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TRANSMISSION OF SIGNALS VIA LAND LINE FOR MAGNETIC TAPE COPYING--ETC(U)

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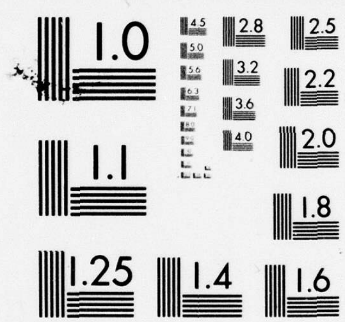

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MECHANICAL ENGINEERING NOTE 370

TRANSMISSION OF SIGNALS VIA LAND LINE FOR MAGNETIC TAPE COPYING AND OTHER APPLICATIONS

by

K. F. FRASER and U. R. KRIESER

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(10) K. F. FRASER and U. R. KRIESER

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SUMMARY

The techniques described enable analogue or digital signals reproduced using one magnetic tape machine to be transmitted via land line cable and copied using another machine situated remotely (at least up to 270 metres). Also signals, generated using transducers for example, may be transmitted from a remote location to a tape recording machine or other receiving equipment.

A frequency divider in conjunction with standard magnetic tape reproducer hardware provides a simple means of the low pass filtering of data recorded in frequency modulated form. Consideration is given to the production of an intermediate tape with filtered data.

POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories,
Box 4331, P.O., Melbourne, Victoria, 3001, Australia.

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CONTENTS

1. INTRODUCTION

Copying magnetic tapes is sometimes required at the Aeronautical Research Laboratories. In a laboratory system designed for airborne data acquisition both analogue data and digital data can be recorded on the same airborne analogue tape recorder.

In normal operation frequency modulation (FM) techniques are used for the analogue recording and pulse code modulation (PCM) techniques are used for the digital recording.

To guarantee the integrity of the original magnetic tape, the data reduction is sometimes performed using a tape copy, particularly if tape loops or extensive analyses are required. At present a reasonably portable tape machine of sufficient reel capacity (at least a 26·7 cm [10½ in.] reel but preferably a 35·6 cm [14 in.] reel is required) is not available for copying if the airborne recorder (an Ampex Model AR200) is committed for flight data acquisition work. In the system of tape copying adopted two large machines (an Ampex Model FR1200 and an Ampex Model FR1260), which are situated a considerable distance apart and in different buildings, enable the tape copy to be generated.

In some instances "copying" of analogue FM data using a different carrier to that associated with the reproduced signal is an advantage. Low pass filtering of the recorded data is a requirement which sometimes arises. Such filtering is readily accomplished (using mainly standard hardware) by dividing the frequency of the modulated signal (using a separate item of hardware developed for this purpose) and re-recording at a lower tape speed.

Time scale expansion in excess of that possible when the recorded FM signal is reproduced at the lowest available tape speed is a further requirement which sometimes arises (particularly when the data are to be converted to digital form and processed using a digital computer). Re-recording of the data using a higher carrier frequency (and a higher tape speed) than that associated with the reproduced signal allows the required time scale expansion.

For tape copying purposes a land line has been installed between the two tape machines (the Ampex FR1200 and the Ampex FR1260). The land line will allow ten channels of information to be transmitted. However all these channels have not yet been committed.

The tape copying facility, mentioned above, has been extended to allow data signals acquired in remote areas to be transmitted to either tape machine for recording purposes. To allow some level of flexibility (but to avoid astronomical transmission cable installation costs) a roll-up cable dispenser has been manufactured. The hardware required at the transmitting point is fairly minimal. This arrangement obviates the need for an in-situ recorder.

The FR1200 tape machine is situated near the major laboratory digital computing facility which includes a PDP10 computer and a PDP11 computer manufactured by Digital Equipment Corporation.

A proposed extension to the data reduction facilities, to be located near the FR1200 machine, is a "Command and Information System" which will provide a ready means of processing analogue data with the digital computers. It is envisaged that direct on-line processing of analogue or digital data generated at remote data acquisition sites will be possible using the above complex.

Expansion of the data reduction facilities in association with the FR1260 machine is in hand. To this end a small digital computer (a PDP11 supplied by Digital Equipment Corporation) and some peripherals have been purchased. Direct on-line processing of data generated at remote data acquisition sites will be possible, in some instances, with the aid of this facility.

To provide the facilities outlined in this report maximum use has been made of commercially available hardware. Type identification details and any modifications required for this application are included. Particular attention has been given to details of special relevance to the operator.

2. GENERAL DESCRIPTION OF SYSTEMS

Hardware configurations for:

(i) copying magnetic tapes recorded using FM techniques;

(ii) copying speech signal (or other signal with up to 20 kHz bandwidth) recorded in Direct mode;

(iii) copying tapes recorded in digital form;

(iv) transmission of analogue signals from a remote data acquisition site to one of the tape recorders;

(v) transmission of digital signals from a remote data acquisition site to one of the tape recorders

are indicated in broad detail in Figures 1–5 respectively.

Specific details on the manner of interconnecting the various items of hardware referred to in those figures are given in Appendix 1.

For tape copying a permanent multi-conductor cable as detailed in Appendix 2.1 has been installed between the two tape machines. General installation details are given in Figure 6.

Each end of the transmission line is conveniently terminated with a Transmission Line Adaptor (Fig. 7). Three such adaptors (details in Appendix 2.2) have been manufactured.

For tape copying purposes the transmission of wideband (DC to 20 kHz) analogue signals via land line forms an essential requirement of the system. Very little degradation in performance relative to IRIG[1] specifications for intermediate bandwidth FM recording can be tolerated. To meet such performance requirements the transmission of the analogue data in FM form has been adopted.

When magnetic tapes recorded using FM techniques are to be copied (Fig. 1) the reproduced signals are transmitted in FM form without demodulation. Line drivers and line receivers (Sections 3.1 and 3.2) have been developed to enable the transmission of the FM signals via the land line.

For straight copying applications (using the same carrier frequency and the same tape speed) the hardware as indicated for alternative 1 of Figure 1 is used.

If low pass filtering of the recorded data is a requirement, the frequency of the transmitted FM signal may be divided (Sec. 3.3) before the signal is recorded at the receiving end of the line. If such filtering is required on all channels, a lower tape speed may be employed for the recording machine than for the reproducing machine. The actual filtering is realized when the tape copy is reproduced. A standard filter, having a bandwidth of about 20% of carrier frequency for intermediate band FM recording, is incorporated in the demodulator. Frequency division is a requirement in this application (in which use is made of standard hardware for Ampex Models FR1200 and FR1260 tape systems) since filter bandwidth and centre frequency cannot be selected separately. Connections as indicated in option 2 (Fig. 1) are used when frequency division is required.

When time scale expansion (Section 1) in excess of that possible when the recorded FM data are reproduced at the lowest available tape speed is required, the recorded data are re-recorded using a higher carrier frequency as indicated for option 3 (Fig. 1).

Excessive input level to the FM reproducing amplifier can cause it to malfunction. For this reason high level signals derived from the line receiver for option 3 are attenuated using an eight channel unit (a photograph of which is given in Figure 8*a*) which gives an output equal to about 0·13 times the input.

The use of the frequency division technique in the low pass filtering of recorded data is considered in detail elsewhere.[2] It is shown that some unwanted noise components may be generated in certain instances but, where necessary, these components can be largely reduced by pre-filtering. A particular example, involving both low pass filtering and time base expansion of recorded vibration data is considered in detail.

In most data acquisition applications speech signals are recorded on one tape track using direct recording techniques. To copy these signals the configuration indicated in Figure 2 is used. The output of the direct reproducing amplifier, located at the sending end of the line, is transmitted in FM form via the line with the aid of the FM recording amplifier (Fig. 2). At the receiving end of the line the FM signal is first demodulated using the FM reproducing amplifier, and the output of that amplifier is then taken to the direct recording amplifier for re-recording by the machine used to generate the tape copy.

In a laboratory system[3,4] of airborne data acquisition, digital data may be recorded[5] in serial form using either one or two tape tracks depending on whether non-return-to-zero-mark (NRZM) or return-to-zero (RZ) codes are employed. There is a need to copy such data and, to this end, the system depicted in Figure 3 has been adopted.

At the sending end of the line the reproduced digital signal (as derived from the output of the pre-amplifier) is first amplified using a direct reproducing amplifier with special plug-in. A photograph of the plug-in is given in Figure 8*b* and circuit details are given in Section 4. The output of the Direct amplifier is first converted to FM form with the FM recording amplifier (Fig. 3) and then transferred to the receiving end of the line.

At the receiving end of the line the following sequence of operations is performed:

(i) the FM signal is demodulated using the FM reproducing amplifier;

(ii) the output of the FM reproducing amplifier is taken to the NRZ reproducing amplifier which generates an output in NRZ code.

(iii) the output of the digital reproducing amplifier is taken to the input of the digital recording amplifier which provides a recording signal in a form which allows a copy to be made of the original tape.

The system of Figure 3 makes maximum use of available hardware. It is appreciated that a system requiring less hardware could be manufactured. However, the use of the same line drivers and line receivers for all data transmissions (as indicated in Figures 1–3) simplifies the hardware requirement considerably. The data rate capability has yet to be assessed but it is anticipated that rates up to 20 kilobit per second will be achieved.

Much of the hardware (line drivers, line receivers, etc.) applicable for the transmission of signals for tape copying purposes may be used for the transfer of signals from remote areas to either of the tape machines.

To enable data from any remote location within range to be transferred to either of the tape machines for recording purposes, a cable of 92·4 m nominal length has been mounted on the dispenser (Fig. 9). Junction boxes (referred to in Figure 6 and Appendix 2.1) allow the line between the two tape machines to be broken and the resulting free cable end to be plugged into one end of the dispenser cable.

Hardware at the remote location includes the following items:

(i) transmission line adaptor (Appendix 2.2) to terminate the line;

(ii) a standard Ampex Model ES-100 electronics tray as used in the two tape machines.

(iii) a power unit (to provide AC power for the tray);

(iv) line drivers (Section 3.1) and other plug-ins to be inserted in the tray and suitably interconnected;

(v) single housing to accommodate the above items.

For convenience in coupling the FM signal outputs to the line driver inputs the former are terminated via jacks mounted on the front panel of the power unit (Fig. 10). Circuit details on this unit are given in Figure 11 and other details in Appendix 3.

The remote data transmitter (comprising items (i)–(v) above) is depicted in Figure 12.

When analogue data are to be transmitted (Fig. 4) these data are first converted to FM form and then transmitted as outlined above (with relation to Figures 1–3). Once again maximum use is made of available hardware. Frequency modulation is performed at the remote data acquisition site using suitable modules plugged into the data transmitter tray (Fig. 12).

Bandwidth of the analogue data transmission and recording is basically DC to 20 kHz, when a 108 kHz carrier and a recording tape speed of 152·4 cm/s (60 ips [inches per second]) are used. The bandwidth is proportionately lower for the lower carrier frequencies used at lower tape speeds.

When digital data are to be transmitted the system of Figure 5 is used. Hardware requirements are almost identical to those which apply when digital signals, recorded on magnetic tape, are to be copied. An input network (Fig. 5), for data generated in NRZ or other two level code, removes the DC and very low frequency components from such data and transfers only the transitions to the FM link. The input coupling network (8 channel) is shown in Figure 8*c* and circuit details are given in Section 4. In realizing the system, maximum use is made of available hardware. It is anticipated that digital data rates up to 20 kilobit per second will be achieved.

Hardware (Section 5) has been manufactured which enables speech intercommunication between persons located at the transmitting end and the receiving end of the line.

Instrumentation allowing the tape machine at the receiving end of the line to be remotely controlled by an operator at the transmitting end of the line has been completed. The "Remote Control" hardware is manufactured in the form of a module which plugs directly into the Ampex ES-100 electronics tray assembly (which forms part of the hardware for each tape machine and which is included in the hardware required at the transmitting end of the line when data are to be transmitted from remote data acquisition sites [Appendix 2]). With this extension the tape recording machine may be switched to the "Record" or the "Stop" state. Lamps incorporated in the Remote Control unit monitor the state of control switches in the recording machine and provide an un-ambiguous indication of whether the machine is recording or is stopped. Details of the Remote Control hardware are given elsewhere.[6] Information on special cables required for operation of the various systems detailed in this report is given in Appendix 7.

3. DETAILED DESCRIPTIONS OF CIRCUITS DEVELOPED FOR USE IN FM DATA TRANSMISSION AND LOW PASS FILTERING

3.1 Line Drivers

Line drivers have been developed to enable FM signals to be transmitted via the line. When data in Direct form (Fig. 2) or Digital form (Figs 3 and 5) are to be transmitted such data are first converted to FM form for compatibility with the line drivers.

An eight channel line driver has been constructed in the form of a single plug-in for the Ampex ES-100 electronics tray. Power is derived from ± 12 V regulated supplies available at appropriate pins of the printed circuit edge connectors used in the tray.

Complete circuit details for a line driver are given in Figure 13 and component layout details in Figure 14. The system of component labelling, and of specification of component values, is described in Appendix 4. Information on the components used in the line drivers is given in Appendix 4.1.

The eight channel line driver is constructed from eight identical line driver units which are soldered to a "master" board which plugs into any spare slot in the Ampex ES-100 electronics tray. Details of interconnections (provided by the master board) to inputs, outputs and regulated supplies are given in Appendix 5. "Areas" on the master board allocated for each "solder-in" line driver (or other unit) are indicated in Figure 15.

Inputs to the eight channel line driver may be connected to the channel 1 to channel 8 input jacks accessible from the front panel of the line driver. These inputs are interconnected with FM recording amplifiers or FM reproducing amplifiers (depending on the type of data to be transferred via the line) which plug directly into the Ampex ES-100 electronics tray. Details of the required interconnections for the various applications referred to in Figures 1–5 are given in Appendix 1.

The minimum input signal amplitude which the drivers are required to handle is about 150 millivolt peak (when signals are derived from the "head return" output monitor[7] J6 of the FM recording amplifier).

The input signal frequency range to be accommodated by the line drivers must be adequate to allow transmission of FM signals generated for intermediate[1] band tape recording over the speed range 4·76 cm/s ($1\frac{7}{8}$ ips) to 152·4 cm/s (60 ips). For $\pm 40\%$ deviation the required limits are

$$\text{Upper limit} = (108)(1\cdot 4)\text{ kHz}$$
$$= 151\cdot 2\text{ kHz}$$
$$\text{Lower limit} = (3\cdot 375)(0\cdot 6)\text{ kHz}$$
$$= 2\cdot 025\text{ kHz}$$

Extension of the capability beyond these frequency limits is desirable (to allow higher order sideband components present in the modulated signal to be accommodated and to enable deviations in excess of 40% of the carrier frequency to be handled) and has been allowed for. For the line driver connected to the line installation (Appendix 2) the lower frequency limit may be extended to 1 kHz and the upper limit to about 200 kHz. However, the signal phase shift down the line increases and the signal to noise ratio reduces as the upper limit is approached.

Input signals to the line driver are first amplified by the stage comprising Q1 (Fig. 13) and associated components. For the range of input levels the driver has been designed to accommodate, the base of Q1 will be overdriven such that Q1 and associated components will form a switch with "square" output irrespective of input signal wave shape.

Q2, Q3 and associated components form a single ended class B push-pull circuit which provides output drive from the transformer T1. Transistors Q2 and Q3 are driven between the saturation state and the cut-off state but in opposite phase. Pulses of current are sequentially drawn from the +12 V and the −12 V supplies.

Supply decoupling components R1, C2, C4, R2, C3 and C5 reduce crosstalk between channels (common supplies used for each driver).

The secondary of transformer T1 provides a balanced output convenient for transmitting signals via twisted pair cables enclosed within a shield. When the line drivers are appropriately coupled to the line, OUTPUT 1 and OUTPUT 2 are connected to the twisted pair conductors and the OUTPUT COM is connected to the shield which is eventually "grounded" at the receiving end of the line. (Performance is not degraded if the connection between the OUTPUT COM and the cable shield is removed as the line becomes self balancing.) The OUTPUT COM is isolated from the COM at the sending end of the line. Ground isolation together with the balanced signal configuration enables good rejection of common mode noise signals to be realized. Further the shielded line provides good immunity to electrostatic interference and the twisted pair configuration provides good immunity to electromagnetic interference.

To enable eight line drivers to be fitted on a single plug-in (compatible with the Ampex ES-100 electronics) the size of the output transformer T1 could not be too large. Further, current drawn from the +12 V and −12 V regulated supplies had to be restricted (say less than 100 milliamp from each supply). The transformer connection allows an efficient output stage, with sufficiently low source impedance to drive the line, to be realized.

Resistors R13 and R14, each of 100 ohm value, are used to terminate the line at the sending end. Signal source impedance at the sending end of the line therefore becomes less than 100 ohm measured between each line and the shield.

Where optimum utilization of the transformer winding area is essential (as applied in this case because of transformer size restrictions) the single ended connection has advantages. The single primary winding is easier to wind and requires only half the total number of primary turns which would be required for a conventional "double ended" push-pull system. More effective primary turns (with due consideration for copper losses) can be wound in the available winding area using the single ended arrangement.

Some performance characteristics of the line driver were measured with the line driver output connected to one of the twisted pair cables in a Nylex 10IED cable (Appendix 2.1). The length of cable used for the test was 365 metres. At the output end of the line each conductor in the twisted pair was terminated with a 100 ohm resistor connected to the shield. Line input (line driver output) and line output voltages are given as a function of frequency in the following table.

Signal frequency (kHz)	Line to line input (volt peak to peak)	Line to line output (volt peak to peak)
10	8·0	7·1
50	5·8	5·6
80	4·8	5·6*
100	4·1	4·4*
150	3·7	2·7
200	2·8	1·8
250	1·7	1·1
300	1·2	0·75
350	1·08	0·56
400	0·85	0·41
500	0·48	0·21
600	0·38	0·14
700	0 24	0·081
800	0·20	0·058
900	0·15	0·040
1000	0·13	0·030

* Peak to peak line output was higher than line input but waveshape was different.

Full peak to peak output (8 V nominal) is obtainable at lower frequencies but below 1 kHz frequency, significant amplitude "droop" occurs due mainly to the inability of transformer T1 to cope with low frequency signals.

The extent of the voltage unbalance at the transmitting and the receiving ends of the 365 m cable was measured at some frequencies. For this test the OUTPUT COM (Fig. 13) was connected to the cable shield and the line was terminated with 100 ohm resistors as before. Unbalance details are provided in the following table.

Signal frequency (kHz)	Line input		Line output	
	Line 1 to shield (volt peak to peak)	Line 2 to shield (volt peak to peak)	Line 1 to shield (volt peak to peak)	Line 2 to shield (volt peak to peak)
27	4·0	4·0	3·6	3·6
54	2·8	2·6	2·9	2·9
108	1·8	2·2	1·7	2·1

No damage to the line driver results if its outputs are shorted (either line to line or line to shield).

Current drawn from each regulated supply line was measured for a single line driver unit (eight required per plug-in). Details are given in the following table.

Condition	Current drawn from +12 V supply (mA)	Current drawn from −12 V supply (mA)
No signal	7·0	8·5
Normal operation	5·5	8·5
Output shorted*	8·5	13·0

* Same current values result if short is applied across the total transformer secondary, or between either side and the centre tap.

Total currents required by the eight channel line driver unit will be about eight times the values indicated in the above table.

The completed line driver module (eight channels) is shown in Figure 16.

3.2 Line Receivers

Line receivers which suitably amplify signals at the receiving end of the line have been developed. An eight channel receiver has been constructed in the form of a single module (similar to the eight channel line driver unit) which plugs directly into the Ampex ES-100 tray. The master board (Appendix 5) on which the receiver units are mounted, is identical to that used for the line drivers.

Complete circuit details for a line receiver unit are given in Figure 17 and component layout details are given in Figure 18. Information on the components used in the line receivers is given in Appendix 4.2.

Basically the receiver comprises a voltage comparator Q1 (Fig. 17) with differential input. INPUT 1 and INPUT 2 are connected (via the Transmission Line Adaptor [Appendix 2.2]) to the respective conductors of the twisted pair line and INPUT COM is connected to the shield surrounding the twisted pair. Resistors R1 and R2, each of 100 ohm value, terminate the line.

Any mains frequency (50 Hz) noise picked up by the line is significantly attenuated by the high pass input filter comprising C1 and R4 on the INPUT 1 line, and C2 and R3 on the INPUT 2 line. The balanced impedances in each input line enhance the rejection of common mode noise signals.

Supply decoupling components R6, C5, C3, R7, C6 and C4 reduce crosstalk between channels (common supplies used for each receiver).

A single ended output is generated in each receiver unit. In each case the OUTPUT COM is connected to the INPUT COM which is, in turn, connected to the shield surrounding the relevant twisted pair cable in the transmission line. AC coupling is provided at the output via capacitor C7. When the receiver output is unloaded, an 11 V peak to peak signal, which is nominally square, is obtained.

Output signals from the eight channel receiver are extracted via the channel 1 to channel 8 output jacks accessible from the front panel. These outputs may be interconnected with FM recording amplifiers or FM reproducing amplifiers (depending on the manner in which the received data are to be handled) which plug directly into the Ampex ES-100 electronics tray. Details of the required interconnections for the various applications referred to in Figures 1–5 are given in Appendix 1.

When the output of a twisted pair cable of 365 m length (Section 3.1) was taken to a line receiver, full amplitude swing (11 V peak to peak nominal) was obtained for line driver input signals with frequencies in the range 1 kHz to 1 MHz. However the line to line output at the receiving end for the latter signal frequency was only about 30 mV peak to peak (as indicated in the table of Section 3.1).

Some common mode noise rejection checks relevant to the line and the receiver have been performed over a broad frequency spectrum. For the test the transmission line cable was reeled onto a drum and a simulated ground noise signal was connected between the sending end ground and the receiving end ground. Noise signals having frequencies in the range 50 Hz to 500 kHz and amplitudes in the order of 10 V RMS had very little effect on the data transmission. When a 108 kHz FM carrier was used a worst case common mode rejection (defined as the input voltage applied between the sending and the receiving end grounds divided by the resulting output voltage from an FM demodulator at the receiving end of the line) of about 50 dB was observed.

No damage to the line receiver results if its outputs are shorted.

Current drawn from each regulated supply line has been measured for a single line receiver unit (eight required per plug-in). Details are given in the following table.

Condition	Current drawn from +12 V supply (mA)	Current drawn from −12 V supply (mA)
No input signal	11·5	1·5
Output shorted for no input signal	11·5	1·5
Normal input signal	7·0	1·7
Output shorted for normal input signal	11·5	1·7

Total currents for the eight channel line receiver unit will be about eight times the values indicated in the above table.

The completed line receiver module (eight channels) is shown in Figure 19.

3.3 Frequency Dividers

Frequency dividers have been developed to enable standard FM reproducing amplifiers to be utilized for low pass filtering of analogue data signals recorded using FM techniques. An eight channel divider has been constructed in the form of a single module (similar to the eight channel line driver and line receiver units) which plugs directly into the Ampex ES-100 tray. The master board (Appendix 5) is identical to that used for the line drivers and receivers.

Complete circuit details for a dual channel frequency divider unit (a total of four such units being required) are given in Figure 20, and component layout details are given in Figures 21 and 22. Each divider unit requires two boards, a lower or "main" board (Fig. 21) and an upper or "sub" board (Fig. 22). Information on the components used in the frequency dividers is given in Appendix 4.3.

When low pass filtering (Section 2) of recorded FM data is a requirement, it may be achieved by dividing the frequency of the modulated signal and by using an effectively lower bandwidth filter in the demodulator. If a tape "copy", containing FM data after frequency division, is to be generated, the frequency divider module is located at the receiving end of the line "after" the line receivers but "before" the FM reproducing amplifiers as indicated in Figure 1. If, on the other hand, there is a requirement for low pass filtering of the recorded data, without the production of an intermediate tape "copy", the hardware configuration indicated in Figure 23 and detailed in Appendix 6 is required. By taking the head pre-amplifier outputs directly to the frequency divider inputs (as indicated in Appendix 6) only one FM reproducing amplifier is required per data channel.

Because the pre-amplifier outputs may be of relatively low level, particularly for low tape reproducing speeds (as indicated in the following table) the frequency dividers have been designed to operate from fairly low level inputs

Tape reproducing speed		Frequency of reproduced FM carrier signal (kHz)	Typical Ampex FR1260 pre-amplifier outputs (mV peak to peak)
cm/s	ips		
152·40	60	108	320
76·20	30	54	250
38·10	15	27	150
19·05	7½	13·5	80
9·53	3¾	6·75	40
4·76	1⅞	3·375	20

As can be seen from Figure 20 the circuit for each divider in the dual frequency divider unit is identical. Hence only the channel 1 portion (comprising Q1, Q3, Q5A, Q6 and associated components) will be referred to in the following description.

The input FM signal is coupled to the voltage comparator comprising Q1 and associated components. Positive feedback via C5 and R9 greatly reduces the tendency of the comparator to produce multiple transitions for slowly changing inputs such as those generated at the lowest tape speed for which both amplitude and frequency are low. To provide some level of immunity to input "ground" noise (evidenced by time varying potential differences between input signal grounds and frequency divider grounds) input grounds have been internally (in the frequency divider unit) separated from the output and power grounds via resistor R2 (having value of 10 ohm). The improved noise immunity thus achieved is essential for low level operation of this circuit.

Nominal ± 5 V supplies are generated from the ± 12 V supplies provided, using zener diodes CR1 and CR2, and associated components. By using these supplies to power the comparator, a TTL (transistor–transistor–logic) compatible output required by the following frequency divider circuit, is obtained.

It is essential that currents drawn from the $+12$ V and -12 V supplies are not excessive (say less than 100 mA from each supply for the eight channel frequency divider unit), otherwise overload of the Ampex ES-100 power supply could occur. To conserve current, low power digital integrated circuits have been used for the frequency division. For the range of repetition rates of interest in this application, the "speed" of the low power devices is quite adequate.

Frequency division in binary steps from 2 to 32 is achieved using the 4-bit binary counter Q3 followed by a divide by two circuit provided by flip flop Q5A. Signals having frequencies equal to that of the input signal divided by factors of 2^0 to 2^5 are simultaneously taken to a single pole switch S1 (Fig. 20). Division factor 2^0 (equal to unity) is not normally required but provides a convenient amplification of a low level FM input signal. Switch S1, which is mounted on the frequency divider sub-board (Fig. 22), is accessible when the frequency divider module is unplugged from the electronics tray. The switch positions have been marked 0 to 5; division factors are given by 2 raised to the power of the switch position number.

All current for the integrated circuits Q3 and Q5 used for the frequency division is derived from the internally generated $+5$ V supply which, in turn draws current from the $+12$ V supply.

The switch S1 output is AC coupled via C10 to the output stage comprising Q6 and associated components. AC coupling to the final output is provided by capacitor C12. When the frequency divider is unloaded, an 11 V peak to peak signal, which is nominally square, is obtained. No damage to the frequency divider results if the output is shorted to common.

Current for the output stage is taken from the -12 V supply. Currents drawn from the $+12$ V and -12 V supplies respectively have been measured for a normally operating dual frequency divider unit (four required per plug-in module). Details are given in the following table.

Current drawn from +12 V supply (mA)	Current drawn from −12 V supply (mA)
19	16·5

The currents required for the eight channel frequency divider module will be about four times the values indicated in the above table.

Division factors, and hence the extent of the low pass filtering provided for each channel, may be independently set for each channel.

Inputs to the eight channel frequency divider module are taken to the multi-pin connector on the front panel and the outputs are taken from the channel 1 to channel 8 jacks on the front panel. Connection details are given in Appendix 5.

When the inputs of the frequency divider module are connected to the line receiver outputs, for tape "copying" with low pass filtering, as indicated in Figure 1, satisfactory performance is readily obtained for all switch positions provided that the output frequency is kept above about 1 kHz (equivalent to about −70% deviation for wide band FM recording at 4·75 cm/s [1⅞ ips] tape speed).

When the inputs of the frequency divider module are coupled to the pre-amplifier output (which has low level at low tape speed) for low pass filtering of recorded data without the production of a tape "copy" (Fig. 23), it is imperative that the hardware configuration detailed in Appendix 6 be strictly adhered to, otherwise intermittent operation will result at the lowest tape speed (for which unity is the only relevant "division" factor).

The completed frequency divider module (eight channels) is shown in Figure 24.

4. DETAILED DESCRIPTION OF CIRCUITS DEVELOPED FOR USE IN THE TRANSMISSION AND RECORDING OF DIGITAL DATA

The hardware configurations used for the transmission and recording of digital data are indicated in Figures 3 and 5, and connection details are included in Appendix 1.

To copy signals which have been recorded in NRZ code (Fig. 3) the reproducing pre-amplifier output signals are first amplified to a suitable level using a Direct reproducing amplifier (Appendix 1) with special plug-in. The output of the Direct reproducing amplifier is then used to modulate an FM carrier. The resulting signal is transmitted via the line using the normal line driver and line receiver hardware as for FM data transmission (Sections 3.1 and 3.2).

