is the following: If a given input flux is assumed and if the beam-gap reluctance is assumed to be shunted by a much smaller front-gap reluctance, the magnitude of the beam-gap flux will be proportional to pole-piece length and the beam-gap flux density will be independent of pole-piece length. With a given beam-gap flux density, the tube output is approximately proportional to pole-piece length.

Further advantages are obtained with the use of the long tube pole pieces in combination with an external core of corresponding width. First, the reduced reluctance between the tube pole pieces and the external core results in increased pickup sensitivity. Second, as shown later, increased core width tends to flatten and extend the low-frequency response of the pickup.

EXPERIMENTAL WINGED CORES

Prior to the work described herein, a winged-core structure for the purpose of extending the low-frequency response of conventional pickups had been successfully developed at Stromberg-Carlson. In the work to be described, means of adapting the winged core to the special requirements of the electron-beam pickup were investigated and an extended study of factors which influence low-frequency response was carried as far as time permitted. In addition to generally recognized factors such as over-all core length, core contour and shield dimensions, core width was found to be important.

Experimental core models of the form shown in Fig. 9 were used in tests concerning the effect of core dimensions. The construction of these models is similar to that previously described for model B except for the increased width and thickness of the magnetic elements and the fact that the outer lamination is formed with a larger radius to provide wings extending in the direction of the tape travel. The C-shaped elements which contact the tube are one inch wide and equal to the corresponding dimension of present tube pole pieces. The thickness of the formed magnetic elements is 14 mils. The effective width of the experimental cores was varied by means of auxiliary Mumetal plates fastened to the original wings as shown in the photograph of Fig. 9.

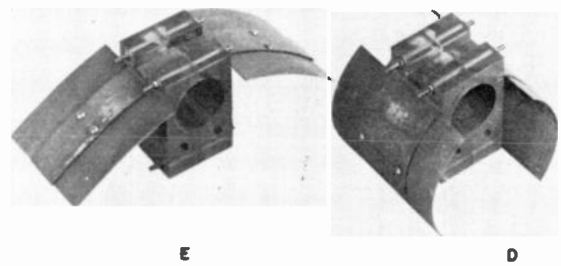


Fig. 9 – Experimental winged core models.

The curves of Fig. 10 show the manner in which long-wavelength response varies with changes in wing radius. For these data the width of the wings was ¼ inch and the over-all length of the wings before bending was four inches. The pickup was centered in a shield box having major dimensions of 1½ inches by 2¾ inches by 10 inches. Under these conditions a radius of approximately three inches was found to provide the best compromise between maximum response at seven inches recorded wavelength and smoothest response between 0.7 and 7 inches recorded wavelength.

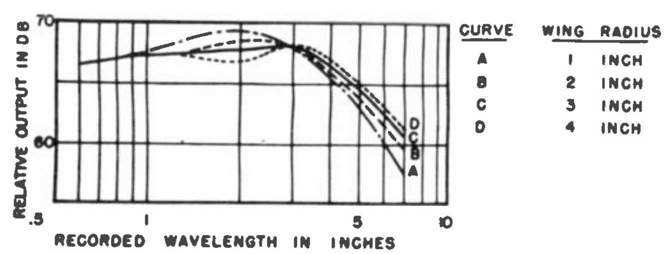


Fig. 10 – Effect of wing radius on long-wavelength response of shielded, wing core model.

Considerable study was given to the fact that means could not be found whereby long-wavelength response could be extended in direct proportion to the over-all length of the core structure. This is an important consideration because the physical length of the winged cores tends to limit their application. On the basis of response as shown in Fig. 8 for a close-fitting core having an outside diameter of approximately ¾ inch, it seems that it should be possible to provide response which is down no more than six decibels at a recorded wavelength of approximately 12 inches when using a core structure having an over-all length of two inches.

The closest approach to that condition was obtained with core model D. With extensions as shown in Fig. 9, the wings have an effective width of two inches and an outside diameter of two inches throughout an arc of approximately 270 degrees. Curve A of Fig. 11 shows that the response of this core, unshielded, is down six decibels at approximately eight inches recorded wavelength. From these and other data it was concluded that increased arc length and wing width provide smoother extended low-frequency response.

