The Westrex 3D StereoDisk System*

C. S. NELSON
Westrex Division of Litton Industries, Hollywood, California
AND
J. W. STAFFORD
Litton Data Systems Division, Canoga Park, California

Technical appraisal of existing systems indicated requirements for improved response, increased efficiency, greater stability, and better power handling capabilities. A redesigned cutter and amplifier embody these improvements and incorporate practical operational advantages, typical of which are self-aligning styli and front-panel amplifier adjustments. Plug-in equalizers associated with cutters ensure constant velocity with cutter interchange. The new amplifier is compatible with new and existing cutters.

INTRODUCTION

SINCE the introduction of its StereoDisk System in 1958, Westrex has from time to time undertaken improvement studies with the aim of increasing flexibility, consistency, efficiency and a reduction of dependence on the technical capability of the user. The most recent improvement study resulted in the 3C StereoDisk Cutter and is described in a paper by Frayne and Davis.[1]

Impetus for changing the present system came from appraisal by the record and related industries as related to operating environment, input function and handling requirements. The corresponding study phase was followed by an improvement design effort, with improved performance and retro-fitting of the 3C Recorder as principal objectives. For reasons of economics, it was decided to modify existing equipment rather than to develop an entirely new system. The results are embodied in the 3D StereoDisk System incorporating such disk cutter improvements as:

1. New torque tube; 2. Quick-change, self-aligning stylus holder; 3. Large-diameter stylus; 4. New torque tube support spring to optimize compliance; 5. New drive coil support springs ribbed to reduce resonances; 6. Twice the drive coil impedance to reduce heat; 7. Special high temperature wire and insulation; 8. 25% greater sensitivity; 9. Quick change heater wire clips; 10. Nearly consistent response characteristics for all 3D Cutters.

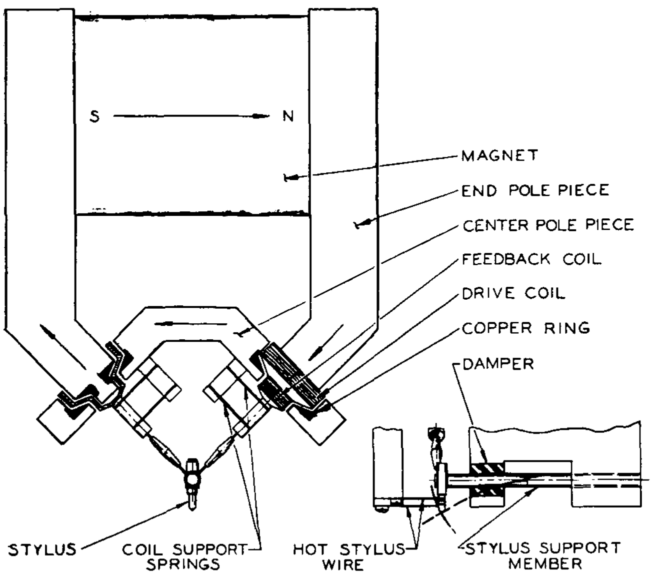
Before attempting to discuss the new 3D Cutter, the theory of operation of such cutters[1] will be reviewed. The recorder shown in Fig. 1 contains two coil assemblies, one associated with each channel. Each comprises a drive coil and feedback coil located in annular gaps in separate pole pieces. V-shaped beryllium copper coil support springs hold and position the assemblies, and by means of these springs the assemblies are constrained to have no motion other than one parallel to their axis. This motion is transmitted to the tubular stylus support member by means of wire links braced with magnesium sleeves. The magnetic gaps of the drive and feedback coils are arranged in series parallel fashion, and magnetic flux is provided to the system by a single magnet. The arrangement of magnetic paths ensures equal flux densities in the corresponding gaps. The shaded areas between the magnetic gaps indicate copper plugs or shields which reduce the inductive crosstalk from the drive coils to the feedback coils.

STEREODISK CUTTING STYLUS

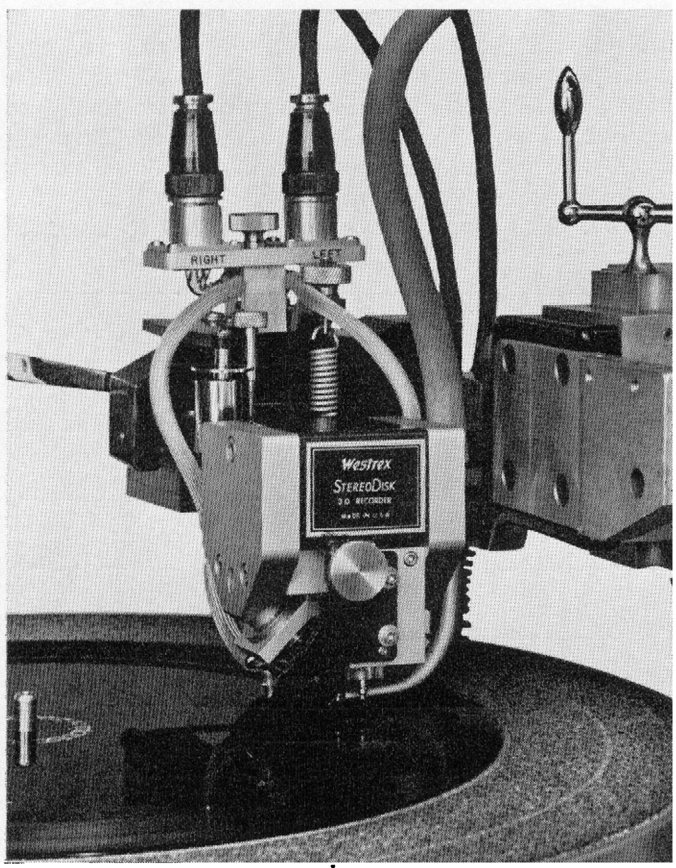
Replacement or readjustment of the stylus as used in the 3C Cutter necessitates removing the instrument from the lathe, inverting it and, by using a special stylus holding

* Presented March 18, 1964 at the Eleventh Annual Spring Convention of the Audio Engineering Society, Los Angeles.