Because the normal equalizer plug-in for a Direct reproducing amplifier does not produce a flat frequency response, a special plug-in (Fig. 8*b*) has been manufactured. Circuit details for the plug-in are indicated in Figure 25*a*. For the values of feedback resistance (R1–R6) chosen via the plug-in the amplitude of the Direct reproducing card (Ampex Cat. No. 69105) output remains very nearly constant for all tape speeds (provided switch S1 is correctly set according to the tape speed). Overall output amplitude is set to 2·8 V peak to peak, nominally, via the "OUTPUT ADJUST" potentiometer accessible from the front panel of the Direct reproducing amplifier.[7] The circuit of Figure 25*a* has been manufactured as a single plug-in which is used in place of an equalizer.

The signal which is coupled from the Direct reproducing amplifier to the FM recording amplifier (Fig. 3) is effectively an amplified version of that generated[8] at the reproducing head (or the head pre-amplifier) when data recorded in NRZ code are reproduced. Low frequency components are not present (as for data in normal NRZ code). Such a signal is less affected by phase shifts in the FM demodulator filter (located at the receiving end of the line in this application) than a normal NRZ signal, particularly at the higher rates of data transfer (20480 bits per second maximum for the application envisaged).

When a digital signal generated at a remote data acquisition site (Fig. 5) is to be transmitted, the same hardware as used for tape copying can be employed, if the normal NRZ data (having TTL compatible levels) are coupled to the FM recording amplifier via the network indicated in Figure 25*b*.

Digital recording amplifiers are not supplied (by the manufacturer) for use with the tape machines under consideration (Ampex FR1200 and FR1260). For this reason a new amplifier has been manufactured to allow for the recording of data in NRZ code. The amplifier has been designed to accept input levels which are TTL compatible. Circuit details of the NRZ digital recording amplifier are given in Figure 26 and component layout details are given in Figure 27. Information on the components used in the NRZ digital recording amplifier is given in Appendix 4.4. The completed amplifier will plug directly into a single slot in the Ampex ES-100 electronics tray.

The operation of an NRZ recording amplifier having a circuit virtually the same as that of Figure 25 has been described elsewhere.[5] However, the circuit of interest in the present application employs different supply voltages (± 12 V is used in the circuit of Figure 25 whereas ± 15 V, after regulation, was used in the circuit described elsewhere). Furthermore the physical layout of the circuit is quite different.

Although the amplifier is referred to as an "NRZ digital recording amplifier" any signal in two level code and generated with TTL compatible levels can be recorded with the aid of this amplifier.

Current drawn from the $+12$ V and -12 V supplies by the NRZ digital recording amplifier is typically about 27 mA for each supply.

The completed NRZ digital recording amplifier is illustrated in Figure 28.

As indicated in Section 2 there is also a need to copy data recorded in RZ code. The particular RZ code used[5,8] requires a three-level input and hence recording with the aid of an NRZ recording amplifier is not possible. Transmission of the reproduced RZ data using the arrangement of Figure 3 is quite feasible, but for the 20 kHz FM channel bandwidth provided by the FM data link connected as detailed in Appendix 1.3, the allowable reproducing speed is limited to 38·1 cm/s (15 ips). To produce a true copy of the recorded RZ data a special RZ recording amplifier (which has not been manufactured) would be required. If re-recording using two tracks were permissible, the two outputs (in NRZ code) of the RZ reproducing amplifier[8] could readily be recorded with the aid of NRZ recording amplifiers of the type indicated in Figure 26; but a true copy of the original would, of course, *not* result.

"Copying" of recorded digital data in FM form is also feasible but an FM reproducing amplifier would be needed "ahead" of the digital reproducing amplifier if such a "copy" were required. Copying of the data in RZ code at a lower (by a factor of four) speed than that used for the reproducing machine is a requirement of the system detailed here.

5. SPEECH INTERCOMMUNICATION SYSTEM

Hardware has been manufactured which allows speech intercommunication between operators located at the sending and the receiving ends of the line respectively. The establishment of the communication link between persons at each end of the line greatly facilitates the transmission and recording of data. In particular it allows the operator at the sending end of the line to indicate, to an operator at the receiving end of the line, when data are ready for recording.

Circuit details of the intercommunication equipment are given in Figure 29 and component layout information is included in Appendix 4.5. A photograph of the equipment is given in Figure 30.

A standard light-weight telephonist's headset HS (Fig. 29) with mouthpiece and earphone integrally mounted is worn by each operator. The connecting cables from each headset are terminated in a connector P1 (Fig. 29) which plugs directly into the Headset 1 or Headset 2 connectors (J1 or J2 respectively) on the "Headset Intercom" units (one required at each end of the line).

Considerable versatility of operation has been allowed for in the design of the Headset Intercom units since they are also required for field use in other applications. Up to two operators situated at the same location may plug their headsets into an Intercom unit via the connectors J1 and J2. Speech signals are transferred both into and out of the Intercom unit via the TM1 and TM2 terminals (Fig. 29). These terminals may be connected to at least two independent locations via external lines. A Headset Intercom unit is required at each location. Thus speech communication between up to two operators from each of up to three locations is achieved using hardware units of the type indicated in Figure 29.

At each location power is derived from a set of four dry batteries (providing a nominal supply of 6 V) housed in each unit. Sockets J3 and J4 allow the battery voltage to be checked externally. Direct current flows to the headset mouthpiece (a granulated carbon type) via R1 and the primary winding of transformer T1 in each unit. For one headset only connected via J1 or J2 the current drawn from the battery is 13·7 mA approximately and rises to about 14·6 mA if two headsets are connected. Generally the level of the received speech signal is increased if the value of resistor R1 is lowered.

When the intercommunication system is used in conjunction with the land line, the combined input to or output from terminals TM1 and TM2 may be connected to any suitable pair of conductors in the land line. Normally the combined input and output is connected to jacks designated Aux Hi and Aux Lo (Fig. 7) on the Transmission Line Adaptor. These jacks are connected via the adaptor to the communications wire and the overall cable shield respectively in the land line cable. Reversing connections at TM1 and TM2 (i.e. connecting TM1 on one headset unit to TM2 on another unit) is quite permissible.

6. PERFORMANCE OF COMPLETED SYSTEMS

6.1 Transfer of Input Signal Zero Crossings from Line Driver to Line Receiver

The line driver (Section 3.1), the line (Appendix 2) and the line receiver (Section 3.2) form a composite transmission system for transferring zero crossing information (associated with an input signal having instantaneous frequency not less than about 1 kHz) from one location to another. In all the applications considered in this report the information is transferred in FM form. Ideally therefore the line receiver generates an FM square wave with zero crossings in time synchronism with (or delayed a fixed time interval relative to) the zero crossings of the FM input to the line driver.

In Section 3.1 details were given of the signal amplitudes measured at the input and the output respectively of a line of length 365 m driven at the transmitting end via the line driver. Signal attenuation at the higher frequencies was apparent. Complete amplitude restoration takes place in the line receiver so that the only observable variable at the output of the receiver is the phase of that output relative to the line receiver input.

There is a significant phase shift associated with the data transmission and this shift does not vary linearly with frequency (a linear phase response results if there is a constant time delay).

Using a 1 V RMS square wave (virtually steady state) input to the line driver the phase shift at the receiver output has been plotted (Fig. 31) for various lengths of line in multiples of 96·4 m (100 yards). Some non-linearity in the characteristics is apparent.

The phase shift and time delay of the receiver output relative to the driver input have been obtained from the curves of Figure 31 for 100 kHz frequency and are tabulated below.

Line length factor K*	0	1	2	3	4	6
Phase shift at 100 kHz (degrees)	98	148	185	213	244	312
Time delay at 100 kHz (microsecond)	2·72	4·11	5·14	5·92	6·78	8·67

* Length of line = K . 96·4 m.

The phase non-linearity of the transmission system will give rise to a form of angle modulation which will contribute to distortion in the FM demodulator output. Sledge[9] and others have considered the distortion resulting when an FM signal passes through a linear passive network (subject to phase non-linearity). Both amplitude and phase responses of the overall FM system (including the tape copying system) will be affected.

6.2 Data Transmission from Remote Locations

Both analogue and digital data transmissions discussed in this report (Figs. 4 and 5) involve the transfer of data in FM form. To isolate the performance characteristics of the FM data transmission system some initial tests, for which tape recording has been excluded, have been performed. In effect hardware comprising items 2–6 of Figure 5 has been used for measuring amplitude and phase responses of such a system. In particular the effect of line length on those responses has been examined for various values of carrier frequency (and hence data bandwidth).

Specifications for intermediate bandwidth FM systems usually indicate a data passband limit frequency for which the response is guaranteed to be within a ± 1 dB passband. The nominal limit frequency is 20 kHz for a 108 kHz carrier system and is correspondingly lower for lower carrier frequencies. For convenience the nominal ± 1 dB passband limit will be referred to as the "corner" frequency.

In Figures 32 and 33 the amplitude and phase responses respectively have been plotted for a 108 kHz carrier system employing various lengths of line. Comparison of curve 2 with curve 1 (Fig. 32) reveals that the driver and the receiver modules accentuate the response at the corner frequency by about 1%. For line lengths of 200–400 m approximately the response at the corner frequency is further accentuated by about 4%, thus giving a net accentuation of about 5%. For a line length of about 600 m the net accentuation drops to about 3·6%.

From the phase responses of Figure 33 it is clear that most phase shift (curve 1) takes place external to the transmission system (which includes hardware from line driver to line receiver) and will be largely determined by the plug-in demodulator filter in the FM reproducing amplifier. Significant additional phase shift is introduced by the transmission line hardware (52 degrees at the corner frequency for a line of 580 m approximate length).

Amplitude and phase responses (Figures 34 and 35 respectively) for a 54 kHz carrier system employing various lengths of line have been plotted. In this instance the maximum amplitude accentuation at the corner frequency is about 1% and the maximum additional phase shift attributable to the line transmission is 30 degrees at that frequency.

At lower carrier frequencies the transmission line and terminations have progressively less effect on the amplitude and phase responses.

As indicated earlier (Figs. 4 and 5), recording of the transmitted signal at the receiving end of the line is a usual requirement. For convenience the effect of recording has been omitted in Figures 32–35. If the recording and reproducing processes had been included, the plotting of phase responses would have been extremely involved.

In Figure 36 the extent to which the recording and reproducing processes modify the amplitude response for 108 kHz carrier FM recording (at 152·4 cm/s [60 ips]) and copying (discussed in further detail in Section 6.3) can be readily observed. For this test a line of length 289·2 m (300 yd) was used in a hardware configuration as given in Figure 4 but with the exception that the start and finish of the cable were both located in close proximity to the Ampex FR1260 machine which was used for simultaneously reproducing the original record and producing a copy.

The recording and reproducing processes accentuate the amplitude response at the corner frequency by just over 2% (about 2·2% for the first recording and reproducing process, and about 2·4% for the second process associated with copying). As before the line transmission gives rise to about 5% accentuation at the corner frequency.

No problems have been encountered in the transfer of FM data from remote areas and the recording of such data at the receiving end of the line. However, the amplitude and phase responses for 108 kHz carrier FM transmission are slightly modified as indicated above.

NRZ digital data (Section 4) with data rates up to 20·48 kilobits per second have been successfully transferred from remote areas and recorded using the hardware arrangement of Figure 5.

6.3 Tape Copying

Using the land line installation shown in Figure 6 signals have been transferred via CBL.1, CBL.2 and CBL.3 from one tape machine to the other for tape copying.

To assess the performance of the FM tape copying system, test signals recorded on an original tape using FM techniques have been copied using hardware indicated in Figure 1 (alternative 1) and further detailed in Appendix 1. To allow automatic plotting of amplitude responses, test signals comprising a full amplitude sinusoidal modulating signal (i.e. one which causes the carrier frequency to deviate between nominal +40% and −40% limits) and a sweep signal (analogue voltage proportional to modulating signal frequency) were simultaneously recorded on different tracks of an original tape.

Original recording, copying and final reproduction were performed at each of the six available tape speeds, 4·76 cm/s (1⅞ ips) to 152·4 cm/s (60 ips). Amplitude responses obtained when the original and the copy tapes respectively were reproduced have been plotted for comparison at each tape speed in Figures 37 to 42. Since the amplitude response varies according to the particular FM reproducing amplifier and the particular plug-in filter used, the same amplifier and filter have been used for plotting both responses.

As indicated in Figures 37 to 41 FM copying via the land line produces very little alteration in the amplitude response for tape speeds below 152·4 cm/s (60 ips). However, at 152·4 cm/s tape speed there is significant variation in the responses obtained from the original and the copy tapes respectively. The variation (Fig. 42) amounts to about 6% at the corner frequency. From details given in Section 6.2 (and Fig. 36) about 2% of the variation is probably introduced by the additional recording and reproducing process required for the copy and the remainder (4%) would be attributable to transmission line effects.

To make some assessment of the quality of the FM tape copy an estimate of the increase in noise resulting from the data transmission and the copying process is essential. To allow some level of quantitative measurement to be made the following signals were recorded on an original tape and copied via the transmission line.

(i) Full amplitude sinusoidal modulating signals (swept from $f_o/40$ to $7f_o/4$ where f_o is the corner frequency) on tracks 1, 2, 3, 5 and 6.

(ii) Analogue voltage signal proportional to modulating signal frequency on track 7.

(iii) Unmodulated carrier on track 4.

Original recording and subsequent copying were performed at each of the available six tape speeds. The output from track 4 was demodulated and taken to an average detecting voltmeter providing readout in terms of root mean square (RMS) value of sinusoidal input. An output from the voltmeter proportional to meter deflection was taken to the "Y" input of an X–Y plotter. The analogue voltage proportional to modulating signal frequency was taken to the "X" input of the plotter. Outputs produced when the original and the copy tapes respectively were reproduced have been plotted for comparison at each tape speed. Plots for the three lower speeds are given in Figure 43 and those for the three higher speeds are given in Figure 44. Any crosstalk arising in the recording and reproducing processes, and in the land line transmission, will add to and be inseparable from noise due to tape flutter and other causes.

As would be expected, the combined noise and crosstalk level (Figs. 43 and 44) tend to be significantly higher for the copy than for the original tape. Except for the lowest tape speed the combined noise and crosstalk level resulting when the copy is reproduced is not more than twice the level obtained when the original is reproduced. In the following table the maximum level (obtained from Figs. 43 and 44) at each tape speed for both the original and the copy tapes has been tabulated.

Tape speed	cm/s	4·76	9·53	19·05	38·10	76·20	152·40
	ips	$1\frac{7}{8}$	$3\frac{3}{4}$	$7\frac{1}{2}$	15	30	60
Combined noise and crosstalk for original	mV RMS	11·6	9·0	3·4	3·8	3·6	5·5
	dB*	−38·8	−40·9	−49·4	−48·4	−48·9	−45·2
Combined noise and crosstalk for copy	mV RMS	15·7	9·0	6·0	4·7	5·8	8·5
	dB*	−36·1	−40·9	−44·4	−46·6	−44·7	−41·4

* Expressed in decibel relative to 100% level (1 V RMS).

Worst case noise figures are obtained for the lowest tape speed. It is probable that some noticeable increase in the transport flutter for the Ampex Model FR1200 tape machine, when run at that speed, gave rise to the increased noise figures.

The quantitative measurements discussed above (i.e. amplitude response and level of combined noise and crosstalk for one specific condition) are not sufficient to allow the quality of the original recording and the copy to be compared. Some qualitative assessment is also essential. In this latter regard it has been noted that, apart from a small increase in noise level, tape copies produced at speeds less than 152·4 cm/s give outputs which are virtually free of amplitude "glitches" (defined here as sudden short duration changes in level) when reproduced. However, when tapes are copied at 152·4 cm/s via the land line and later reproduced, amplitude glitches are likely to occur. The glitches tend to occur when the modulating frequency is high (say 20 kHz), they tend to be very very intermittent and arise when FM signals on some tracks only of the copy tape are reproduced.

It was found experimentally that some transmission channels (where a transmission channel is considered to comprise a line driver circuit, a line between the tape machines of 270 m length, and a line receiver circuit) tended to produce noisier copies at 152·4 cm/s than at other tape speeds. Some assessment of the quality of the transmission could be obtained by copying an FM signal obtained by fully deviating ($\pm$40%) a 108 kHz carrier at 35 kHz modulating signal frequency and observing the output level obtained when the copy is reproduced. "Good" channels provide an output of about 0·1 V RMS and "noisy" channels give a significantly higher output (0·3–0·9 V RMS) when measured with a simple average detecting AC voltmeter. For the two line drivers and two line receivers which have been manufactured the results indicated in the following table were obtained.

Configuration used for data transmission (LD = line driver, LR = line receiver)	Output (Volt) obtained when FM signal (35 kHz modulation frequency) copied via various data transmission channels (ch. 1 to ch. 8) is later reproduced							
	ch. 1	ch. 2	ch. 3	ch. 4	ch. 5	ch. 6	ch. 7	ch. 8
LD1, LR1	0·47*	0·93*	0·10	0·50*	0·08	0·08	0·09	0·10
LD1, LR2	0·47*	0·92*	0·10	0·54*	0·30*	0·08	0·09	0·10
LD2, LR1	0·11	0·11	0·52*	0·35*	0·09	0·15	0·09	0·11
LD2, LR2	0·12	0·11	0·52*	0·35*	0·35*	0·15	0·09	0·11

* Noisy transmission channels are indicated with an asterisk.

From the above table it may be deduced that channels 1, 2 and 4 of LD1, channels 3 and 4 of LD2 and channel 5 of LR2 tend to produce "noisy" copies. A typical amplitude response which results when a noisy channel is used for copying at 152·4 cm/s is shown in Figure 45.

It is to be emphasized that copying of a signal of 35 kHz frequency is not a requirement. For intermediate band FM recording the maximum frequency would be 20 kHz. Differences in the performance of the various line driver and receiver channels no doubt gives rise to the different noise levels. In most applications quite satisfactory copies can be produced at the highest tape speed even if noisy channels are used.

Because of the noise effects and the changes (6% maximum) in the amplitude response which apply for copying at maximum tape speed it is recommended that, where possible, copying be not performed at that speed.

If FM signals are demodulated at the receiving end of the line and the demodulator output then used to re-modulate a carrier (of the same frequency as that for the received signal), an improvement in signal to noise ratio, relative to that which applies for straight copying as detailed above, seems to result. Such copying would modify the amplitude response significantly (as the data would be filtered twice before reaching the final demodulator output at the time the copy is reproduced). Improved signal to noise ratio is due, no doubt, to reduction in noise on the FM signal (just prior to the copying) as a result of the low pass filtering which takes place in the demodulator. Significant reduction in the amplitude of the higher frequency sideband components, present in the copied FM signal, would result.

Further to the comparison of the quality of the copy produced when FM signals are copied with and without intermediate demodulation respectively, it is worth considering the following statement of Howard and Ferguson:[10]

> "Recordings made with FM carrier recording electronics may be dubbed by the direct recording process. However, tests indicate that even though unsupported by theory, better results can be obtained when the FM recorded data is demodulated in the normal manner and re-recorded on an FM recording machine."

It is likely that the improvement is due to the sideband component attenuation which takes place when the reproduced output from the original tape is first demodulated, then re-modulated, before the copy is made.

Using the hardware configuration indicated in Figure 2 and further detailed in Appendix 1 recorded speech signals have been copied. Virtually no difference in quality has been observed between the signals derived from the original and the copy respectively.

Digital signals recorded in NRZ code have been copied using the hardware configuration of Figure 3. Because special equipment to read the data has not been completed as yet, a full assessment of this form of copying has not been made. However, indications obtained from examination of retrieved signals, suggest that NRZ signals with data rates of up to about 20 kilobit per second can be copied at the highest tape speed and proportionately lower rates at the lower tape speeds.

6.4 Other Functions

The frequency divider module has been used in the low pass filtering of recorded data signals both during a straight reproduction of an original tape and in the production of a filtered "copy". Performance has been quite satisfactory but as indicated in Section 2 and analysed in detail elsewhere[2] some unwanted noise components of significant amplitude can be generated in certain instances.

The speech intercommunication system has been used whenever tapes have been copied with the aid of the transmission line and when data have been transferred from remote areas to a tape recording machine. Performance has been quite satisfactory. However, more sophisticated headsets (which include active devices for signal amplification) may be needed if operation in very noisy areas is required.

7. CONCLUSIONS

(*a*) Analogue signals with frequencies in the range 0–20 kHz may be transferred in frequency modulated form from a remote location to a tape recording machine using a transmission line and associated hardware.

(*b*) Analogue signals recorded in frequency modulated form may be transferred from a reproducing machine to a remotely located recording machine for copying without the need for intermediate demodulation.

(*c*) Speech signals recorded in direct form may be transferred in frequency modulated form from a reproducing machine to a remotely located recording machine for copying purposes.

(*d*) Digital signals may be used to frequency modulate a suitable carrier and the resulting signal transferred via transmission line to a tape recording machine for initial recording or for tape copying.

(*e*) Low pass filtering of signals recorded using frequency modulation techniques may be achieved by dividing the frequency of the modulated signal and passing the resulting signal to a demodulator with a lower bandwidth filter.

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(ii) assistance with engineering development, testing of completed hardware and performance checking of completed systems by Mr. R. W. Jackson;

(iii) assistance with engineering development by Mr. B. Drazenovic.

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APPENDIX 1

General Details on Hardware Configurations for Transfer of Data over Land Line

The following tables list the hardware required at both the transmitting and the receiving ends of the land line for tape copying (Figs. 1, 2 and 3) and for recording of data collected at remote data acquisition sites (Figs. 4 and 5). In each of the figures (Figs. 1–5) a circle with enclosed number at the top left hand corner of the hardware block allows identification of that item in the following tables. For example Item 3–5 in the third table refers to Item 5 of Figure 3.

Details of input and output connections, modifications to standard hardware and the like are included in the "Comments" column.

Hardware relating to the line and its actual terminations has not been listed in these tables, but details are given in Appendix 2.

1.1 Hardware for Copying Tapes Recorded Using FM Techniques

Refer to hardware configuration of Figure 1.

Item ref. no.	Detail	Comments
1–1	Ampex Model FR1260 (or FR1200) tape machine	The machine is set to operate in the reproducing mode.
1–2	Ampex FM reproducing amplifier Cat. No. 69108	The filter plug-in is not required and no card alignment is necessary. The tape dubbing input at J5 is connected to front panel jack TP3. TP3 is taken to the line driver input. As for conventional reproduction, the amplifier is plugged into the appropriate slot in the ES-100 electronics tray which forms part of the tape machine (Item 1–1) hardware.
1–3	Eight channel line driver	Hardware (Section 3.1 of text) has been developed at ARL for this application. It is plugged directly into any spare slot in a standard ES-100 electronics tray, and is designed to be operated from the supply rails provided.
1–4	Eight channel line receiver	Hardware (Section 3.2 of text) has been developed at ARL for this application. It is plugged directly into any spare slot in a standard ES-100 electronics tray, and is designed to be operated from the supply rails provided.

Item ref. no.	Detail	Comments
1–5	Ampex FM recording amplifier Cat. No. 69107-14 (or 69107-15)	The available amplifiers comprise some "old" and some "new" style circuits. The old style circuit includes components to select the carrier frequency for each speed, whereas the new style circuit includes components selected for 108 kHz carrier frequency or. In the latter instance a frequency divider is used to transfer the data to a lower carrier frequency. Since the requirements for the old and the new style circuits differ, they will be considered separately. (*a*) Old Style (Cat. No. 69107-14) No card alignment is necessary. The frequency selector switch, accessible from the side face of the amplifier, must be switched such that the wiper rests between contacts. As the "gap" between contacts is very broad such positioning is very simple. Correct setting of the switch can be readily verified by removing the input and checking that the output at J4 (normally connected to the TP3 jack) disappears. The tape dubbing input at J5 is taken to front panel jack TP3. The output from the line receiver is taken to TP3. For hardware available at ARL for use with the FR1260 machine FM recording amplifiers Nos. 1, 2, 3 and 4 (ARL identification) are old style. (*b*) New Style (Cat. No. 69107–15) No card alignment is necessary. The original circuit does not provide a convenient point of access to the amplifier output stage. An internal modification is required to allow such an amplifier to be used as Item 1–5. The modification involves the disconnection of R17 from J5 and the attachment of a flying lead to the resulting free end of R17. For normal operation the flying lead is plugged into J5, but for the present application R17 is disconnected from J5 by plugging the flying lead into a specially introduced anchor post not internally connected to any part of the circuit. For hardware available at ARL for use with the FR1260 machine, FM recording amplifiers Nos. 5, 6 and 7 (ARL identification) have been modified. Thus for these amplifiers the following steps are required: (i) Disconnect internal flying lead from J5; (ii) Internally connect J5 to the TP3 jack. In this case the wiper of the frequency selector switch need not be set such that the wiper rests between contacts. (*c*) Applies for both old and new style. As for conventional recording, the amplifier is plugged into the appropriate slot in the ES-100 electronics tray which forms part of the tape machine (Item 1–6) hardware.

Item ref. no.	Detail	Comments
1–6	Ampex Model FR1200 (or F1260) tape machine	The machine is set to operate in the recording mode.
1–7	Eight channel frequency divider	Hardware (Section 3.3 of text) has been developed at ARL for this application. It is plugged directly into any spare slot in a standard ES-100 electronics tray, and is designed to be operated from the supply rails provided.
1–8	Attenuator	The eight channel attenuator (Figs. 8*a* and 23) has been specially manufactured at ARL. It provides an output equal to 0·13 times its input.
1–9	Ampex FM reproducing amplifier (Cat. No. 69108) fitted with appropriate filter (Cat. No. 46390)	TP3 is connected internally to J2 (input monitor point). The output of the attenuator is coupled to the TP3 jack accessible from the front panel. The card is aligned in the normal manner. To prevent interference between the pre-amplifier output and the input from the attenuator one of the following steps must be taken. (i) The card may be plugged into a slot not internally wired to the pre-amplifier output. Such slots are readily available on the FR1260 machine but not on the FR1200 machine used in this application. (ii) The card may be plugged into a slot normally wired internally to the pre-amplifier output, and the pre-amplifier interconnecting cable unplugged internally from the ES-100 electronics tray.

1.2 Hardware for Copying Speech Signal (or Other Signal with up to 20 kHz Bandwidth) Recorded in Direct Mode

Refer to hardware configuration of Figure 2.

Item ref. no.	Detail	Comments
2–1	Ampex Model FR1260 (or FR1200) tape machine	The machine is set to operate in the reproducing mode.
2–2	Ampex Direct reproducing amplifier (Cat. No. 69105) fitted with equalizer Cat. No. 69117	The amplifier is aligned in the normal manner but this may be done fairly approximately for speech transmissions. As for conventional reproduction, the amplifier is plugged into the appropriate slot in the ES-100 electronics tray, which forms part of the tape machine (Item 2–1) hardware.

Item ref. no.	Detail	Comments
2–3	Ampex FM recording amplifier (Cat. No. 69107-14)	An old style (refer to Item 1–5) amplifier must be used. The selector switch is set to the 30 ips position and the amplifier is aligned in the normal manner. The normal output of the Direct reproducing amplifier is coupled to the normal input to the recording amplifier. The tape dubbing input at J5 is taken to front panel jack TP3. The input to the line driver is taken to TP3. The amplifier is plugged into any spare slot in the ES-100 electronics tray which forms part of the tape machine (Item 2–1) hardware.
2–4	Eight channel line driver	Comments as for Item 1–3 apply. Only one channel of the line driver is required for transfer of the speech data.
2–5	Eight channel line receiver	Comments as for Item 1–4 apply. Only one channel of the line receiver is required for transfer of the speech data.
2–6	Attenuator	Comments as for Item 1–8 apply.
2–7	Ampex FM reproducing amplifier (Cat. No. 69108) fitted with 60 ips filter plug-in (Cat. No. 46390-11)	Comments as for Item 1–9 apply. The normal output of the FM reproducing amplifier is connected to the input of the Direct recording amplifier (Item 2–8).
2–8	Ampex Direct recording amplifier (Cat. No. 69279F)	The Direct recording amplifier is adjusted in the normal manner. The normal input of this amplifier is connected to the normal output of the FM reproducing amplifier. As for conventional recording, the amplifier is plugged into the appropriate slot in the ES-100 electronics tray which forms part of the tape machine (Item 2–9) hardware.
2–9	Ampex Model FR1200 (or FR1260) tape machine	The machine is set to operate in the recording mode.

1.3 Hardware for Copying Tapes Recorded in Digital Form

Refer to hardware configuration of Figure 3.