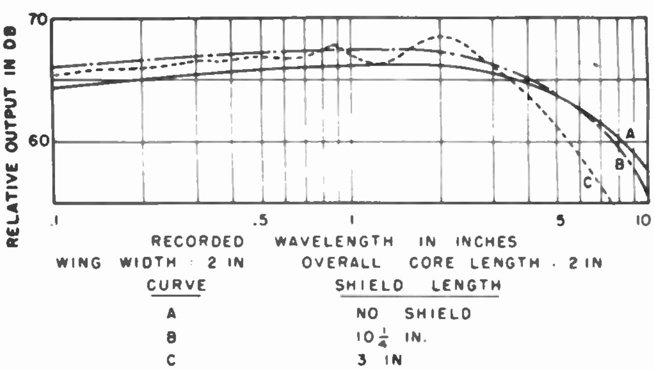


Fig. 11 – Wavelength response curves for core model D showing effects of variation in shield dimensions.

Curve A of Fig. 12 shows the long-wavelength response of core model E which has an over-all length of 3⅞ inches as compared with two inches for model D discussed above. As may be seen by comparing Curve A of Fig. 12 with Curve A of Fig. 11, the long-wavelength response of model E extends further, but is less smooth than that of model D.

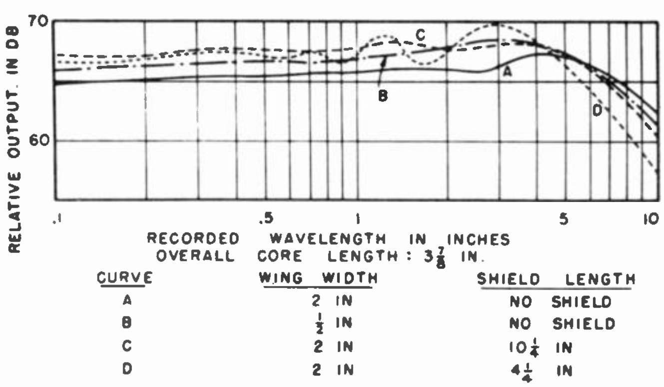


Fig. 12 – Wavelength response curves for core model E showing effects of variation in shield dimensions.

Comparison of Curves A and B of Fig. 12 show clearly the improvement in long-wavelength response which results from an increase in the wind width of core model E. The remaining curves of Figs. 11 and 12 with tabulated data show in detail the manner in which the long-wavelength response of core models D and E varies with changes in shield dimensions.

EDDY CURRENT LOSS

Fig. 13 shows the loss in high-frequency response caused by eddy currents for three of the experimental core models discussed above. Curve C for the winged core which is formed of 14-mil thick Mumetal strip shows a high-frequency loss of three decibels at 10 kc. Curve A for the core having a stack of conventional laminations and Curve B for the core having a pair of concentric laminations show less loss. Although the loss for the strip-type cores is appreciable, it represents only a small portion of the total attenuation at the upper frequency limit when conventional tape speeds are used. In view of the simplicity of the strip core, it seems advisable to consider the use of more complex laminated structures only for special applications requiring higher upper-frequency limits.

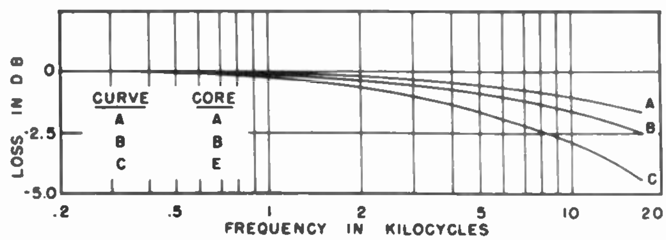


Fig. 13 – Response loss due to eddy currents.

OVER-ALL RESPONSE OF WINGED CORE MODEL OF FINAL DESIGN

The final winged core model is identical to the experimental model E, shown in Fig. 9, except for the substitution of a solid wing having a width of one inch. The complete electron-beam pickup and the rear half of the shield box as mounted on a conventional tape loop drive mechanism are shown in Fig. 14. The dial which shows in the photograph behind the shield permits tape speed to be adjusted over a range of 10:1. A set of conventional erase, record and playback heads is located at the lower center of the front panel. Circuits and controls for mixing recording bias and signal are located at the left end of the drive unit.

