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THE DESIGN OF A HIGH-PERFORMANCE TAPE DUPLICATING SYSTEM

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INTRODUCTION

The explosive growth of the prerecorded tape market has placed unprecedented production burdens on manufacturers of music-on-tape. The techniques used to produce reel-to-reel copies in moderate quantities are simply inadequate for high-volume duplication to the cassette and cartridge formats. The combination of production requirements and the critical nature of narrow track, short wavelength copies has created the need for a new generation of tape duplicating equipment, which is the subject of this paper.

SYSTEM REQUIREMENTS

The high-volume duplication of cartridge tapes as we know it today implies the use of a continuous-loop master transport, reproducing a 7-1/2 in/sec master tape at 120-in/sec. The signals from the master tape must then be equalized and routed to the appropriate heads on the slave recorders along with a high frequency (typically 1 MHz) bias signal. The system design should permit removal of one or more slaves from the line without affecting the operation of the remaining units. The line should be easily convertible from cassette to cartridge operation. Monitoring facilities should be provided to easily set up or troubleshoot the line. Enough flexibility should be built in to accommodate foreseeable changes in duplicating speed, equalization or format. Frequency response, distortion and signal-to-noise ratio should be tape-limited only.

PHYSICAL SYSTEM DESCRIPTION

The master console (See Figure 1) houses a 1-inch, 8-track, bin-loop transport and all the electronics to drive up to twenty slaves. The main emphasis of this paper is on the electronic system, but a few words on the bin-loop transport are in order. The master transport was designed to be extremely rugged and reliable, since the daily duty cycle may approach 100%. Such niceties as a double capstan pinch roller to avoid motor bearing side load, a vacuum pretensioner for low flutter and constant tension, and a polonium source for static elimination, were incorporated. The

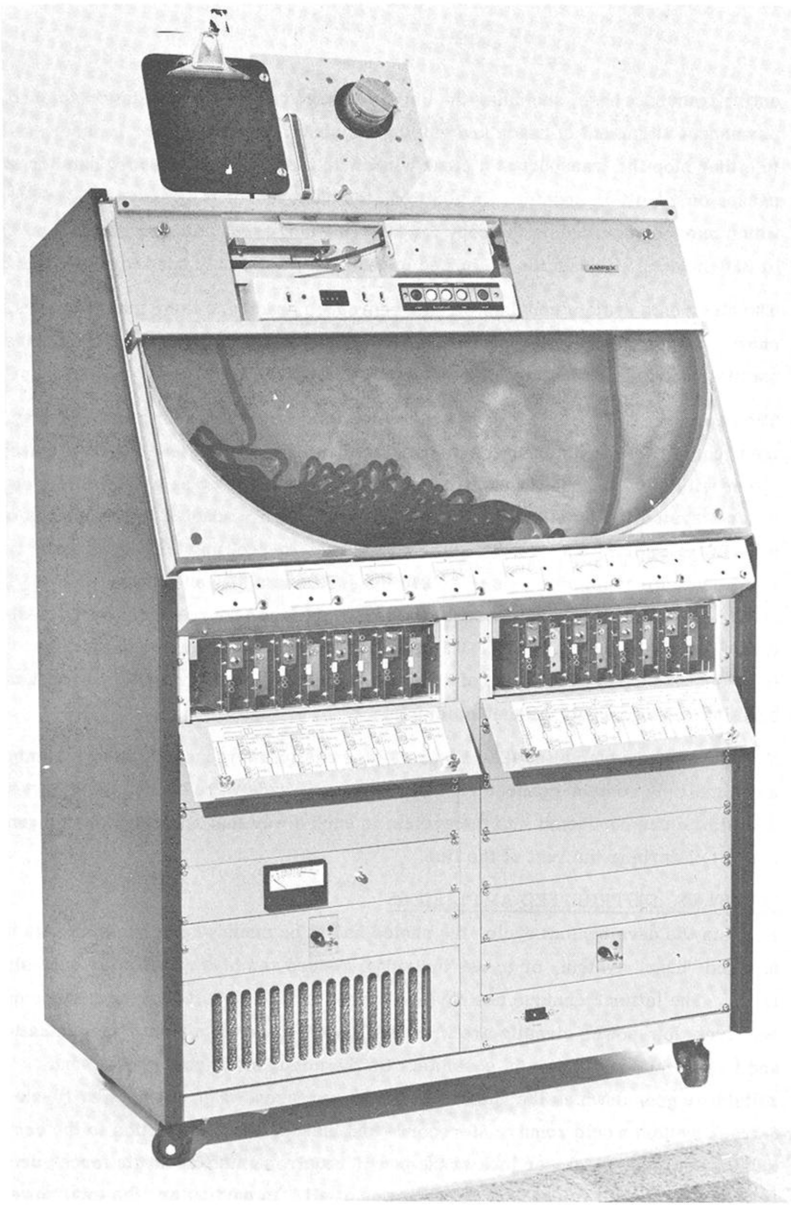

Figure 1 BLM 200 Master Console

entire transport base, including the bin, is a large casting, accurately machined for permanent alignment of heads and guiding elements. A photosensor is incorporated to either stop the transport at a clear window in the tape, or to record number of passes on a built-in counter. In addition, the photosensor triggers a 120-Hz burst which may be recorded on the copy for tailoring purposes. The transport runs at 60 or 120-in/sec, although the 60-in/sec speed is normally only used for loading the bin.