Item ref. no.	Detail	Comments
3–1	Ampex Model FR1260 (or FR1200) tape machine	The machine is set to operate in the recording mode but the recording head cable from the ES-100 electronics tray is disconnected and a dummy shorting connector is inserted at the rear.
3–2	Ampex Direct reproducing amplifier (Cat. No. 69105) with special plug-in in place of the equalizer	The amplifier is fitted with a special plug-in (refer to Figures 8*b* and 25*a*, and Section 4 of text) developed at ARL to provide flat amplitude versus frequency response (in contrast to that provided when the equalizer is used). The output of the amplifier is adjusted to about 1·4 V peak. As for conventional reproducing, the amplifier is plugged into the appropriate slot in the ES-100 electronics tray which forms part of the tape machine (Item 3–1) hardware.
3–3	Ampex FM recording amplifier (Cat. No. 69107-14 [or 69107-15])	The selector switch is set to the 60 ips position and the amplifier aligned in the normal manner. The output of the Direct reproducing amplifier is coupled to the FM recording amplifier input. The TP3 jack is internally connected to the J4 output which is coupled to the line driver input. In order to obtain an output at TP3 the procedure detailed in 3–1 must be adhered to. The TP3 output is coupled to the line driver input. The amplifier is plugged into any spare slot in the ES-100 tray which forms part of the tape machine (Item 3–1) hardware.
3–4	Eight channel line driver	Comments as for item 1–3 apply.
3–5	Eight channel line receiver	Comments as for Item 1–4 apply.
3–6	Attenuator	Comments as for Item 1–8 apply.
3–7	Ampex FM reproducing amplifier (Cat. No. 69108) fitted with 60 ips filter plug-in (Cat. No. 46390-11)	Comments for Item 1–9 apply. The output of the FM reproducing amplifier is connected to the input of the digital reproducing amplifier.
3–8	Digital reproducing amplifier	Amplifiers[8] have previously been developed for handling data recorded in NRZ or RZ code (separate amplifiers are used for each). The front panel mounted switch is set to 60 ips. The amplifier is plugged directly into any spare slot in a standard Ampex ES-100 electronics tray, and is designed to be operated from the supply rails provided.

Item ref. no.	Detail	Comments
3–9	Digital recording amplifier	Refer to Section 4 of text. Hardware has been developed at ARL for this application. The amplifier is plugged, as for conventional reproduction, into the appropriate slot in the ES-100 electronics tray which forms part of the tape machine (Item 3–10) hardware.
3–10	Ampex Model FR1200 (or FR1260) tape machine	The machine is set to operate in the recording mode.

1.4 Hardware for Transmitting Analogue Signals to Remotely Located Tape Recorder

Refer to hardware configuration of Figure 4.

Item ref. no.	Detail	Comments
4–1	Ampex FM recording amplifier (Cat. No. 69107-14 [or 69107-15])	The amplifier is aligned in the normal manner. Analogue signals to be transmitted are taken to the normal inputs of the amplifiers which plug into an Ampex ES-100 Record Tray Assembly (Cat. No. 69570-11) located at the remote data acquisition site. More details on this hardware are given in Appendix 3. The recording amplifier output may be taken from the TP3 jack (which must be connected internally to the J4 post on the amplifier), or from connectors J2 or J3 which are mounted on the front panel of the Power Unit (Appendix 3) which forms an essential part of the remote data transmitter hardware. Low value resistors (100 ohm) mounted in the Power Unit are connected across the "head" outputs. The Power Unit is interconnected with the ES-100 electronics tray assembly via connectors at the rear. More details are given in Appendix 3.
4–2	Eight channel line driver	Comments as for Item 1–3 apply.
4–3	Eight channel line receiver	Comments as for Item 1–4 apply.
4–4	Ampex FM recording amplifier	Comments as for Item 1–5 apply.
4–5	Ampex Model FR1260 (or FR1200) tape machine	The machine is set to operate in the recording mode.

1.5 Hardware for Transmitting Digital Signals to Remotely Located Tape Recorder

Refer to hardware configuration of Figure 5.

Item ref. no.	Detail	Comments
5–1	Input network	Hardware has been manufactured at ARL for this application (refer to Figures 8*c* and 25*b*, and to Section 4 of text). The network is designed to accept TTL (transistor–transistor–logic) level input signals. It typically provides an output of 2·6 V peak to peak for the FM recording amplifier.
5–2	Ampex FM recording amplifier	Comments as for Item 4–1 apply but the selector switch is set to 60 ips for all data transmissions.
5–3	Eight channel line driver	Comments as for Item 1–3 apply.
5–4	Eight channel line receiver	Comments as for Item 1–4 apply.
5–5	Attenuator	Comments as for Item 1–8 apply.
5–6	Ampex FM reproducing amplifier (Cat. No. 69108) fitted with 60 ips filter plug-in (Cat. No. 46390-11)	Comments for Item 1–9 apply. The output of the FM reproducing amplifier is connected to the input TP3 of the digital reproducing amplifier.
5–7	Digital reproducing amplifier	Comments as for Item 3–8 apply.
5–8	Digital recording amplifier	Comments as for Item 3–9 apply.
5–9	Ampex Model FR1260 (or FR1200) tape machine	The machine is set to operate in the recording mode.

APPENDIX 2

Land Line and Termination

2.1 Land Line

General details on the cable installation at these laboratories are given in Figure 6. All main cables external to buildings (i.e. cables designated CBL.1 to CBL.4 in Figure 6) contain ten individual smaller cables each comprising a twisted pair surrounded via a shield and a jacket (for insulation purposes). An insulated single core "communications" wire and an overall outer shield are included together with the twisted pair cables. The cable is a type 10IED183 of Nylex manufacture and has an outer diameter of 1·66 cm.

Approximate lengths of the main cables are given in the following table.

Cable	Approximate length
CBL.1	65 m
CBL.2	145 m
CBL.3	65 m
CBL.4	92 m

Junction boxes JB1 and JB2 (Fig. 6) are mounted on external walls of buildings. CBL.4 from the roll-up cable dispenser may be plugged into either junction box in place of CBL.1, CBL.2 or CBL.3 as required.

Connectors (Fig. 6) are of the types tabulated below.

Reference	Description
J2, J3, J4, J5, J8 (also J1, J6 and J7 on adaptors)	Plug, chassis mounting, 37 pin, Cannon type MS3102E28-21P
P1, P2, P3, P4, P5, P6, P7	Socket, cable mounting, 37 pin, Cannon type MS3106E28-21S with extension shell manufactured according to ARL Dwg. No. SK9001.

For convenience the wires associated with each twisted pair cable are designated Hi (white wire), Lo (black wire) and Shd (shield). A particular wire in one of the twisted pair cables is identified in the form 7-Hi meaning the Hi wire in the seventh twisted pair. (There are ten twisted pairs referenced 1 to 10.) The following table gives details relevant to the pin connections for all the connectors mentioned in the above table. In the case of the junction boxes, connectors J2 and J3 (Fig. 6) in JB1, and connectors J4 and J5 in JB2 are interwired with lighter duty twisted pair cable (Raychem type 44A1121-22-9-0-9).

Pin connections for all plugs and sockets indicated in Figure 6 are given in the following table.

Connector Pin No. (J1→J8, P1→P7)	Connected to	Connector Pin No. (J1→J8, P1→P7)	Connected to
A	1-Hi (white wire)	a	8-Hi (white wire)
B	1-Lo (black wire)	b	Aux-Hi (orange wire)
C	2-Hi (white wire)	c	
D	2-Lo (black wire)	d	
E	9-Lo (black wire)	e	Aux-Shd (outer shield)
F	1-Shd	f	4-Lo (black wire)
G	10-Shd	g	7-Lo (black wire)
H	2-Shd	h	7-Shd
J	3-Hi (white wire)	j	6-Shd
K	9-Hi (white wire)	k	5-Shd
L	9-Shd	m	5-Hi (white wire)
M	10-Hi (white wire)	n	7-Hi (white wire)
N	10-Lo (black wire)	p	6-Lo (black wire)
P	3-Shd	r	6-Hi (white wire)
R	3-Lo (black wire)	s	5-Lo (black wire)
S	8-Lo (black wire)		
T	8-Shd		
U			
V			
W			
X	4-Shd		
Z	4-Hi (white wire)		

Hardware details for the juction boxes JB1 and JB2 (Fig. 6) are given in ARL drawings Nos. 10197, 16879 and 16880.

2.2 Land Line Termination

For convenience of connection to line drivers, line receivers or other signal sources the line is terminated in "Transmission Line Adaptors" (TLA1, TLA2 and TLA3 in association with the Ampex FR1260 tape machine, the Ampex FR1200 tape machine and the remote data transmitter respectively as indicated in Figure 6). The adaptors, which have been manufactured at these laboratories each occupy a standard 10·5 cm ($4\frac{1}{8}$ in.) by 17·8 cm (7 in.) panel space. The line may be plugged directly into chassis mounted connectors J1, J6 and J7 (Fig. 6) respectively which are mounted at the rear of the adaptors.

Each conductor in the transmission line is interwired via the adaptor to jacks mounted on the front panel. Alternative signal input/output connections are provided by front panel mounted connectors J1 and J2 (Fig. 7). These connectors (which are not to be confused with J1 and J2 of Figure 6) are interwired with the jacks. J1 provides for convenient connection to line driver outputs or line receiver inputs whereas J2 provides for convenient connection to remote control[6] circuits.

The components used in the adaptors are listed in the following table.

Reference	Location	Description
Jacks labelled 'Hi"	Front Panel	(i) For TLA1 and TLA3 (Fig. 6) Jack, Johnson Co., Minnesota, Cat. No. 105-0601-001, white. (ii) For TLA2 Socket, banana, Belling Lee, 4 mm, white.
Jacks labelled "Shd"	Front panel	(i) For TLA1 and TLA3 Jack, Johnson Co., Minnesota, Cat. No. 105-0603-001, black. (ii) For TLA2 Socket, banana, Belling Lee, 4 mm, black.
Jacks labelled 'Gnd"	Front panel	(i) For TLA1 and TLA3 Jack, Johnson Co., Minnesota, Cat. No. 105-0604-001, green. (ii) For TLA2 Socket, banana, Belling Lee, 4 mm, green.
Jacks labelled "Lo"	Front panel	(i) For TLA1 and TLA3 Jack, Johnson Co., Minnesota, Cat. No. 105-0610-001, blue. (ii) Socket, banana, Belling Lee, 4 mm, blue.
J1 (front panel marking)	Front panel	Socket, 25 pin, sub-miniature, Cannon type DB-25S.
J2 (front panel marking)	Front panel	Socket, 9 pin, sub-miniature, Cannon type DE-9S.
Heavy duty rear panel connector (referred to as J1, J5 and J7 in Figure 6)	Rear panel	Plug, chassis mounting, 37 pin, Cannon type MS3102 E28-21P.

Details of the interconnections in the Transmission Line Adaptors (TLA1 to TLA3) are given in the following table.

Rear panel connector pin	Connected to		Rear panel connector pin	Connected to	
	Front panel jack	Front panel connector		Front panel jack	Front panel connector
A	1-Hi	J1-1	a	8-Hi	J1-24
B	1-Lo	J1-2	b	Aux-Hi	J2-4
C	2-Hi	J1-15	c		
D	2-Lo	J1-16	d		
E	9-Lo	J2-2	e	Aux-Shd	J2-9
F	1-Shd	J1-14	f	4-Lo	J1-19
G	10-Shd	J2-3	g	7-Lo	J1-11
H	2-Shd	J1-3	h	7-Shd	J1-23
J	3-Hi	J1-4	j	6-Shd	J1-9
K	9-Hi	J2-1	k	5-Shd	J1-20
L	9-Shd	J2-6	m	5-Hi	J1-7
M	10-Hi	J2-7	n	7-Hi	J1-10
N	10-Lo	J2-8	p	6-Lo	J1-22
P	3-Shd	J1-17	r	6-Hi	J1-21
R	3-Lo	J1-5	s	5-Lo	J1-8
S	8-Lo	J1-25			
T	8-Shd	J1-12			
U					
V					
W					
X	4-Shd	J1-6			
Z	4-Hi	J1-18			

All front panel mounted jacks labelled "GND" are shorted together and connected to J1-13 and J2-5.

APPENDIX 3

Details on Remote Data Transmitter Hardware

The remote data transmitter is photographed in Figure 12 and referred to in Section 2. Essential hardware items are:

(i) an Ampex ES-100 electronics tray (capable of accepting 16 single width modules) which is powered from 115 V AC and provides regulated ± 12 V for the various modules;

(ii) a power unit (Figs. 10 and 11) which provides 115 V AC for the tray and which includes other features detailed below;

(iii) a transmission line adaptor (Appendix 2.2).

The line drivers (8 channel unit occupies one plug-in space) and the FM recording amplifier, both of which are required at the transmitting end of the line as indicated in Figures 4 and 5, plug directly into the tray.

Power derived from a stepdown transformer (240–115 V AC) in the power unit is taken to the ES-100 tray via connector J4 (Fig. 11) at the rear of that tray.

Normally the FM recording amplifiers provide current outputs for the recording heads in the tape machine. In this instance the head outputs taken to connectors J5 and J6 at the rear of the tray, need to be terminated with resistors for proper operation of the amplifiers. For convenience the resistors have been mounted in the power unit. Outputs of suitable level to be taken to the line drivers, are made available on the front panel of that unit at jacks J0H and J0L, etc. These jacks may be used to interconnect the outputs of appropriate batches of FM recording amplifiers with a line driver, when these amplifiers are plugged into appropriate slots in the ES-100 electronics tray. Connections to the front panel mounted jacks are as tabulated below:

Output designation (Fig. 11)	Ampex ES-100 edge connector* from which output is derived	Jack on front panel of power unit to which output is connected
0-Lo 0-Hi	J200 (Aux A)	J0L J0H
1-Lo 1-Hi	J201 (CH.1)	J1L J1H
2-Lo 2-Hi	J202 (CH.2)	J2L J2H
3-Lo 3-Hi	J203 (CH.3)	J3L J3H
4-Lo 4-Hi	J204 (CH.4)	J4L J4H
5-Lo 5-Hi	J205 (CH.5)	J5L J5H
6-Lo 6-Hi	J206 (CH.6)	J6L J6H

Output designation (Fig. 11)	Ampex ES-100 edge connector* from which output is derived	Jack on front panel of power unit to which output is connected
7-Lo 7-Hi	J207 (CH.7)	J7L J7H
8-Lo 8-Hi	J208 (CH.8)	J8L J8H
9-Lo 9-Hi	J209 (CH.9)	J9L J9H
10-Lo 10-Hi	J210 (CH.10)	J10L J10H
11-Lo 11-Hi	J211 (CH.11)	J11L J11H
12-Lo 12-Hi	J212 (CH.12)	J12L J12H
13-Lo 13-Hi	J213 (CH.13)	J13L J13H
14-Lo 14-Hi	J214 (CH.14)	J14L J14H
15-Lo 15-Hi	J215 (Aux B)	J15L J15H
+12 V COM −12 V		J16P J16L J16N

* Refer to Dwg. No. 69165H provided by Ampex.[7]

Regulated outputs (±12 V) are also made available at front panel mounted jacks as indicated in the above table and Figure 11.

Inputs to the power unit are taken to connectiors J1, J2 and J3 (Fig. 11) mounted on the rear of that unit. Interconnections between J1, J2 and J3 on the power unit, and J4, J5 and J6 respectively on the Ampex ES-100 electronics tray, are accomplished with the cables detailed below.

Cable reference	Interconnects
CBL.1	J1 on power unit with J4 on ES-100 electronics tray
CBL.2	J2 on power unit with J5 on ES-100 electronics tray
CBL.3	J3 on power unit with J6 on ES-100 electronics tray

Interconnection details for these cables are given below.

(i) CBL.1 Interconnections

CBL.1 connects P4 (mates with J4 on ES-100 electronics tray) to P1 (mates with J1 on power unit).

Interconnections		Signal Description
Pin of P4*	Pin of P1	
H	A	115 V—Line 1
J	B	115 V—Line 2
R	D	CH.0—Hi
M	E	CH.0—Lo

* Pins N and P of P4 are joined together, and similarly pins K and L of P4 are joined together at the rear of the P4 connector.

(ii) CBL.2 Interconnections

CBL.2 connects P5 (mates with J5 on ES-100 electronics tray) to P2 (mates with J2 on power unit).

Interconnections		Signal Description
Pin of P5	Pin of P2	
D	1	CH.13—Hi
J	2	CH.13—Lo
BB	3	CH.11—Shd
B	4	CH.9—Hi
F	5	CH.9—Lo
AA	6	CH.7—Shd
C	7	CH.5—Hi
H	8	CH.5—Lo
CC	9	CH.3—Shd
A	10	CH.1—Hi
E	11	CH.1—Lo
X	12	COM
	13	No connection
DD	14	CH.13—Shd
L	15	CH.11—Hi
R	16	CH.11—Lo
W	17	CH.9—Shd
M	18	CH.7—Hi
S	19	CH.7—Lo
T	20	CH.5—Shd
K	21	CH.3—Hi
P	22	CH.3—Lo
N	23	CH.1—Shd
U	24	−12 V
Y	25	+12 V

(iii) CBL.3 Interconnections

CBL.3 connects P6 (mates with J6 on ES-100 electronics tray) to P3 (mates with J3 on power unit).

Interconnections		Signal description
Pin of P6	Pin of P3	
D	1	CH.14—Hi
J	2	CH.14—Lo
BB	3	CH.12—Shd
B	4	CH.10—Hi
F	5	CH.10—Lo
AA	6	CH.8—Shd
C	7	CH.6—Hi
H	8	CH.6—Lo
CC	9	CH.4—Shd
A	10	CH.2—Hi
E	11	CH.2—Lo
Z	12	CH.15—Lo
V	13	CH.15—Hi
DD	14	CH.14—Shd
L	15	CH.12—Hi
R	16	CH.12—Lo
W	17	CH.10—Shd
M	18	CH.8—Hi
S	19	CH.8—Lo
T	20	CH.6—Shd
K	21	CH.4—Hi
P	22	CH.4—Lo
N	23	CH.2—Shd
	24	No connection
	25	No connection

The 240 V AC mains input connector J17 (Fig. 11) is mounted on the rear panel of the power unit.

Components (Fig. 11) for the power unit are listed in the following table. Information on component identification (legend) is given in Appendix 4.

Components for power unit (incorporated in remote data transmitter):

Legend	Description
F1	Fuse, Belling Lee type L575 holder, Belling Lee type L562/1A fuse link.
S1	Switch, toggle, double pole, changeover, Alco MST215N.
LP1	Indicator lamp, neon, Telite, 0·3 W, 240 V, FP7/CD/NR, red.
R1→R16	Resistor, fixed, carbon, 100 ohm, Philips type CR16, 0·125 W, 5%.
T1	Transformer, stepdown, 250 V primary, 115 V secondary, 100 W, A & R Transformers Pty. Ltd. Part No. 2164.
PCB1, PCB2	Printed circuit board, special.
J1	Socket, chassis, Cannon type KPT02E10-6S.
J2, J3	Plug, 25-pin, sub-miniature, Cannon type DB-25P.
J0L→J16L	Jack, Johnson Co., Cat. No. 105-0603-001, black.
J0H→J15H	Jack, Johnson Co., Cat. No. 105-0601-001, white.
J16N	Jack, Johnson Co., Cat. No. 105-0610-001, blue.
J16P	Jack, Johnson Co., Cat. No. 105-0602-001, red.
J17	Plug, chassis, Cannon type XLR-LNE-32.
P1	Socket, cable, Cannon type KPT06A10-6S.
P2, P3	Socket, 25-pin, sub-miniature, Cannon type DB-25S.
P4	Socket, cable, Winchester, 26 contact, type XMRE26S-GIA500.
P5, P6	Plug, cable, Winchester, 26 contact, type XMRE26P-GIC500.

APPENDIX 4

Component Lists

The following tables list the components used in various circuits detailed in this report. Components used on these circuits have been given an identification label (or legend) consisting of a letter prefix followed by a number. The letter prefix identifies the class of component as indicated in the following table:

Class of component	Letter prefix
Resistor	R
Capacitor	C
Transformer	T
Diode	CR
Transistor or Integrated Circuit	Q
Switch	S
Cable Mounted Connector	P
Chassis Mounted Connector	J
Fuse	F
Printed Circuit Board	PCB
Terminal	TM
Headset	HS
Battery	B
Battery Holder	BH
Wire or Cable	W

The number following the letter prefix identifies the particular component of the specified class.

Resistance and capacitance values given in the component lists (and also marked on the circuit diagrams) are respectively in ohm and picofarad (where $K = 10^3$ and $M = 10^6$). Thus a capacitance value designated 4·7 K means 4700 picofarad and a capacitance designated 22 M means 22 microfarad.

4.1 Components for Line Driver

Legend	Value	Description
R1	56	Resistor, fixed, glass-tin-oxide, style RFG5-F, Electrosil.
R2	56	As for R1
R3	470K	As for R1
R4	33K	As for R1.
R5	15K	As for R1.
R6	100	As for R1.
R7	3·9K	As for R1.
R8	47K	As for R1.
R9	39K	As for R1.
R10	3·9K	As for R1.
R11	22	As for R1.
R12	22	As for R1.
R13	100	As for R1.
R14	100	As for R1.
C1	56K	Capacitor, fixed, ceramic, Vitramon type VK33BW473.
C2	22M	Capacitor, fixed, electrolytic, tantalum, 16VW, ITT TAG series.
C3	22M	As for C2.
C4	10K	Capacitor, fixed, ceramic, Vitramon type VK33BW103.
C5	10K	As for C4.
C6	56K	As for C1.
C7	1K	Capacitor, fixed, ceramic, Vitramon type VK33BW102
Q1		Transistor, silicon, NPN, type AY1103.
Q2		Transistor, silicon, PNP, type AY1104.
Q3		Transistor, silicon, NPN, type AY1103.
T1		Transformer, Mullard Vinkor type LA2517 core, primary (wound first) 460 turns 38B&S, transformer case connected to finish of primary winding, secondary 92 turns +92 turns 34 B&S, layer of insulation between primary and secondary.
J1H to J8H		Jack, for 0·080 inch dia. plug, E. F. Johnson Co. Cat .No. 105-0851-001, white.
J1L to J8L		As for J1H to J8H but Cat. No. 105-0853-001, black.
J9		Plug, 25 pin, sub-miniature, Cannon type DB-25P.

4.2 Components for Line Receiver

Legend	Value	Description
R1	100	Resistor, fixed, glass-tin-oxide, style RFG5-F, Electrosil.
R2	100	As for R1.
R3	10K	As for R1.
R4	10K	As for R1.
R5	1·2K	As for R1.
R6	91	As for R1.
R7	91	As for R1.
C1	100K	Capacitor, fixed, ceramic, Vitramon type CK06BX104.
C2	100K	As for C1.
C3	10K	Capacitor, fixed, ceramic, Vitramon type VK33BW103.
C4	10K	As for C3.
C5	22M	Capacitor, fixed, electrolytic, tantalum, 16VW, ITT TAG series.
C6	22M	As for C6.
C7	100K	As for C1.
Q1		Integrated circuit, voltage comparator, type LM311D, 14 pin dual-in-line package, mount in socket.
J1H to J8H		Jack, for 0·080 inch dia. plug, E. F. Johnson Co., Cat. No. 105-0857-001, yellow:
J1L to J8L		As for J1H to J8H but Cat. No. 105-0853-001, black.
J9		Plug, 25 pin, sub-miniature, Cannon type DB-25P.

4.3 Components for Frequency Divider

Legend	Value	Description
R1	100	Resistor, fixed, glass-tin-oxide, style RFG5-F, Electrosil.
R2	10	As for R1.
R3	10	As for R1.
R4	100	As for R1.
R5	10K	As for R1.
R6	10K	As for R1.
R7	10K	As for R1.
R8	10K	As for R1.
R9	1·8K	As for R1.
R10	1·8K	As for R1.
R11	1·2K	As for R1.
R12	1·2K	As for R1.
R13	4·7K	As for R1.
R14	10K	As for R1.
R15	10K	As for R1.
R16	4·7K	As for R1.
R17	1·2K	As for R1.
R18	1·2K	As for R1.
R19	1K	As for R1.
R20	390	As for R1.
R21	33	As for R1.

Legend	Value	Description
C1	100K	Capacitor, fixed, ceramic, Vitramon type VK33BX104.
C2	100K	As for C1.
C3	100K	As for C1.
C4	100K	As for C1.
C5	330	Capacitor, fixed, ceramic, Vitramon type VK23BX331.
C6	330	As for C5.
C7	100K	As for C1.
C8	100	Capacitor, fixed, ceramic, Vitramon type VK23BX101.
C9	100	As for C8.
C10	100K	As for C1.
C11	100K	As for C1.
C12	100K	As for C1.
C13	100K	As for C1.
C14	6·8M	Capacitor, fixed, electrolytic, tantalum, Sprague type 196D, 35VW.
C15	6·8M	As for C14.
C16	10K	Capacitor, fixed, ceramic, Vitramon type VK33BX103.
C17	10K	As for C16.
CR1		Diode, silicon, Zener, 5·1 V, BZY88.
CR2		As for CR1.
Q1		Integrated circuit, voltage comparator, type LM311H, 8-pin T05 package, mount in socket.
Q2		As for Q1.
Q3		Integrated circuit, 4-bit binary counter, type SN74L93N, 14-pin dual-in-line package.
Q4		As for Q3.
Q5		Integrated circuit, dual D-type edge triggered flip flop, type SN74L74N, 14 pin dual-in-line package.
Q6		Transistor, silicon, PNP, type 2N4250.
Q7		As for Q6.
S1		Switch, single pole, 8-position (but 6 positions only used), ERG type DIL switch 16, 16-pin dual-in-line package.
S2		As for S1.
J1H to J8H		Jack, for 0·080 inch dia. plug, E. F. Johnson Co., Cat. No. 105-0857-001, yellow.
J1L to J8L		As for J1H to J8H but Cat. No. 105-0853-001, black.
J9		Plug, 25 pin, sub-miniature, Cannon type DB-25P.

4.4 Components for NRZ Digital Recording Amplifier

Legend	Value	Description
R1	10	Resistor, fixed, glass-tin-oxide, style RFG5-F, Electrosil.
R2	10	As for R1.
R3	10	As for R1.
R4	11K	As for R1.
R5	1·8K	As for R1.
R6	1·8K	As for R1.
R7	47K	As for R1.
R8	1K	As for R1.
R9	1K	As for R1.
R10	1K	As for R1.
R11	1K	As for R1.
R12	2·2K	As for R1.
R13	330	As for R1.
R14	820	As for R1.
R15	820	As for R1.
R16	470	Resistor, fixed, glass-tin-oxide, style C5, Electrosil.
R17	470	As for R16.
C1	22M	Capacitor, fixed, electrolytic, tantalum, 16VW, ITT TAG series.
C2	22M	As for C1.
C3	100K	Capacitor, fixed, ceramic, Vitramon type CK06BX104.
C4	100K	As for C2.
CR1		Diode, silicon, type OA202.
CR2		As for CR1.
Q1		Transistor, silicon, NPN, type AY6101.
Q2		Transistor, silicon, PNP, type AY6102.
Q3		As for Q2.
Q4		As for Q1.
Q5		As for Q2.
TP1		Test point, white, Amp Part No. 3-582118-9.
TP2		Test point, black, Amp Part No. 3-582118-4.
TP3		Test point, yellow, Amp Part No. 3-582118-0.
J1		Plug, chassis mounted, Kings type KM-71-04.

4.5 Components for Headset Intercom

Legend	Description
R1	Resistor, fixed, 330 ohm, glass-tin-oxide, style RFG5-F, Electrosil.
T1	Transformer, audio, miniature, multi-ratio, Fortiphone type MM1B, turns ratio as indicated in the following table:
J1	Socket, chassis, sub-miniature, Cannon DE-9S.
J2	As for J1.
J3	Socket, Oxley, miniature, red, type 60P/156.
J4	Socket, Oxley, miniature, black, type 60P/156
TM1	Terminal, yellow, Acme Part No. C42-01.
TM2	Terminal, black, Acme Part No. C42-01.
B1 to B4	Battery, dry, 1·5 V, size AA, Ever Ready type 1015.
BH	Battery holder, National, holds four 1015 cells. (Battery harness adaptor with leads also included.)
HS	Headset, STC, type 4408A.
W1	Cable, connecting, STC, type 04/030.
P1	Plug, cable, sub-miniature, Cannon DE-9P.

Winding	Relative turns
BC	1
C, D	1
VZ	1

APPENDIX 5

Master Printed Circuit Board Interconnections

The master printed circuit board is a general purpose board which will accommodate:

(i) eight line driver units (Fig. 13); or
(ii) eight line receiver units (Fig. 17); or
(iii) four dual frequency divider units (Fig. 20).

Each of these units is fitted with pins which are soldered directly to the master board.

The master board includes 22 edge contacts which mate with the 22 pin edge connectors contained in the Ampex ES-100 electronics tray. A standard front panel (Ampex Part No. 69225-11) and a module shield assembly (Ampex Part No. 69162-11) are attached to the master board so that a module which will plug directly into an Ampex ES-100 electronics tray results.