The unequalized frequency-response curve for one of the final core models using a tape speed of 10 inches per second and constant-current recording is shown in Curve A of Fig. 15. The response, as shown for a pickup enclosed in a shield having dimensions of 2¾ inches by

2¾ inches by 10 inches, is flat within plus or minus three decibels from 1.2 to 1600 cycles per second. The lower response limit is extended to approximately 0.9 cps when no shield is used. The general effect of shield dimensions for a similar core model is shown in Fig. 12.

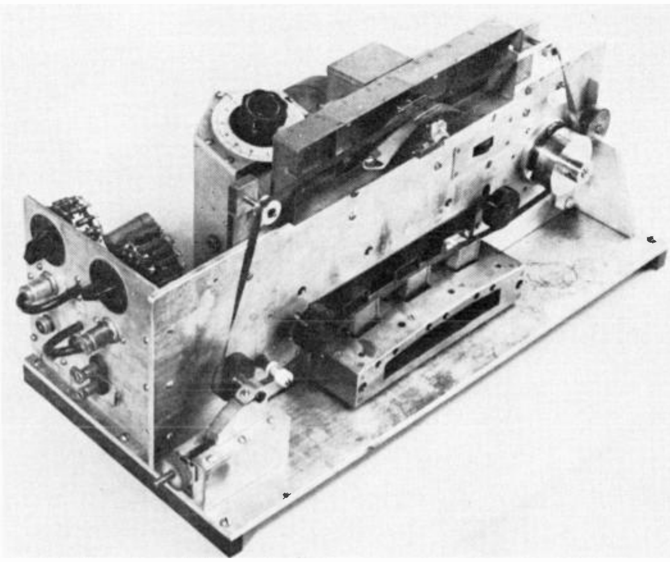


Fig. 14 – Tape drive unit with electron-beam tube pickup.

Curve B of Fig. 15 shows the effect of superimposing the cathode-ray-tube pickup response on a frequency characteristic which rises at six decibels per octave, as would be obtained with a conventional pickup of comparable dimensions for which the output voltage is proportional to the time derivitive of flux. It should be noted that the differentiation of flux in the conventional pickup produces, in effect, equalization which greatly improves the apparent high-frequency response of the pickup. With the addition of equivalent high-frequency equalization it will be seen that the high-frequency performance of the cathode-ray-tube pickup is comparable with that of high-quality conventional pickups.

With the addition of a single-section R-C high-frequency equalizer, the calculated equalized response is flat within plus or minus three decibels from 1.2 to 10,000 cycles per second, as shown in Curve C of Fig. 15. With the addition of a dual-section R-C high-frequency equalizer, the calculated equalized response is flat within plus or minus three decibels from 1.2 to 15,000 cps, as shown in Curve D. In both cases the lower response limit is extended to approximately 0.9 cps when no shield is used. The equalized response curves were calculated assuming the use of high-frequency equalizer sections of conventional form with the ratio of resistances sufficiently great to allow the equalizer response to rise at six decibels per octave to the highest frequency shown.

Curves A and C of Fig. 15 show that high-frequency equalization of approximately 20 db at 10 kc is required to obtain response flat within plus or minus three decibels from 1.2 to 10,000 cps using the cathode-ray-tube pickup. With this amount of high-frequency

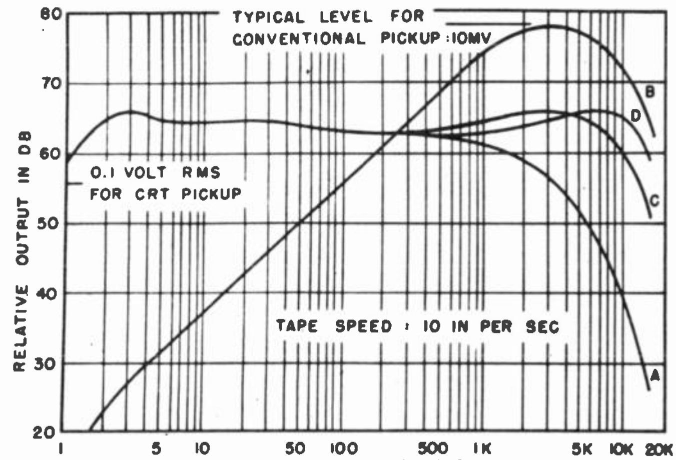


Fig. 15 – Comparison of electron-beam and conventional pickups.