1. John G. Frayne & R. R. Davis, "Recent Developments in SteroDisk Recording", *J. Audio Eng. Soc.* 7, 147 (1959).



a



b

FIG. 1. Westrex StereoDisk 3D Cutter. *a*. Schematic diagram of the cutter. *b*. Photograph of the recorder in position on the recording lathe.

tool, "eyeballing" the cutting face normal to the torque tube (See Fig. 2). The sapphire stylus is cemented into a tapered brass shank which in turn is inside a tapered receptacle in the torque tube. Unfortunately, this type of removable mount is not impervious to foreign materials and accidental physical damage. Repeated manipulation of this combination invariably results in looseness, a consequence of imperfect mating.

To circumvent this problem, a new sapphire stylus and stylus holder has been designed embodying such features as automatic alignment, increased stylus diameter for strength, rigid mounting and the ability to leave the cutter mounted in the lathe. The new one-piece sapphire cutting stylus is 1.5 times greater in diameter than the previous type used in the 3C and has a flattened face 6 mil deep and 39 mil wide ground the full length of the sapphire. This ground surface serves as the cutting face and for flat location for mating to a precision mount designed to

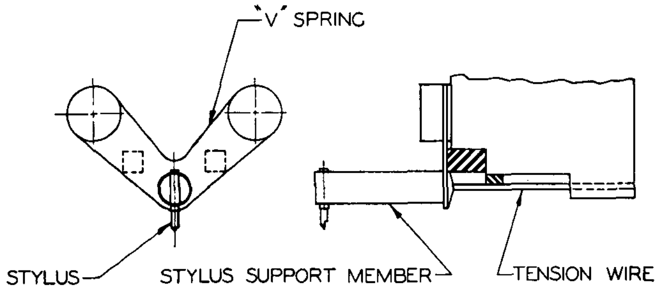


FIG. 2. Schematic diagram of the stylus support for the Westrex 3C Cutter.

give precise alignment of burnishing facets and cutting face. This 0.43-in. long sapphire inserts in a V-way at the end of a new torque tube specifically designed to accommodate the new stylus.

Torque Tube

The V-mount designed to hold the new stylus is an integral part of the new torque tube. Two 2-96 screws located adjacent to the V bind on a wedge that in turn applies pressure to the stylus wall, thereby securing the sapphire in a rigid mount (Fig. 3). Accommodating the two 2-96 screws, wedge and V requires a torque tube diameter considerably larger than that used on the 3-type-series cutters. Unfortunately, an increase in size also means an increase in mass and, therefore, a material other than beryllium copper tubing, as used on the 3C, must be used since the previous 3C system already exhibits characteristics of being too heavy. After considerable investigation, hard aluminum was chosen for the new torque tube material with bonding of links and spring to the tube by means of a thixotropic epoxy.

Heater Wire

The heater wire may be quickly changed by depressing two spring loaded wire crimping clips located on the advance ball assembly mounting block.

Coil Support Springs

Drive coil assembly support springs have exhibited spuri-

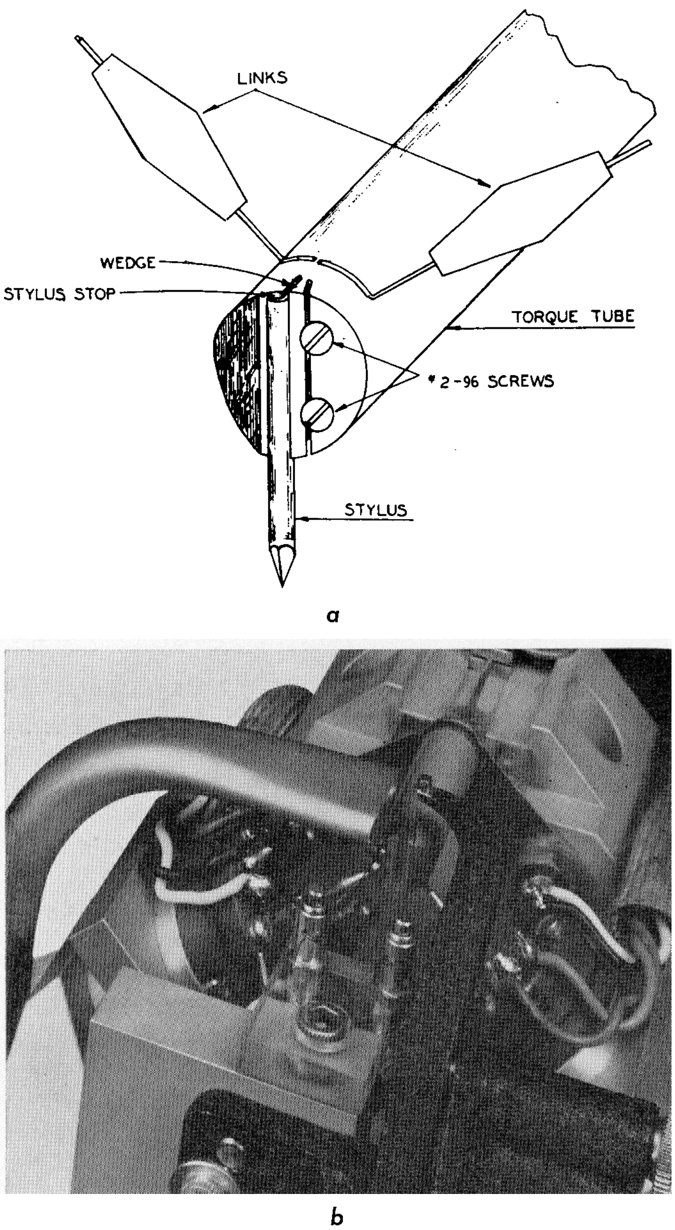


FIG. 3. Stylus support for the Westrex 3D Cutter. *a*. Schematic diagram. *b*. Closeup view showing torque tube, self-aligning stylus, and heater wire clips.