Power for the units (which are soldered to the master board) is derived from the 22 pin mating edge connector in the electronics tray. All inputs and outputs are accessible from the front panel which is specially drilled, labelled and fitted with appropriate connectors. Front panels for each of the three assemblies (i)–(iii) as indicated above are identical (apart from the name). In the case of the line drivers eight front panel mounted jacks J1H–J8H (Appendix 4) and associated "common" jacks J1L–J8L allow the inputs to be coupled to the line drivers, and a 25 pin connector J9 (Appendix 4) allows the outputs to be coupled to the twisted pair line via a Transmission Line Adaptor (Appendix 2.2). For the line receivers the arrangement is reversed (inputs enter via J9 and the outputs are taken via the jacks). For the frequency dividers the inputs and outputs conform to the same arrangement as used for the line receivers.

Basically the master board transfers signal inputs, signal outputs and power supplies to locations compatible with the "solder-in" units. In the master board layout of Figure 15, eight equal "areas" are specified as AR1–AR8. For each of these areas connection points 1–7 (and also 2* which is internally connected to point 2 on the master board) are indicated. When any of the units is to be connected to the master board, input, output and power supply pins are soldered to the corresponding points on the master board.

For convenience the line drivers are designated LD1–LD8, and the line receivers as LR1–LR8. Similarly the dual frequency divider units are designated as FD1–FD4.

Each of the line drivers (LD1–LD8) is allocated an area AR1–AR8 respectively, and similarly for the line receivers. In the case of the frequency dividers (dual) two areas are required for each unit. For FD1 areas AR1 and AR2 are allocated; for FD2 areas AR3 and AR4, and so on. Terminal points marked on the frequency divider circuit (Fig. 20) are identified as "3a" and "3b", etc. Points with an "a" identifier are terminated in an "odd" area (AR1–AR7) and those with a "b" identifier are terminated in the corresponding "even" area (AR2–AR8).

Inputs and outputs from the units are transferred to points in close proximity to the front panel connectors via the master printed circuit. These points are designated X1–X16 and Y1–Y24 respectively as indicated in the master board layout of Figure 15. They are connected to the front panel jacks (J1H–J8H and J1L–J8L) and to the 25-pin plug (J9) via flexible wires. Details of input and output connections from the front panel, via the printed circuit tracks on the master board, to the various "solder-in" units are given in the following table.

Front panel connection	Flexible wire connection to	Master board track connection to	Connections to various units		
			Line driver	Line receiver	Frequency divider
J1-H	X1	AR1-1	LD1-1 (input)	LR1-1 (output)	FD1-1a (output 1)
J1-L	X2	AR1-2 (2*)	LD1-2 (input com.)	LR1-2 (output com.)	FD1-2a* (output 1 com.)
J2-H	X3	AR2-1	LD2-1 (input)	LR2-1 (output)	FD1-1b (output 2)
J2-L	X4	AR2-2 (2*)	LD2-2 (input com.)	LR2-2 (output com.)	FD1-2b* (output 2 com.)
J3-H	X5	AR3-1	LD3-1 (input)	LR3-1 (output)	FD2-1a (output 3)
J3-L	X6	AR3-2 (2*)	LD3-2 (input com.)	LR3-2 (output com.)	FD2-2a* (output 3 com.)
J4-H	X7	AR4-1	LD4-1 (input)	LR4-1 (output)	FD2-1b (output 4)
J4-L	X8	AR4-2 (2*)	LD4-2 (input com.)	LR4-2 (output com.)	FD2-2b* (output 4 com.)
J5-H	X9	AR5-1	LD5-1 (input)	LR5-1 (output)	FD3-1a (output 5)
J5-L	X10	AR5-2 (2*)	LD5-2 (input com.)	LR5-2 (output com.)	FD3-2a* (output 5 com.)
J6-H	X11	AR6-1	LD6-1 (input)	LR6-1 (output)	FD3-1b (output 6)
J6-L	X12	AR6-2 (2*)	LD6-2 (input com.)	LR6-2 (output com.)	FD3-2b* (output 6 com.)
J7-H	X13	AR7-1	LD7-1 (input)	LR7-1 (output)	FD4-1a (output 7)
J7-L	X14	AR7-2 (2*)	LD7-2 (input com.)	LR7-2 (output com.)	FD4-2a* (output 7 com.)
J8-H	X15	AR8-1	LD8-1 (input)	LR8-1 (output)	FD4-1b (oututp 8)
J8-L	X16	AR8-2 (2*)	LD8-2 (input com.)	LR8-2 (output com.)	FD4-2b* (output 8 com.)
J9-1	Y1	AR1-3	LD1-3 (output 1)	LR1-3 (input 1)	FD1-3a (input 1)
J9-2	Y12	AR1-5	LD1-5 (output 2)	LR1-5 (input 2)	FD1-5a (input 1 com.)
J9-3	Y8	AR2-4	LD2-4 (output com.)	LR2-4 (input com.)	
J9-4	Y7	AR3-3	LD3-3 (output 1)	LR3-3 (input 1)	FD2-3a (input 3)
J9-5	Y6	AR3-5	LD3-5 (output 2)	LR3-5 (input 2)	FD2-5a (input 3 com.)
J9-6	Y2	AR4-4	LD4-4 (output com.)	LR4-4 (input com.)	
J9-7	Y14	AR5-3	LD5-3 (output 1)	LR5-3 (input 1)	FD3-3a (input 5)
J9-8	Y16	AR5-5	LD5-5 (output 2)	LR5-5 (input 2)	FD3-5a (input 5 com.)
J9-9	Y17	AR6-4	LD6-4 (output com.)	LR6-4 (input com.)	

Front panel connection	Flexible wire connection to	Master board track connection to	Connections to various units		
			Line Driver	Line receiver	Frequency divider
J9-10	Y22	AR7-3	LD7-3 (output 1)	LR7-3 (input 1)	FD4-3a (input 7)
J9-11	Y21	AR7-5	LD7-5 (output 2)	LR7-5 (input 2)	FD4-5a (input 7 com.)
J9-12	Y23	AR8-4	LD8-4 (output com.)	LR8-4 (input com.)	
J9-13	N.C.*1				
J9-14	Y11	AR1-4	LD1-4 (output com.)	LR1-4 (input com.)	
J9-15	Y4	AR2-3	LD2-3 (output 1)	LR2-3 (input 1)	FD1-3b (input 2)
J9-16	Y9	AR2-5	LD2-5 (output 2)	LR2-5 (input 2)	FD1-5b (input 2 com.)
J9-17	Y5	AR3-4	LD3-4 (output com.)	LR3-4 (input com.)	
J9-18	Y10	AR4-3	LD4-3 (output 1)	LR4-3 (input 1)	FD2-3b (input 4)
J9-19	Y3	AR4-5	LD4-5 (output 2)	LR4-5 (input 2)	FD2-5b (input 4 com.)
J9-20	Y15	AR5-4	LD5-4 (output com.)	LR5-4 (input com.)	
J9-21	Y19	AR6-3	LD6-3 (output 1)	LR6-3 (input 1)	FD3-6b (input 6)
J9-22	Y18	AR6-5	LD6-5 (output 2)	LR6-5 (input 2)	FD3-5b (input 6 com.)
J9-23	Y20	AR7-4	LD7-4 (output com.)	LR7-4 (input com.)	
J9-24	Y13	AR8-3	LD8-3 (output 1)	LR8-3 (input 1)	FD4-3b (input 8)
J9-25	Y24	AR8-5	LD8-5 (output 2)	LR8-5 (input 2)	FD4-5b (input 8 com.)

*1 No connection.

Details of power supply connections from the printed circuit board edge connector are given in the following table.

Supply line	Derived from printed circuit board edge pin	Master board track connection to	Connections to various units		
			Line driver	Line receiver	Frequency divider
+12 V	10	AR1-6, AR2-6, AR3-6, AR4-6, AR5-6, AR6-6, AR7-6, AR8-6	LD1-6, LD2-6, LD3-6, LD4-6, LD5-6, LD6-6, LD7-6, LD8-6	LR1-6, LR2-6, LR3-6, LR4-6, LR5-6, LR6-6, LR7-6, LR8-6	FD1-6a, FD2-6a, FD3-6a, FD4-6a
−12 V	9	AR1-7, AR2-7, AR3-7, AR4-7, AR5-7, AR6-7, AR7-7, AR8-7	LD1-7, LD2-7, LD3-7, LD4-7, LD5-7, LD6-7, LD7-7, LD8-7	LR1-7, LR2-7, LR3-7, LR4-7, LR5-7, LR6-7, LR7-7, LR8-7	FD1-7a, FD2-7a, FD3-7a, FD4-7a
COM	3, 13, 21	AR1-2, AR2-2, AR3-2, AR4-2, AR5-2, AR6-2, AR7-2, AR8-2	LD1-2, LD2-2, LD3-2, LD4-2, LD5-2, LD6-2, LD7-2, LD8-2	LR1-2, LR2-2, LR3-2, LR4-2, LR5-2, LR6-2, LR7-2, LR8-2	FD1-2a*, FD1-2b*, FD2-2a*, FD2-2b*, FD3-2a*, FD3-2b*, FD4-2a*, FD4-2b*

In the case of the line drivers (Fig. 13) transformer T1 and resistors R13 and R14 are soldered directly to the master board.

APPENDIX 6

Hardware Configuration for Low Pass Filtering of Recorded Data without the Production of a Tape Copy

The following table gives details of the hardware required and the manner in which it must be interconnected for low pass filtering of recorded data (without the production of an intermediate tape copy). A circle with enclosed number at the top left hand corner of the hardware block (Fig. 23) allows identification of that item in the table.

Item ref. no.	Detail	Comments
1	Ampex Model FR1260 tape machine.	The machine is set to operate in the reproducing mode. To extract the required pre-amplifier outputs the cable from the pre-amplifier, which normally plugs into J5 at the rear of the Ampex ES-100 reproducing tray, is disconnected from J5. Interconnection with the frequency divider is achieved using a specially prepared cable (cable LL3 detailed in Appendix 7) which mates with the pre-amplifier cable.
2	Eight channel frequency divider (refer to Section 3.3 of text)	Hardware has been developed at ARL for this application. It is plugged directly into any spare slot in a standard Ampex ES-100 electronics tray, and is designed to operate from the supply rails provided. Frequency division factors of 2^0 to 2^5 may be independently selected via six position switches associated with each channel.
3	Attenuator	A simple eight channel attenuator unit (Figs. 8*a* and 23) has been manufactured.
4	Ampex FM reproducing amplifier (Cat. No. 69108).	An appropriate plug-in filter is selected and the card is aligned for the modulated carrier resulting after frequency division. Inputs derived from the attenuator are coupled to the TP3 inputs (internally connected to J2 in this case) accessible from the front panels of the reproducing amplifiers.

APPENDIX 7

Special Cables for Hardware Interconnections

Details of cables manufactured specifically for interconnection of hardware referred to in this report are given in this section. Information on the heavy duty transmission line cable is given in Appendix 2.1 and that on cables used in the Remote Data Transmitter in Appendix 3.

Basically the cables may be divided into two classes:

(*a*) multi-conductor cables;

(*b*) single conductor "patch" cables.

For ease of identification the multi-conductor cables have been marked with a cable reference number (LL1, etc., where the "LL" identifier signifies that the cable is for use with the land line hardware).

Details on connectors and wire used in the various cables are given in the following tables. Subsequently such connectors and wire will be referred to via the identifiers defined in these tables.

Cable Connector Details

Identifier	Description
P1	Plug, cable mounted, 25 pin, sub-miniature, Cannon type DB-25P
P2	Socket, cable mounted, 25 pin, sub-miniature, Cannon type DB-25S
P3	Plug, cable mounted, sub-miniature, E. F. Johnson Co., Cat. No. 105-0777-001, yellow
P4	Plug, cable mounted, sub-miniature, E. F. Johnson Co., Cat. No. 105-0773-001, black
P5	Plug, cable mounted, Winchester, 26 contact, type XMRE26P-GIC500
P6	Socket, Winchester, 26 contact, type XMRE26S-G2C500
P7	Socket, sub-miniature, Cannon DE-9S
P8	Plug, sub-miniature, Cannon DE-9P
P9	Plug, cable mounted, sub-miniature, E. F. Johnson Co., Cat. No. 105-0771-001, white

Cable Wire Details

Identifier	Description
W1	Cable, twisted pair (black and white insulation respectively) shielded, Raychem type 44A1121-22-9-9
W2	Cable, single core, insulated, Raychem type 44A0111-22-9.
W3	Cable, 4 conductors, STC, type 04/030

(*a*) Multi-conductor Cables

(i) Cable LL1 (terminated with P1 and P2 connectors)

Cables of this type interconnect the line drivers or the line receivers to the Transmission Line Adaptor front panel connector J1 (Appendix 2.2). Wiring details are provided in the following table.

Interconnections		Signal description	Wire details*
Pin of P1	Pin of P2		
1	1	1—Hi	W1-1—White
2	2	1—Lo	W1-1—Black
3	3	2—Shd	W1-2—Shield
4	4	3—Hi	W1-3—White
5	5	3—Lo	W1-3—Black
6	6	4—Shd	W1-4—Shield
7	7	5—Hi	W1-5—White
8	8	5—Lo	W1-5—Black
9	9	6—Shd	W1-6—Shield
10	10	7—Hi	W1-7—White
11	11	7—Lo	W1-7—Black
12	12	8—Shd	W1-8—Shield
13	13	Ground	W2
14	14	1—Shd	W1-1—Shield
15	15	2—Hi	W1-2—White
16	16	2—Lo	W1-2—Black
17	17	3—Shd	W1-3—Shield
18	18	4—Hi	W1-4—White
19	19	4—Lo	W1-4—Black
20	20	5—Shd	W1-5—Shield
21	21	6—Hi	W1-6—White
22	22	6—Lo	W1-6—Black
23	23	7—Shd	W1-7—Shield
24	24	8—Hi	W1-8—White
25	25	8—Lo	W1-8—Black

* Individual wires in a W1 cable are indentified in the form W1-3—White, W1-3—Black and W1-3—Shield where the "3" is an individual cable reference number (differs for each individual cable within the composite cable).

(ii) Cable LL2 (terminated at one end with a P2 connector and at the other with eight P3 connectors)

A cable of this type interconnects the line receiver output and the frequency divider inputs. Wiring details are provided in the following table.

Interconnections			
Pin of P2	P3 connector pin	Signal description*	Wire details
1	P3-1	1—Hi	W3 (marked with "1" identifier)
2			
3			
4	P3-3	3—Hi	W3 (marked with "3" identifier)
5			
6			
7	P3-5	5—Hi	W3 (marked with "5" identifier)
8			
9			
10	P3-7	7—Hi	W3 (marked with "7" identifier)
11			
12			
13			
14			
15	P3-2	2—Hi	W3 (marked with "2" identifier)
16			
17			
18	P3-4	4—Hi	W3 (marked with "4" identifier)
19			
20			
21	P3-6	6—Hi	W3 (marked with "6" identifier)
22			
23			
24	P3-8	8—Hi	W3 (marked with "8" identifier)
25			

* No connections are made to the "Lo" signal inputs. In this instance it is assumed that, because of the high level signals involved, the return path through the common power supply will suffice.

(iii) Cable LL3 (a three connector harness which includes P2, P5 and P6 connectors)

This cable harness diverts the normal Ampex ES-100 pre-amplifier outputs to the frequency divider input (Section 3.3). All harness conductors are wired to the P6 connector which mates with the pre-amplifier cable (normally plugged into the J5 [Ampex description] input at the rear of the Ampex ES-100 reproducing electronics tray). Power only is connected to the P5 connector which is plugged into the J5 input to the ES-100 reproducing electronics tray. Pre-amplifier outputs only are coupled to the P2 connector which is connected to the frequency divider input.

Wiring details are provided in the following table.

Interconnections		Signal description	Wire details
Pin of P6	Pin of P2 or Pin of P5		
A	P2-1	1—Hi	W1-1—White
E	P2-2	1—Lo	W1-1—Black
N	P2-14	1—Shd	W1-1—Shield
K	P2-15	2—Hi	W1-2—White
P	P2-16	2—Lo	W1-2—Black
CC	P2-3	2—Shd	W1-2—Shield
C	P2-4	3—Hi	W1-3—White
H	P2-5	3—Lo	W1-3—Black
T	P2-17	3—Shd	W1-3—Shield
M	P2-18	4—Hi	W1-4—White
S	P2-19	4—Lo	W1-4—Black
AA	P2-6	4—Shd	W1-4—Shield
B	P2-7	5—Hi	W1-5—White
F	P2-8	5—Lo	W1-5—Black
W	P2-20	5—Shd	W1-5—Shield
L	P2-21	6—Hi	W1-6—White
R	P2-22	6—Lo	W1-6—Black
BB	P2-9	6—Shd	W1-6—Shield
D	P2-10	7—Hi	W1-7—White
J	P2-11	7—Lo	W1-7—Black
DD	P2-23	7—Shd	W1-7—Shield
U	P5-U	+12 V DC	W2
X	P5-X	COM	W2
Y	P5-Y	−12 DC	W2

(iv) Cable LL5 (terminated at one end with a P7 connector and at the other with a P8 connector)

Cables of this type are used as extensions for those wired to the headsets. Wiring details are provided in the following table.

Interconnections		Signal description	Wire details
Pin of P9	Pin of P10		
1	1	Earphone—in	W3—Green
5	5	Mouthpiece—in	W3—White
6	6	Earphone—out	W3—Red
9	9	Mouthpiece—out	W3—Blue

(*b*) Patch Cables

Cables of various lengths incorporating P3, P4 or P9 connectors have been manufactured. These cables are required for:

(i) coupling from FM reproducing amplifiers to the line driver;
(ii) coupling from FM recording amplifiers to the line driver;
(iii) coupling from the line receiver to FM recording amplifiers;
(iv) coupling from the frequency divider to FM recording amplifiers; and
(v) other applications.