The electronic system consists of: the reproduce heads and their preamplifiers, as shown in Figure 2; reproduce equalizer amplifiers; record drive amplifiers; bias oscillator/driver; and associated power supplies.

The reproduce and record boards are mounted side-by-side, four pairs per tray, and the preamplifiers are mounted four per board, so that the system can be supplied either with four channels of electronics for cassette only, or as a convertible eight-channel system. The electronic components are readily adapted to other types of master transports, such as the 3201 or 3301 reel-to-reel master. Frequency response is adequate for master speeds up to 240 ips. This is a "buss" system, that is, the record and bias drivers are essentially zero impedance sources, centrally located, driving multiple record heads. The isolation and adjustment networks for the individual slave heads are part of the head assemblies, and are factory preset, allowing head interchangeability without readjustment.

The slave head assemblies (See Figure 3) are easily interchanged via two thumbscrews and a multiple contact connector. Ferrite-cored heads were chosen for long wear. The slaves are connected into the system in such a way that any slave can be removed without disturbing the rest of the line.

"BUSS" VS. DISTRIBUTED AMPLIFIERS

Early in the development cycle, the choice had to be made whether to stay with the time-honored "buss" system, or to use individual record and bias drivers for each slave track. The latter technique has obvious appeal for the circuit designer, since only relatively low-power circuits are involved, isolation between tracks is automatic, and individual equalization is possible. On the minus side, cost goes up and reliability goes down as the number of heads increases. For example, a 10-slave, 8-track system would require 80 record- and bias-drivers in addition to the centrally located sources. A closer look at the power requirements for "brute force" drivers reveals that these are not very large brutes at all. In particular, the total power required for the record driver isvery modest indeed. 20 slaves driven at normal