ous mechanical resonances in the upper frequency spectrum in 3-type-series cutters. Damping material has been placed between the two springs in an effort to reduce this undesirable effect with, at the best, partial success. Therefore, a new spring has been designed that virtually eliminates undesired resonances and standing waves. This improvement is accomplished by ribbing 80% of the straight portion of the coil-support spring, thereby forcing flexure at the support or mount end of the spring. The results have been very gratifying.

Drive Coil Efficiency

Efficiency of a stereodisk cutter is principally dependent on the mass of the system in motion, total magnetic flux encompassing the drive coil winding, dc resistance of the drive coil winding and a complex pole-zero combination of mechanical and electrical terms. While it is well beyond the scope of this paper to discuss the poles and zeros of mechanical and electrical terms in combination, the effect might be best likened to an M section of a maximally flat network with varying Q. Every effort has been made to reduce mass in all moving parts. Magnetic flux has been maximized by using the highest flux density materials available. The remaining variable, dc resistance of the drive coil, was examined closely in terms of flux reduction, a consequence of increased flux gap with an increase in turns and increased mass caused by additional turns. It is immediately apparent that since force is proportional to flux density times current times the total conductor length, doubling the number of turns would reduce the current required for a given force to half. Since heat loss in the drive coil varies as I^2R, an efficiency increase of 2 to 1 in power (or 3 db) could be realized. To accommodate a larger drive coil, the flux gap must be altered in a manner that reduces the total magnetic flux encompassing the drive coil winding. Additional loss results from fringing flux, now greater as a consequence of an increased gap. Integrating all constants and variables resulting from the higher impedance drive coil was in essence an empirical determination. Averaging test data from several 3C and 3D cutters showed a conservative increase in efficiency of 25% (See Fig. 4). This graph shows comparative I^2R losses of

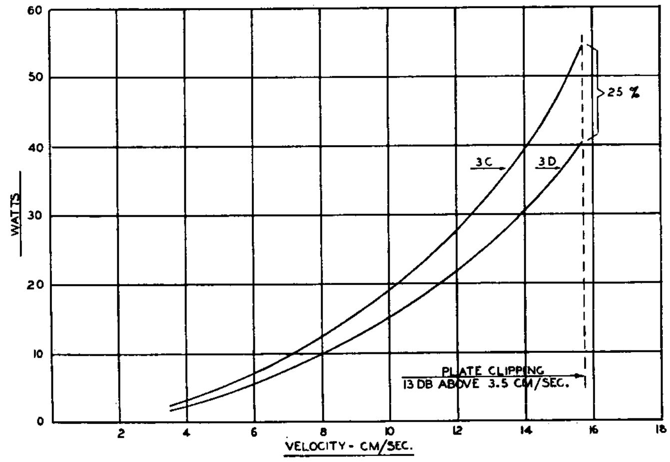


FIG. 4. I^2R losses for the drive coils of 3C and 3D Cutters.

typical 3C and 3D drive coils. The seriousness of excessive power drive on either cutter is plainly seen when viewed in terms of 40 to 55 w of heat dissipated in a mass of 0.4 g. Special high-temperature wire and varnish rated for continuous operation at 220°C for 20,000 hours is used in the 3D cutter. Many tests to prove the worthiness of this new material were made, using repeated frequency sweeps from 1 kc to 15 kc with true RIAA record characteristics and program material causing 3 db of plate clipping in the final amplifier.

The RIAA frequency sweep test was referenced to a level that would record a velocity of 3.5 cm/sec at 1 kc. The new RA-1574-D amplifier was used for all electrical tests and evaluation. Frequencies causing plate clipping power in excess of 75 w in the program material test fall within the frequency spectrum of 7 kc through 10 kc, and were subjected to the drive coil for 15 hours of continuous operation. The 3D cutter did not fail, nor did the 1 amp fuse. Examination of the drive coil after these tests showed that temperatures in excess of 300°C had been reached.

Cutter Feedback

Analyzing phase-shift and feedback characteristics of the 3C Cutter revealed a positive feedback condition from 5 kc to 12 kc (Fig. 5). This function depends entirely on

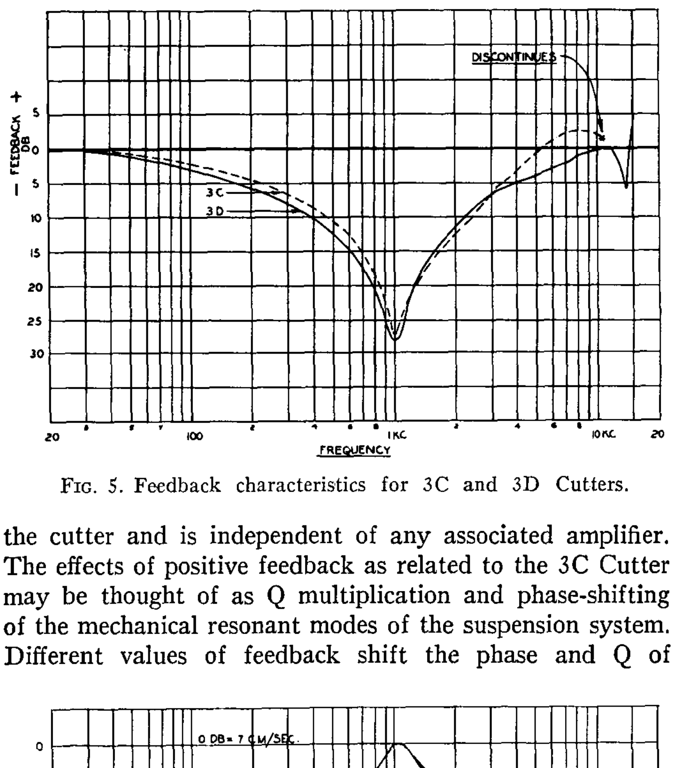


FIG. 5. Feedback characteristics for 3C and 3D Cutters.