equalization, the signal-to-noise ratio exceeds 40 db. By contrast, from Curve B it will be seen that approximately 60 db of low-frequency equalization would be required to obtain the same range of response with the conventional pickup. At one cycle per second the output of a conventional high-impedance pickup is of the order of 10 microvolts when a high recording level is used. The required equalization cannot be provided without excessive loss in signal-to-noise ratio.

A general comparison for the over-all frequency characteristics of the electron-beam pickup with winged core and that of the conventional pickup may be summarized in the following manner: With no external equalization, the response of the electron-beam pickup is flat within plus or minus three decibels over a recorded wavelength range having high and low limits in a ratio exceeding 1500:1. The corresponding range for a conventional pickup is less then 15:1. With typical equalization the range of the electron-beam pickup is approximately 15,000:1. The typical equalized range for high-quality commercial equipment using a conventional pickup is 300:1.

CAUSES OF HIGH-FREQUENCY LOSS

Fig. 16 shows a breakdown of high-frequency losses as determined for one of the final core models. The data are plotted versus recorded wavelength since three of the four factors considered are a function of recorded wavelength. The procedure used is essentially that presented by R. L. Wallace[4] in a recent paper. The heavy curve shows the over-all measured response. Circled points are calculated or measured values representing the individual losses. The level of zero loss is assumed to be that of the measured response at 0.1-inch recorded wavelength, at which point the effect of low-frequency irregularities becomes negligible.

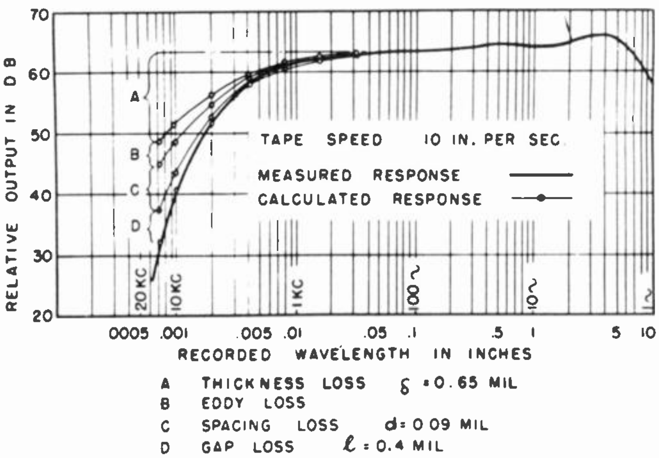


Fig. 16 – Comparison of experimental and calculated response of final pickup model.

The loss associated with the coating thickness of the recording medium was calculated from the following expression as given by Wallace:

$$\text{Thickness loss} = 20 \log_{10} \frac{2\pi\delta/\lambda}{1-e^{-2\pi\delta/\lambda}}$$

where δ = coating thickness

λ = recorded wavelength.

The loss in response attributed to eddy currents actually includes all losses which are a function of frequency only. These losses are believed to be due primarily to eddy currents. To determine this loss, a small coil is wrapped closely around the core of the pickup at the gap; the coil is then driven with constant current throughout the frequency range of interest and the voltage output of the electron-beam tube is measured.

Spacing loss is attributed to a lack of perfect contact between the recording medium and the core of the pickup. The loss was calculated from the following formula as given by Wallace:

$$\text{Spacing loss} = 54.6\, d/\lambda \text{ db}$$

where d = effective spacing between the core and the recording medium

λ = recorded wavelength.

Since it is impossible to measure the spacing, Wallace's procedure was to attribute to spacing the loss which remained after subtracting all known losses as determined by other means. Since the characteristic shapes of the various loss functions differ appreciably, the fact that the calculated points fall close to the measured over-all response is considered good evidence of the validity of the procedure.

