SYMPOSIUM ON TRANSMISSION METERS

A CONTINUOUS LEVEL RECORDER FOR ROUTINE STUDIO AND THEATER MEASUREMENTS*

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Graphic records of gain-frequency and acoustical response measurements on sound recording and reproducing equipment are normally obtained by making measurements at sufficient points to permit drawing an average curve on appropriate graph paper. Measurements made in this manner require considerable time and equipment and become very cumbersome when numerous routine measurements are necessary.

The value of an automatic device for such measurements has been recognized for some time, and units have been developed for such work; but due to their expense, complicated equipment, and limited application, they have not superseded the manual methods of measurement.

In the motion picture studio, the large quantity of sound recording and reproducing equipment necessitates numerous routine measurements, to insure proper operation and maintenance of the equipment. The measurements, although reduced to the most practical form of daily tests, with standard test equipment, require considerable time and personnel, and, in addition, as they do not indicate the actual response at each frequency in the operating range, introduce the possibility of error. Recognizing the advantages of such a recorder, M-G-M Studios have designed and constructed a unit primarily for routine tests, although applicable to laboratory and development work also.

In making such measurements, automatically in permanent recorded form, the fundamental units listed below are required. These units are indicated in Fig. 1.

"Send" Equipment.—(*1*) An audio-frequency oscillator, of the beat-frequency type with a frequency range of at least 20 to 10,000 cps. and with a constant output level over this frequency range; appropriate matching and attenuating networks, level indicator, and output controls.

(*2*) Automatic drive (frequency variation) for the oscillator, with frequency indicating device, and also a warble unit if acoustic measurements are desired.

"Receive" Equipment.—(*1*) A bridging amplifier for measurements, without disturbing operating equipment; a preamplifier for low-level measurements from microphone output, *etc.*

(*2*) A rectifier, linear or logarithmic, for conversion of input audio frequency to direct current for operation of the recording device.

(*3*) A direct-current amplifier.

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(4) A graphic recorder: Esterline-Angus recording milliammeter—0 to 5 ma. A detailed description of the equipment follows:

"SEND" APPARATUS

Beat Frequency Oscillator.—The beat frequency oscillator, as well as the remainder of the apparatus, was designed for standard rack mounting. The oscillator is in three units: the radio-frequency oscillator and detector unit are mounted on a $12^1/_4 \times 19$-inch panel; the audio-frequency amplifier, volume indicator, output impedance control and frequency standard reeds, on an $8^3/_4 \times 19$-inch panel; and the power supply on a 7×19-inch panel, making an overall panel size of 28×19 inches.

As an oscillator of constant output, over the range of 20 to 14,000 cps., was

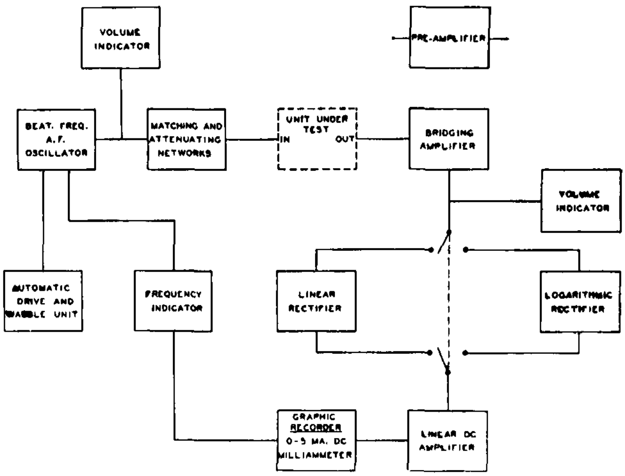

FIG. 1. Diagram of automatic recorder.

required, it was necessary to develop such a unit. The maximum deviation from the 1000-cycle output level is 0.2 db. in the present unit. The output at 10 cycles is down 4 db. from the 1000-cycle output level. The frequency range of 20 to 14,000 cps. is covered by a dial length of 14 inches. In order to make this unit a multi-purpose oscillator, it was necessary to use a multiple-winding output transformer.

