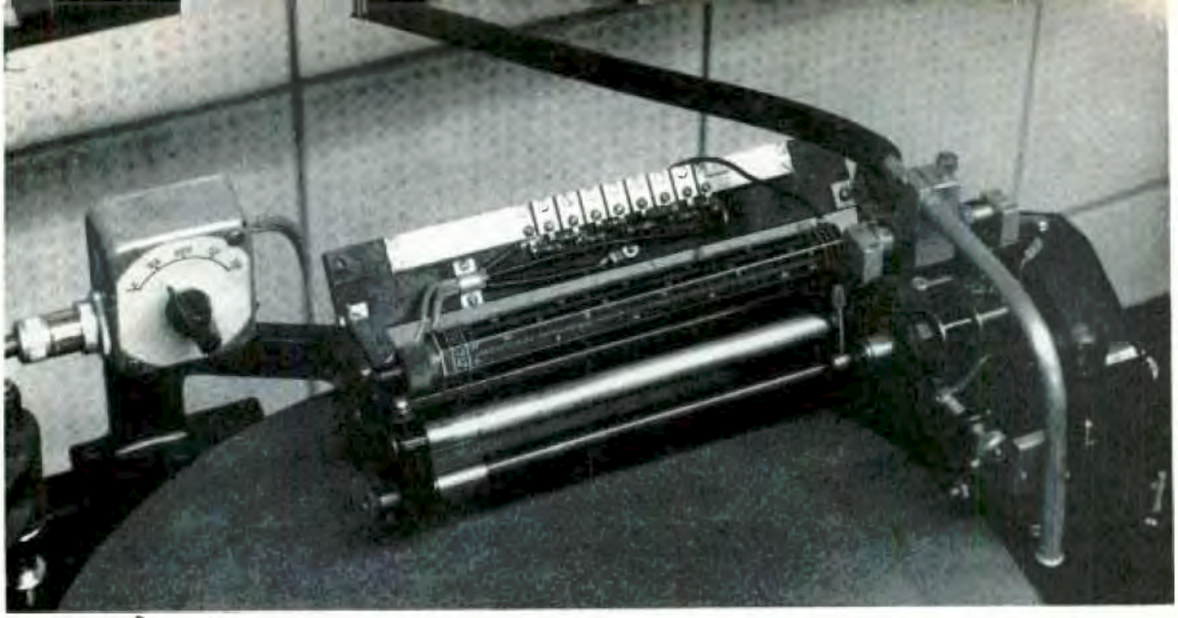

Fig. 2. Automatic radius-equalizer fabricated for Fairchild 199 recorder. Control switch is located at left of equalizer.

Disc Recording for Broadcast Stations

W. J. MAHONEY*

Technical details of a successful, high-quality studio installation.

With the recent improvements made in recording and reproducing equipment, it is now possible for medium-size broadcast and recording studios to obtain results comparable with the finest in the industry, within limitations of their acoustical studio facilities. However, there is little information available to guide the recording engineer who wishes to custom-build his installation to obtain maximum performance in each of the various services it must perform. In furtherance of this cause, the author wishes to describe the flexible recording system designed for the new studios of WSAI, Cincinnati. This paper also includes a discussion of a number of the practical problems involved in designing a complex system of recording equalizers.

The first requirement of the system was simplicity of routine operations, such as transcribing network and studio presentations for delayed broadcast, or file. The second requirement was ability to record transcription masters, phonograph record masters, composite dubbings and all the various services required of a studio. In each of these special applications the proper equalization and levels must be employed. The final requirement demands a rapid method of providing substitution when equipment failures arise.

Two RCA 73-B recorders and two Fairchild 199 recorders with magnetic cutters were considered adequate to handle the volume of work. Duplicate sets of amplification and control equipment were provided for each pair of machines. The only variation was the necessity to mount controls and amplifiers in one rack for the Fairchild position, due to space limitations, and the use of separate control turret and amplification rack for the RCA machines.