It is interesting to note that the minimum effective spacing achieved by Wallace in his work was 0.23 mil as compared with the 0.09 mil determined in this work. The flexible recording medium used in this work would be expected to allow better contact than could be achieved with a plated drum such as was used by Wallace. In this connection it was found that relative high-frequency response varies appreciably with tape wear. In order to obtain reproducible results, measurements were made using slightly burnished tape loops which were found to provide reasonably consistent results for an appreciable period of time. Gap loss was determined from the well-known expression:

$$\text{Gap loss} = 20 \log_{10} \frac{\pi l/\lambda}{\sin \pi l/\lambda}$$

where l = effective gap length,

λ = recorded wavelength.

The nominal thickness of the gap spacer was 0.30 mil and the physical gap length as measured under a microscope was approximately 0.40 mil. The effective gap length,[5] which is usually assumed to be 50 to 100 per cent greater than the physical length, could not be determined by inspection of response data at higher frequencies. Therefore, in arriving at the values shown in Fig. 16, both the effective gap length and effective spacing were treated as unknowns. Several values of each unknown were tested in the respective loss expressions to determine what values were required to give a total loss best matching that shown by the measured response. Combinations other than those shown were found to result in an appreciable departure from the measured response.

In evaluating the results shown in Fig. 16 the following points are of particular interest:

[4]R. L. Wallace, Jr., "The reproduction of magnetically recorded signals," The Bell Sys. Tech. Jour., vol. XXX, no. 4, Part II; October, 1951.

[5]S. J. Begun, "Magnetic recording," Murray Hill Books, Inc.,; p. 85.

(a) Thickness loss appears to be the most important single factor contributing to the total high-frequency attenuation. Two different formulas[4,6] have been recommended for the computation of thickness loss. Measurements were made on available tape samples having different coating thicknesses in an effort to determine whether either of the proposed formulas could be verified experimentally but results were not conclusive. Wallace's formula, which gives considerably lower loss, was used in calculating thickness loss for Fig. 16.

(b) Recording demagnetization[6] was assumed to be negligible for the recording conditions of these measurements. Recording bias current was determined by a somewhat unconventional procedure. Since signal-to-noise specifications for the pickup were stated in terms of that signal level which produces three per cent total harmonic distortion, curves of output voltage and recording current versus bias current for constant three per cent total harmonic distortion with a 400 cps signal were first determined. Curves of output versus bias at higher signal frequencies were then obtained using the recording-current values which were determined at 400 cps. From these curves the bias which provided best over-all performance was found to be approximately two milliamperes as compared with 3.4 ma when determined by conventional procedures, and it corresponds approximately to that bias which gives maximum high-frequency output. Specific changes in the performance characteristics and operating conditions which resulted from the change from 3.4 to 3.0 ma bias are as follows: 400 cps distortion, unchanged at three per cent; relative response at one mil recorded wavelength, +4.2 db; 400 cps output, -0.9 db; recording-bias and recording-signal current, -4.6 db and -3.8 db, respectively.

(c) The assumed level of zero loss is somewhat arbitrary. The general slope of the low-frequency response varies with shield dimensions, core length, core width and front-gap length. For example, a change in wing width from one-half inch to two inches was found to produce a drop in response which varies progressively from zero decibels at one mil recorded wavelength to approximately 2½ db at the wavelength of maximum response. Hence, an increase in wing width appears to reduce the high-frequency attenuation relative to the assumed level of zero loss.

(d) Further study of the procedure for evaluating the specific sources of high-frequency attenuation appears worthwhile.* The data originally presented by Wallace, and the supplementary data presented herein for a pickup of unconventional size and general design both show a good correlation between total measured loss and the sum of the deduced individual losses. However, in view of questions which have been raised during the later tests it seems quite likely that further work might show an appreciably different distribution of losses. If the data as presented are correct, a recording medium having a thinner magnetic coating could be used to very good advantage with the electron-beam pickup.