the cutter and is independent of any associated amplifier. The effects of positive feedback as related to the 3C Cutter may be thought of as Q multiplication and phase-shifting of the mechanical resonant modes of the suspension system. Different values of feedback shift the phase and Q of the mechanical resonances, resulting in a frequency response characterized by hills and valleys that do not appear as a family of curves but rather are extreme in magnitude and irregular in position (See Fig. 6). After considerable testing and data integrating, a condition approximating a fourth-order effect was found to result from improper shaping of the copper rings that control inductive crosstalk between the drive coil and feedback coil. After modification of the copper rings, within the limitations of the existing mechanical design, feedback was made negative or unity over the critical portion of the frequency spectrum.

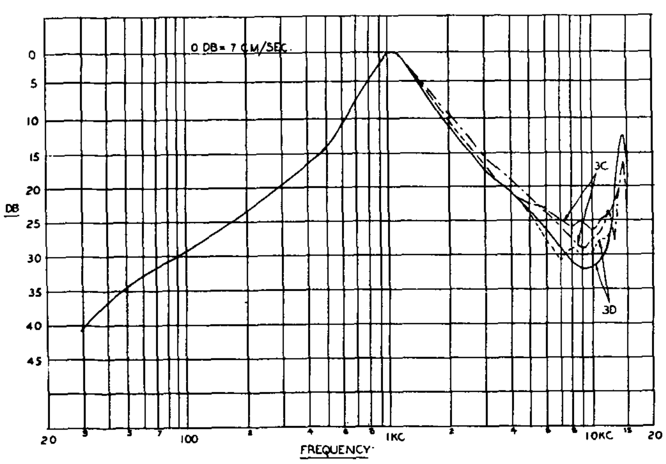


FIG. 6. Resonance characteristics without feedback for 3C and 3D Cutters.

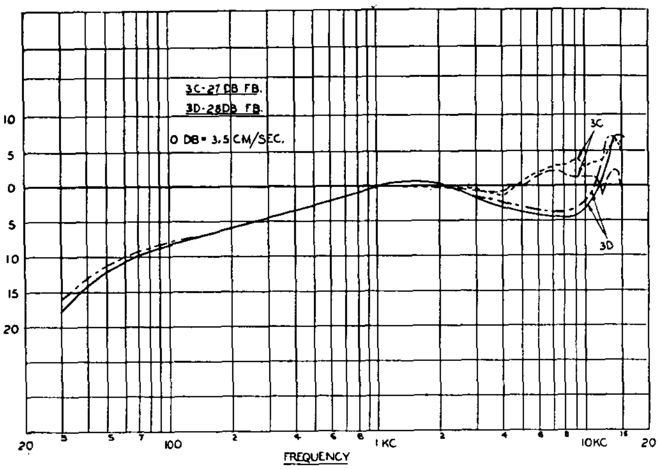


FIG. 7. Response characteristics, with feedback, for 3C and 3D Cutters.

Reference is made to Fig. 6 illustrating the response characteristics, without feedback, of the 3C and 3D Cutters for two extremes of mass and compliance. Note the similarity of extremes between the two cutters. Figure 7 shows the same cutters with feedback, 27 db for the 3C and 28 db for the 3D. The response characteristics of the 3C

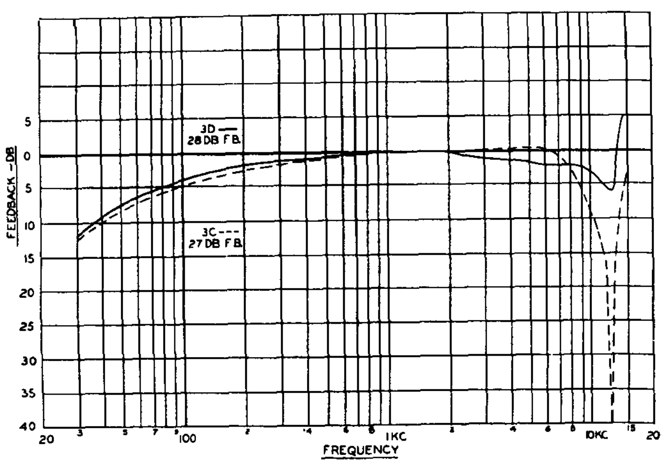


FIG. 8. Feedback coil voltage in db for 3C and 3D Cutters.

2. J. W. Stafford, "Maximum Peak Velocity Capabilities of the Disk Record" *J. Audio Eng. Soc.* 8, 162 (1960).

3. B. B. Bauer, "The Vertical Tracking Angle Problem in Stereophonic Record Reproduction" *IEEE Trans. on Audio* AU-11, 47 (1963).