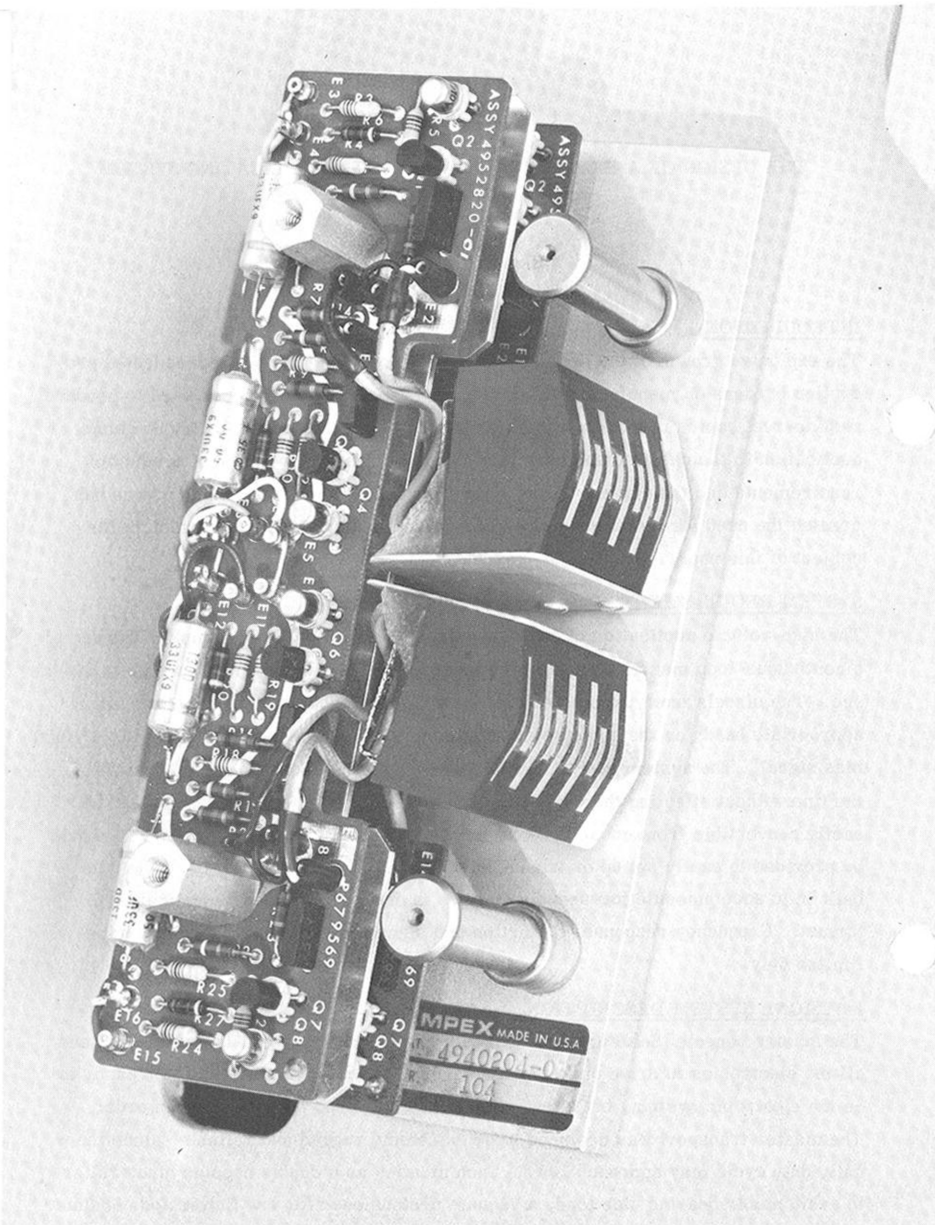

Figure 2 Master Heads and Preamplifiers

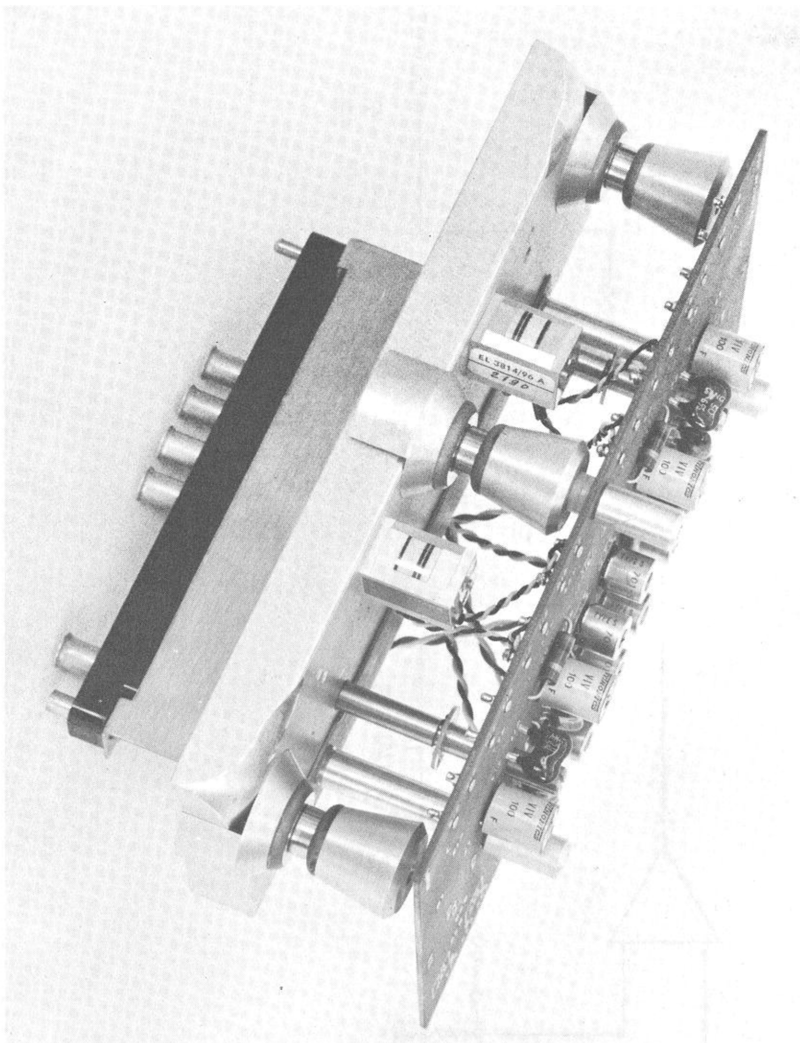

Figure 3 Slave Head Assembly

operating level require typically 30 milliwatts; at 20 db above this level, only 3 watts are required. The bias power requirement is somewhat higher, typically 10 watts for 20 cassette slaves.

The design of the bias driver presented the challenge of delivering moderate power at high frequencies, while maintaining essentially zero output impedance. This turned out to be possible, as will be discussed in a later section. The equalization limitation imposed by the "buss" system proved to be a boon rather than a disadvantage. It turned out in practice that record head frequency response was so uniform that individual equalization adjustments would have merely confused the issue and slowed the setup procedure.