Program Sources

The amplification layout itself is unique. The studio control systems were complete and totally independent of the recording installation, so it was only necessary to design the recording amplification from the output of the studio system. At WSAI, which has separate control rooms, it was decided to make the recorder bus connection to shunt the channel-amplifier input at the channel side of the interlock system. Feeding from the input side of the channel was necessary because the recorder bus connection consisted of a bridging pad, which in absence of a line or 600-ohm resistive load, would not provide proper loading for a channel amplifier. The values of the series arms of the pad were 1300 ohms, the shunt arm was 500 ohms, providing a total loss of 15 db. These recording pads are permanently located in the transmission racks and provide the dual purpose of isolating the recording busses in case of short circuit, and minimizing the loading effect of paralleling many amplifier bridging-inputs.

The same type of pads was used to bridge a radio tuner system, the incoming network, and a "remote" jack on the master control bay. This remote position is used for all additional sources of program material.

Referring to the block diagram shown in *Fig. 1*, note that the input-selector switching system allows both recording and monitoring circuits to be bridged independently or in tandem across each recording bus. Following the switches are 16,000/500 bridging transformers, which provide the proper circuit for location of the standard 500-ohm "T" attenuators. The monitor and booster amplifiers fed by each attenuator are identical, with a power output of +30 dbm, and a maximum gain of 70 db.

With a normal attenuator setting, 21 db, the total losses up to the input of the monitor-booster amplifiers will be approximately 52 db. Assuming the studio is feeding a level of +8 vu, the output of the booster-monitor will be +14 vu. The monitor amplifier works

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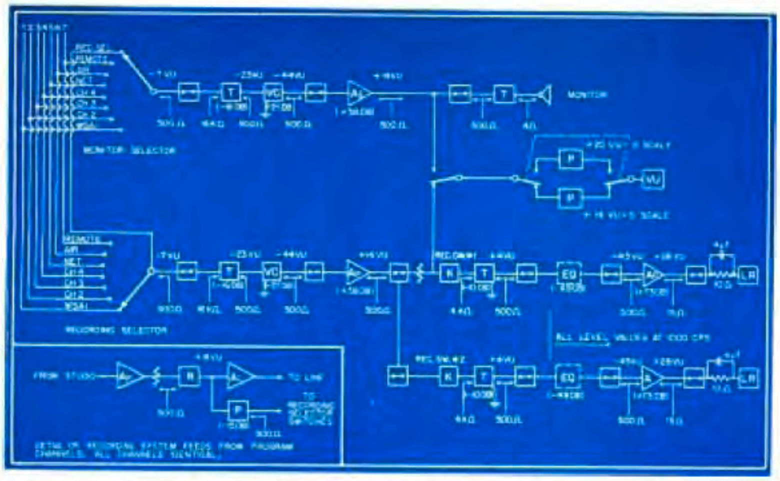


Fig. 1. Block diagram of recording installation. Program sources are fed to bridging-input pads at 8 vu.

into a speaker-matching transformer, the booster amplifier into a 500-ohm resistive load.

The volume indicator is bridged across the output of the booster, with a standard pad designed to permit the meter to read 0 vu when the booster is providing +14 dbm on steady tone. An additional pad is available on the switch, to shift the 0 vu point to +20 dbm from the booster. The additional 6 db output, obtained by advancing the master fader, is used when cutting phonograph or transcription masters. The vu meter and pads may also be transferred to the output of the monitor amplifier by a momentary-push switch. This feature, along with the ability to switch the input of the monitor amplifier independently, allows the operator to predetermine the levels to be encountered on a subsequent program from another channel without interrupting the recording in progress.

Power Amplifiers

Shunting the booster load resistor are the power amplifier input switches. The 4000/500 bridging transformers connected to these switches feed the various equalizers. The input impedance of each power amplifier is 500 ohms, with the secondary loaded by a potentiometer calculated to reflect the proper impedance. The amplifiers, Brook 12D, have a maximum gain of 80 db and a power output of 30 watts.[1]

The losses in the equalizer system are of the order of 50 db. This may seem high, but it must be remembered that some of the equalizing positions are capable of producing as much as 25 db rise at 10,000 cycles. At 200 cps, the power into the cutters is about +28 vu for instantaneous transcriptions, +34 vu or better for master recording, at 200 cycles. The equalizers have been designed so that there is no change in the level at 200 cps on any of the positions.