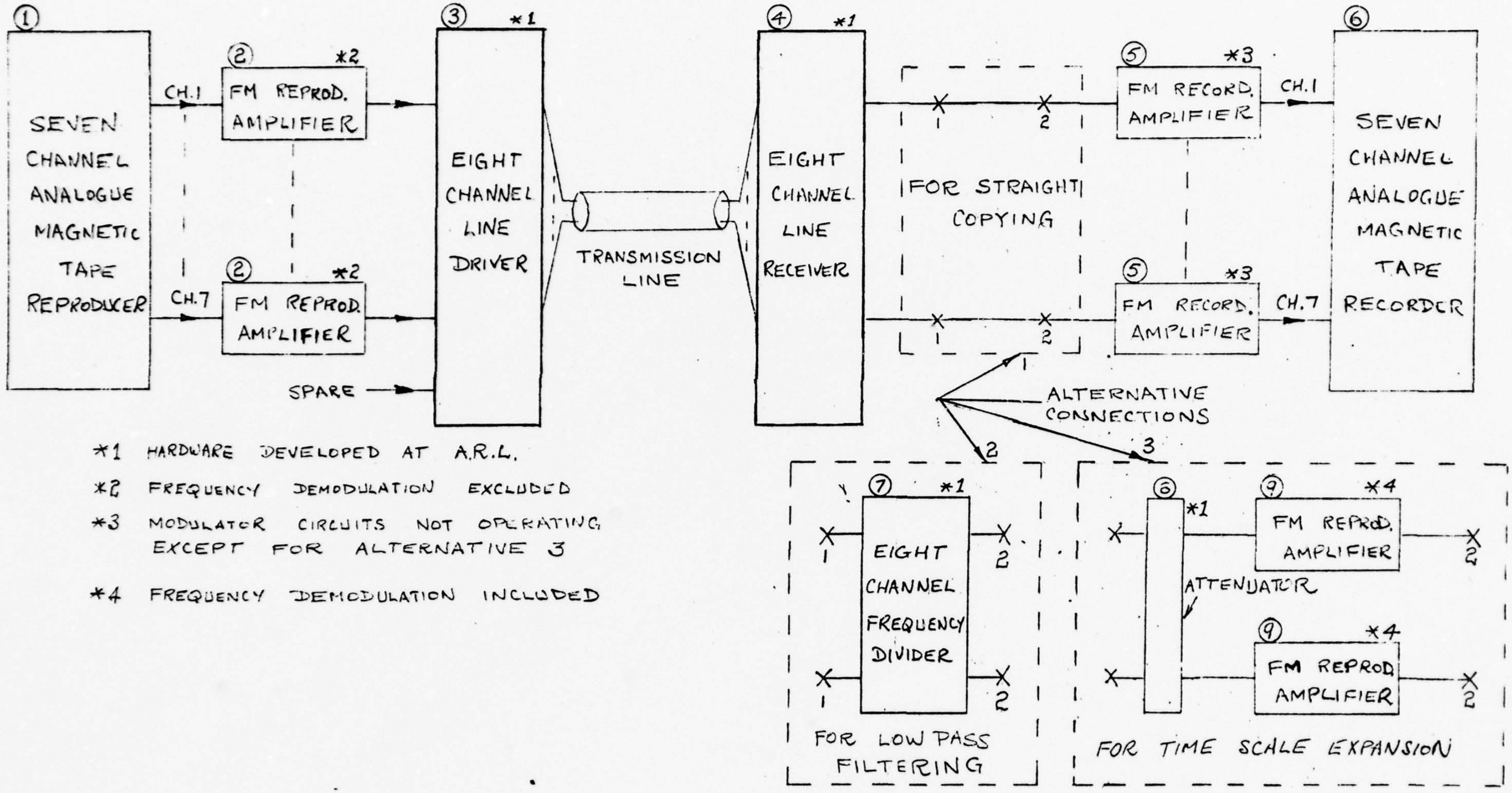


FIG. 1 SYSTEM FOR COPYING TAPES RECORDED USING FM TECHNIQUES

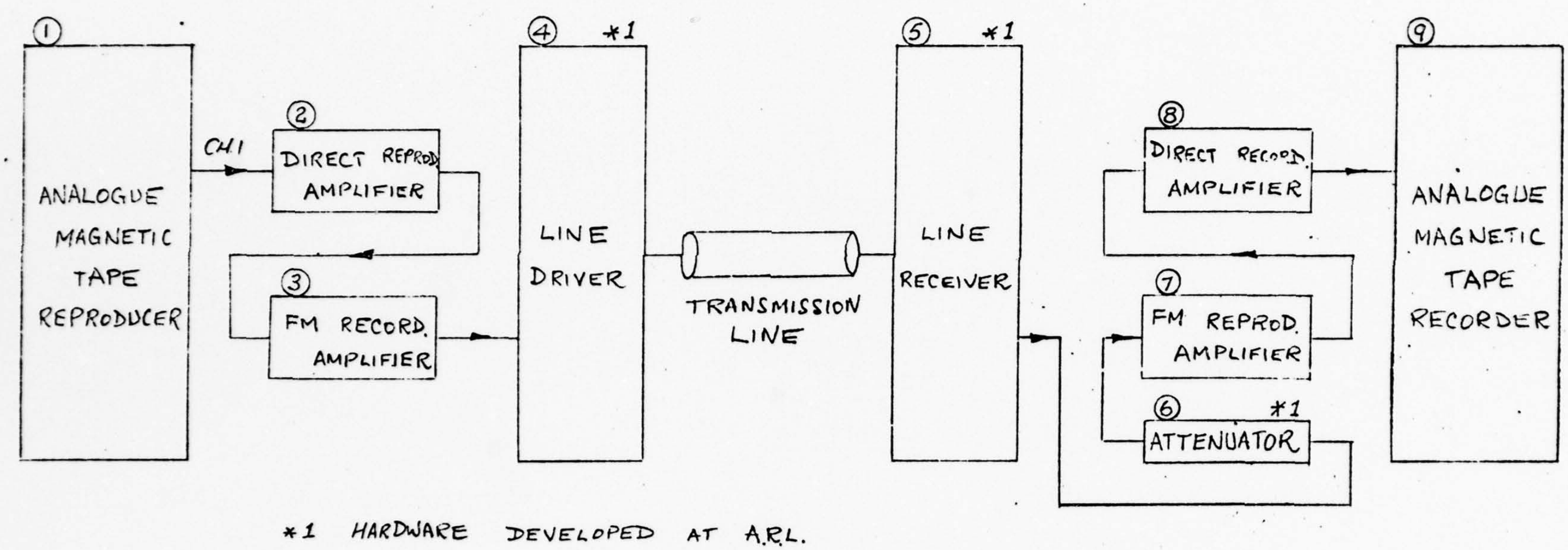


FIG. 2 COPYING OF SPEECH SIGNAL (OR OTHER SIGNAL WITH UP TO 20 kHz BANDWIDTH) RECORDED IN DIRECT MODE

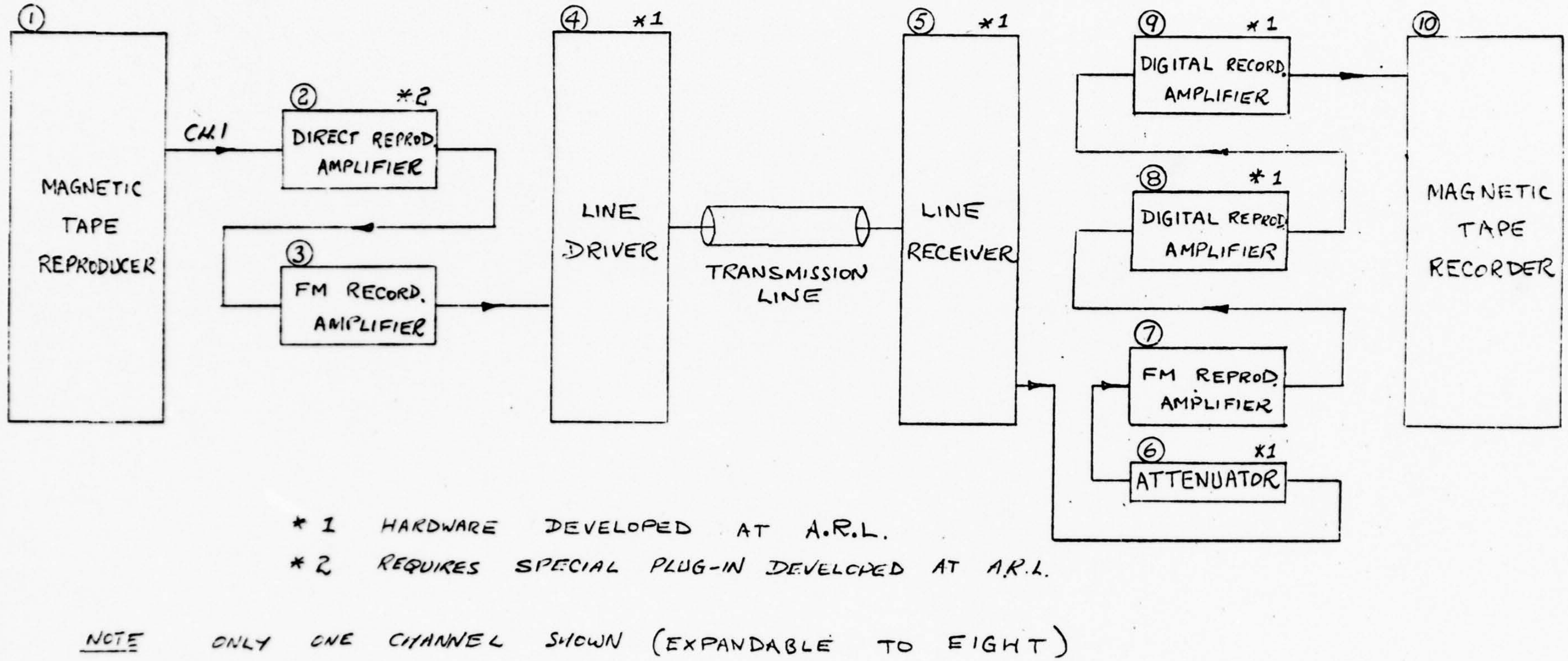


FIG. 3 COPYING OF TAPES RECORDED IN DIGITAL FORM

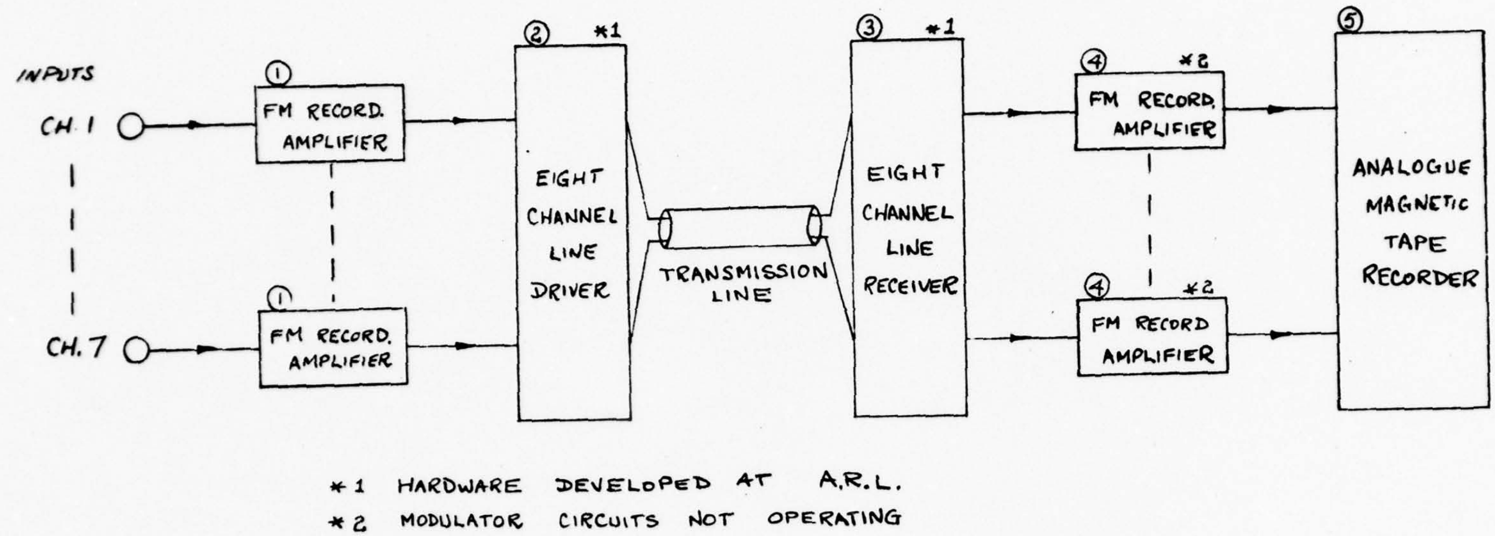


FIG. 4 TRANSMISSION OF ANALOGUE SIGNALS TO REMOTELY LOCATED TAPE RECORDER

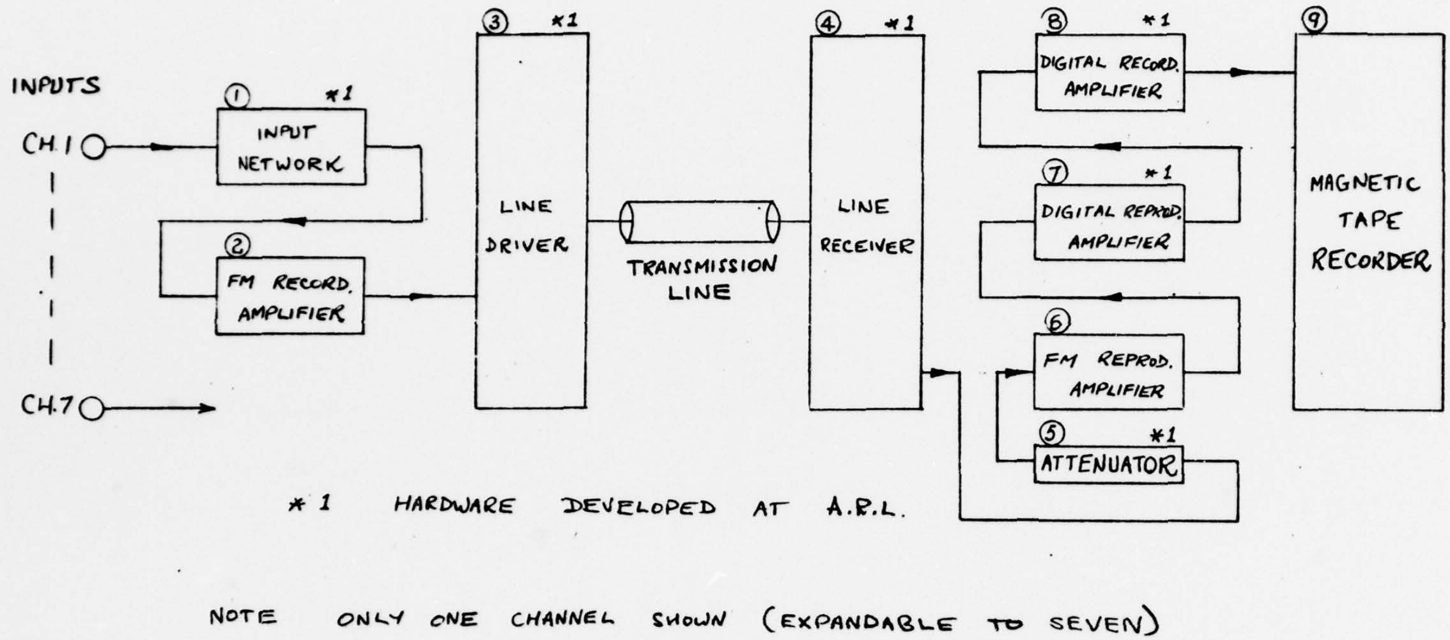
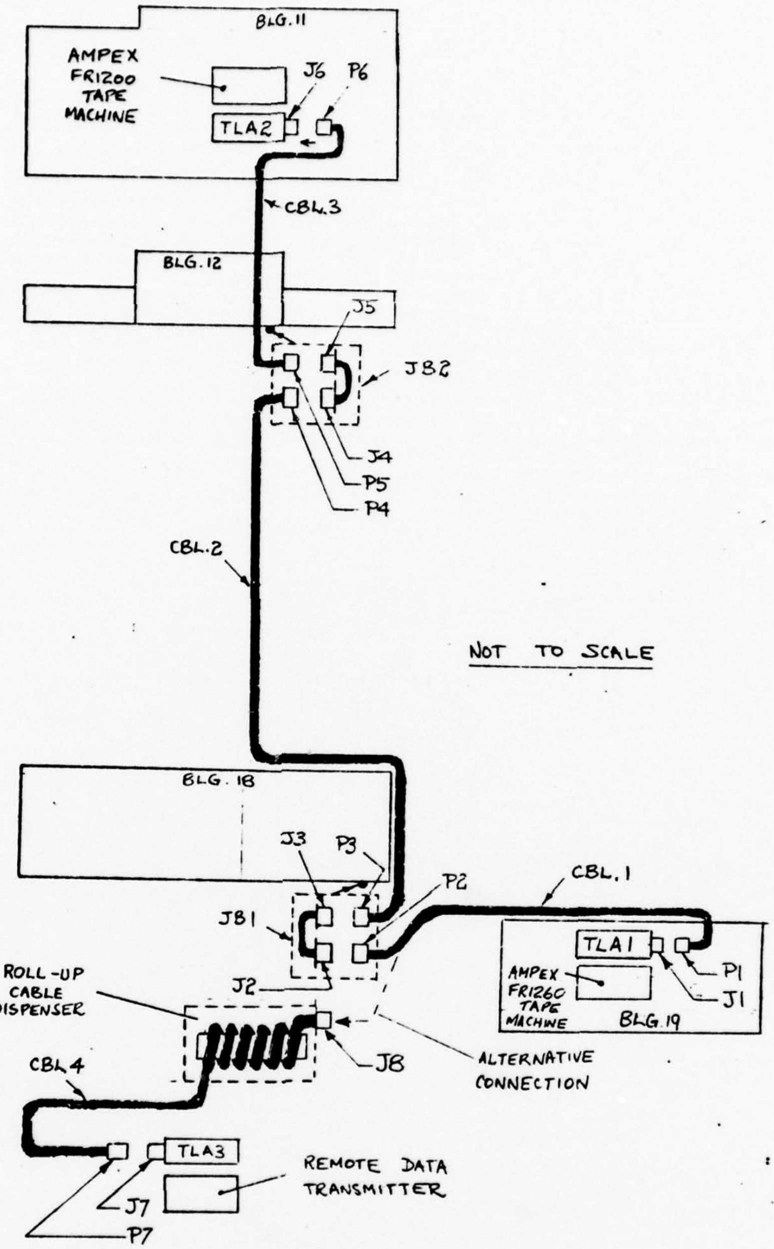


FIG. 5 TRANSMISSION OF DIGITAL SIGNALS TO REMOTELY LOCATED TAPE RECORDER



MEANING OF SYMBOLS

TLA	–	TRANSMISSION LINE ADAPTOR
JB	–	JUNCTION BOX
CBL	–	CABLE
P	–	CABLE MOUNTED CONNECTOR
J	–	CHASSIS MOUNTED CONNECTOR
BLG	–	BUILDING