THE SYSTEM COMPONENTS

1) Master Heads and Preamplifiers

The master reproduce head and the first amplifier it sees are the two elements in the system which most profoundly affect the overall signal-to-noise ratio and frequency response. The reproduce head is designed for high efficiency and low core loss to optimize signal-to-noise ratio. The head and the shunt capacitance it sees resonate at about 180 KHz, and the gap length is tailored so that the gap loss and the resonant rise effectively cancel. The preamplifier is mounted where common sense says it should be, right behind the head. This has several desirable effects: the shunt capacitance across the head is minimized, allowing a maximum number of turns for the given resonant frequency; RFI is minimized by localizing the sensitive high impedance points within the shielded head enclosure; finally, the use of a special low-capacitance shielded cable with its loose inner conductor and attendant microphonics is avoided. The preamplifier is essentially an impedance converter with a voltage gain of 2. The input impedance is 700 Kilohms shunted by 5 pf. The output impedance is about 140 ohms. The circuit (See Figure 4) is a FET-bipolar feedback pair, with the necessary attributes of high input impedance and low output impedance with a minimum number of components, rather important in view of space limitations. The amplifier has about 24 db head room above normal operating level, and negligible distortion. Bandwidth is greater than 500 kHz.

2) Reproduce Amplifier

The reproduce amplifier is depicted in Figure 5: an integrated operational amplifier and its feedback loop comprise the reproduce equalizer, followed by a gain control and an integrated buffer amplifier. The equalizer fixed components are mounted on

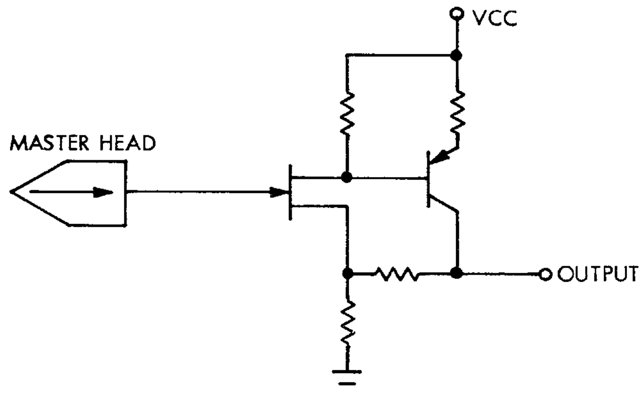

FIGURE 4 PREAMPLIFIER

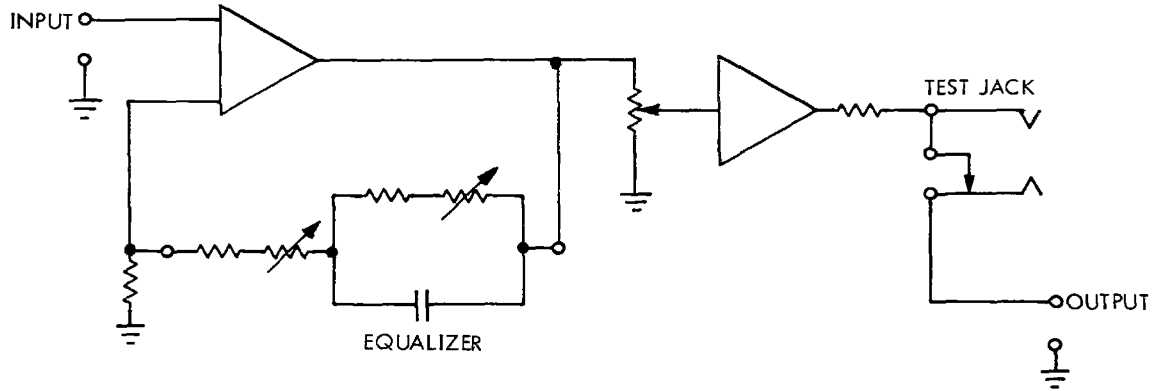

FIGURE 5 REPRODUCE AMPLIFIER

terminals to allow for equalizer changes if necessary. In addition, traces are supplied for a relay and an extra set of equalizer components for the contingency of more than one type of master equalization. The output of the buffer amplifier is connected through a 75-ohm resistor to a test jack, which serves both as a monitoring point with "flat" output, and for signal insertion to the record amplifier. The series resistor protects the circuit from inevitable short circuits or excessive signal inputs.

The signal level at the test point is nominally 0 db (0.78 volts). The frequency response of the reproduce amplifier, exclusive of equalizer, is greater than 500 kHz. Frequency response of the entire reproducer is largely determined by head gap and resonance. When reproducing an NAB 7-1/2 in/sec test tape, the frequency response is ± 1 db from 50 Hz to 10 kHz (real time frequencies). The reproducer noise characteristics are shown in Figure 6. The measurements were made with a Hewlett Packard model 3590A sweeping wave analyzer at a constant bandwidth of 3100 Hz. The equipment noise curve is dominated by amplifier 1/f noise at the low end of the spectrum, whereas head noise starts to contribute at higher frequencies, and finally dominates in the vicinity of resonance. Broad-band noise measurements were also made, using an ASA "A" weighted filter translated up in frequency by a factor of 16. Typical values obtained were: biased tape - 63 db, bulk erased tape - 67 db, no tape - 73 db, all referenced to Ampex Operating Level.