The use of this transformer necessitated the addition of an audio-frequency equalizer to compensate for the reduction in low-frequency output in the transformer (-2 db. at 20 cps.). The range of output impedance is from $2^1/_2$ to 500 ohms in 11 steps.

The oscillator unit contains the output control (RF input to detector), with a useful range of 25 db. The audio amplifier unit contains a step control calibrated for 0.02–0.2–2.0 watts' output. This oscillator was designed for a normal channel plate supply voltage of 350. The filament supply is alternating current.

On the 500-ohm output tap, into a load of 500 ohms, the harmonic content at 1000 cps. is as follows:

Db. Out	3rd Harmonic (*Per Cent*)	2nd Harmonic (*Per Cent*)
0	0.02	
+10	0.05	0.03
+20	0.11	0.12
+24	0.27	0.25

The frequency stability is high. A change in the 350-volt supply of ±30 volts changes the frequency 2 cps. at 500 cps., or approximately $^1/_2$ per cent.

The oscillator is a fixed-frequency oscillator at 94 kilocycles, and is electron coupled-resistance stabilized, using a *36* type of tube. The variable-frequency RF oscillator, 80–94 kilocycles, uses a similar tube and circuit. A band-pass filter is used in the variable-frequency oscillator output. Although not required for sinusoidal output, it was found helpful in controlling the overall output characteristic of the unit. The two RF oscillators may be operated at the same frequency (zero-frequency output) without tendency toward interlocking.

The detector unit is push-pull, employing two *WE-262A* tubes operated as full-wave square-law rectifiers. These tubes are not efficient as detectors but were selected for their low microphonic output.

Spurious beat notes are entirely eliminated by a 3-section, 40-kc cut-off, low-pass filter in the detector plate circuit. The minimum level difference between oscillators, at the detector input, is 20 db.

The audio-frequency amplifier is a 3-stage push-pull, resistance-coupled unit, with a gain of 60 db. The first two stages use *WE-262A* tubes and the output stage *WE-271A* tubes. These tubes were selected for their low microphonic and hum levels.

A volume indicator with a range of −10 to +30 db., in 4-db. steps, is normally across the amplifier output.

For calibration, two reeds are used, operated by a phonograph pick-up switched across the amplifier output. The primary reed is tuned to 118 cps. and the secondary reed to 475 cps. The calibration control is a 60 $\mu\mu f$ variable condenser in the fixed-frequency RF oscillator circuit, with an 80 to 1 gear control. Provision was made for indication of zero beat in the detector plate circuit, but, due to the low detection efficiency of the *262A* tubes, this meter was not included in the final assembly.

Drive Control.—A novel method of drive and warble control is employed. The oscillator frequency control is driven by a rack and pinion, engaged by a cone friction clutch to a small driving motor. This drive has an adjustable speed, covering the range of 20 to 14,000 cps. in a minimum time of 35 seconds and adjustable for any intermediate time up to 1 minute, 45 seconds. Control is by rheostat in the motor circuit. The frame or stator of the driving motor is suspended in a cradle and is free to move through an angle of 5 degrees.

A short arm, connected to the motor stator, is held in contact with a cam by spring tension. This cam is mounted on the rotor of a second small motor, the stator or frame of which is secured to the panel (see Fig. 2). The driving motor is then oscillated by the second motor, at a rate of $7^1/_2$ cps. This oscillating motion is transmitted to the rotor of the driving motor and results in a like motion of the driving rack, and consequently, the oscillator frequency control dial. The warble is approximately 5 per cent at 100 cps.; 4 per cent at 1000 cps. and $1^1/_2$ per cent at 10,000 cps. It may be switched on or off at any instant, during the steady drive period, or while the oscillator is fixed at one frequency. The motors are small a-c. geared induction motors. The cam arrangement on the warble drive is removable for changes in the rate of warble. The drive control panel is 7 × 19 inches in size.