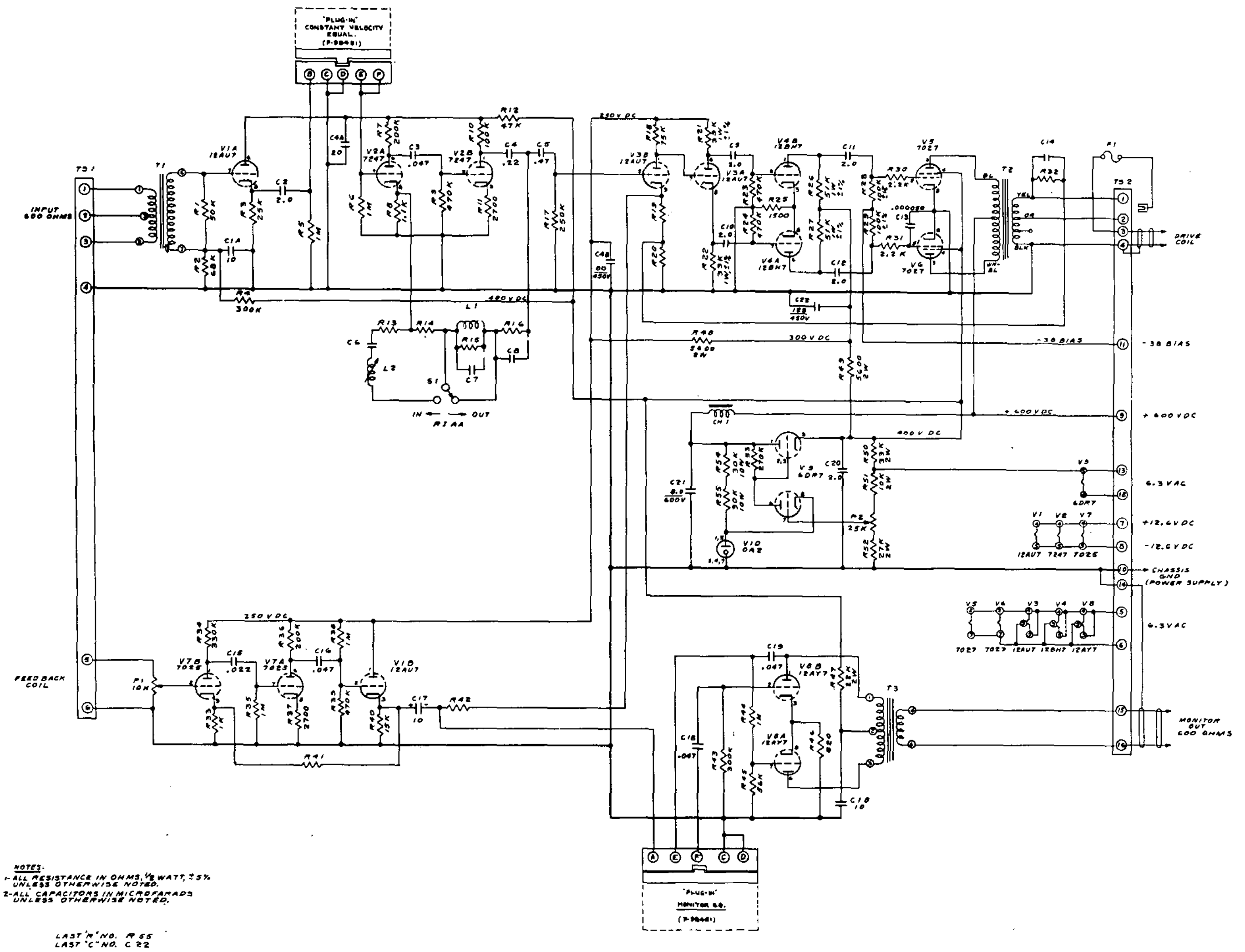


FIG. 9. Schematic diagram of the RA-1574-D Amplifier.

typify the variances expected from a positive feedback condition, while the response of the 3D Cutter with negative feedback is smooth, without hill and valley irregularities, and may be easily equalized by using simple passive networks. The drop in response of the 3D Cutter in the spectral region of 3 kc to 11 kc results from the elimination of positive feedback; i.e., the boost factor is no longer present. A side effect of the foregoing improvement is in the feedback voltage derived from the 3D Cutter. Figure 8 shows the familiar dip between 12 kc and 13 kc associated with the 3C cutter, while the 3D Cutter has no nulling and makes possible true monitoring of the feedback voltage.

RA-1574-D AMPLIFIER

Before attempting to redesign an amplifier for the Westrex StereoDisk System, desirable improvements and deficiencies of existing amplifiers that are associated in use with Westrex cutters, were appraised; the most controversial of these is the power necessary to drive the Westrex cutters.

A study of power necessary to drive a 3C Recorder to the maximum space limits of standard disk recordings has previously been reported.[2] The maximum peak power that would be required in microgroove recording turned out to be about 25 w at 5000 cps in the case of 45 rpm recording.

It should be pointed out that at 78 rpm the maximum peak power approximates 70 w, computed on the same basis. The playback stylus for 78 rpm reproduction is 2.5 mil instead of 0.5 mil as used in the above computations, so that the limiting high-frequency amplitude would be reached before the 70 w peak power level had been used. Since the limiting velocity at high frequencies is proportional to the stylus tip radius, a power reduction of 7 db results.

In view of the foregoing considerations, a power source in excess of 75 w rms is not justified.