Total harmonic distortion of the entire reproduce chain, as measured by injecting an induction loop signal of 5 kHz into the reproduce head, is less than .05% at a level corresponding to a tape flux of 185 nWb/m (Ampex Operating Level). At 17 db above this level, total harmonic distortion is less than 0.35%.

3) Record Driver

Figure 7 shows the record circuitry. An input gain control allows trimming of the output level ± 2 db about its nominal +8 db value (referenced to 0.78 volts RMS). An emitter-peaked stage serves as the record equalizer. The curves in Figure 8 are typical equalizations used to make 1-7/8 in/sec cassette copies on tape such as BASF PES-18. The extra lift achieved with the resonant equalizer extends the frequency response from 8 kHz to 10 kHz, but at the cost of dynamic range. Care must be taken in the mastering process to avoid excessive high-frequency peaks. Similar equalization is appropriate for 3-3/4 in/sec cartridge copies on Ampex 681 tape. Again, terminals are provided for easy equalizer change, and relay-

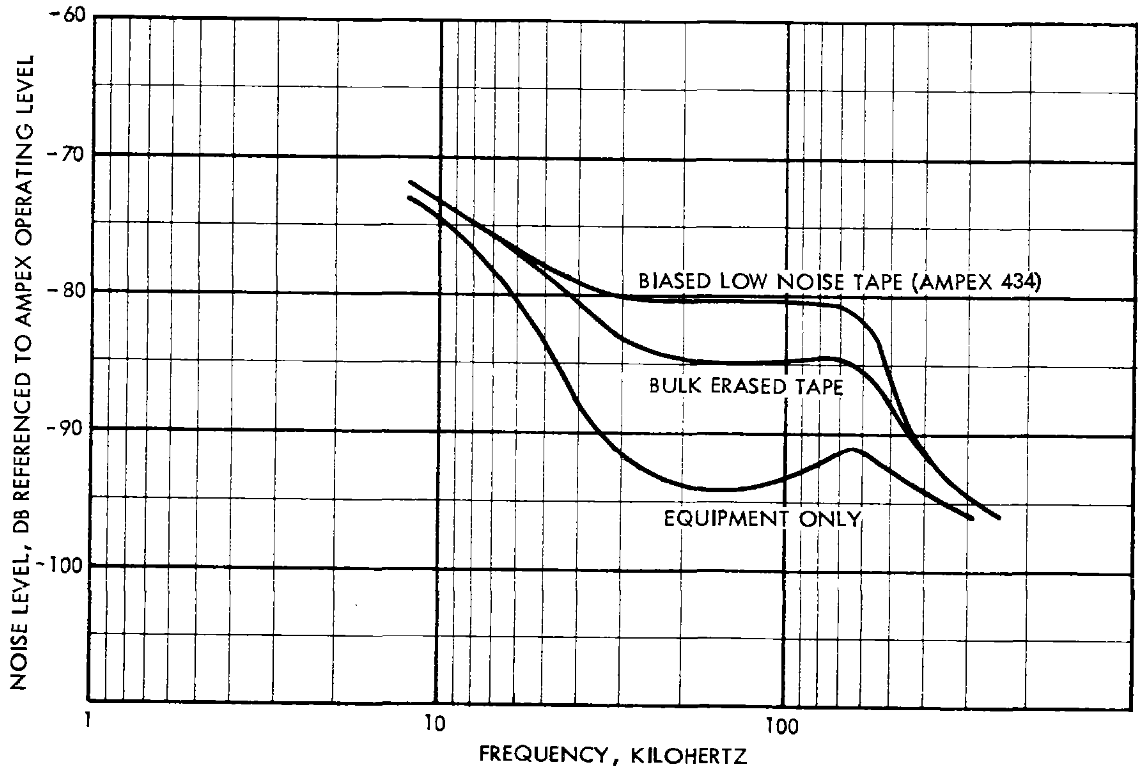

FIGURE 6 NOISE PERFORMANCE OF THE REPRODUCE CHAIN

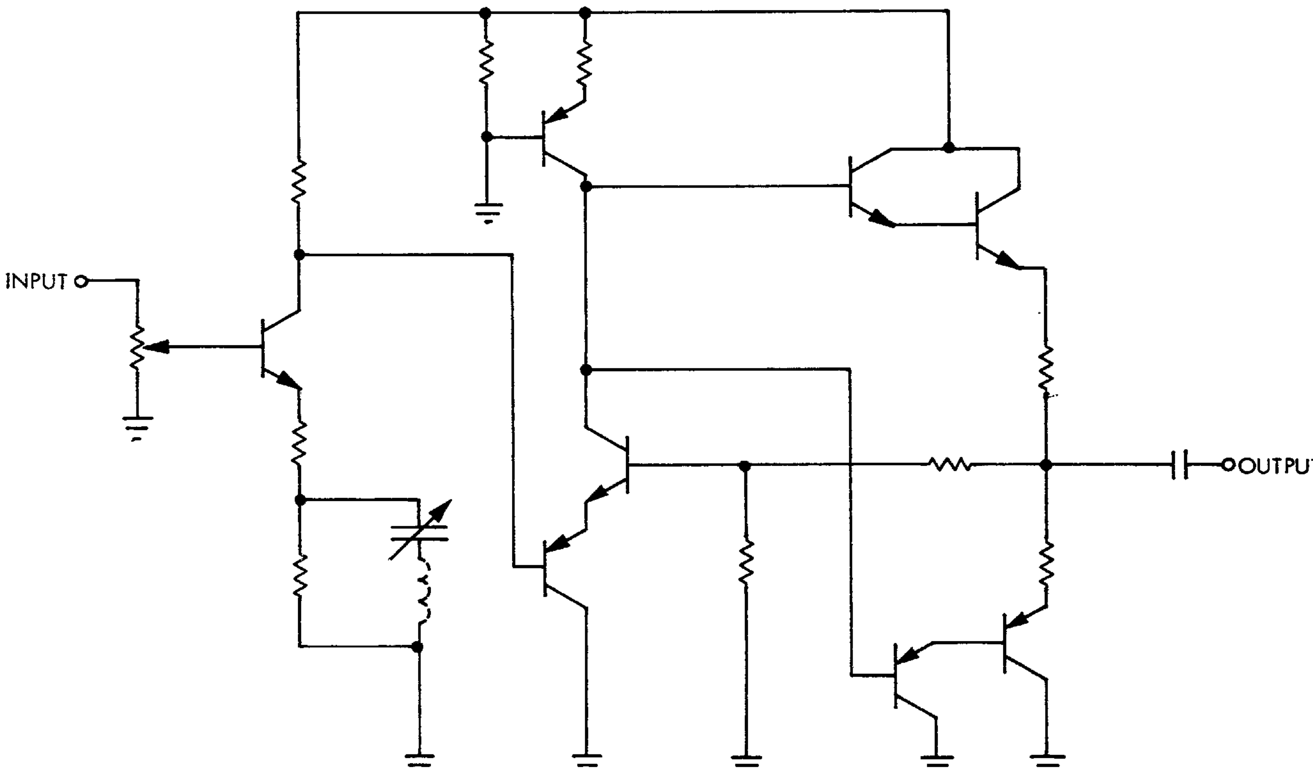

FIGURE 7 RECORD DRIVER

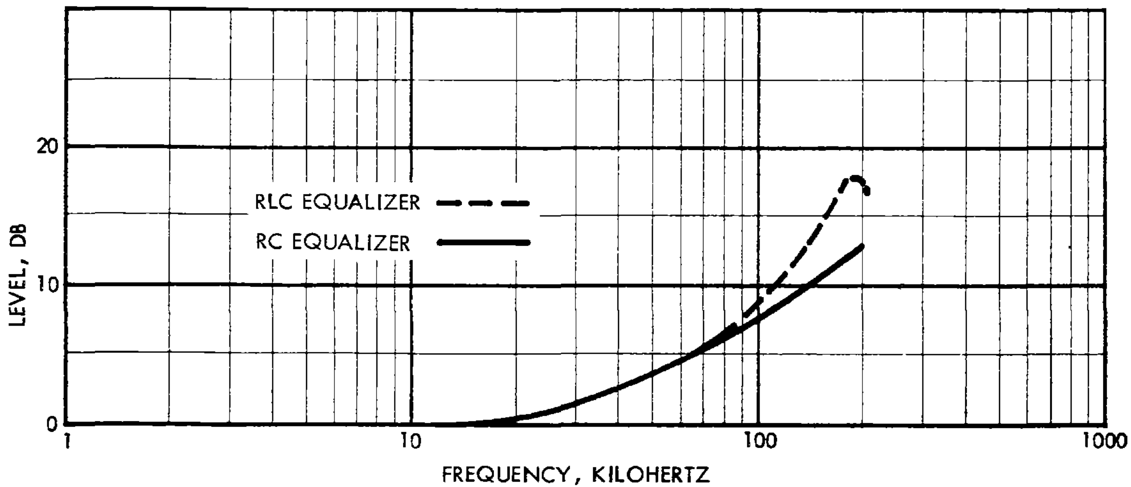

FIGURE 8 TYPICAL RECORD EQUALIZATIONS

operated switching may be incorporated. The equalizer is followed by a complementary-symmetry output feedback amplifier optimized for low distortion. Total harmonic distortion was found to be less than 0.1% at all levels up to 20 db above nominal at frequencies of 8 kHz and 80 kHz. Frequency response, exclusive of equalizer,is in excess of 500 kHz. Output impedance is less than 1 ohm, assuring negligible interaction among slaves. Output short-circuit protection is provided by the output emitter resistors. No damage results from short circuit under normal operating conditions, but if a high-level test signal is applied under short-circuit conditions, the output-emitter resistors act as slow fuses, protecting the output transistors. The output of the record driver is monitored on a VU meter and test jack panel.