After completing the sweep to 14,000 cps., the drive and warble motors are automatically stopped by means of a cut-out switch operated from the drive rack. Manual reset requires only a fractional turn of the drive clutch for release and turning the oscillator dial back to the desired starting frequency. Again, spinning

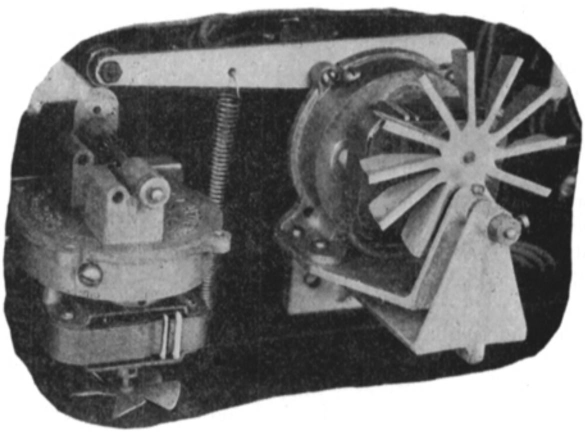

FIG. 2. Drive and warble unit.

in the cone clutch knob engages the drive and the oscillator frequency is again varied, without necessitating turning the drive motors off and on manually.

Frequency Indicator.—Frequency indication during this automatic sweep is by two methods. On the back of the oscillator frequency dial are placed 16 small adjustable *L*-shaped contactors. These contactors operate a single-pole, single-throw switch, mounted behind the dial, as each contactor passes the switch. Contactors are placed at 30, 50, 100, 200, 300, 500, 1000, and at each thousand cycles up to and including 10,000 cps.

Due to the inclusion of the warble feature in the drive system, a simple switching circuit could not be used for frequency indication, as the backward and forward movements of the dial caused a minimum of four operations of the switch in approaching the indicating frequency, and a similar number when leaving this frequency. Also a slow operating indicator, necessarily used to interrupt the frequency for indication, would remove too large a section of the frequency band for most measurements. A time-delay impulse relay is used. This relay circuit was designed to be inoperative during the unavoidable impulses due to warble operation, and operative for the small time intervals between frequency-indicating periods at high-speed drive. The frequency indication is by means of a momentary shorting switch on the oscillator amplifier output circuit. This causes a dip in the output and results in a 2-db. reduction as indicated on a high-speed volume indicator meter. The duration of the short-circuit is 0.07 second, and on the high-speed drive it causes a gap of 14 cycles at 1000 cps. The frequency-indicating device is also equipped to operate a second relay for frequency indication on the graphic recorder. This relay punches a small hole in the paper at the indicating frequency.

Both indicating relays may operate simultaneously or individually, and frequency indication may also be by manual operation of the control key, making possible indication at any desired frequency.

The time-delay impulse relay indicating unit is self-contained, a-c. operated, and is mounted on a 7 × 19-inch panel. An a-c. power panel with main switch and fuses is used to turn all equipment on and off.

A series of *H* pads is supplied for level control and impedance matching, and a jack row provides flexibility, permitting any desired combination of output units.

The entire "send" equipment mounts on a standard rack, requiring 56 inches of panel space. The unit is shown in Fig. 3, and is the bay on the right side. The equipment from top to bottom is as follows: (*1*) equalizer and *H* pads; (*2*) jack row; (*3*) beat-frequency oscillator, including AF amplifier, oscillator-detector unit, and oscillator power supply; (*4*) drive control panel; (*5*) frequency indicator panel; (*6*) a-c. power panel.

"RECEIVE" APPARATUS

The second or left-hand rack in Fig. 3 contains the "Receive" equipment. A detailed description of this apparatus follows:

AF Amplifiers.—Two amplifiers are supplied, one a bridging amplifier, permitting recording from operating circuits, and the other a preamplifier to permit operation directly from a microphone. The bridging amplifier has a gain of 14 db. (bridging 250 ohms.); a frequency characteristic flat within $\pm ^1/_{10}$ db. from 20 to 10,000 cps.; a gain control of 20 db. in 2-db. steps. Two *6C5* tubes are used in push-pull, the plate supply is 350 volts, and the filament a-c. At the normal maximum output level of +10 db. there is $^1/_{10}$ per cent third harmonic at 1000 cps. This amplifier is mounted on a $3^1/_2$ × 19-inch panel.