Features embodied in the new RA-1574-D amplifier, based on the foregoing analysis and appraisals from the record and related industries, are:

1. Compatibility with all Westrex disk cutters;

2. 75 w power @ less than 1% distortion, 30 cps to 15 kc including all stages;
3. —15 dbm input level for 3.5 cm/sec;
4. +4 dbm output level from monitor amplifier when cutting 3.5 cm/sec;
5. Inverse RIAA in monitor amplifier giving ±2 db from 50 cycles to 15 kc;
6. All circuits high level, medium and low impedance for increased stability;
7. Constant 600 ohm input impedance to amplifier;
8. "RIAA-IN," "RIAA-OUT" switch mounted in front panel to allow equalization for constant velocity;
9. Plug-in card for precise constant velocity correction for individual cutters;
10. Plug-in equalization card for monitor amplifier;
11. Noise at least 80 db below 75 w;

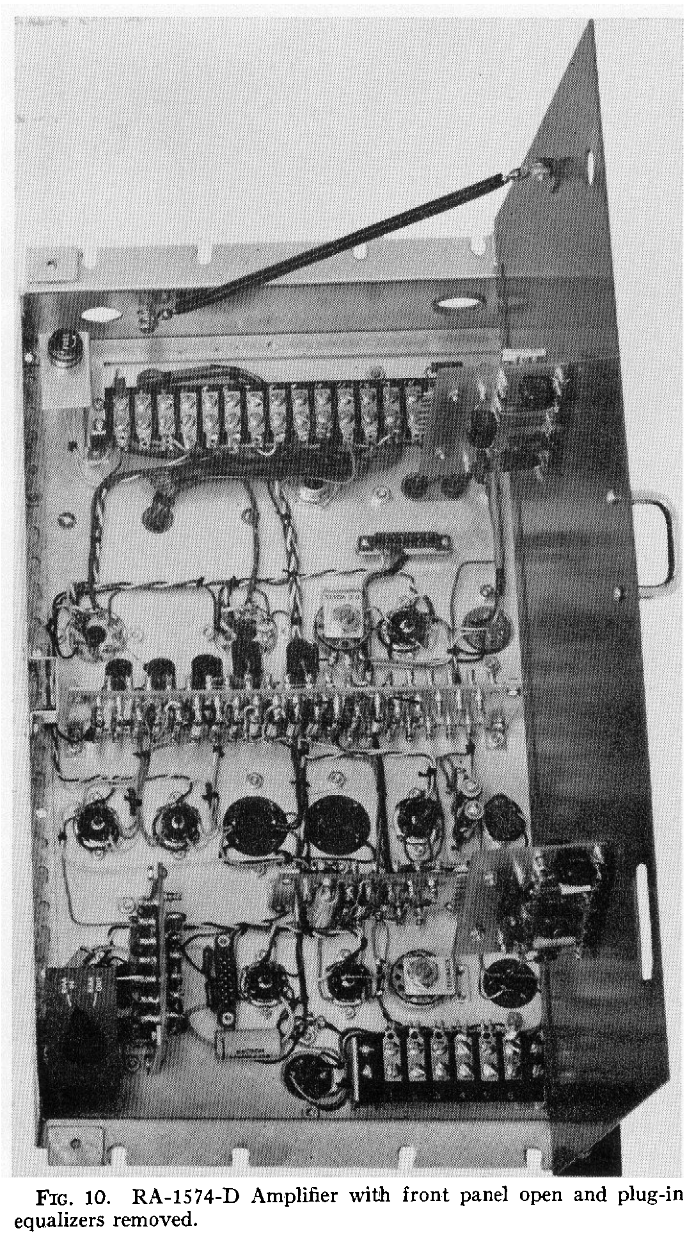


FIG. 10. RA-1574-D Amplifier with front panel open and plug-in equalizers removed.

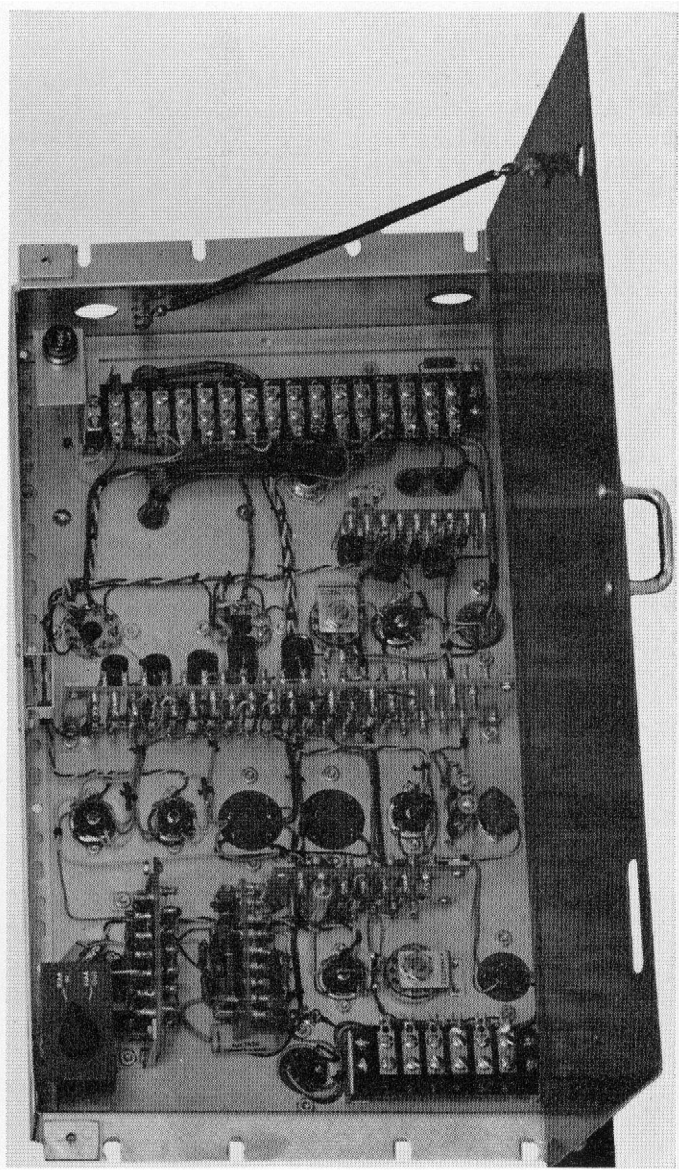


FIG. 11. RA-1574-D Amplifier with front panel open and plug-in equalizers in place.