4) Bias Oscillator/Driver

The bias source for a duplicator line must have the attributes of ultra-low even harmonic distortion for low-distortion, low-noise copies, very low output impedance to avoid interactions, and extreme ruggedness to survive output fault conditions.

Figure 9 shows the circuit arrangement. A low-power L-C oscillator generates a sinewave signal which is routed to the driver; additional driver units may be fed through a bias coupling connector. The oscillator frequency is adjustable $\pm 10\%$ about its nominal value by an adjustable inductor. Nominal frequencies in the range from 500 kHz to 2 kHz can be selected with appropriate LC combinations.

The driver consists of wave shaping circuits feeding a push-pull tuned output stage, which operates somewhere between Class B and Class C as a compromise between efficiency and distortion. The output transistors are conservatively rated for V_{CBO} and I_C so that neither output open-circuit nor short circuit will cause damage. An active AGC circuit keeps output voltage essentially constant from no load to the full-load capability of 30 watts. Output impedance is therefore essentially zero. The output voltage is adjustable from 10 volts to 60 volts RMS by front panel control. A meter is provided for monitoring the output. The long-term stability of the unit is in the order of 0.5 db, including warm-up time. Balance controls are provided to null out even harmonics to typically .05%.

5) Signal and Bias Distribution Network (See Figure 10)

This is the classical bias distribution network. Capacitor C_1 serves the dual purpose of resonating the record head and helping isolate signal channels. In addiition, the output of the bias unit presents a virtual short circuit to signal frequencies eliminating feedthrough from channel to channel. The bias trap isolates the shunt capacitance of the record signal line from the record head, increasing bias efficiency. The

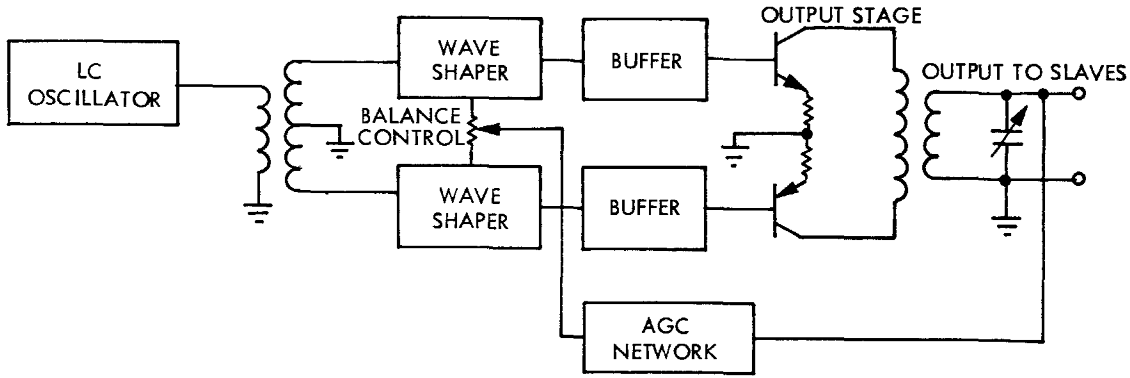

FIGURE 9 BIAS OSCILLATOR/DRIVER

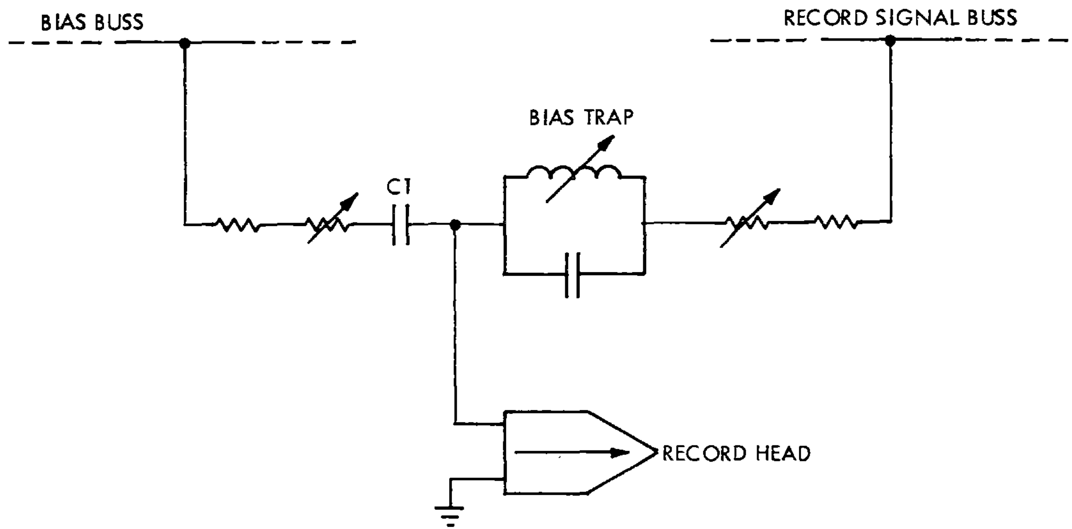

FIGURE 10 SIGNAL AND BIAS DISTRIBUTION NETWORK

distribution components are mounted close to the head stacks, avoiding the capacitive shunting of the heads by long cables. Since the controls are part of the head assembly, interchangeability without readjustment is assured.