FOR MORE DETAILS REFER TO APPENDIX 2

FIG. 6 GENERAL DETAILS ON TRANSMISSION LINE INSTALLATION

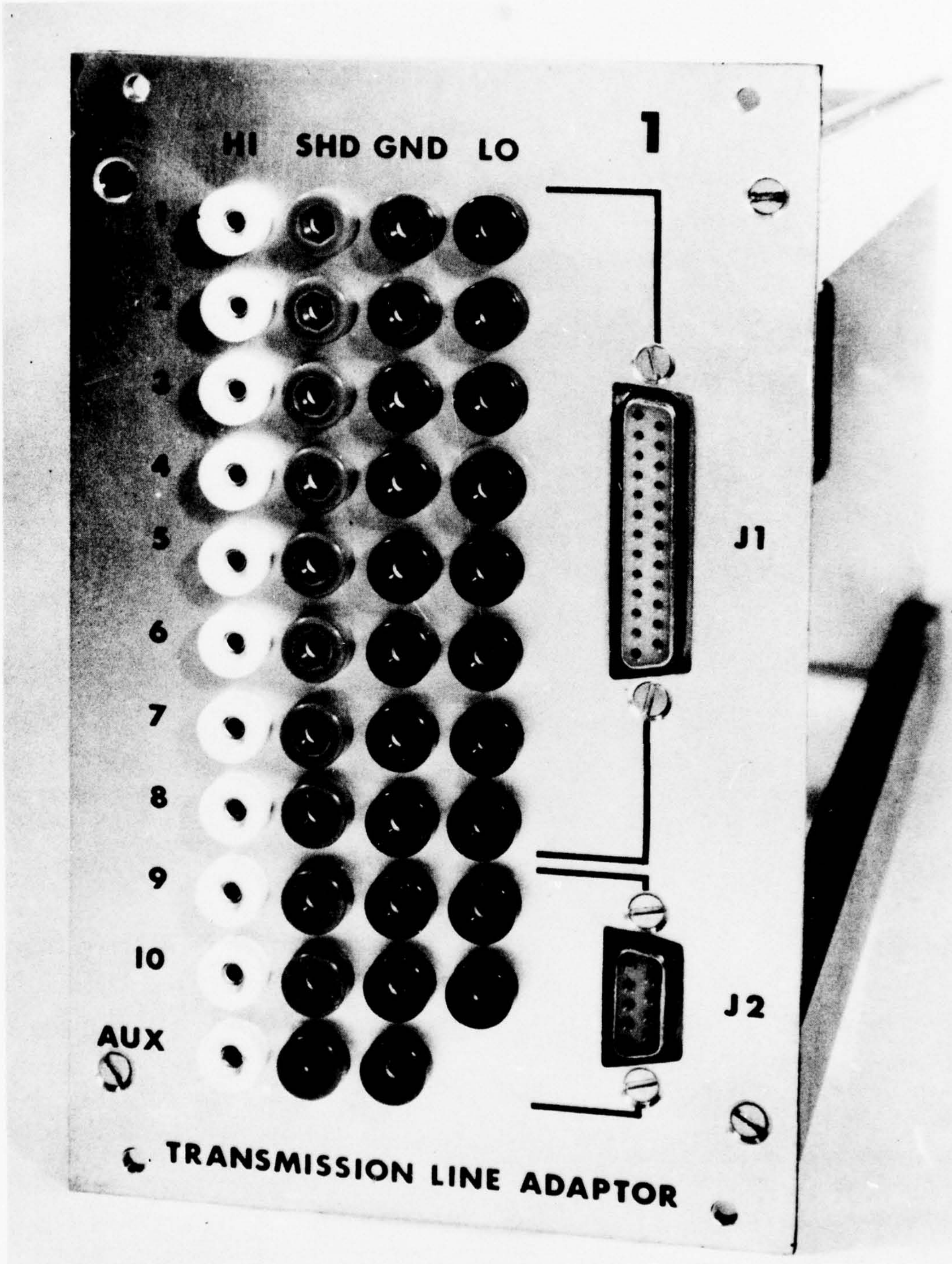


FIG. 7 PHOTOGRAPH OF TRANSMISSION LINE ADAPTOR

FIG. 8a PHOTOGRAPH OF ATTENUATOR

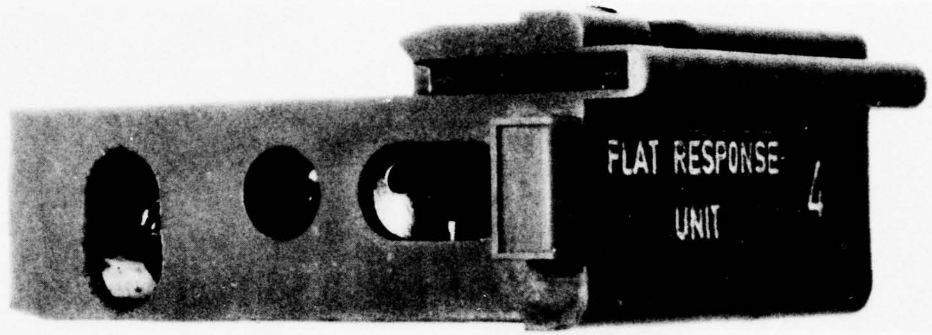


FIG. 8b PHOTOGRAPH OF FLAT FREQUENCY RESPONSE PLUG-IN

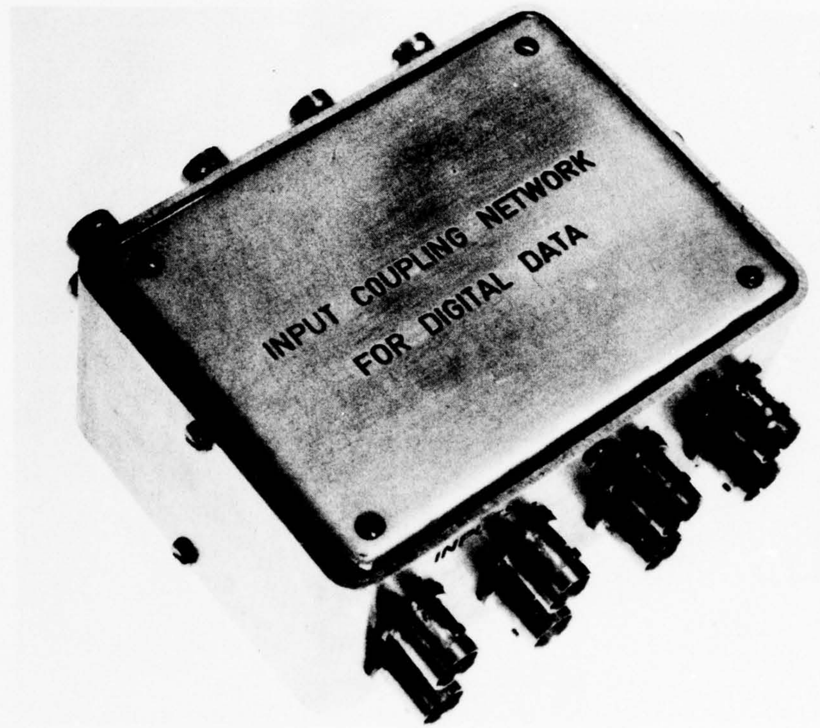


FIG. 8c PHOTOGRAPH OF INPUT COUPLING NETWORK

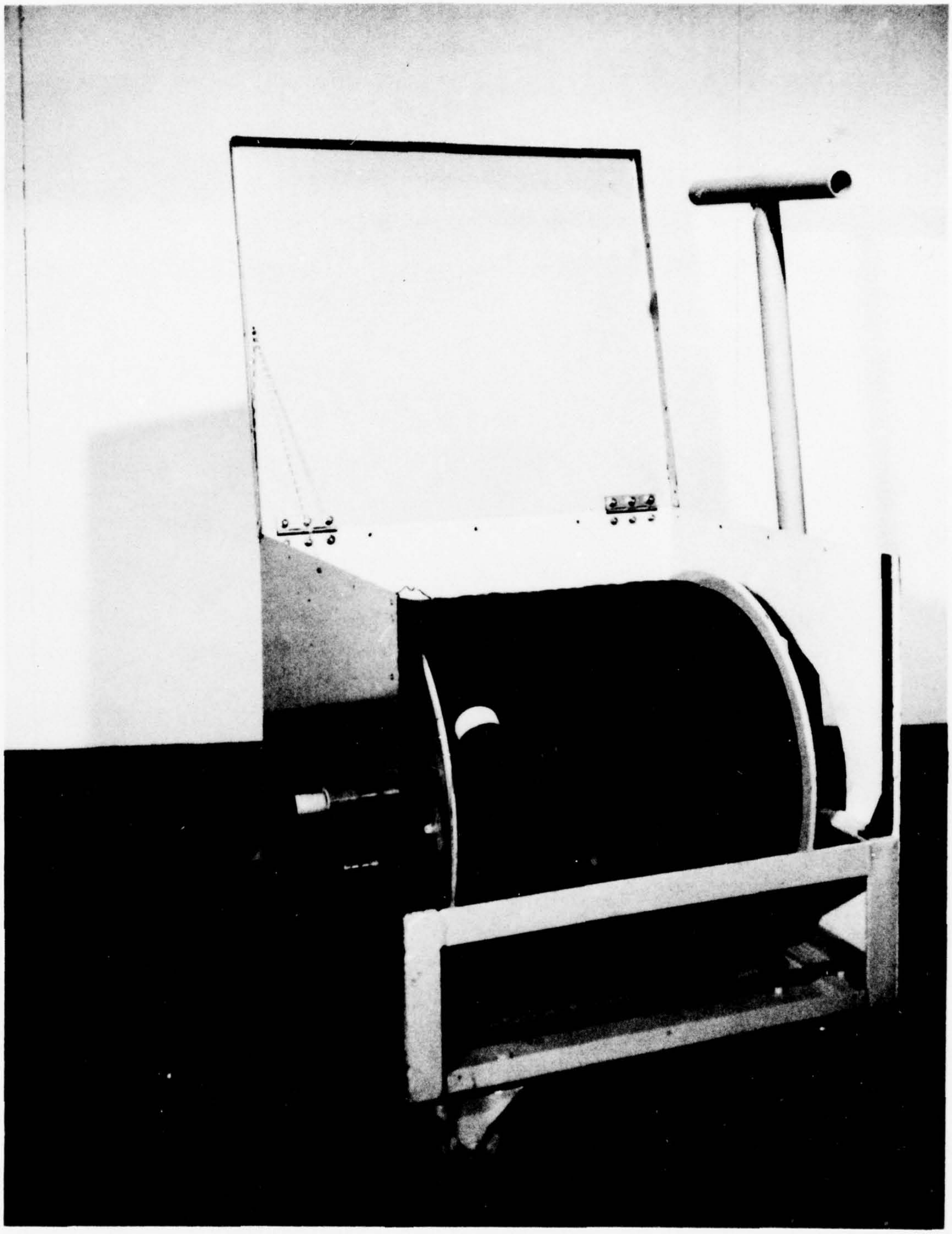


FIG. 9 PHOTOGRAPH OF ROLL-UP CABLE DISPENSER

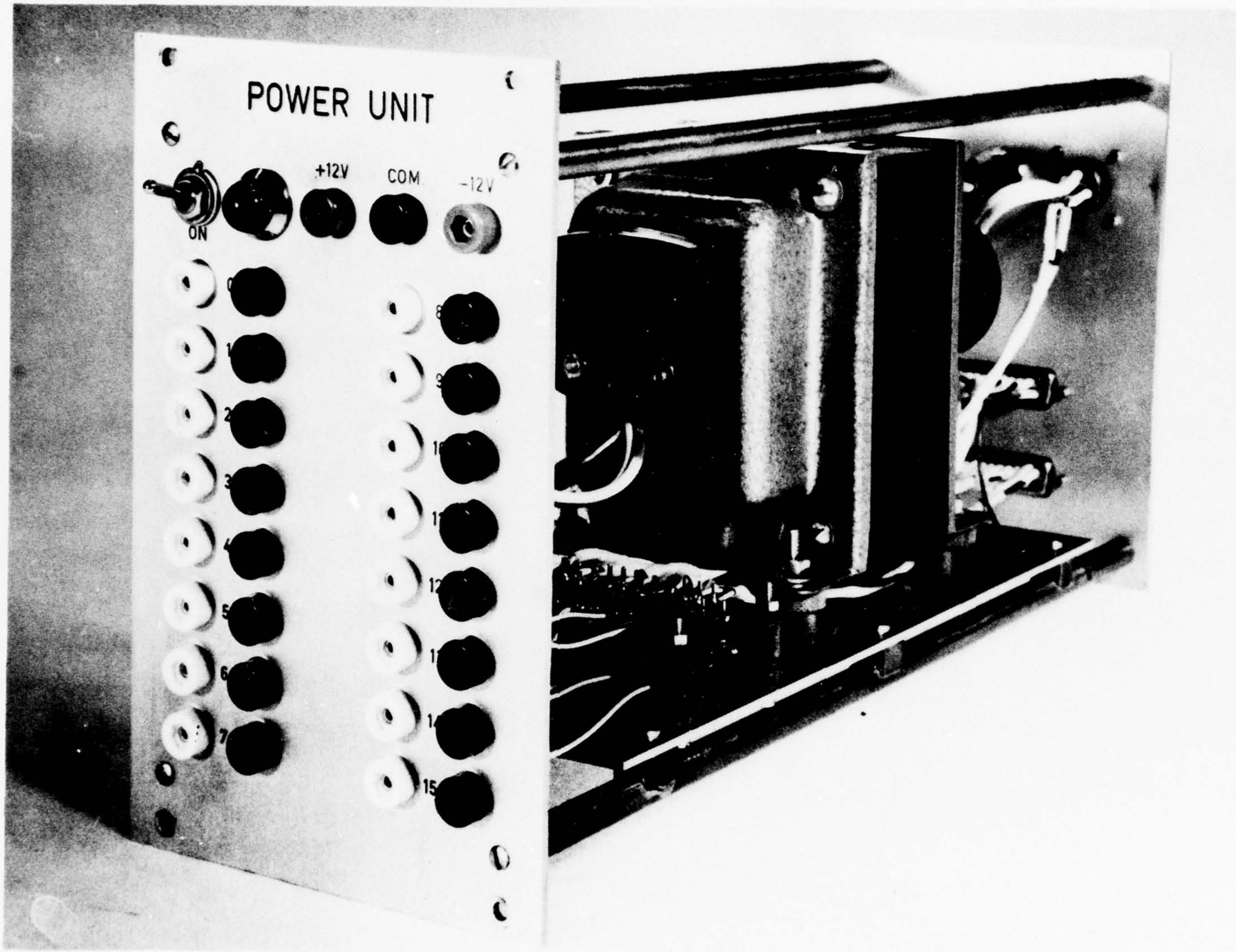


FIG. 10 PHOTOGRAPH OF POWER UNIT

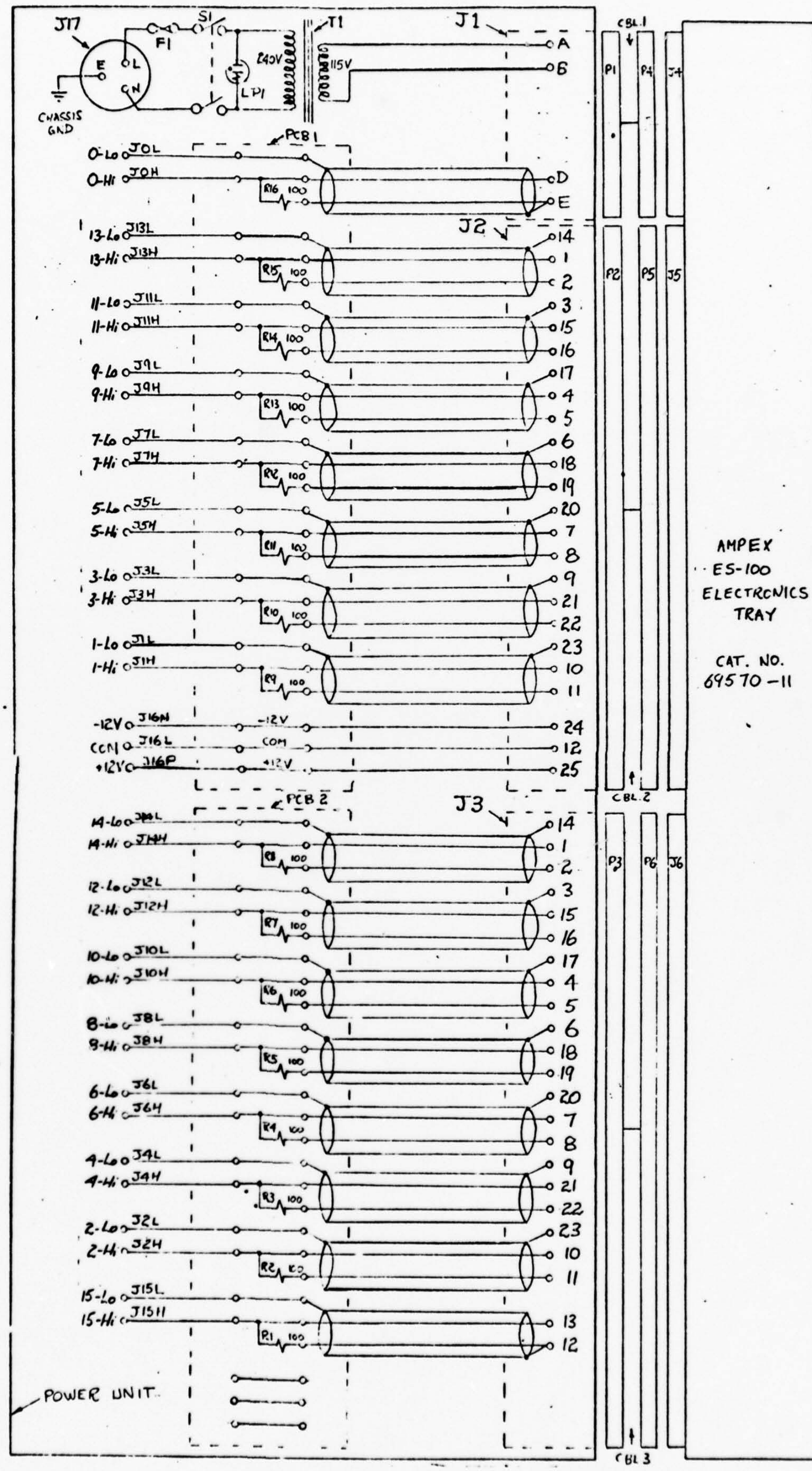


FIG. 11 POWER UNIT WIRING DETAILS

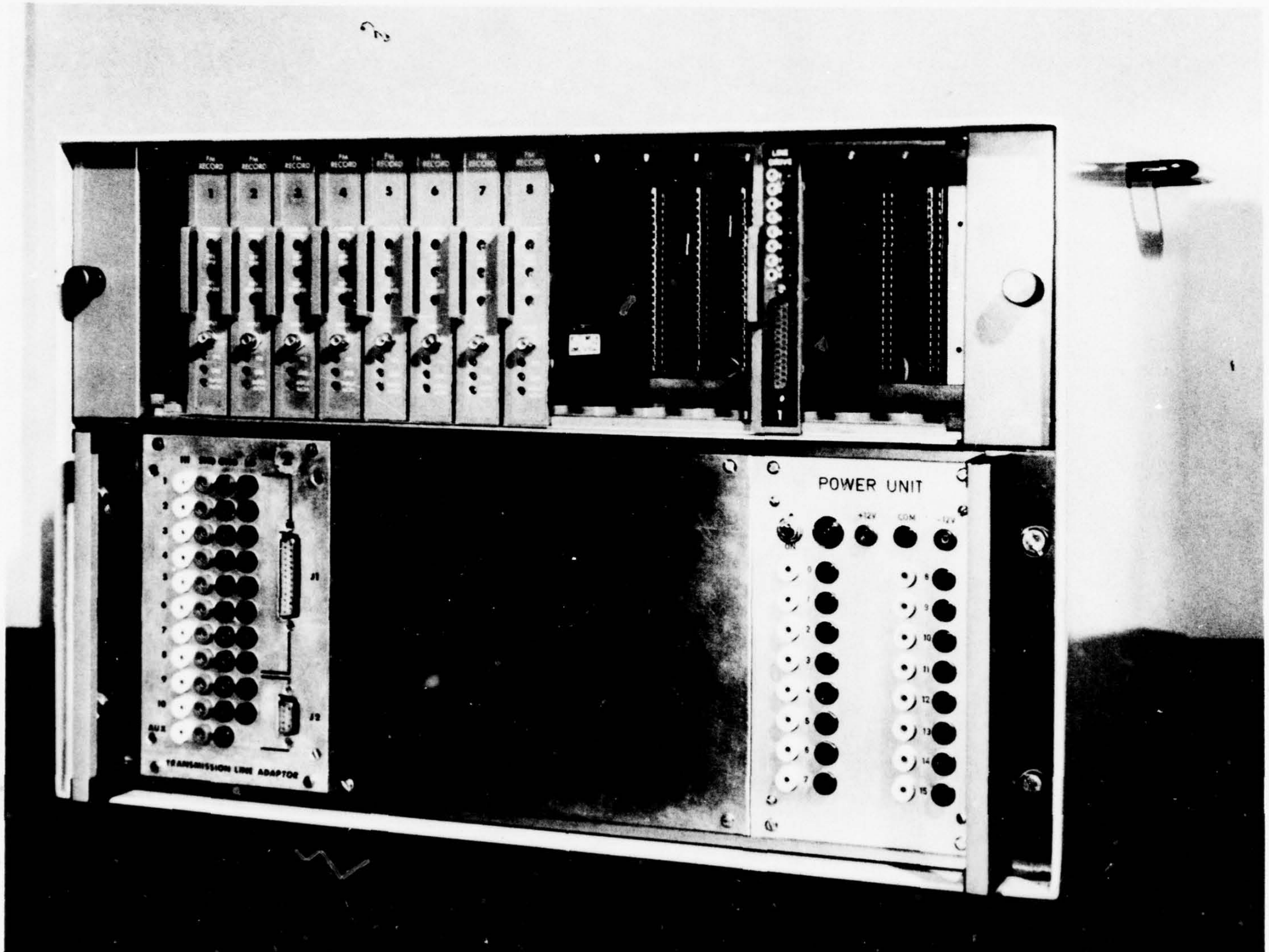


FIG. 12 PHOTOGRAPH OF REMOTE DATA TRANSMITTER

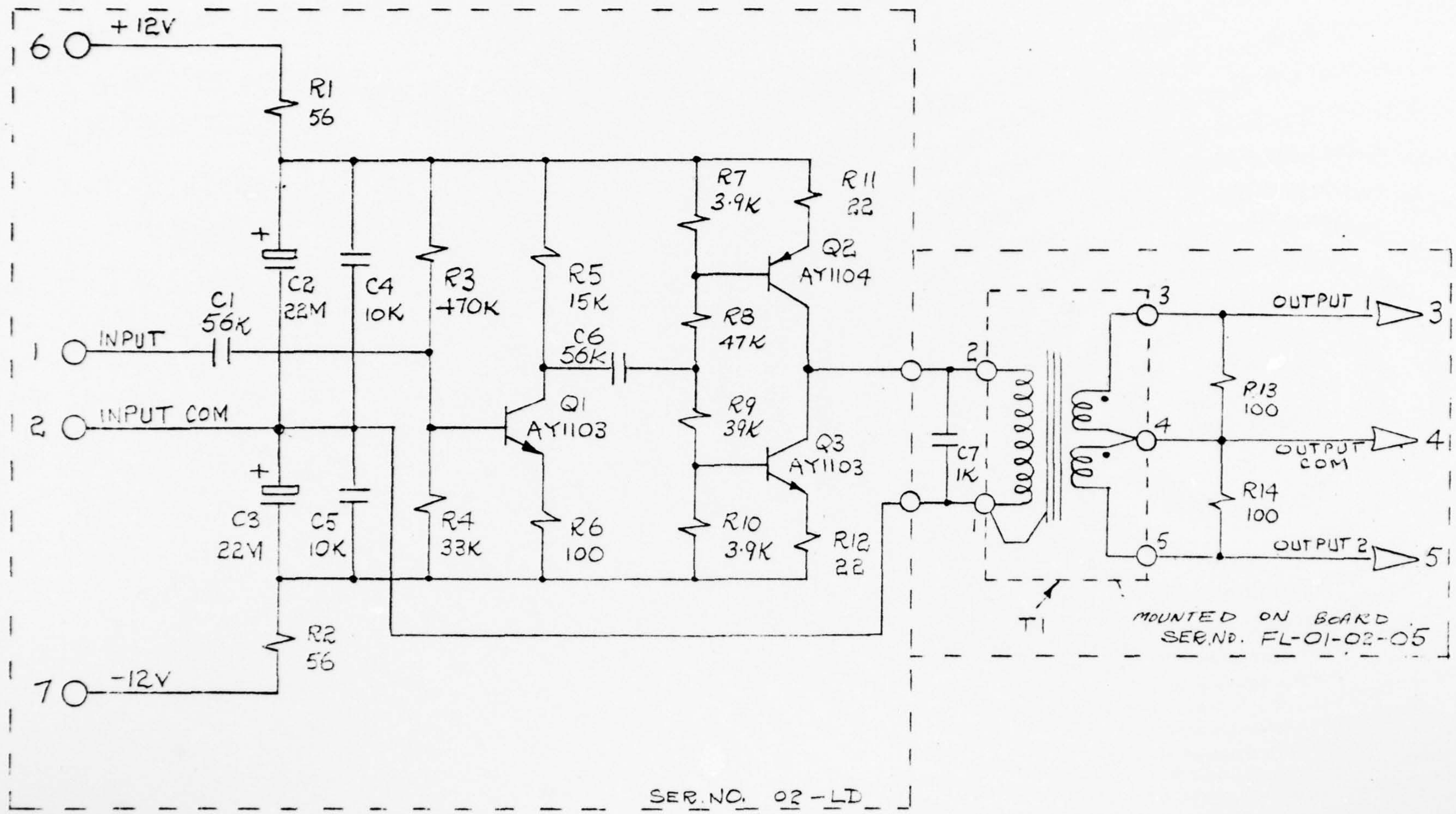


FIG. 13 LINE DRIVER UNIT (LD1 TO LD8)

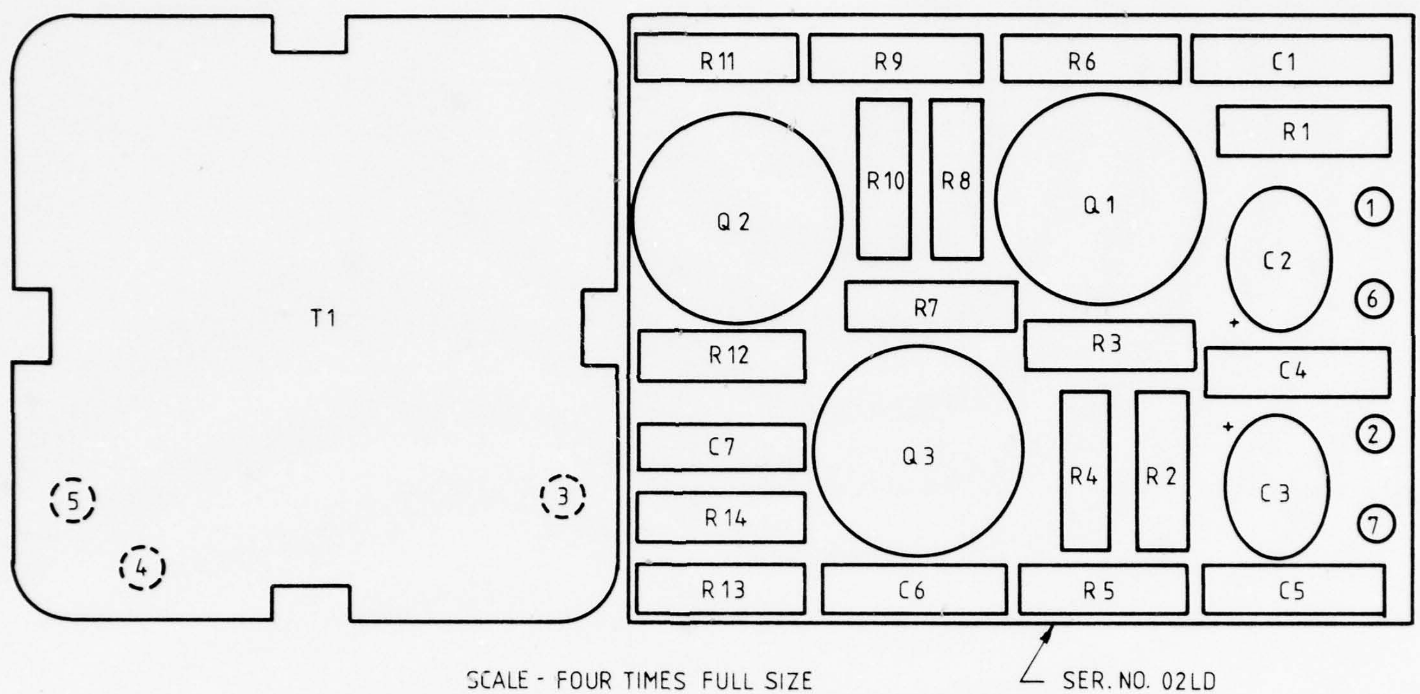
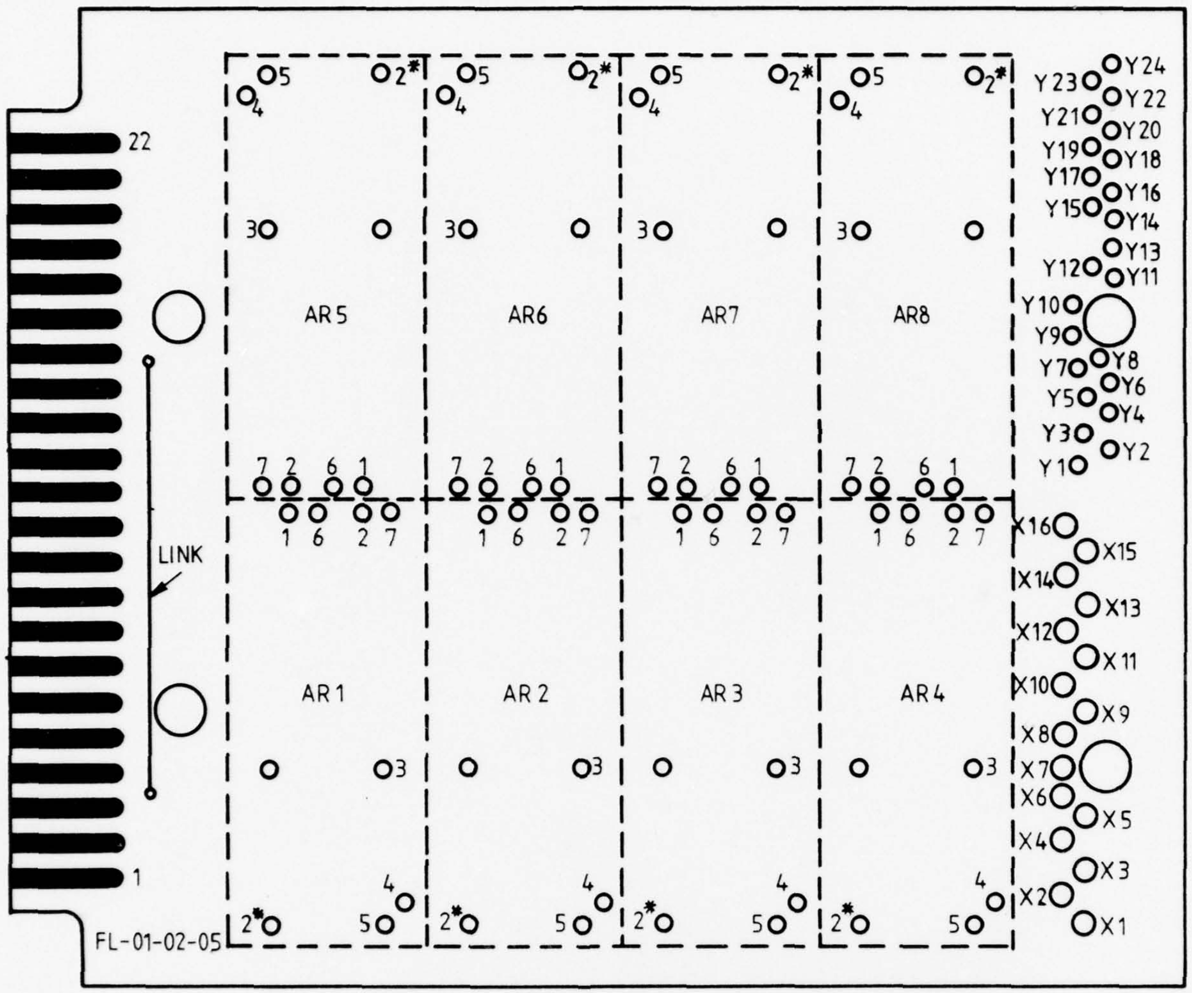


FIG. 14 COMPONENT LAYOUT FOR LINE DRIVER UNIT



Note 2 and 2* for each section are shorted together on master board

FIG. 15 SPACE ALLOCATION ON MASTER BOARD

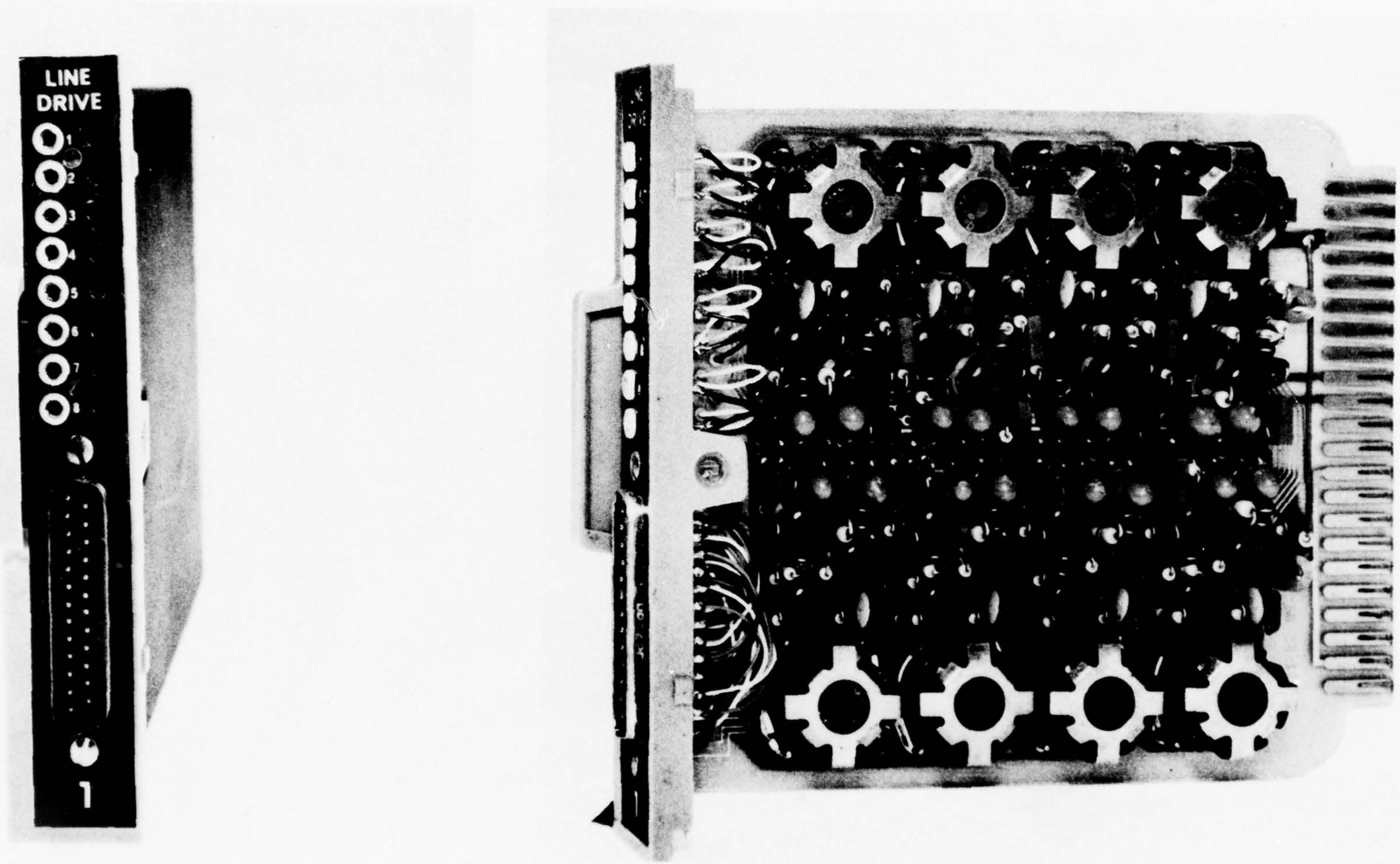
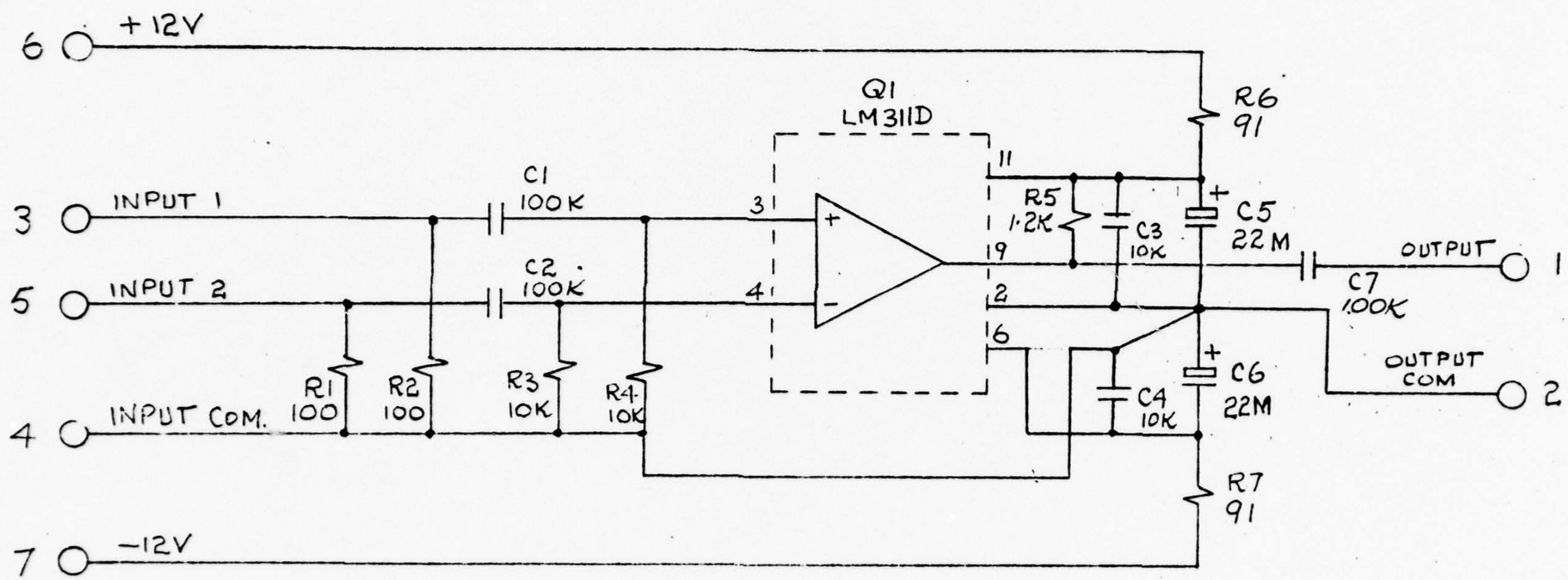
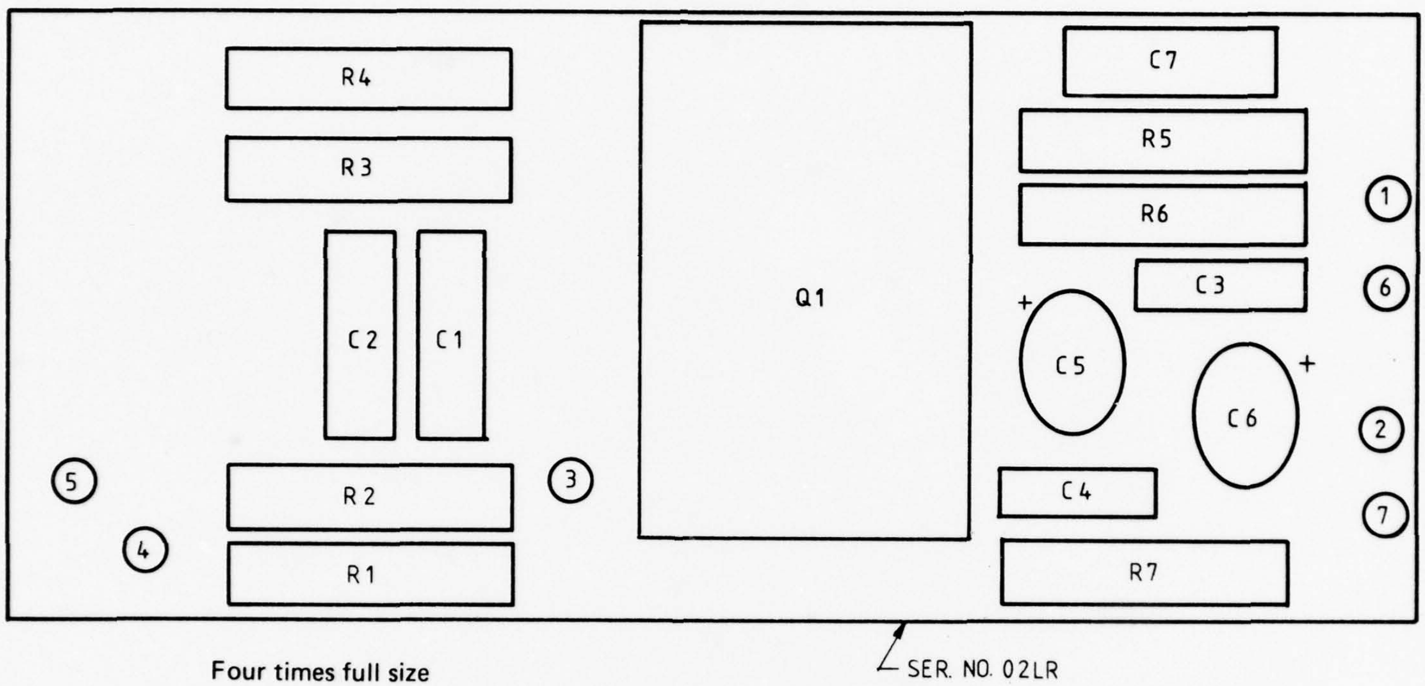


FIG. 16 PHOTOGRAPHS OF LINE DRIVER MODULE



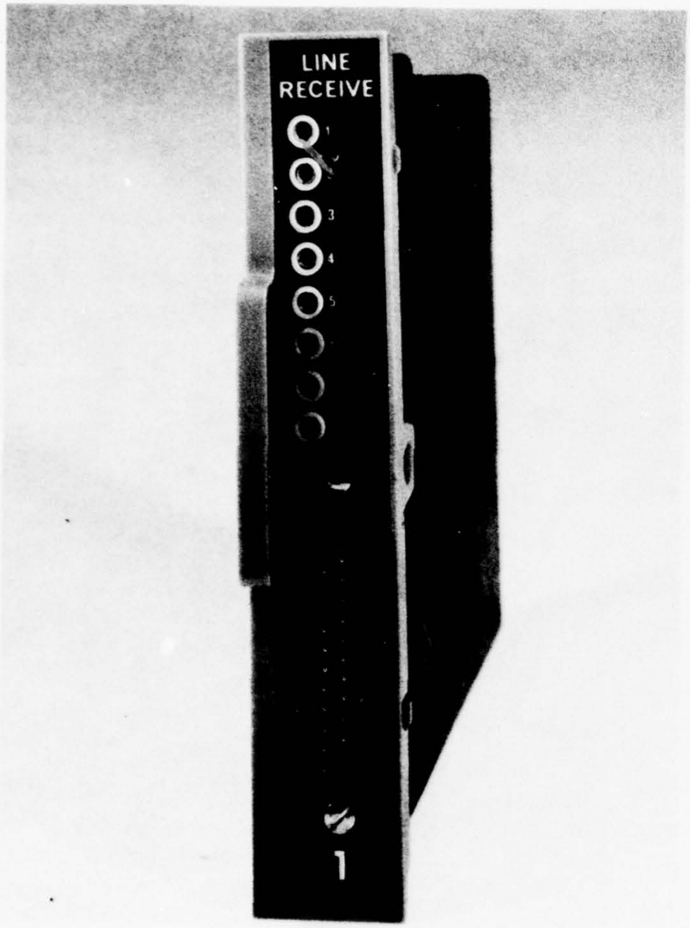
SER. NO. 02-LR

FIG. 17 LINE RECEIVER UNIT (LR1 TO LR8)