12. Hinged front panel for quick access;
13. All adjustments on panel side for convenience;
14. Regulated power supply for all stages and final amplifier screens;
15. Regulated bias supply for the final amplifier;
16. Solid state rectifier;
17. Output impedance for new and old cutters.

In an age of micro-miniaturization, transistors and exotic design, it may seem strange that Westrex has retained vacuum tubes and spacious layouts in the design of the RA-1574-D Amplifier. However, this retention of the old has a very good reason. The Westrex monaural and StereoDisk systems are used throughout the world, operated by personnel with varied experiences and language barriers. Material procurement necessitated by component failure is often from foreign local stock, generally not of the calibre, value or tolerance specified in the original equipment.

It is then that the type of material used, ease of repair, straightforward design, margin of design, cost and modification flexibility without the fear of generating instabilities become especially important. In order to reduce the cost of the RA-1574-D amplifier, redesign incorporates the existing RA-1567 Power Supply, output transformer, choke and input transformers from the RA-1574 amplifier.

Description

This redesigned amplifier functions like the previous type but has many additional features not presently available in amplifiers used with the Westrex record cutters. As envisioned, the RA-1574-D Amplifier may be used with any Westrex cutter, past, present or future. This flexibility has been realized by excluding all compensated variables from the amplifier and consolidating them on plug-in cards. High and low-output impedance may be selected by a quick-change jumper. All controls and plug-in cards are accessible from the wired side of the chassis and covered by a hinged panel that opens to expose 90% of the chassis. A series voltage regulator provides constant pressure to the screens of the final amplifier tubes and all stages within the amplifier. Large open-loop gain with heavy feedback ensures a low dynamic impedance, gain stability and phase shift reduction in all stages of the RA-1574-D Amplifier. The schematic for the new amplifier is shown in Fig. 9.

Constant Velocity Plug-in Card

Constant velocity equalization from 1 kc to 15 kc and RIAA equalization from 30 cps to 1 kc is provided by passive networks mounted on a plug-in card (See Figs. 10 and 11). This card is driven from a constant voltage generator, V_1 in Fig. 9, which in turn receives its signal source from input transformer T_1. Termination for the equalizer network is on the plug-in card and is independent of the high-impedance amplifier input it drives (See schematic, Fig. 12).

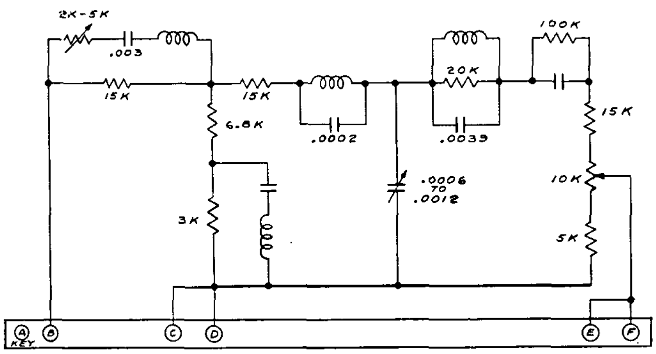


FIG. 12. Schematic diagram of plug-in equalizer card.

One plug-in card will be provided with each channel of the new 3D Cutter and equalized to ± 1 db from 50 cps to 12 kc and ± 2 db from 12 kc to 15 kc.

RIAA Equalization

For reasons of reproduction and light pattern evaluation, the constant velocity method of record cutter equalization is most desirable and has been provided for in the RA-1574-D Amplifier. When the RIAA switch protruding through the front panel of the amplifier cover is in the *OUT* position, the amplifier is flat in frequency response characteristic, and thus does not affect the constant velocity equalization provided by the plug-in card (See Fig. 13).

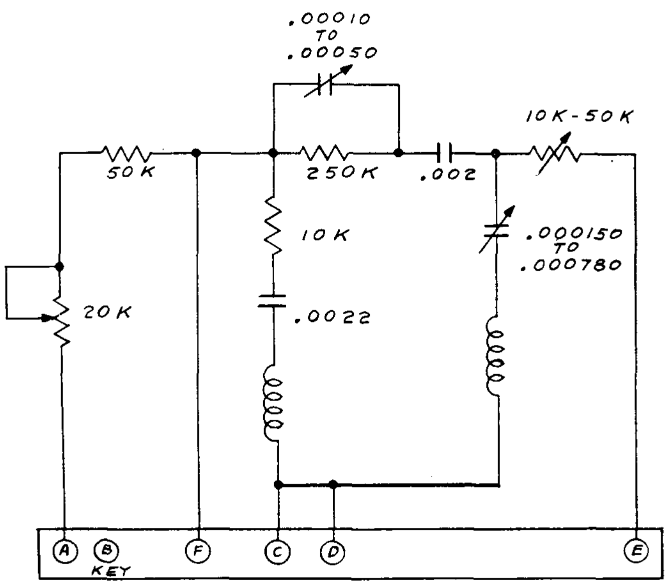


FIG. 13. Schematic diagram of plug-in equalizer card for the monitor amplifier.

Positioning the RIAA switch to *IN* will add the RIAA pre-emphasis frequency response characteristic to any existing function from 1 kc to 15 kc. Gain change at 1 kc is less than 0.5 db.

POWER SUPPLY

The RA-1567-D Power Supply is essentially the same as in previous models. The interlock switch has been removed and is replaced by a potentiometer that provides bias voltage adjustment to grids of the final amplifier. The bias voltage supply is zener-diode regulated. The time-delay relay previously mounted on the RA-1574-C Amplifier chassis is now incorporated into the power supply. The design of this relay is new and greatly improved. Vacuum tube rectifiers have been replaced with solid state types, with wiring remaining as is.