SETUP OF THE LINE

The setup operation is extremely simple, by virtue of the convenient test points. The reproduce section is calibrated by playing a 7-1/2 ips NAB 8-track test tape such as Ampex No. 4690007-01. Equalizer and gain adjustments are made while monitoring the reproduce test jack. A chart recorder is helpful, and provides permanent records. The record equalizer is set by inserting a test signal into the record amplifier, and monitoring the output test jack. To set the individual record and bias adjustments, the use of the model 221 accessory monitor head assembly is recommended. This assembly includes a single-track reproduce head whose height is micrometer adjustable. and a battery-operated equalized amplifier. With this assembly, it is possible to monitor the recording as it is made, making short work of the slave setup procedure. It also avoids the inevitable errors incurred by using a separate real time reproducer for level and frequency response measurements. Figure 11 is a typical frequency response obtained with the accessory monitor head. The input signal frequency to the record amplifier was swept, and the output from tape was recorded. Bias was peaked at long wavelength, and non-resonant record equalization was used. With this technique, extremely consistent outputs from track to track were noted, very rarely requiring bias readjustment to improve frequency response, and even where readjustment was required, it was of such small magnitude that low-frequency level and distortion were not noticeably affected.

CONCLUSION

Throughout the design of the system, the considerations of reliability, flexibility, and ease of setup and maintenance were kept in sight. Although it is not possible to predict the more radical changes in duplicating technology which will occur in the future, certain improvements are forseeable, such as better tape performance and increased duplicating speed. These contingencies have been provided for by adequate frequency response and careful design. It should continue to be true in the future, as it is now, that copy quality is determined entirely by tape characteristics.

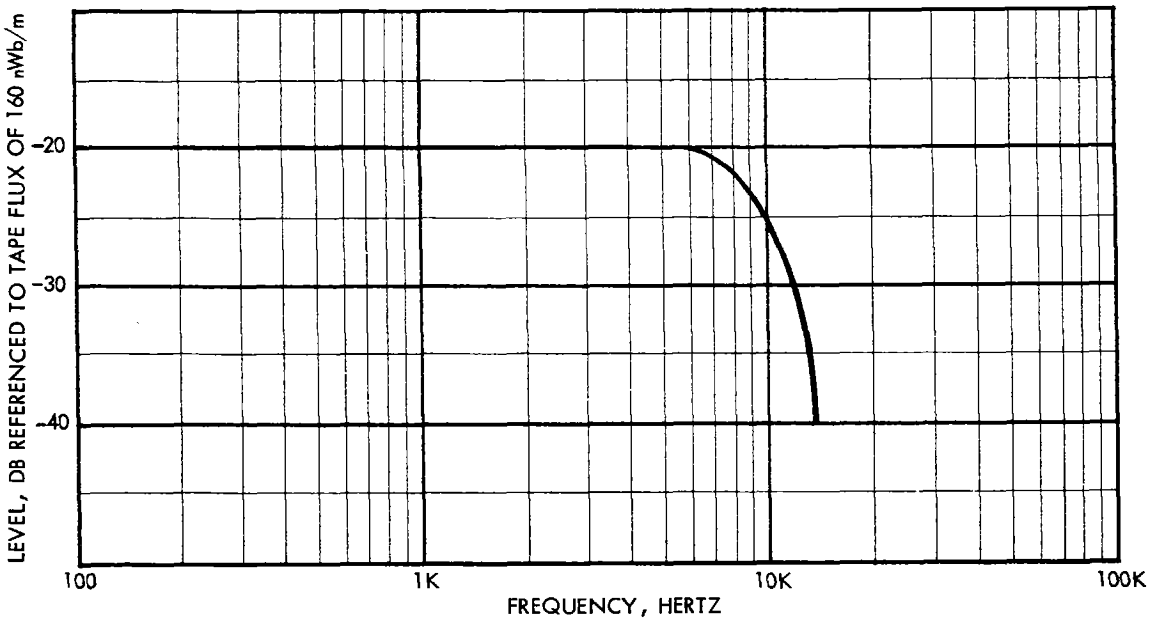

FIGURE 11 COPIED FREQUENCY RESPONSE OBTAINED WITH ACCESSORY MONITOR HEAD MOUNTED ON SLAVE TRANSPORT. FREQUENCIES ARE SCALED DOWN TO REAL TIME.

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