The preamplifier operates between 200 and 500 ohms, has a maximum gain of 88 db. and a gain control of 70 db. in $^3/_4$-db. steps. The frequency characteristic is flat within $\pm ^1/_4$ db. from 20 to 10,000 cps., and at the normal maximum operating output level of −4 db. the second harmonic is $^1/_4$ per cent of the fundamental 1000 cps. The combination of the two amplifiers makes available a maximum gain of 102 db. and permits recorder operation from an input of −92 db.

The preamplifier uses one *6F5* tube and two *6C5* tubes, resistance coupled. The plate supply is 350 volts and the filament supply a-c. This amplifier mounts on a 7 × 19-inch panel.

Rectifiers.—The preceding amplifiers feed into either a logarithmic or linear rectifier circuit. The linear rectifier is used for measurements requiring maximum accuracy. The useful range is 25 db., and the indications may be read most accurately at peak levels where a variation of $^1/_{10}$ db. is easily discernible. This linear rectifier consists of a full-wave rectifier using a *6H6* tube. A single-section low-pass filter is used. The unit is linear over a 30-db. range and the frequency characteristic is flat within $\pm ^1/_{10}$ db. from 20 to 10,000 cps. The peak output current required is 6 ma., and the output voltage 3 volts at the load resistor of 500 ohms.

The alternate rectifier is of the logarithmic type. It covers a range of 45 db. in true logarithmic manner, and the frequency response is flat within ±0.2 db. from

FIG. 3. Continuous level recorder.

20 to 10,000 cps. In this type of rectifier the transformation of volts or milliamperes to db. is automatically made in the rectifier unit, with the result that uniform level changes, in db. at the input, produce uniform current or voltage changes at the output. The graphic recorder is a milliammeter, necessitating converting to decibels the indications recorded with the linear rectifier. This manual conversion is not required when using the logarithmic rectifier. In this unit each division of the 50-division paper (over a range of 45 db.) indicates 1-db. change in

input level. The direct-reading feature, plus the increased range, makes possible many measurements involving large level changes not conveniently made with the linear rectifier. The logarithmic rectifier uses two *6F5* tubes as drivers, two *956* tubes as log amplifiers, and one *6H6* tube as linear rectifier. The *956* tubes are of the variable-mu type in which the relation between mutual conductance and grid voltage is logarithmic over a considerable portion of the operating range. By proper selection of circuit constants these tubes amplify the input negative half-cycles in a logarithmic manner, so that the output voltage is proportional to the logarithm of the input grid voltage. The *965* output is rectified by a half-wave *6H6* rectifier, passed through a low-pass filter, appearing as a d-c. voltage at the output circuit. The approximate logarithmic range of a single *956* tube, as used, is 15 db. By suitably combining the output of two of these tubes in a parallel circuit, the range may be extended to 45 db. In order to secure the 45 db. range, over the frequency band of 20 to 10,000 cps. and with an error not exceeding 0.25 db., equalization in the *956* plate circuits is necessary. This equalization necessitates pre-equalization of the overall unit for linear frequency response.

Due to the inherent frequency error in logarithmic rectifiers of the preceding type, the replacement unit will employ a fixed-frequency oscillator exciting the logarithmic rectifier. This oscillator will then be modulated in a linear manner by the operating audio input. By this method a true logarithmic range of 60 db., the practical limit set by the graphic recorder, with negligible frequency and amplitude distortion, will be obtained in a stable compact unit.

The plate supply of the present unit is 350 volts and the filament supply is a-c. This unit mounts on an $8^3/_4 \times 19$-inch panel.