DETERMINATION OF BEAM-GAP FLUX DENSITY AND TUBE SENSITIVITY

In the early stages of the tube development an estimate of beam-gap flux density under typical recording conditions was required. The equipment which was used in the experimental verification of initial estimates of beam-gap flux density is shown in Fig. 17. As shown, a

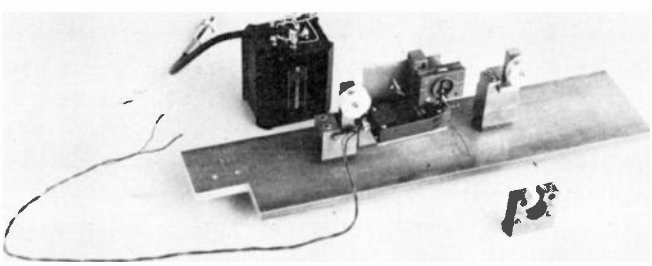


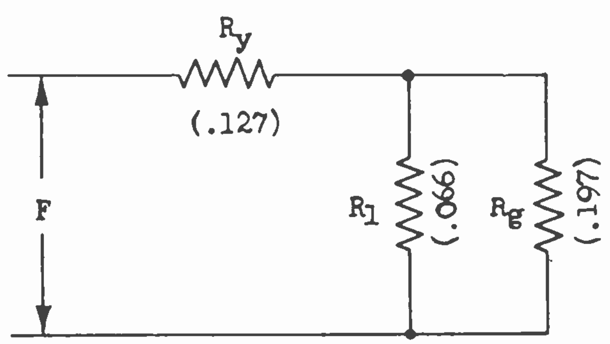
Fig. 17 – Apparatus used in measurement of beam-gap flux density.

[6]O. William Muckenhirn, "Recording demagnetization in magnetic tape recording," *Proc. I.R.E.*, vol. 39, no. 8; August 1951.

*Comparison of these results with those published by E. D. Daniel, since the preparation of this paper, are of particular interest. (*The Proc. Inst. Elec. Eng.*, vol. 100, Part III, no. 65, pp. 168-175; May, 1953.) Fig. 10 of that paper shows a recording loss, at 1.5 mils recorded wavelength, of 13 db which approximately equals the corresponding loss, exclusive of reproducing gap and eddy-current loss, as shown in Fig. 16 of this paper. However, Daniel attributes only six decibels of this total loss to effects associated with the thickness of the magnetic medium and the remainder to other effects such as self-demagnetization. Daniel's analysis which takes into account non-uniform magnetization through the medium seems more sound fundamentally than one which assumes uniform magnetization. On the other hand, the following assumptions which appear to be implied in Daniel's work may cause appreciable error and seem worthy of further study: a) The "effective susceptibility versus bias-field-strength curve" for a signal of short wavelength represents the performance of an infinitesimal surface layer rather than the average performance of a layer of substantial thickness. b) The shape of the susceptibility curve for a surface layer is substantially identical to that for a layer located deeper within the magnetic tape coating. c) The magnitude of the susceptibility curve at any given depth within the medium depends only on the magnitude of the field intensity in the plane through the center of the recording gap; it is therefore independent of the shape of the recording field at the trailing edge of the gap[3], i.e., the associated variations in recording demagnetization[7] at different signal wavelengths and at different depths within the tape coating are negligible.

pair of tube pole pieces are mounted in their proper relative positions in a phenolic dummy structure simulating the tube. An experimental core model is mounted in its normal position with respect to the tube pole pieces. In use, the core structure is excited by drawing prerecorded tape over the idlers and core. The resulting beam-gap flux density is measured by means of a small rectangular pickup coil located in a probe which is vibrated by a crystal cutting head. The pickup, which contains no magnetic material, was initially calibrated in a known field of relatively high intensity. The usable sensitivity of this equipment when limited by a pickup coil of given size, was found to be approximately 5000 times that of a light-beam type fluxmeter having a constant of 400 flux linkages per millimeter. Measurements on the earliest core models showed that beam-gap flux density under given simulated recording conditions was of the order of one per cent of the flux density obtained in conventional pickup cores having comparable front-gap lengths.