Four times full size

FIG. 18 COMPONENT LAYOUT FOR THE LINE RECEIVER UNIT



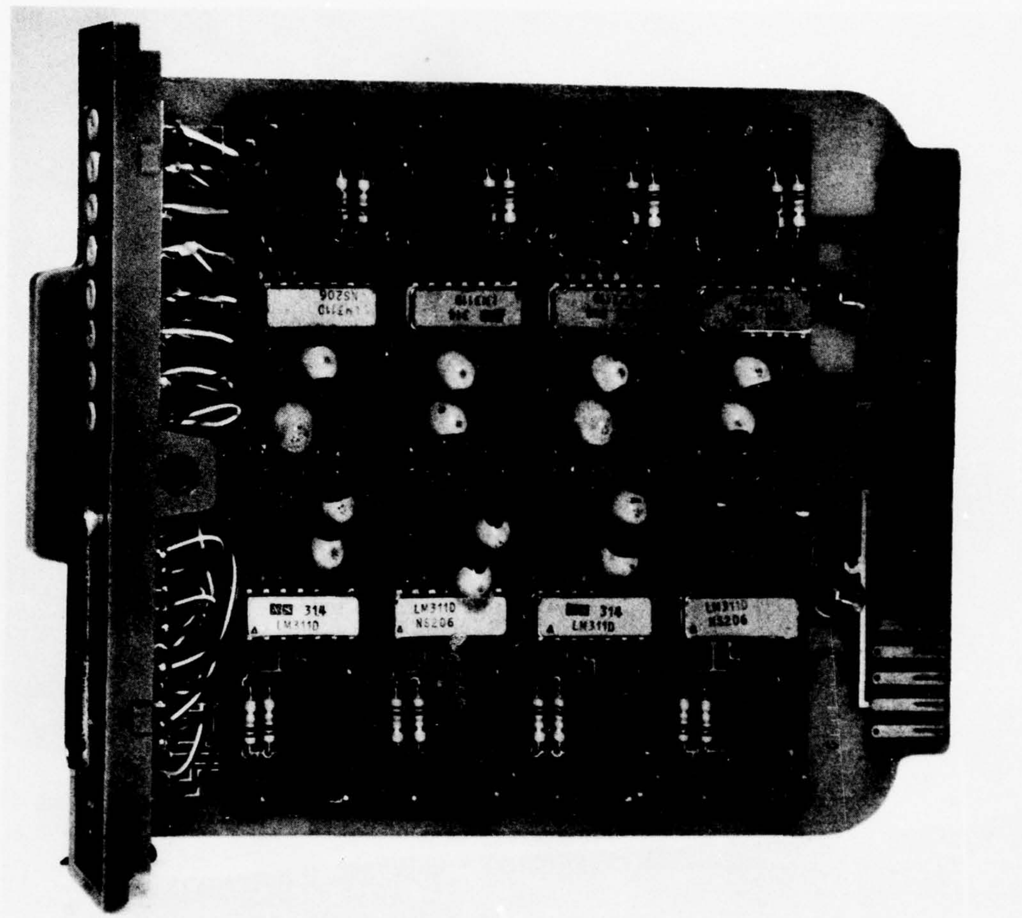


FIG. 19 PHOTOGRAPHS OF LINE RECEIVER MODULE

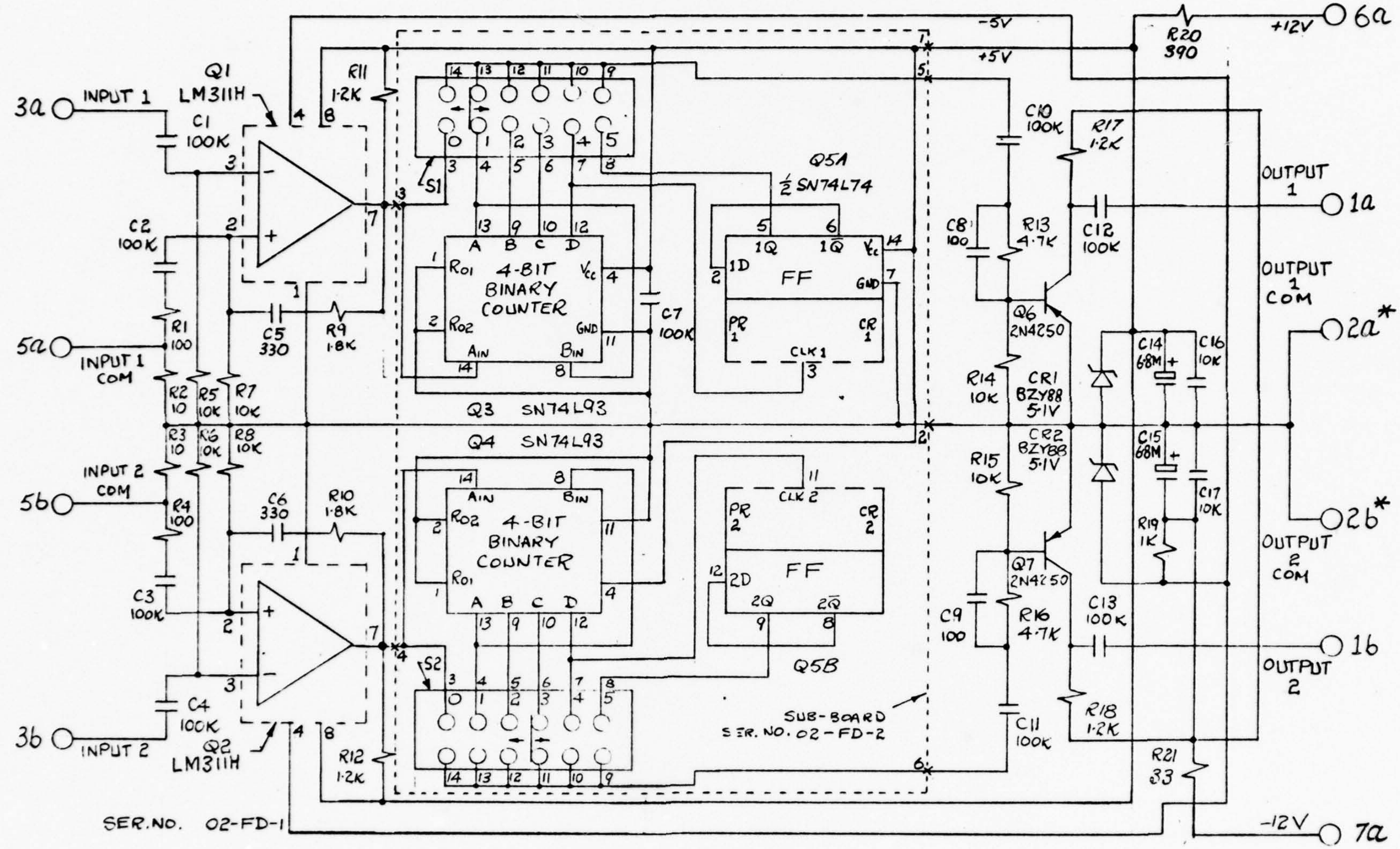
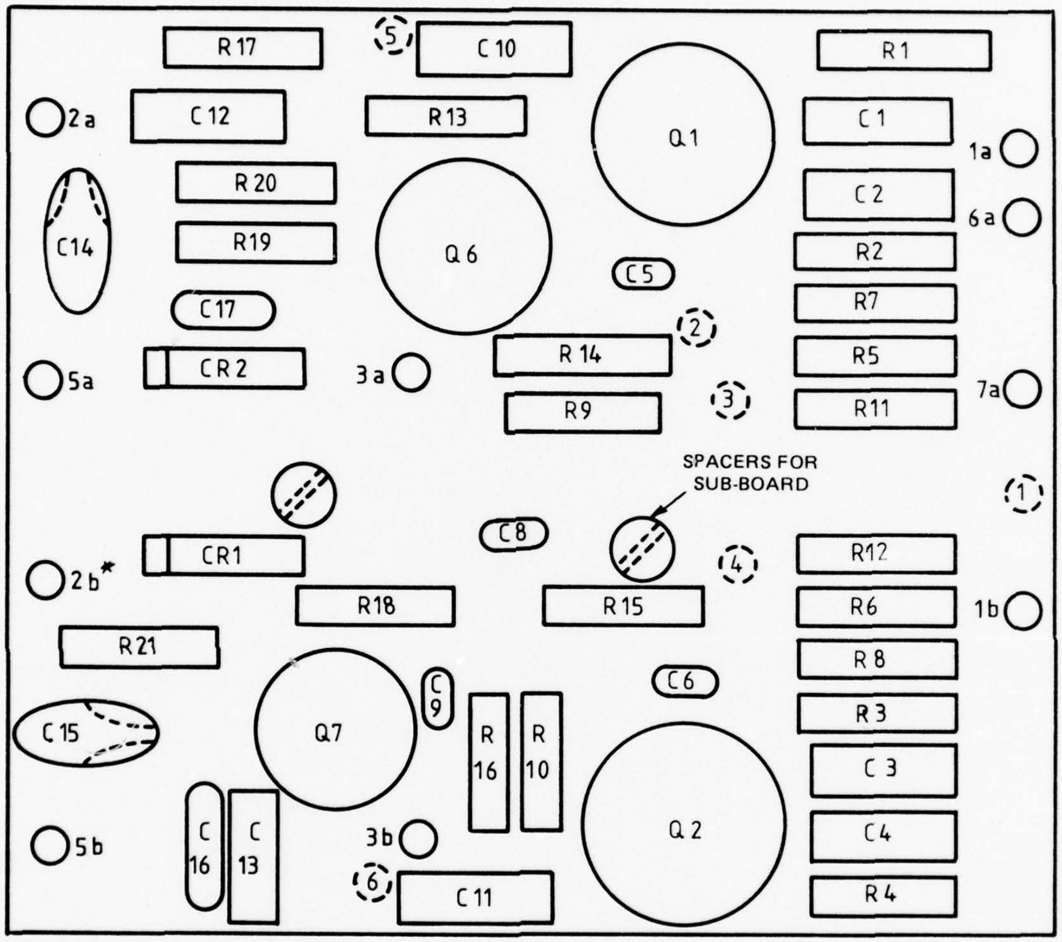


FIG. 20 FREQUENCY DIVIDER UNIT (DUAL)



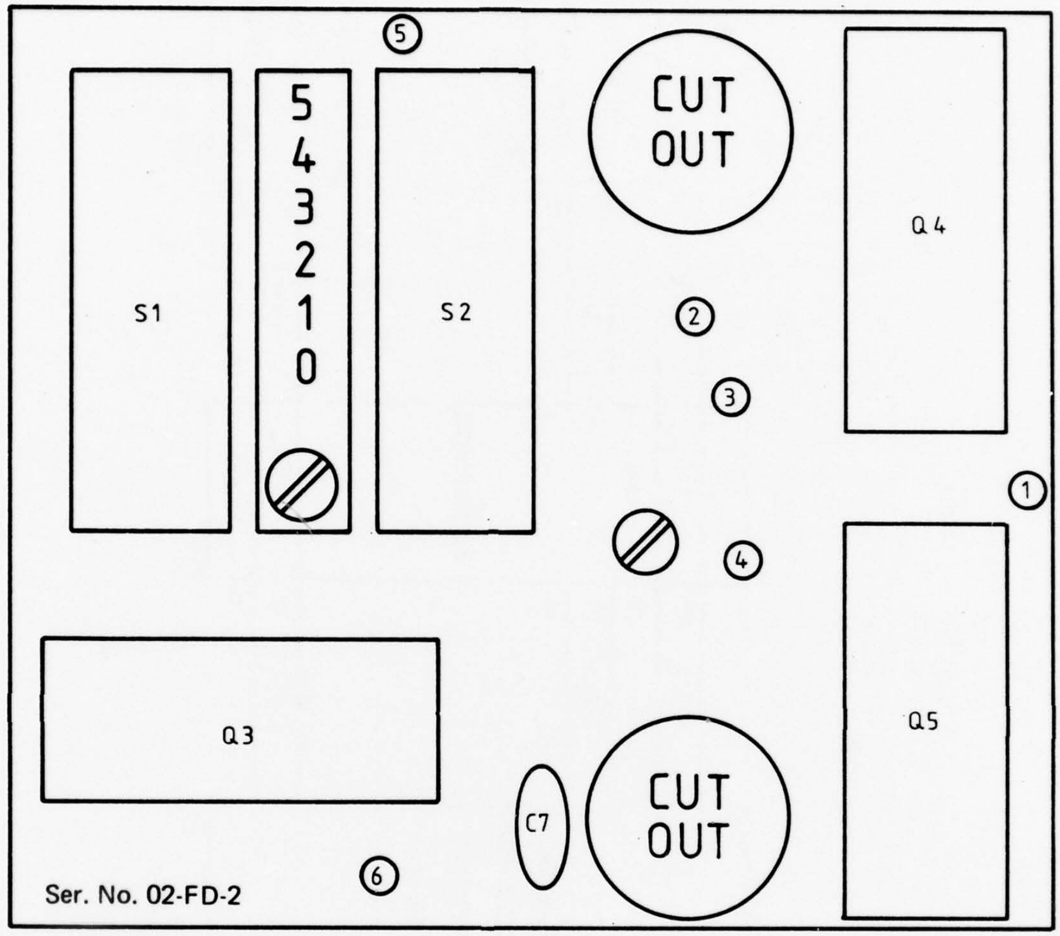
Ser. No. 02-FD-1

Four times full size

Note

(1) All capacitors are folded over because of height restrictions
(2) Dotted circles indicate hard-wire connections to sub-board

FIG. 21 COMPONENT LAYOUT FOR FREQUENCY DIVIDER (DUAL) MAIN BOARD



Four times full size

FIG. 22 COMPONENT LAYOUT FOR FREQUENCY DIVIDER (DUAL) SUB-BOARD

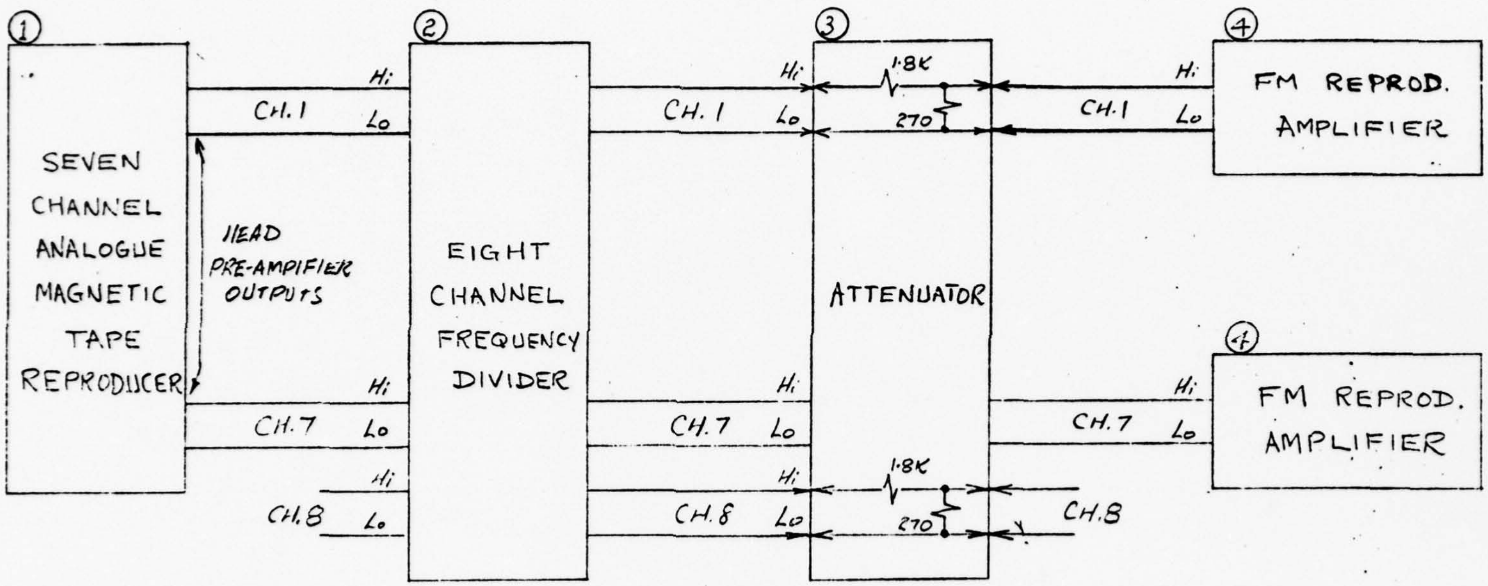


FIG. 23 FILTERING OF RECORDED DATA WITHOUT THE PRODUCTION OF A TAPE COPY

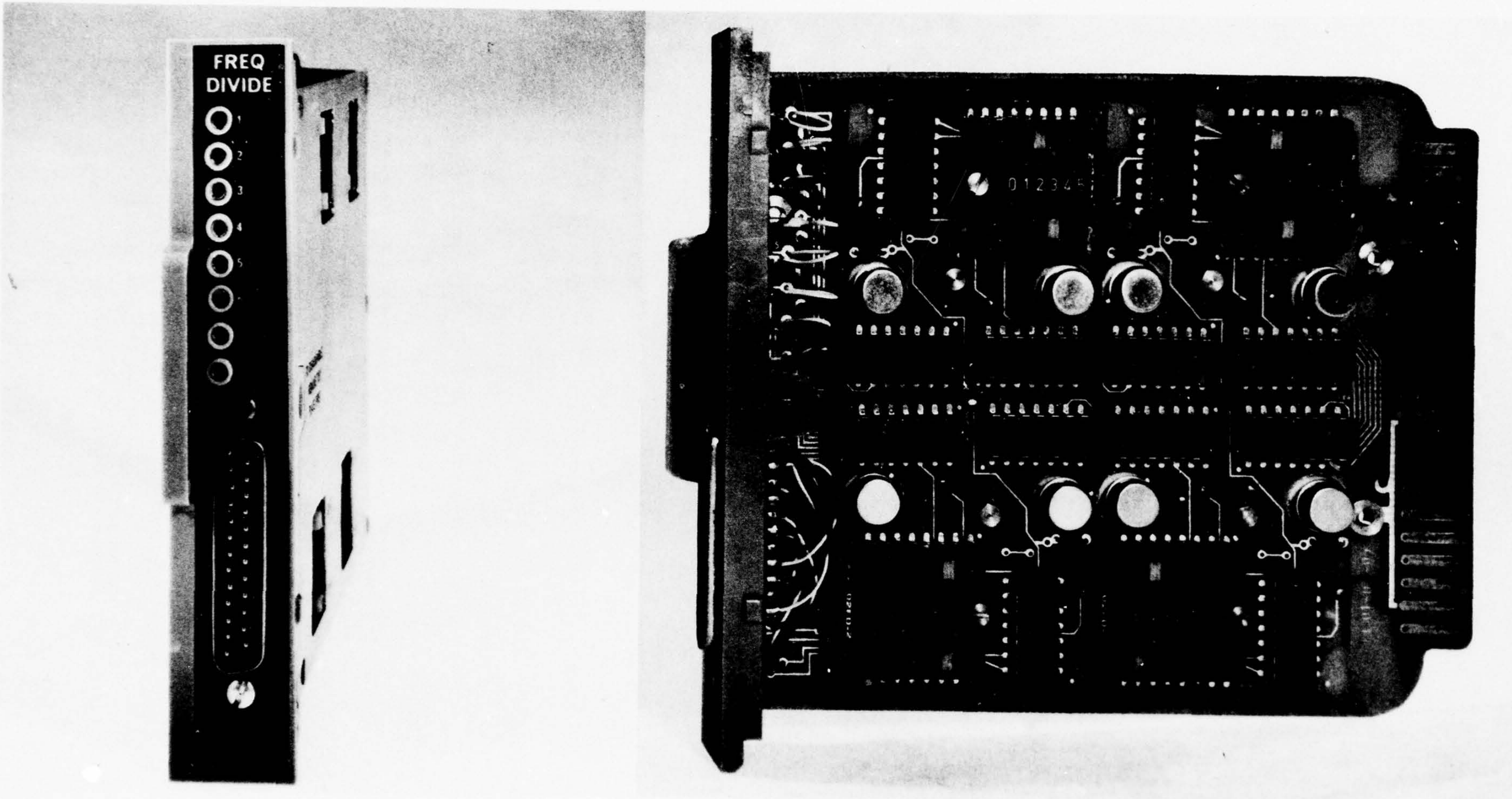


FIG. 24 PHOTOGRAPHS OF FREQUENCY DIVIDER MODULE

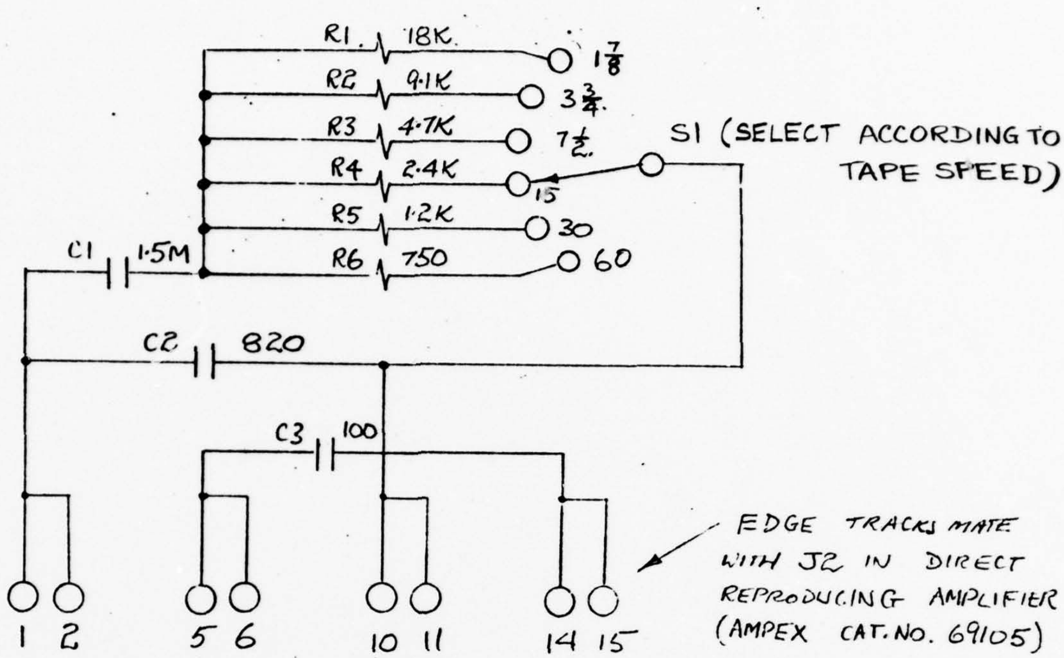


FIG. 25a DIRECT REPRODUCING AMPLIFIER PLUG-IN FOR FLAT FREQUENCY RESPONSE

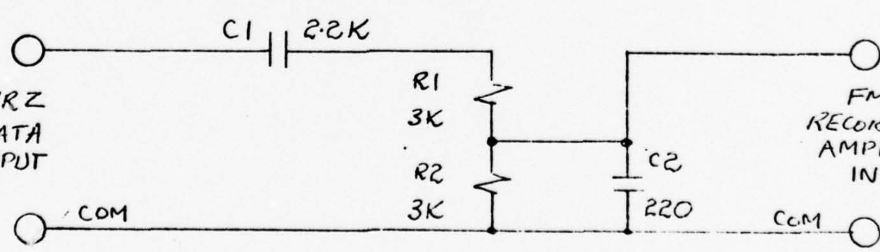
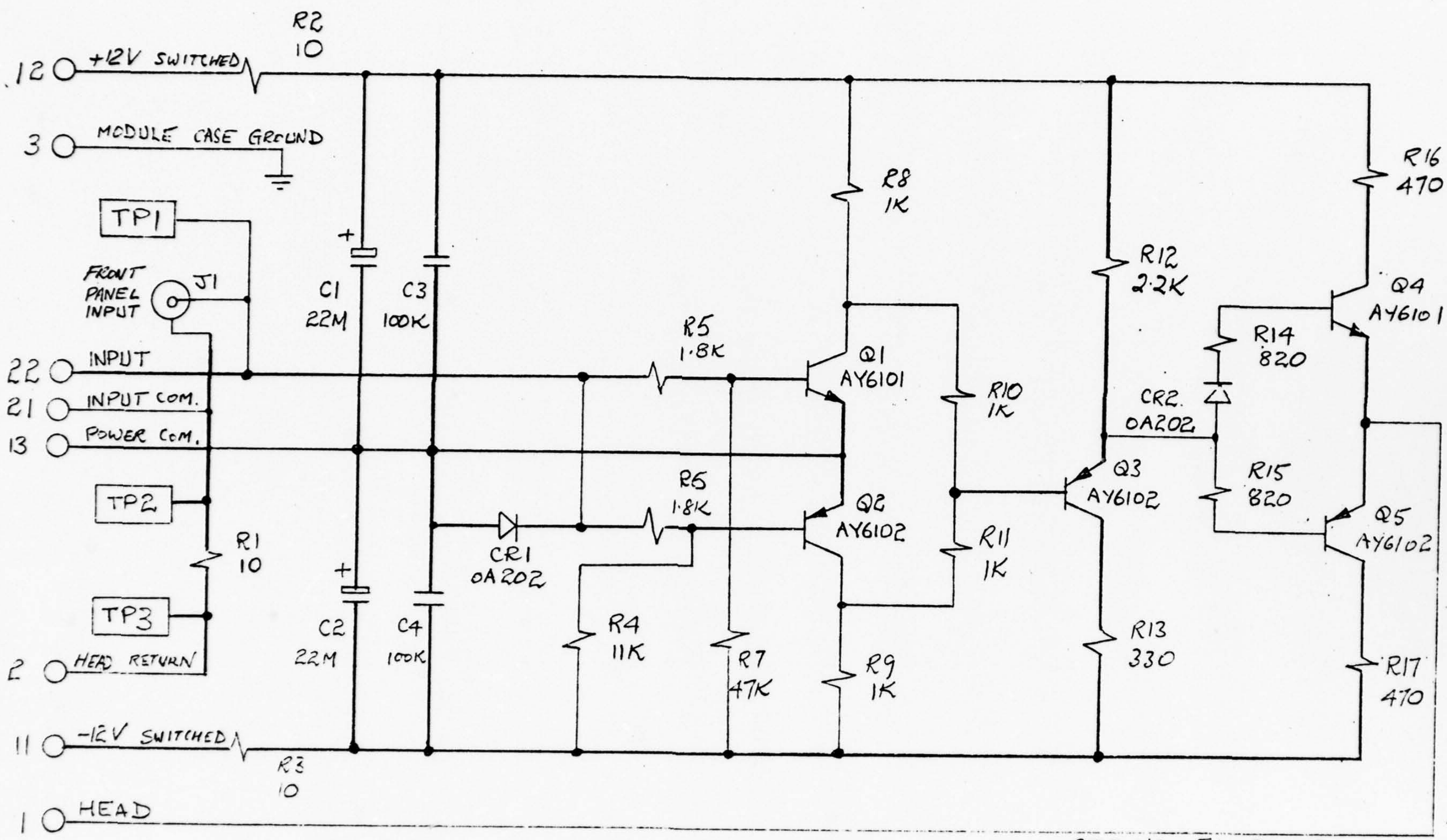