D-C. Amplifier.—The next unit in the series is the linear direct-current amplifier. This amplifier uses a *6C5* and a *6F6* tube. The plate supply is 350 volts and the filament supply is a-c. This amplifier is linear over a range considerably greater than the graphic recorder demands. The recorder requires 5 ma. for full-scale deflection, making a 10-ma. output necessary at the d-c. amplifier due to the bridge output circuit used. This amplifier is very stable; a change of ± 15 volts in the 350-volt plate supply causes no change in operating characteristics. It works into the 500-ohm load of the graphic recorder.

The d-c. amplifier input voltage necessary for the peak indication of the recorder is 3 volts. The accuracy over the entire range is 0.02 db. This unit is provided with a 3-position input key, selecting the logarithmic or the linear rectifier output, the third position being for calibration (zero adjustment).

In normal operation, using the linear rectifier, the recorded chart reads from right to left, or backward, with respect to accepted methods of reading. To correct this defect, the logarithmic rectifier is so designed that for no input the recorder deflection is maximum (5 ma.). Increasing input causes a reduction in this indication, producing a completed graph reading from left to right, in the normal manner. The present logarithmic rectifier, designed for 50-division paper, produces a deflection of one division for each decibel of input, resulting in an easily readable graph.

The linear rectifier record must, of course, be translated by the standard method (20 $\log_{10}$ ratio of currents). This rectifier necessarily compresses the record as the level decreases. While such a record is not conventional, compared to present records in decibels, its accuracy is high and a minimum of equipment is required.

Familiarity in reading records of this type is readily acquired.

Fig. 4 is a frequency response curve of a standard recording channel, with a 7500-cps. cut-off low-pass filter. This record was made with the linear rectifier. In Fig. 5 is the same measurement using the logarithmic rectifier. Both measurements were made at high speed in order to reduce the size of the graph. Note the frequency indications made by the shorting relay, described previously.

Graphic Recorder.—The recorder used in this installation is an Esterline-Angus recording milliammeter, with a full-scale deflection of 5 ma. and a resistance of 500 ohms. The unit is very rugged and reliable, and relatively inexpensive. It is not normally used for high-speed recording, and requires minor modifications for this work.

The recorder, as adjusted, has a maximum recording speed of 80 db. per second when used with the logarithmic rectifier of 60-db. range. The recording needle

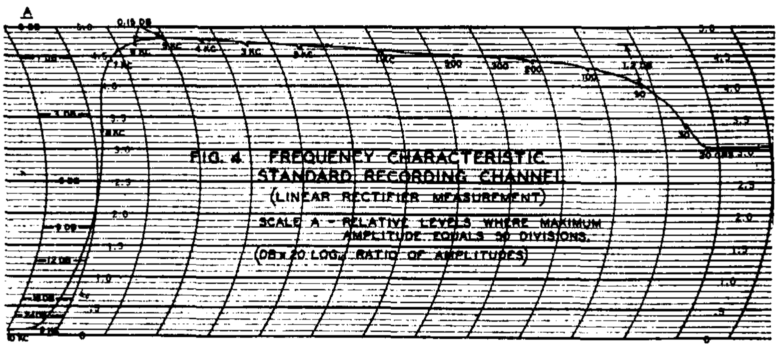

FIG. 4. Frequency characteristic made with linear rectifier.

completes the 9-inch travel across the paper, and back to zero again, in $1^1/_2$ seconds.

The meter movement is very rugged, and withstands overloads of several hundred per cent. The ink-well holds one ounce, a supply sufficient for several days of normal recording. A siphon supplies the glass recorder pen with ink. The pen will remain in contact with the paper for all but extremely high-speed, high-level impulses, not encountered in normal recording.

The drive is a synchronous motor. The range of paper speed is from a maximum of 12 inches per minute to a minimum of $^3/_4$ inch per hour, with the standard gears supplied. The chart paper is supplied in standard 90-foot rolls, and is 6 inches wide with a recording width of $4^1/_2$ inches. Recordings roll up on a take-up roller exerting a uniform tension on the paper.