It will be noted that the patch field allows considerable flexibility. A tip, ring, and sleeve system is used throughout, all with double jacks in parallel except "Recording Switch #1 & #2." Substitution for input selector switch, bridging coil, fader, booster amplifier, equalizer network and power amplifier may be made by appropriate patching. Also, by use of a single patch cord from "Monitor Amplifier Output" to "Recording Switch #2," the bridging coil, #2 amplifier, and cutter may be connected to the output of the monitor-amplifier system, across the normaled loudspeaker transformer. This will allow emergency use of the two recording machines as completely independent channels. The vu meter may be transferred momentarily to the monitor channel for occasional checks of the program level.

General Design

In designing the recording system, it was felt that sufficient care should be taken to enable the installation to handle complex re-recording work and still maintain a faithful likeness to the original material. Obviously, such a system must have an accurately controlled frequency response, minimum distortion, low noise level and speed variation, and last, but fully as important as any, an intelligent operating procedure.

The distortion, noise level, and speed variation factors are inherent in the original equipment. The frequency response is reasonably subject to the control of the system designer, assuming that first-class equipment is used throughout.

In planning the equalizers, some alteration was made to the basic NAB pre-emphasis curve to provide for radius equalizing, at least on the transcriptions cut for instantaneous playback. This is a radical departure from accepted practice and, with the present degree of standard pre-emphasis (100 μ-sec), admittedly difficult to apply to all types of program material. Consequently, a compromise design was employed to permit substantially flat playback up to 5,000 cycles at the inside radius of 3¾ inches, corresponding to 15 minutes at 128 lines per inch.

Surprisingly enough, there seems to be a difference in interpretation of the NAB curve. Some authorities maintain that the present standard was set up, not only to improve the signal to noise ratio, but to compensate for the poor response of the cutters and pickups in use at that time. A new committee of standards is at work on a revision of the recording section of the NAB code, and it is hoped that a more realistic approach to the radius and pre-emphasis problem will be presented. Certainly there is no valid basis to the belief that a fixed pre-emphasis curve will overcome, in any way, the serious losses encountered with a varying radius.

In addition to the NAB equalization for transcriptions, it was desirable to have a separate pre-emphasis network for phonograph records, and a setting for flat response of the system with optional radius-equalizing.

Automatic Radius Equalizing Device

RCA has manufactured a simple automatic equalizer which has proven quite practical. It consists of several resistors, totalling 4600 ohms, soldered to a segmented rod, which in turn is wiped by a contactor attached to the cutter carriage. The contactor is wired to two different capacitance values, available through a switch, making in effect a potentiometer having capacitance in series with the variable arm. A similar device was fabricated in the shop for use on the Fairchild machines, *Fig. 2*. It consists of a dual-section RC network encompassing both radius and pre-emphasis functions and includes the automatic equalizer described above. However, it was necessary to treat the Fairchild and RCA cutters as separate problems, due to the difference in crossover frequencies of the two makes. The Fairchild, and most standard cutters, have a crossover at 500 cps. The RCA heads cross-over at slightly above 1000 cps, making a difference of about 3 db in the region from 50 to 1000 cps between the two brands.

Due to the varying impedances presented to the amplifier by the cutter head, most manufacturers provide a

[1] J. R. Edinger, High Quality Audio Amplifier with Automatic Bias Control, AUDIO ENGINEERING, June, 1947.

series resistor approximating the nominal impedance value of the head. In a 15-ohm cutter, the actual impedance varies from 2 ohms at 50 cps to 30 ohms at 10,000 cps. The constant-amplitude response of the head is determined partly by the value of the series resistance, and partly by the internal mechanical damping. The RCA heads were provided with a resistor tapped from 5 to 15 ohms, in steps of 0.5 ohms. A capacitor is used in shunt with this resistance to improve the high-frequency response of the cutter. Experiment will be necessary to determine the settings which will provide the maximum response at 10,000 cps without appreciably altering the spectrum from 2000 to 5000 cps. Values from 2 to 4 μf will usually be necessary in a 15-ohm circuit. As the compensator supplied with the Fairchild recorder has no easy adjustment, it is difficult to use this method of altering frequency response.