When electron-beam tube models became available they were found to offer the most convenient means of testing experimental core models, but an independent test to determine tube sensitivity was also required. The following procedure proved satisfactory: A magnetic yoke, of the form shown in the foreground of Fig. 17, is slipped over the tube and centered on the tube pole pieces in the position normally occupied by the external core structure. A known direct current is applied to the coil of the yoke and the change in plate-to-plate tube voltage is measured. The tube sensitivity in volts per gauss is then determined from the tube voltage output per unit of yoke current divided by the yoke constant in gausses per unit of yoke current.



F = Applied yoke mmf

R_y = Total effective yoke-to-pole-piece reluctance

R_l = Effective pole-piece leakage reluctance

R_g = Beam-gap reluctance

Fig. 18 – Magnetic parameters of calibrating yoke and tube pole pieces.

The yoke constant applies only to the combination of yoke and given tube pole pieces. To determine this constant, the pole pieces are dummy-mounted in their proper positions and the yoke is substituted for the core shown in Fig. 17. With a known yoke current, beam-gap flux density is measured through the use of a light-beam type fluxmeter and an accurately formed search coil. A flux density of approximately 200 gausses is required for this measurement, whereas the electron-beam tube is normally operated with a beam-gap flux density of less than 0.1 gauss. The yoke calibration was shown to be constant throughout the range of 200 to 0.1 gauss through measurements with the more sensitive, but somewhat less convenient, vibrating probe which was previously described.

EFFECT OF PARAMETERS OF THE MAGNETIC CIRCUIT ON OVER-ALL PICKUP SENSITIVITY

The parameter of the magnetic circuit which was found most difficult to determine was the effective leakage reluctance of the tube pole pieces. Because of the complex shape of these structures and the large ratio of leakage to gap flux, field-mapping techniques provide only a poor approximation. The procedure which was used with reasonable success involved the measurement of the beam-gap flux density produced by a given yoke magneto-motive-force as explained below.

The magnetic circuit of the calibrating yoke in combination with the tube pole pieces may be represented as shown below. (Fig. 18) Beam-gap flux density for a given yoke current was determined by measurement as previously described to be

$$B_g = 278\, I \text{ gauss,}$$

where I = yoke current in amperes.

For a yoke having a coil of 100 turns,

$$F = 126\, I \text{ gilberts.}$$

Assuming all beam-gap fringing flux to be included in the pole-piece leakage flux, the area and reluctance of the beam gap as calculated from the actual gap dimensions are, respectively

$$A_g = 0.644 \text{ cm}^2$$
$$R_g = 0.197 \text{ cgs unit.}$$

With allowance for fringing, the total yoke-to-pole-piece reluctance as calculated from the effective gap dimensions is $R_y = 0.127$ cgs unit. Solving for R_1 in the circuit of Fig. 18, with substituted values as determined above, gives

$$R_1 = \frac{A_g B_g B_g R_y}{F - B_g A_g (R_g + R_y)} = 0.066 \text{ cgs unit.}$$

It is interesting to note that $R_g = 3.0\ R_1$ and that pole-piece leakage flux is therefore 3.0 times as great as the flux which exists in the beam gap.

Using the constants determined above, the magnetic circuit of the external core in combination with the tube pole pieces may be represented as shown in Fig. 19. With allowance for fringing, the total core-to-pole-piece reluctance as calculated from the effective gap dimensions is

$$R_c = 0.042 \text{ cgs unit.}$$

Assuming the tape to act as a source of constant input flux, ϕ_i, the circuit of Fig. 19 may be solved to show that

$$\phi_i = 12.1\ \phi_g$$

where ϕ_g = the flux in the beam gap.