The frequency indicating punch, previously mentioned, is a small impulse relay operated from the time-delay relay unit in the oscillator bay. This relay when operated, makes a pin-point hole at the instant of operation in the arc of pen travel, at the edge of the paper. This punch, interlocked with the oscillator drive, thus makes a permanent record of frequency *vs.* response. Pencil notations, as to frequency, *etc.*, may easily be made directly upon the chart during operation.

The recording milliammeter is 13 inches high, $8^1/_2$ wide, and $9^1/_2$ deep, and is mounted on a 14 × 19-inch control panel (see Fig. 6).

This panel contains the motor drive key and also an input key, which transfers the d-c. amplifier output to the recording milliammeter or to a standard *301* type, 5-ma. meter in a 500-ohm circuit. This meter is used for all preliminary adjustments, as its scale is similar to the recording milliammeter scale. The recording milliammeter is fused with $^1/_8$-ampere "littlefuses."

The 350-volt plate supply and the a-c. filament supply for all units in the recorder bay is from a power supply unit mounted on a 7 × 19-inch panel.

The a-c. power panel at the bottom of the bay contains the a-c. line switch and fuses, and a Variac and a-c. voltmeter, which also may be patched to the oscillator bay for regulation of the a-c. input voltage to the normal 120-volt value. This control is required when field measurements are made, as the a-c. line voltage is frequently below 100 volts.

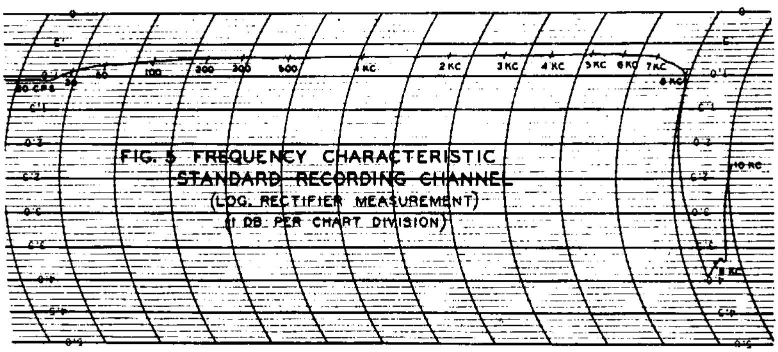

FIG. 5. Frequency characteristic made with logarithmic rectifier.

A standard rectifier type of volume indicator is also included, at the top of the bay. This unit has a range of −10 to +30 db., and when used with the preamplifier and bridging amplifier, forms a standard acoustic meter. The volume indicator is normally used with the graphic recorder for preliminary level adjustments.

The recording unit has been designed for a +10-db. output level at the bridging amplifier for full-scale deflection of the recording milliammeter, with the linear rectifier. This level is sufficiently low to permit economical amplifier design, and high enough to prevent trouble from pick-up.

Further refinement of equipment is unnecessary, due to the limitations of the recording milliammeter. The hysteresis inherent in a medium priced instrument of this type is of the order of $^1/_2$ per cent of full-scale deflection. The recorder bay has 56 inches of panel space. Patchable equipment appears at the jack row, below the volume indicator panel.

In Fig. 3 the equipment from top to bottom (left-hand rack) is as follows: (*1*) volume indicator; (*2*) jack row; (*3*) preamplifier; (*4*) graphic recorder; (*5*) logarithmic rectifier; (*6*) bridging amplifier; (*7*) linear rectifier; (*8*) d-c. amplifier; (*9*) power supply; (*10*) a-c. power panel.

All equipment has been constructed as compactly as possible for practical operation and maintenance. The two bays are rigidly mounted upon a wheeled base for rapid transportation. Microphonic response is negligible in the unit. The only source of supply necessary is 110 volts $^{50}/_{60}$-cycle a-c. The power consumption of the entire unit is 350 watts.