Playback Standard

Unless the designer has an instrument such as the FM Calibrator[2] or a reliable method of optically measuring the stylus tip, it will be necessary to set up a playback device capable of acting as an accurate standard for frequency measurements. The light-pattern method[3] of measuring a severely pre-emphasized cutter response is far too tedious and inaccurate, although valuable for constant-velocity measurements. By means of careful light-calibration of the Columbia test record YTNY-170 it was determined that a Pickering pickup was reliable within 1 db at all frequencies covered on the test record. Thereafter, the Columbia record was used as a control to ascertain that the characteristics of the pickup were not changing. It is also advisable to record your own light pattern test-record as a double check. The next step in setting up the standard was careful plotting of the NAB playback equalizer. This was accomplished by use of a variable frequency oscillator and a gain-set capable of inserting sufficient loss to equal the voltage from the pickup. By adding this source in series with the inductance of the pickup and measuring the equalizer through the playback amplifier, an accurate reading of the network may be made[4]. The response of this circuit was found to be within 0.5 db of the complement of the NAB pre-emphasis curve. While set up for this measurement, it will be wise also to check the flat-response position of the equalizer, because some networks will be found to start the bass boost above 1000 cps, thus throwing off all readings above this frequency by 1 or 2 db. Additional standard equipment should consist of a good variable-frequency oscillator and a gain-set capable of presenting proper transmission characteristics to the amplifying system. The gain-set output meter should be accurate over a range of 30 db.

Before beginning the design procedure, it will save much confusion if several styli are tested and set aside for measuring purposes. Even a newly sharpened stylus, with slightly dull burnishing facets, may give a reduced response from 8 to 10 db at 10,000 cps. A recommended procedure is to cut bands of 8 kc, 9 kc, and 10 kc of exactly the same light pattern width as 1000 cps. With a calibrated pickup, these frequencies should not show any deviation when the playback filter is set for flat response. Obviously, these styli must also be acceptable for quietness of cut, but almost invariably the satisfactory points will possess both attributes. A short-shank stylus is desirable, as the long-shank type possesses an undesirable mass resonance at 8000 cps. We do not wish to enter into the discussion of 70° versus 87° styli, but it should be pointed out that there is a difference in the ability of a playback stylus to reproduce high frequencies from the different cutting angles. We have found the 70° angle to have about 2.5 db higher response at 10,000 cps when played with a .0025" radius reproducing point, with a slight increase in distortion between 1000 and 5000 cps. Of course, when recording phonograph record masters, the wide angle stylus is mandatory.

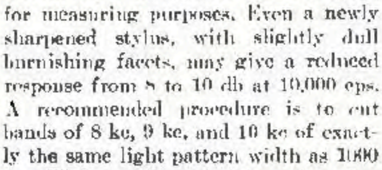


Fig. 3. Basic circuit of combined NAB and radius-equalizing networks. (Values explained in text.)

Heating Effect

When the recording heads are subject to signal, there will be some increase in efficiency due to the heating of the damping material. The resultant increased output is therefore considerably more evident in the damped, or constant-amplitude, portion of the curve. Because of this, the reference tone may be found to be as much as 2 db higher when repeated somewhere in the middle of a frequency run. The RCA MI-11850-C head is equipped with a built-in heater unit and thermostatic control to minimize this heating effect on program material; however, this is not sufficient protection to warrant disregarding the effects of steady tone during measurement. For this reason it was found necessary to resort to alternating two-second tone bursts with fifteen seconds of program at normal level when working within the 4000 to 10,000 cps region of the equalized curve. In this spectrum the amplifiers will be delivering 8 to 16 db higher power levels than the unequalized portion of the curve. For additional protection, the tone input to the equalizer system should be at least 6 db below the meter peaks of the program material. When working in the 50 to 2000-cps region, such a technique of alternation is not essential if the tone is kept considerably lower than normal program peaks. Incidentally, comparable troubles may be encountered on non-temperature-controlled heads due to ambient temperature changes. The author had a disagreeable experience when trying to duplicate a previous day's work on the following morning with an ambient temperature change of only 10 degrees. To avoid this trouble, it is good practice to introduce program at normal level for at least thirty minutes before attempting any measurement.

As a last word of caution before proceeding to the actual equalizer design, it should be impressed upon the reader that *all* measurements from 4000 to 10,000 cps at 33 1/3 rpm, *must* be made at the outer edge of a 16" disc, unless actually working upon the problem of radius losses. The 10,000-cps playback response will drop 1.5 db within one inch of the edge, and will drop 9 db at three inches with .0025" radius stylus.