VERTICAL ANGLE

Considerable thought and study was devoted to the vertical cutting angle problem. The excellent work of Bauer at Columbia[3] and Woodward and Fox of RCA[4] was reviewed, particularly to determine what Westrex could do, if any-

4. J. G. Woodward & E. O. Fox, "A Study of Tracking Angle Errors in Stereodisk Recording", *IEEE Trans. on Audio* **AU-11**, 56 (1963).

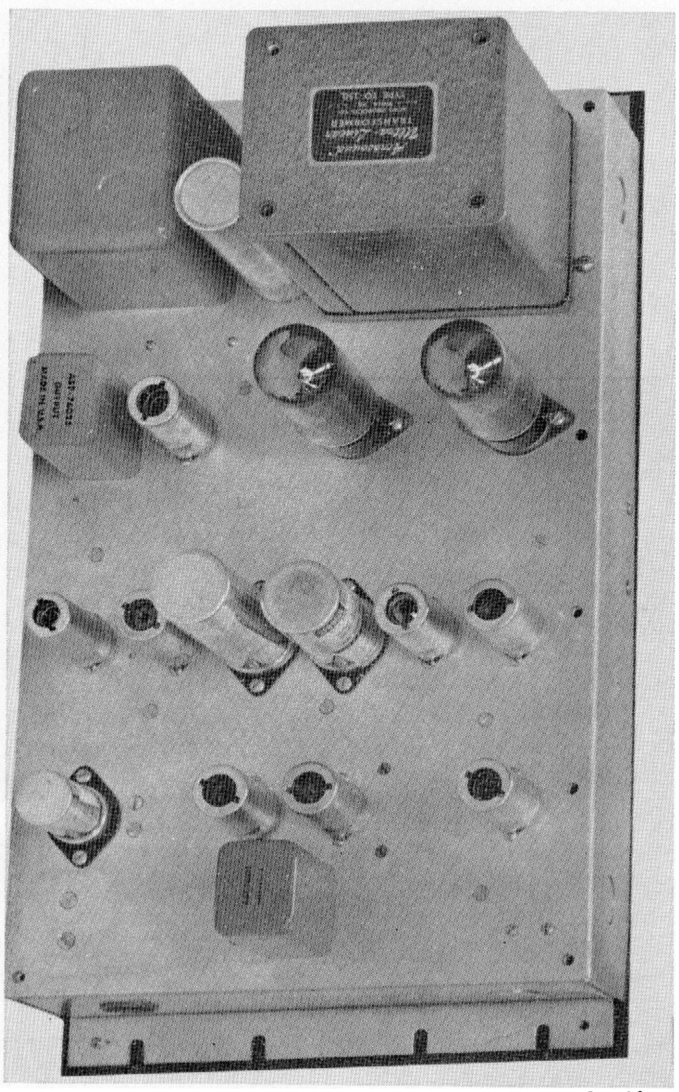


FIG. 14. RA-1574-D Amplifier viewed from the vacuum-tube side.

thing, toward industry standardization of vertical tracking angle. Preliminary tests were made. However, two facts were quite obvious from the beginning—first, standardization is primarily a problem of the reproducing equipment manufacturers and should be agreed upon by RIAA standards before changing present recording equipment specifications; and secondly, the problem of distortion *vs* effective vertical cutting angle is extremely complex, involving such factors as frequency, peak stylus velocities, groove diameter, groove spacing, depth of cut, plastic properties of the master disk, etc., and would require an excessive amount of time and effort for an analytical solution.

On the basis of this vertical cutting angle study, it was decided to maintain the 23° angle as presently established in the 3C Recorder, bearing in mind that in the future a change might be necessary.

CONCLUSION

The design objective of the new Westrex StereoDisk System was to improve fllexibity, compatibility, stability and efficiency of existing amplifiers and cutters by means of mechanical and electrical modification. Every effort has been made to reduce cost by incorporating into the new design many non-moving parts of the earlier 3-type series cutters. The RA-1567-C Power Supply, input transformer, output transformer and choke from the RA-1574-C Amplifier are retained.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Otto Hepp for his invaluable assistance in this program. Without Mr. Hepp's meticulous attention to detail, patience and exceptional ability as a mechanical designer and precision machinist, the Westrex 3D Cutter would not be a reality.

The authors also wish to thank the many professionals and laymen in the recording industry who gave of their time to advise and appraise the Westrex StereoDisk System.

THE AUTHORS

Carl S. Nelson is Manager, Recording Engineering of Westrex Division of Litton Industries. He received a B.S. in electronics engineering from Utah State College in 1951. He has wide experience in the magnetic recording field, and has designed various types of magnetic recorders and associated components, including oscillators and magnetic recorders for airborne and satellite use.

Mr. Nelson is a member of Sigma Tau and the Institute of Electrical and Electronic Engineers.

●

Jerome W. Stafford, a research engineer with Litton Data Systems Division, received an A.B. in mathematics from Pomona College in 1926, and a B.S. in physics from Massachusetts Institute of Technology in 1928. His experience has been in the design and development of optical recording devices, sound recording systems, cinemascope magnetic sound printing systems with automatic electronic inspection, and associated devices. He also acted as project engineer and consultant on the Radar anti-aircraft fire control trainer and the Radar and visual bombing coordination trainer.

Mr. Stafford holds patents on a range indicating system and a comparator device, and has one pending for a photochromatic analyzer. In 1955 he received a technical award from the Academy of Motion Picture Arts and Sciences for "An Electronic Sound Printing Comparison Device." He has written several technical papers and is a member of various societies, including S.M.P.T.E., I.E.E.E. and the Academy of Motion Picture Arts and Sciences.