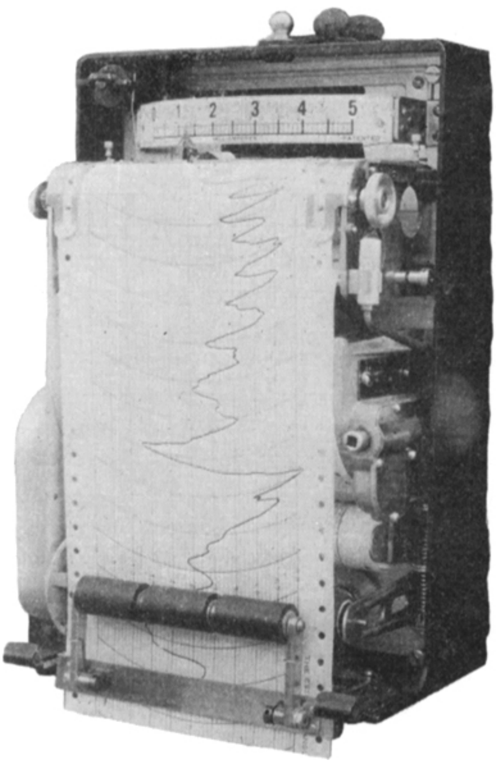

FIG. 6. Graphic recorder.

The assembly is very flexible and individual units are available, thus not confining the unit strictly to graphic recording.

The recording unit may be used also for reverberation measurements, using the 60-db. logarithmic rectifier. With increased speed of the synchronous chart drive, the exciting frequency may be interrupted and the decaying sound impulse recorded. The recorded chart of sound intensity *vs.* time, over a 60-db. range, may then be used to indicate reverberation time. This makes a complicated timing device unnecessary for normal reverberation period measurements.

The conception of this unit and its development into a practical transmission meter was by J. K. Hilliard, *Transmission Engineer;* the design and construction of the automatic recording unit was under the direction of G. M. Sprague, *Engineer,* and the new type of drive and warble unit was developed by O. L. Dupy, *Recording Engineer,* all of the Sound Department, M-G-M Studios.

This equipment has proved a very valuable tool in the measurement of filters, equalizers, calibration of microphones, acoustic response of loud speakers, and in the standardization of review rooms. The characteristics of prints, printers, and noise and signal components from film have also been studied at length to great advantage.

A CURVE-PLOTTING TRANSMISSION METER*

L. A. AICHOLTZ**

The most important feature of the transmission recording meter described here is the compressor circuit. Fig. 1 shows the complete measuring system, comprising an oscillator, at the center, the compressor circuit at the left, and the recording meter at the right. The object next to the meter is a device made to hold a *630* microphone and either a *705* or *D-97689* Western Electric headphone for making routine microphone and headphone measurements.

The oscillator is an RCA serviceman's oscillator, with a few refinements and a new panel which mounts the synchronous motor drive and other accessories. The recording meter is an Esterline Angus recording milliammeter, also with synchronous motor drive.

The purpose of the compressor circuit (Fig. 2) is to obtain a current in the recording meter having a straight-line relationship in decibels to the input signal. If for this purpose we employ a vacuum tube V_2 having its input circuit arranged like the familiar grid-leak-and-condenser detector, the bias for this tube, normally at zero, will increase negatively for any input signal, up to a value that is approximately equal to the positive peak value of the input signal, and the plate current will decrease accordingly. Fig. 3 shows that for minimum signal the plate current is maximum.

If, then, the tube used has a grid voltage-plate current characteristic that is logarithmic, the change of d-c. plate current will bear the desired relation to the a-c. signal. The best vacuum tubes available for this purpose are the so-called "super control" or variable-mu tubes, such as the RCA type *58*. If one such tube is used in position V_2 the input signal-output characteristic will be as shown by curve *OA* of Fig. 3. Note that this curve is reasonably straight over a range of 10 or 12 decibels. However, a much greater range is desired, and it is possible to employ a second tube for this purpose, so connected as to place its response curve at the position *BD*. The departures from linearity of the two tubes are

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