RADIUS (inches)	7.5	6.75	6	5.25	4.5	4	3.5
1000~	0	-.2	-.5	-.6	-.7	-1.5	-1.5
5000~	0	-.7	-1.9	-3	-4.6	-7.2	-10.2
7500~	0	-2.2	-4.5	-7.7	-11.7	-17.7	-22
10000~	0	-2	-6	-12	-20	-21	-25.2

Fig. 4. Typical radius losses encountered on playback with RCA Vertical-lateral Pickup .0025" radius stylus.

Also, because of these radius losses, checks involving comparative portions of the high-frequency spectrum should be made at as nearly the same radius as possible. In the further interests of uniformity, the experimenter should use the best brand of discs, and preferably from the same package, in order to minimize the chance of error due to non-uniform coating consistency. The "softer" types of coatings will usually produce a slightly reduced

[2] R. A. Schlegel, FM Calibrator for Disc Recording Heads, AUDIO ENGINEERING, June 1947.

[3] C. J. Lebel, Light Pattern Calibration Chart, *Communications*, April 1940. Extended Experimental Study of Optical Pattern *Communications*, December, 1940.

[4] C. G. McProud, Elements of Residence Radio Systems, AUDIO ENGINEERING, November, 1948.

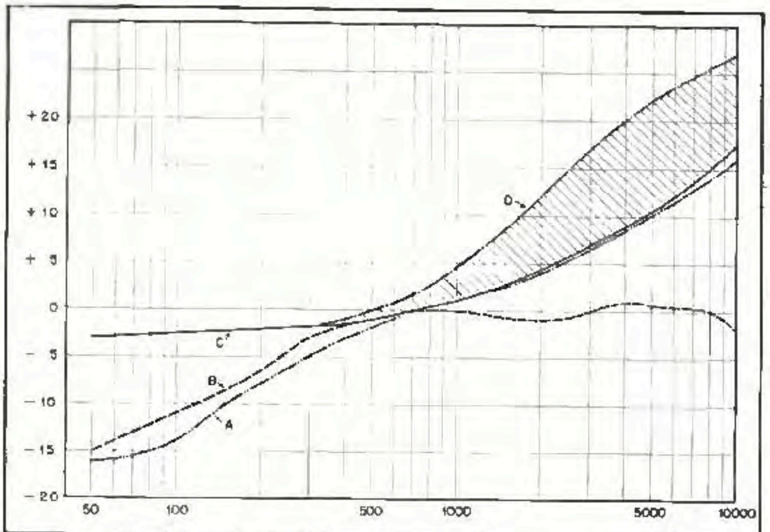


Fig. 5. A—NAB standard recording characteristic. B—Typical response of cutter with 500 cycle crossover. C—Response of NAB position on equalizer shown in Fig. 7 with radius-equalizer at minimum or off. Shaded area-Action of automatic-equalizer, continuously variable to the maximum shown by line D.

high-frequency playback response, approximately 1.5 db at 10,000 cps, probably due to the elasticity of the coating under the tremendous accelerations of the pickup stylus.

Network Design

In proceeding with the network design, the author desired to insert the experimental equalizer in the physical portion of the circuit where it would finally be used. In this way it is possible to compensate directly for all high-frequency losses due to long cable runs, amplifier deficiencies, and so on. The test signal was introduced into the front of the entire recording circuit at the program selector switch, and readings were taken from the output of the recording amplifier. Inasmuch as the selector input switch feeds a bridging coil, the oscillator or gain-set must work into a 500- or 600-ohm resistive load. For accurate measurement purposes the recording amplifier must feed a resistive load instead of the inductive load of the cutter.

The experimental form of the equalizer, with the exception of the fixed isolation pads at the input and output of the equalizer, consisted of variable carbon potentiometers and an assortment of small tubular paper capacitors ranging from .001 to .01 μf. All values of capacitance within this range should be covered in steps of .001 μf. Also, several capacitors from .01 to 0.5 μf will be necessary. Three or four of each value should be available, with actual measured values marked on the outside. Considerable later confusion will be avoided by this precaution.