Hence ϕ_i = 0.31 line and the beam-gap flux density for a saturated recording is:

$$B_g = \phi_g / A_g = \phi_i / 12.1\ A_g = 0.040 \text{ gauss.}$$

The sensitivity of the tube at the time of the following correlation was

$$S = 14.9 \text{ volts per gauss.}$$

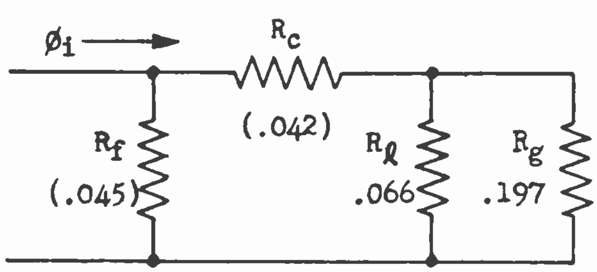
Hence, the expected tube voltage output for a saturated recording is:

(1) $V = B_g S = 0.040 \times 14.9 = 0.60$ volt, peak, plate-to-plate. Tests on ten core models showed an average output at 100 cps of $0.20\sqrt{2}$ volt, peak, plate-to-plate for a recording level of approximately six decibels below saturation. (It is important to note that the output level relative to saturation was determined on a peak basis by reading relative outputs on an oscilloscope. Readings on a vacuum-tube voltmeter were found to introduce an appreciable error, probably because of the difference in signal waveform at saturation and at lower levels.) Thus for a saturated recording, the average voltage output for the ten core models becomes:

(2) $V = 2 \times 0.20\sqrt{2} = 0.57$ volt, peak, plate-to-plate. The calculated output of (1) checks the experimentally determined output of (2) well within limits of accuracy of the procedures involved.

ALTERNATE, WINGLESS, STRIP-TYPE CORE

A brief study has been made of the performance of a wingless core model, F, which is similar to the previously described model B except that the core width is



R_c = Total effective core-to-pole-piece reluctance

R_f = Effective front-gap reluctance

Fig. 19 – Magnetic parameters of core and tube pole pieces.

If ϕ_i is assumed to be equal to the flux developed within the recording medium its value may be determined from the following dimensions and characteristics of the recording medium:

Track width = 0.125 inch

Coating thickness = 0.65 mil

B_R = 600 gausses

one inch. The outside diameter of the magnetic structure is approximately 0.75 inch. Loss in high-frequency response due to eddy currents was measured as 1.5 db at 10 kc and 3.0 db at 20 kc.

The measured unequalized response for this core in combination with the electron-beam tube is shown as the solid-line curve of Fig. 20. The dotted-line curve shows the calculated high-frequency response assuming the use of two ideal R-C equalizer sections having half-power frequencies one octave apart. The dashed curves show the manner in which the low-frequency response hump may be reduced by means of an auxiliary plate positioned a small distance above the reproducing gap. The two dashed curves correspond to two different positions of the plate and provide an indication of the degree of control which is possible. These measurements were made with the pickup enclosed in a 10½-inch-long shield box. Additional tests showed that the shield length may be reduced to three inches without introducing low-frequency irregularities exceeding plus or minus one-half decibel.

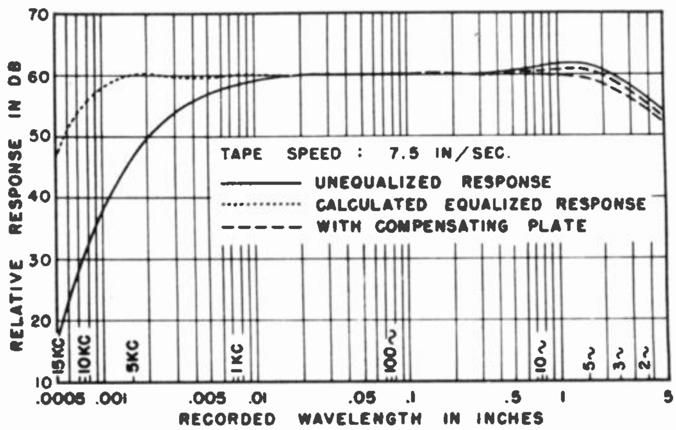


Fig. 20 – Wavelength response for core model F.

From these curves it appears possible to provide equalized response which is flat within plus or minus one decibel from approximately three to 7500 cps at a tape speed of 7½ inches per second using a commercial tape and a core having an outside diameter of approximately 0.75 inch. Under the same conditions the equalized response is flat within plus or minus three decibels from approximately two to 10,000 cps. At a tape speed of 15 inches per second an equalized response of approximately three to 20,000 cps, plus or minus four decibels, would be obtained.

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