To isolate the inductive and capacitive effects of the transformer windings adjacent to the equalizer, T-pads should be used at both ends of the network. An attenuation of 9 db is sufficient to provide complete isolation, but it is possible to use only 6 db attenuation if the over-all network losses become too great.

Two methods may be used to provide the proper working load for the equalizer and T-pads. If the input transformer to the recording amplifier must be operated without secondary loading, due to inclusion within feedback loops, for example, then the primary winding must be loaded with the proper value of resistance (in this case, 500 ohms). However, if the secondary can be loaded, then the step-up ratio of the transformer should be figured and the proper resistance shunted across it to reflect 500 ohms to the primary.

It may be convenient to utilize the secondary loading resistance as a potentiometer to control the gain of the amplifier. Loading the secondary aids in reducing distortion, and is preferred whenever it can be done conveniently.

The layout of the equalizer is shown in *Fig. 8*. In its experimental form R_3, R_4, and R_5 are potentiometers; R_1 and R_2 are the series and shunt arms of the isolation pads. Values of 2000 ohms for R_4 and 20,000 ohms for R_5 will allow sufficient range for test purposes. R_3, substituting for the radius equalizer, should be 5000 ohms.

The radius losses should now be charted. Without any pre-emphasis equalization, record bands of 1000, 5000, 7000 and 10,000 cps at radii of 7, 5, 6¾, 6, 5¼, 4½, 4 and 3½ inches. Tabulate the playback readings of these test cuts, as in *Fig. 4*. The desired response of the radius equalizer will now become apparent. Usually the losses at the smaller radii will be too great for any practical amount of compensation to overcome entirely, especially when added to an already pre-emphasized response. It is satisfactory to employ sufficient equalization to maintain flat playback to about 5000 cps at these inner radii.

Computation of NAB Equalizer

It is now possible to compute the equalization necessary to provide the equivalent of the NAB recording curve. The responses of the cutter itself should be taken by plotting the playback readings from the calibrated pickup. Test frequencies should be 50, 100, 200, 500, 800, 1000, 2000, 4000, 8000, 10,000 cps with the highest frequency at the outer edge of the disc. By adding the irregularities of the cutter algebraically to the NAB standard curve, the desired response of the equalizer will be shown. For example, if the cutter is -3 db at 10,000 cps where the NAB standard calls for +16 db, the desired response of the equalizer should be +19 db. Thus the *reproducing complement* of the NAB pre-emphasis curve will be met, and the system will produce a flat playback response from any standard reproducing system. In these computations the designer should be careful to use 800 cps as the reference point. Of course, a cutter that departs from flat response at the high end of the spectrum by more than 4 or 5 db cannot be fully compensated, and it is also impractical to attempt to neutralize large peaks or valleys within the spectrum by this method.

The most crucial problem will be the treatment of the region from 100 to 1,000 cps. Any departure from flat playback in this spectrum, which includes most music and speech fundamentals, will be serious when the system is called upon for complex dubbing work. If the ideal curve of a recording head with standard 500-cps crossover is plotted against the NAB curve, *Fig. 5*, it will be seen that the spectrum from 50 to 500 cps will be higher than the NAB curve by about 2 db. To correct this, the equalizer must start to rise as low as 300 cps and reach +3 db at 1000 cps.

However, with any combination of R_4 and R_5 that did not provide too much loss for the system to handle, such a curve became asymtotic at about 5000 cps when the proper capacitance C_2 was employed to provide the correct slope from 3000 to 4000 cps. In order to keep the response rising from 5000 to 10,000 cps, it proved necessary to add an auxiliary capacitance, C_3, across the entire radius-equalizer resistance. Obviously, any capacitance added here detracts from the effectiveness of the automatic radius-equalizer unless the shunt resistance R_4 is lowered. This, in turn increases the loss of the network, and a constant check of the output level from the recording amplifier must be made while working with trial values to ascertain that sufficient power is still available to drive the cutter. The radius-equalizer also must be observed periodically to determine that the curve is capable of being increased by the amount necessary to add full equalization up to 5000 cps at the inner radius.

The final values of the components in the equalizing system, as set up on breadboard, should be capable of providing a curve to fulfill the requirements of both NAB pre-emphasis and radius losses. After these values have been ascertained, the size of the series resistors between the segments of the automatic radius-equalizer may be determined. In order that the over-all gain of the system should not change by more than 1 db when the sliding contactor momentarily shorts two segments, the value of each resistor should be kept small. The device built at WSAI was divided into nine segments, providing a change of response every 1½ minutes. The values of resistance necessary were found by measuring the settings of potentiometer R_3 when adjusted to give the desired response at the various radii. In regards to radius losses, it was found that the combination vertical-lateral pickups used in the regular studio turntables were less efficient than the Pickering Pickups used in the re-recording setup. Therefore, use was made of the switch supplied with the automatic radius-equalizer to change capacitance values, in order to provide a less steep curve for transcriptions made expressly for copying. Additional positions were provided on switch to make the maximum radius-equalizer responses available as fixed curves.

Network For RCA Cutters

The network designed for use on RCA recording heads will differ from the above only in the detail of treatment to the spectrum from 100 to 2,000 cps. With the high crossover frequency, 1000 cps, it will be noted that the constant-amplitude portion of the curve already fits the NAB Standard *before* any pre-emphasis is added. Inasmuch as it is impossible to make a rising curve of 4 db per octave with a total of 15 db from 1000 to 10,000 cps and which has *no* effect on the region from 1000 cps down, the real problem is to minimize any change in the lower spectrum. Fortunately, most RCA cutters have a 2 db rise at 2000 cps. By taking advantage of this existing hump, it is only necessary to design the network with a slow beginning rise and a rapid increase at the high frequencies. This can easily be done by adding auxiliary capacitance across the radius equalizer resistance R_3.

Listening tests indicated that a slightly less steep pre-emphasis curve seems to be in general use today for phonograph records. A 75-μsec network, with a total rise of 10 db at 10,000 cps sounds quite acceptable. A value of C_2/R_3 was chosen which provided such a curve. The value of R_1 was so adjusted as to hold the signal level of the unequalized portion of the frequency spectrum at the same level as the NAB position. Inasmuch as it is impractical to use radius equalization with phonograph records, the automatic equalizer is turned off in this service. However, it is still available if desired.

A flat position of the equalizer network was also provided for test and other purposes. Without pre-emphasis, it is practical to include a greater degree of radius equalization at the inner diameters. The section C_2-R_5 is removed and the loss increased in the rear pad, so that there is again no increase in over-all level when this position is used. It is practical to find the necessary pad value by substituting a standard variable attenuator and reading the loss directly from the dial.

Due to the necessity of keeping the automatic equalizer common to all positions of the selector switch, the auxiliary capacitor C_3, used on the NAB position, became shunt to ground through 800 ohms when the switch was moved to another position. The resultant high-frequency attenuation could be counteracted on the PHONOGRAPH position by increasing the value of C_2. However, on the FLAT position the presence of C_3 caused 4 db attenuation at 10,000 cps. To correct this, it became necessary to shunt the series arms of the output pad with a .01-μf capacitor. *Figure 6* is a schematic of the entire equalizer and *Fig. 7* shows the control panel.

Operating Techniques

The operating staff was introduced to several techniques which enable the studio to produce competent work. For instance, in handling quantities of direct-copy material, the original record is made with the cutter carriage in a direction of travel opposite to that of the finished copy. This, in conjunction with the action of the automatic equalizer, produces an amazingly faith-

(Continued on page 45)

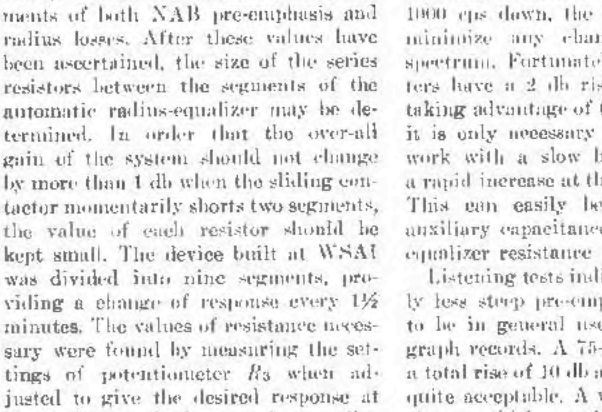
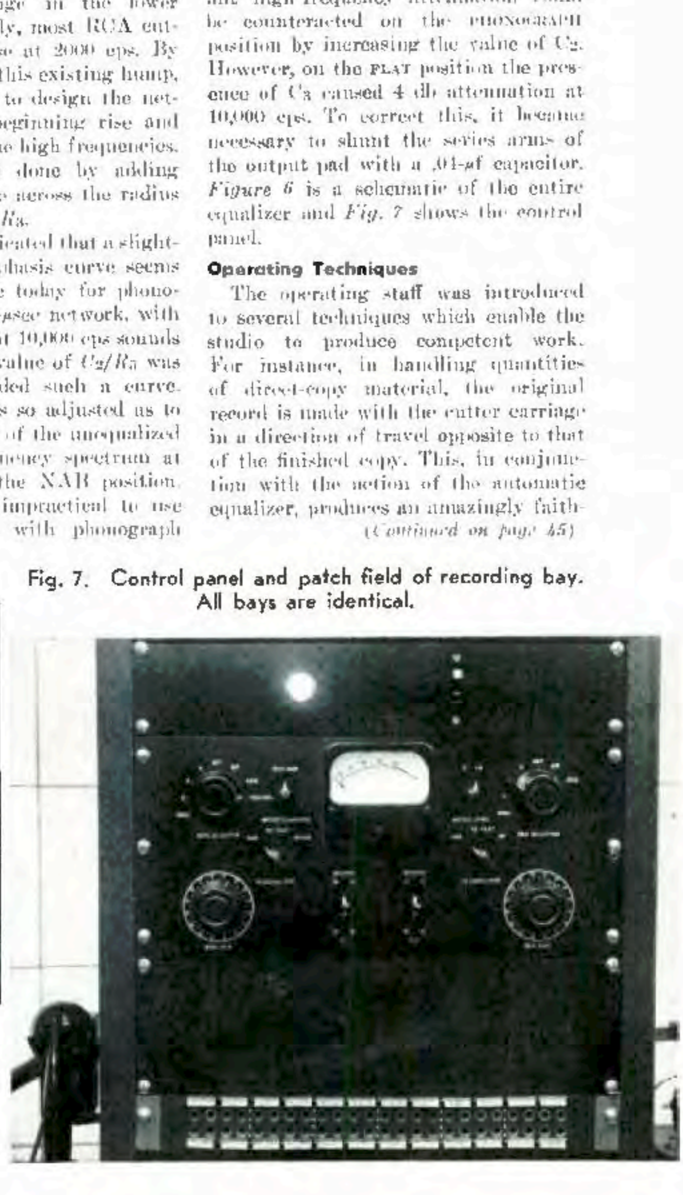


Fig. 6. Complete equalization system for 500 cps crossover cutter, showing NAB phonograph and flat equalizers, and the two-position radius equalizer available for each curve.

Fig. 7. Control panel and patch field of recording bay. All bays are identical.



DISC RECORDING

[from page 13]

ful copy. Also, when making recordings purposely for dubbing, lower levels are used in order to take advantage of the reduced cutter distortion, and care is taken to work at the outside radii as much as possible. By careful attention to response and distortion, it has proven possible to re-record speech program as many as five times with very little deterioration of quality. The accuracy of the complementary NAB pre-emphasis and de-emphasis networks allows the faithful preservation of the original response of any phonograph record or transcription recorded at outside sources. Good advantage is taken of this factor when dubbing flip sides of phongraph albums used in daily symphony programs. To keep the radius losses at 78 rpm from doubling during this procedure, additional equalization is available during the last minute of travel by moving the radius-equalizer control switch from "off" to "low-fixed." By addition of the "off," "low-fixed" and "high-fixed" positions to the three basic curves, nine curves are available.

Although such a system of equalization is not applicable to all conditions of recording, it has proven remarkably practical for speech, for all network recording, and for most music. The tracing distortion generated by this system does not become severe until the last equalization step is reached, and even that is tolerable when played with a good magnetic pickup capable of rejection o fall vertical components. The segues and overlaps of the sections of a half-hour show are unnoticeable even on better-than-average home radios.

Photographs by Rueben Lawson, Jr.