FIG.25b INPUT NETWORK FOR TRANSMISSION OF DIGITAL SIGNALS TO REMOTELY LOCATED TAPE RECORDER



SER. NO. FL-01-02-06

FIG. 26 NRZ DIGITAL RECORDING APLIFIER

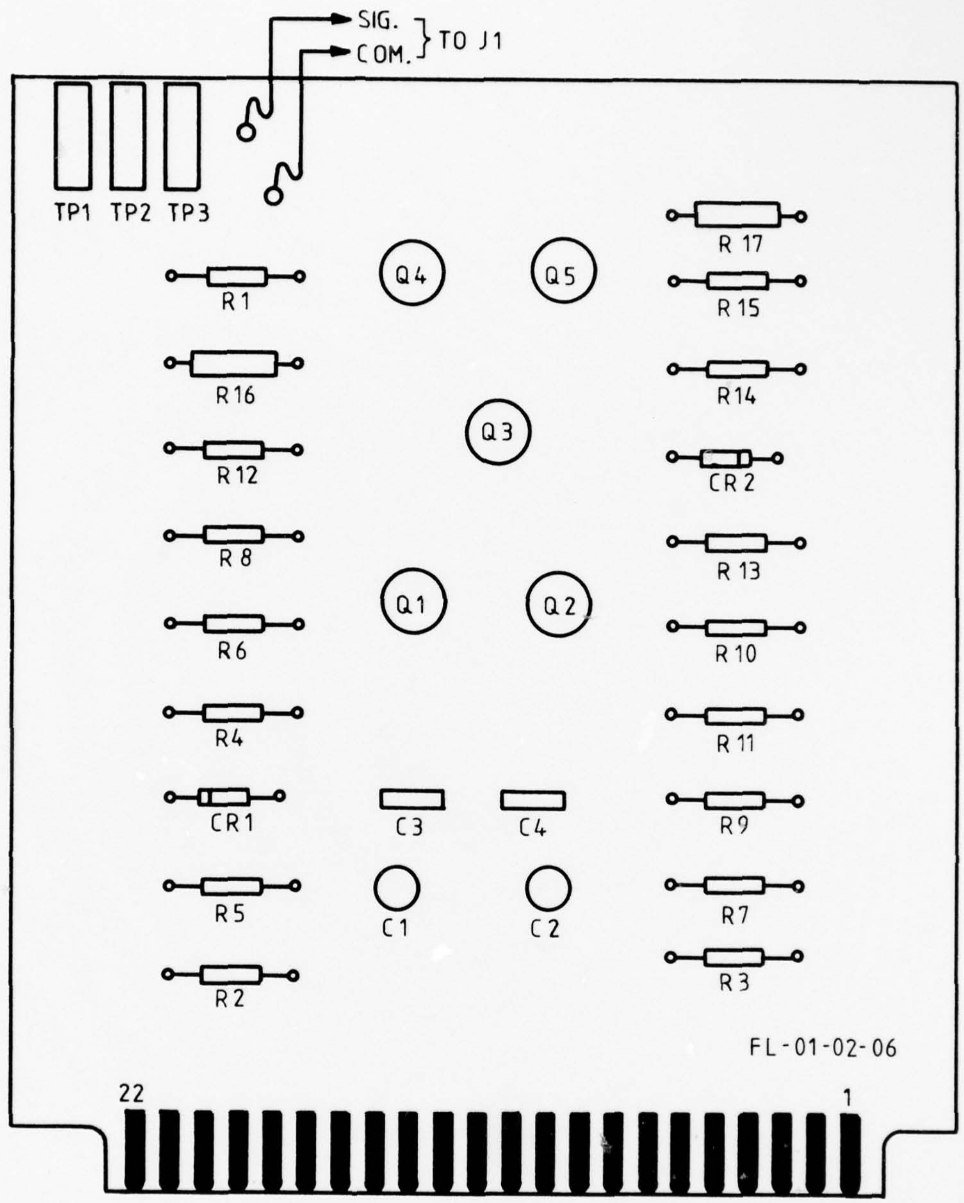


FIG. 27 COMPONENT LAYOUT FOR NRZ DIGITAL RECORDING AMPLIFIER

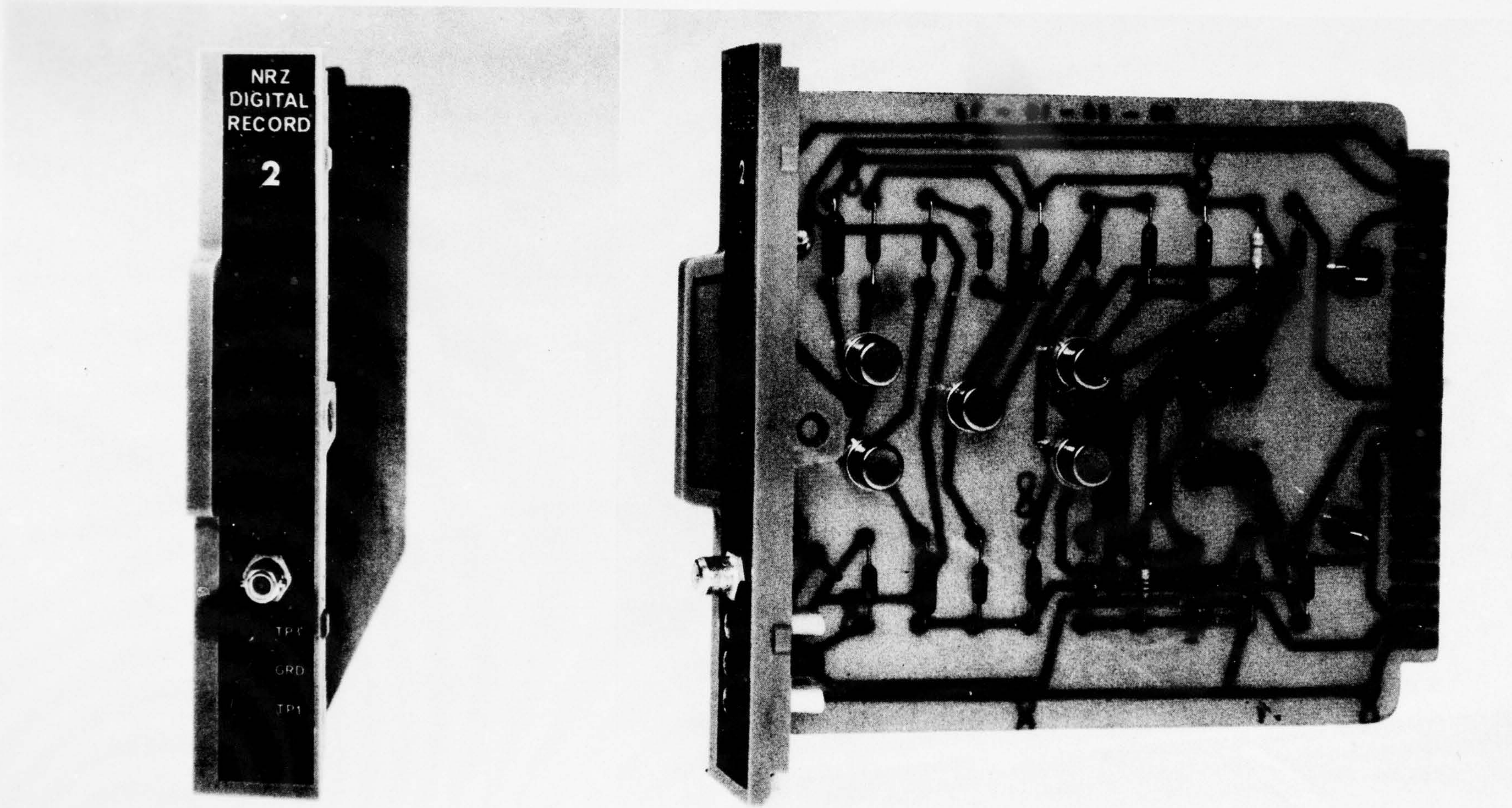


FIG. 28 PHOTOGRAPHS OF NRZ DIGITAL RECORDING AMPLIFIER

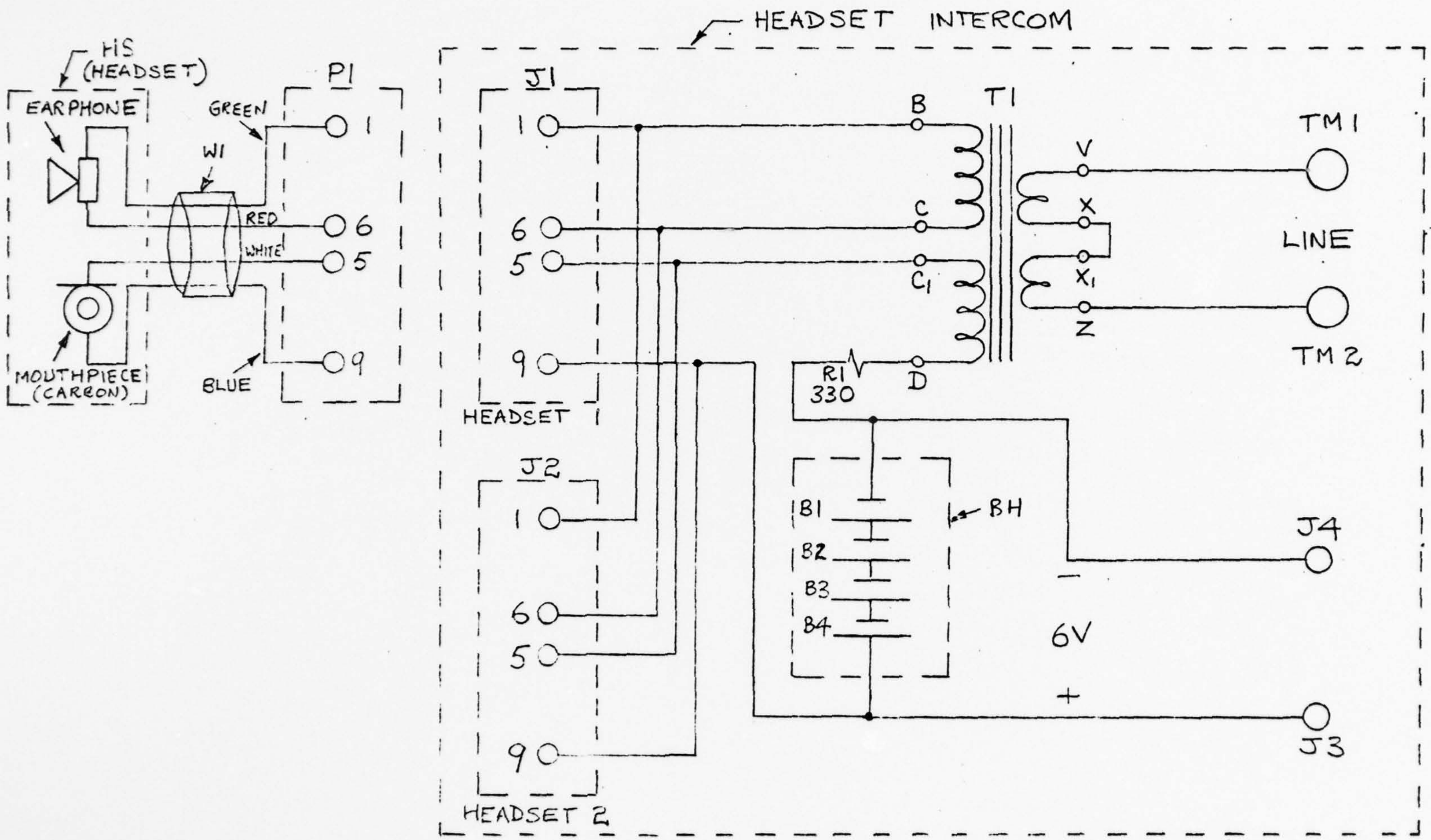


FIG. 29 HEADSET INTERCOM WIRING

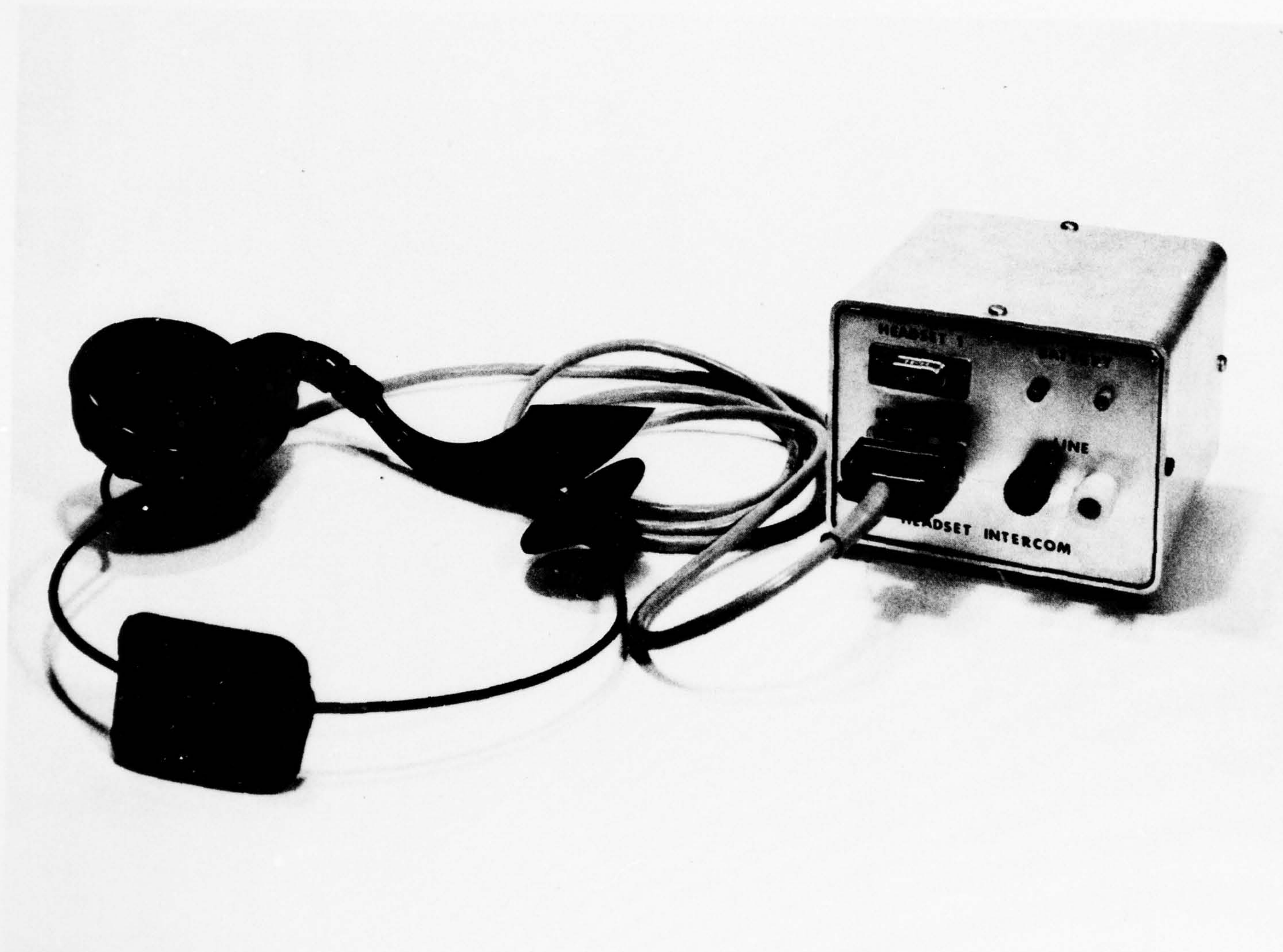


FIG. 30 PHOTOGRAPH OF INTERCOM HARDWARE

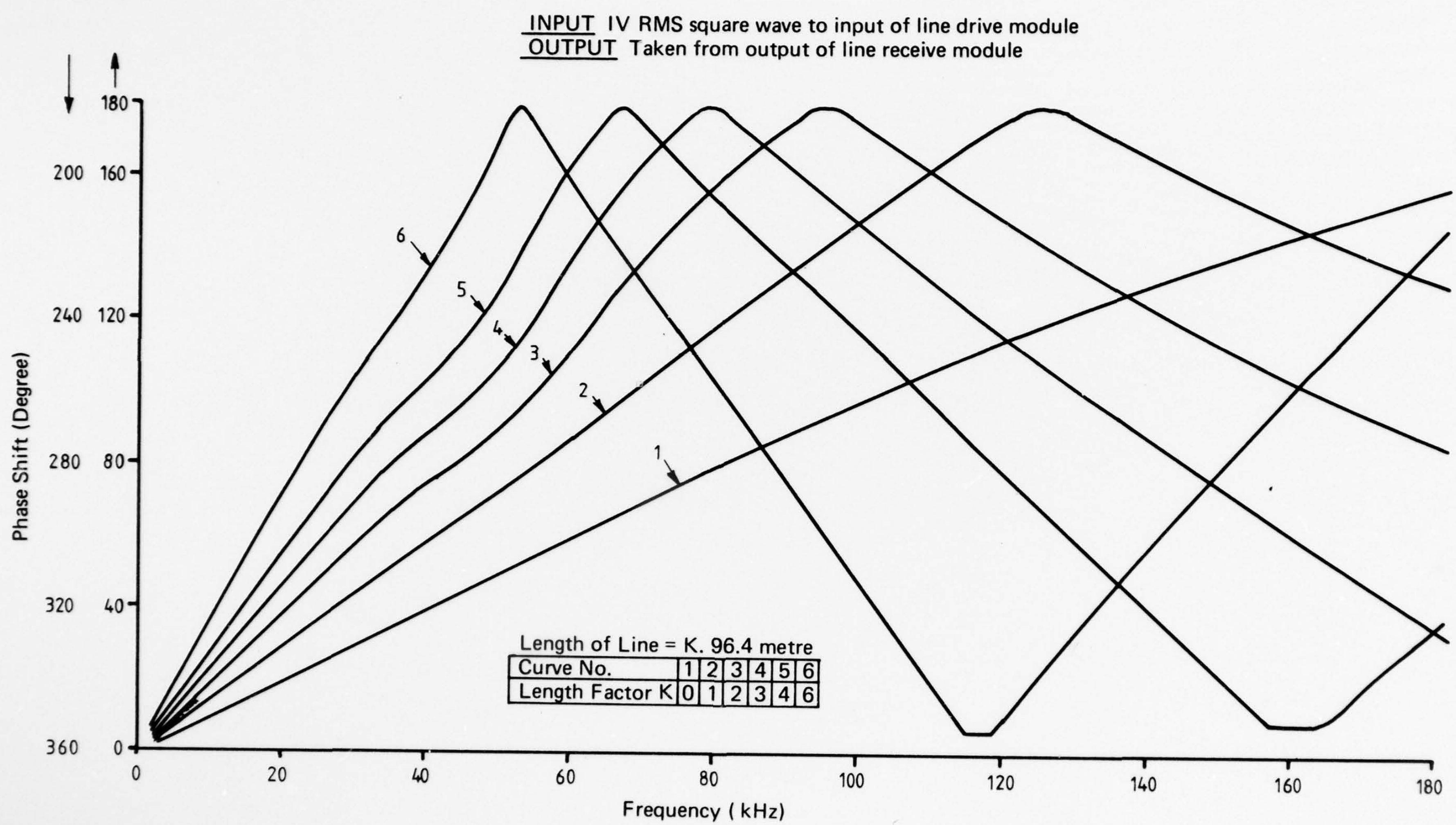


FIG. 31 LINE SYSTEM PHASE RESPONSE

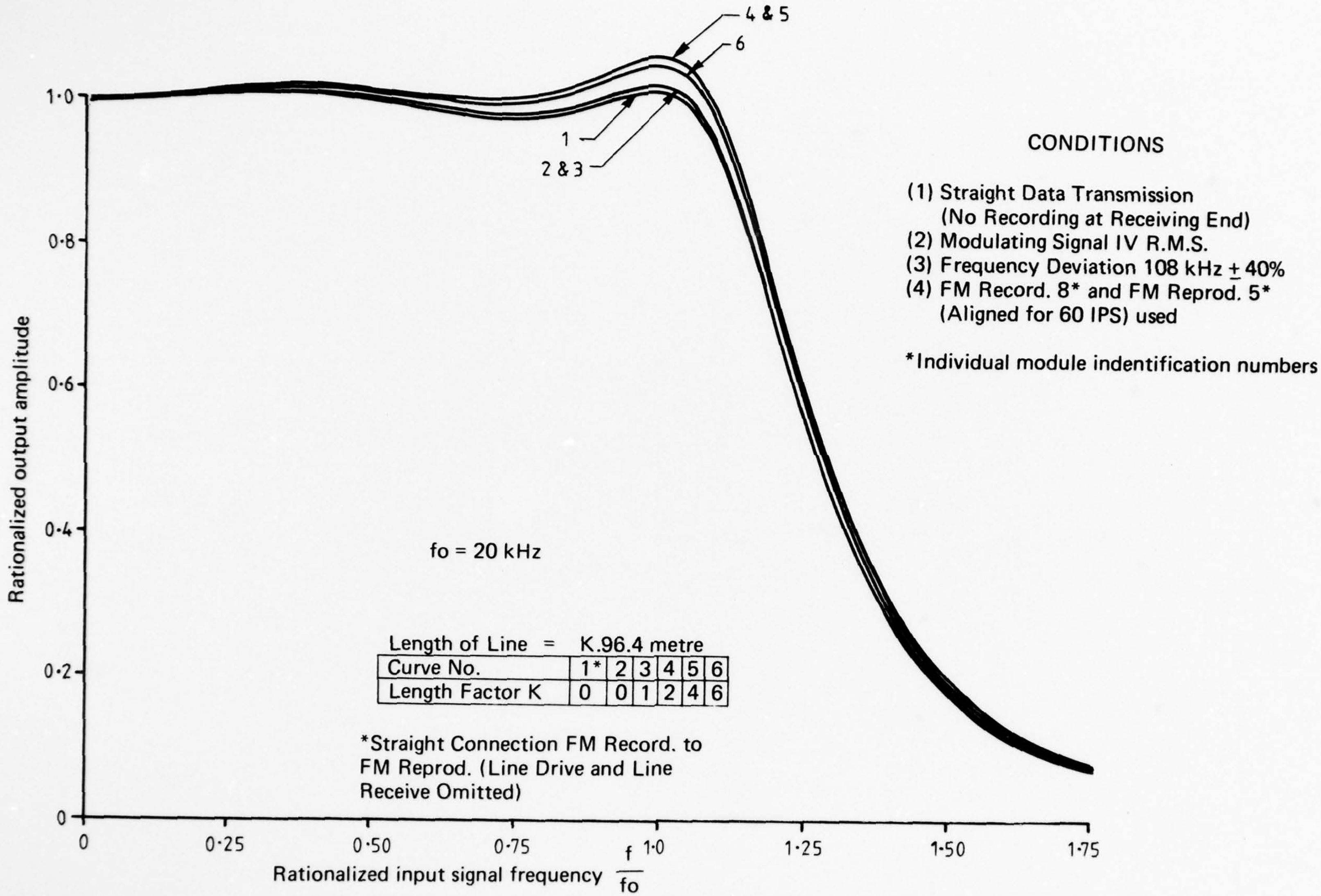


FIG. 32 EFFECT OF LINE LENGTH ON AMPLITUDE RESPONSE OF 108 kHz CARRIER FM SYSTEM

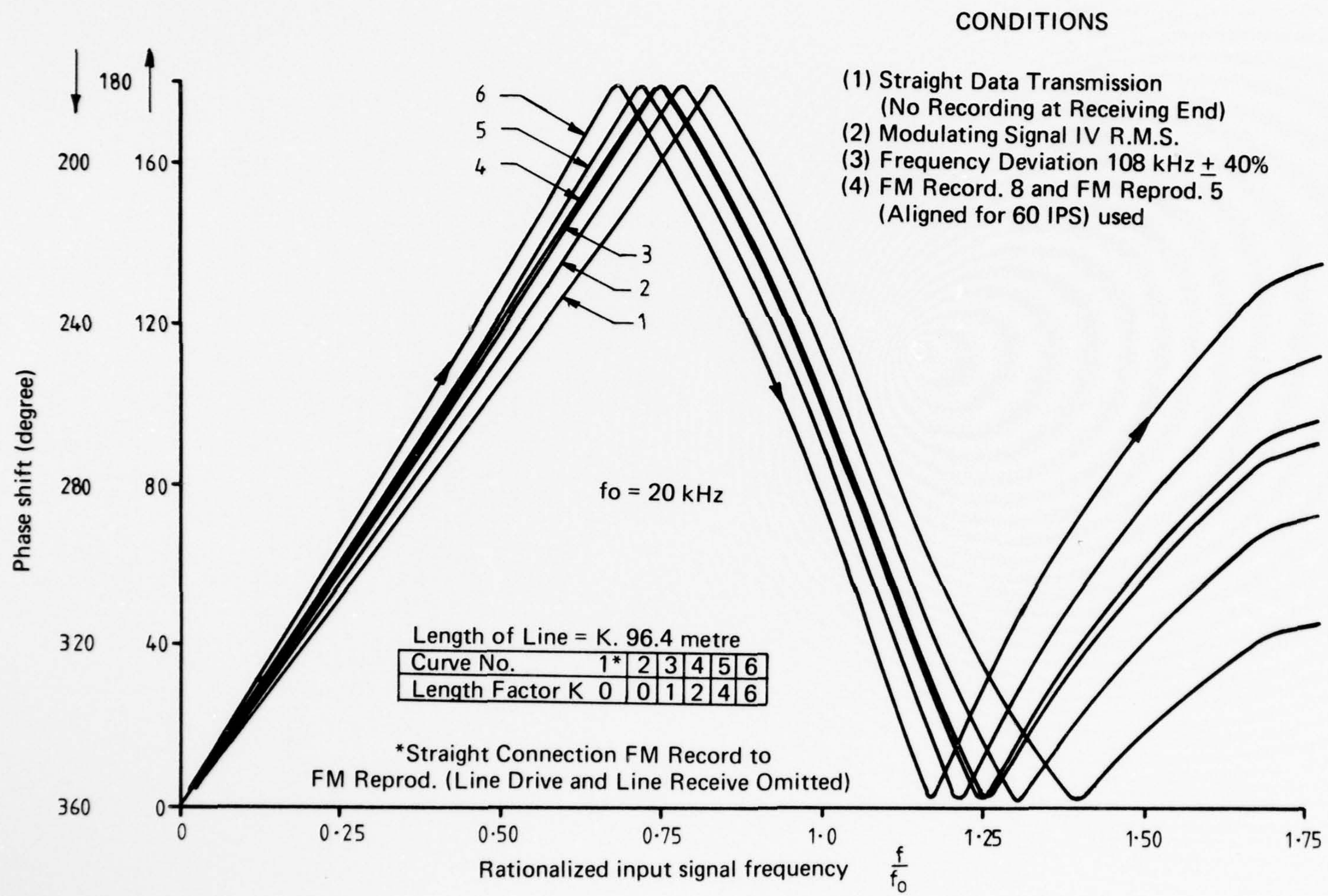


FIG. 33 EFFECT OF LINE LENGTH ON PHASE RESPONSE OF 108 kHz CARRIER FM SYSTEM

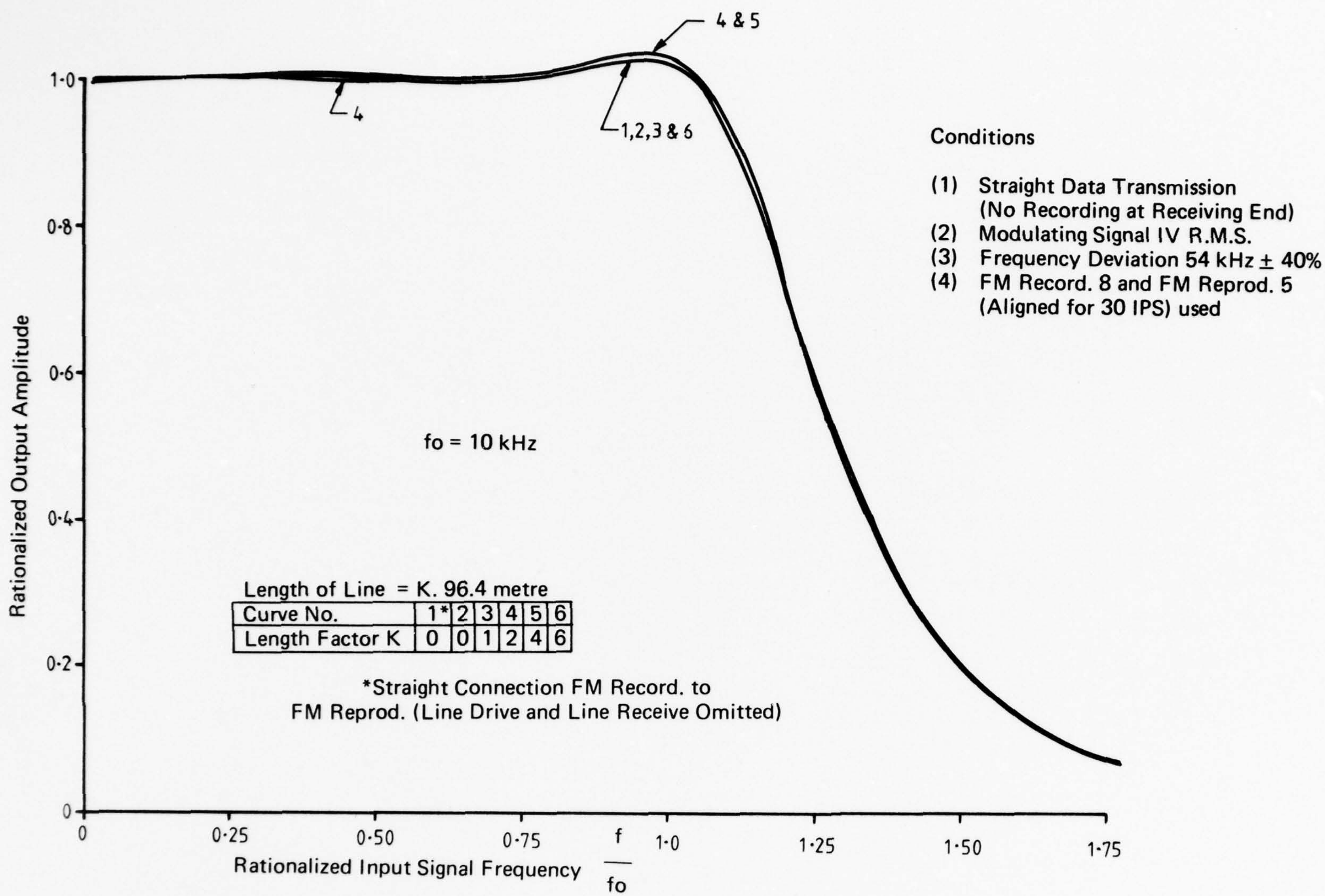


FIG. 34 EFFECT OF LINE LENGTH ON AMPLITUDE RESPONSE OF 54 kHz CARRIER FM SYSTEM

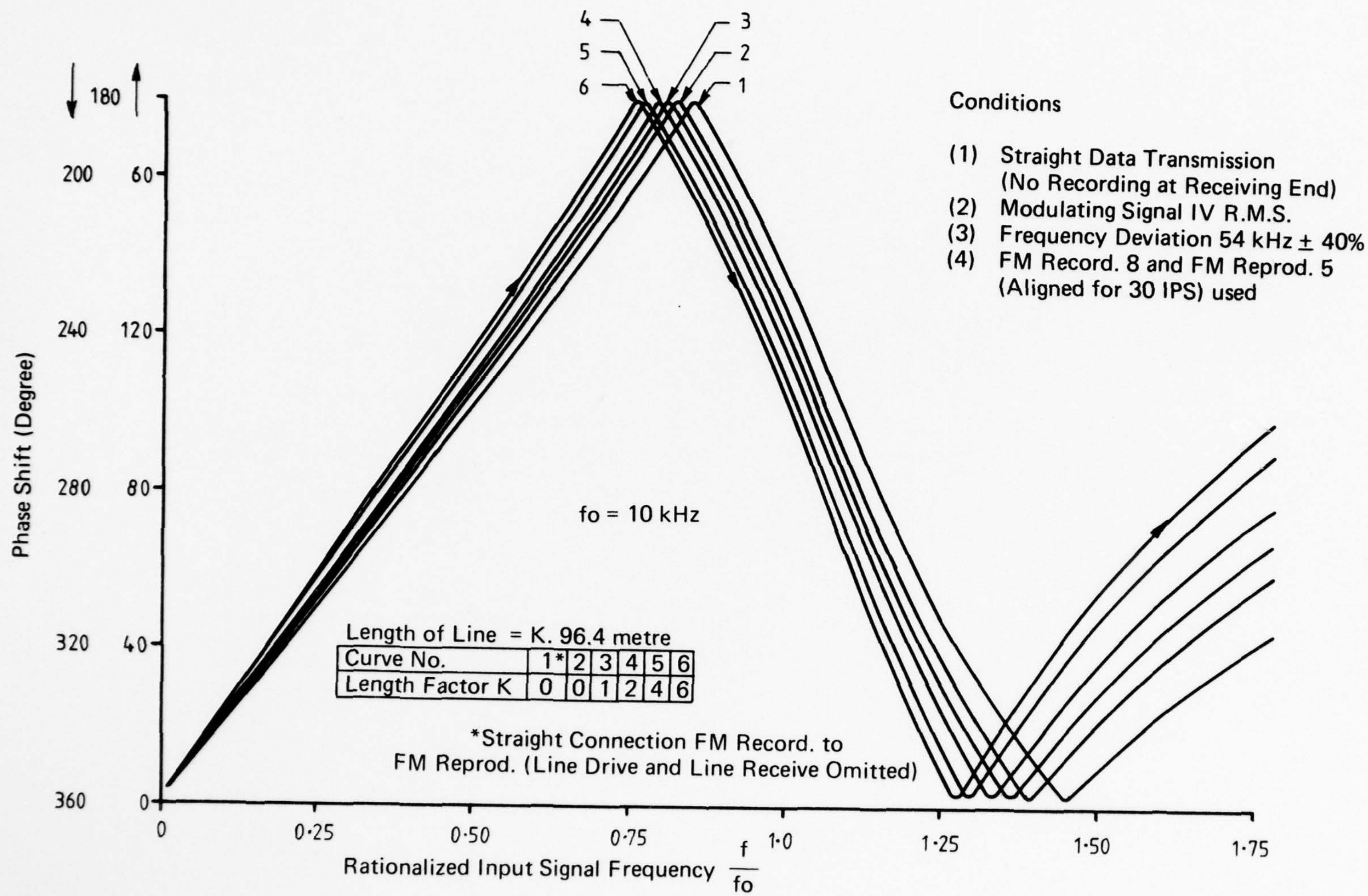


FIG. 35 EFFECT OF LINE LENGTH ON PHASE RESPONSE OF 54 kHz CARRIER FM SYSTEM

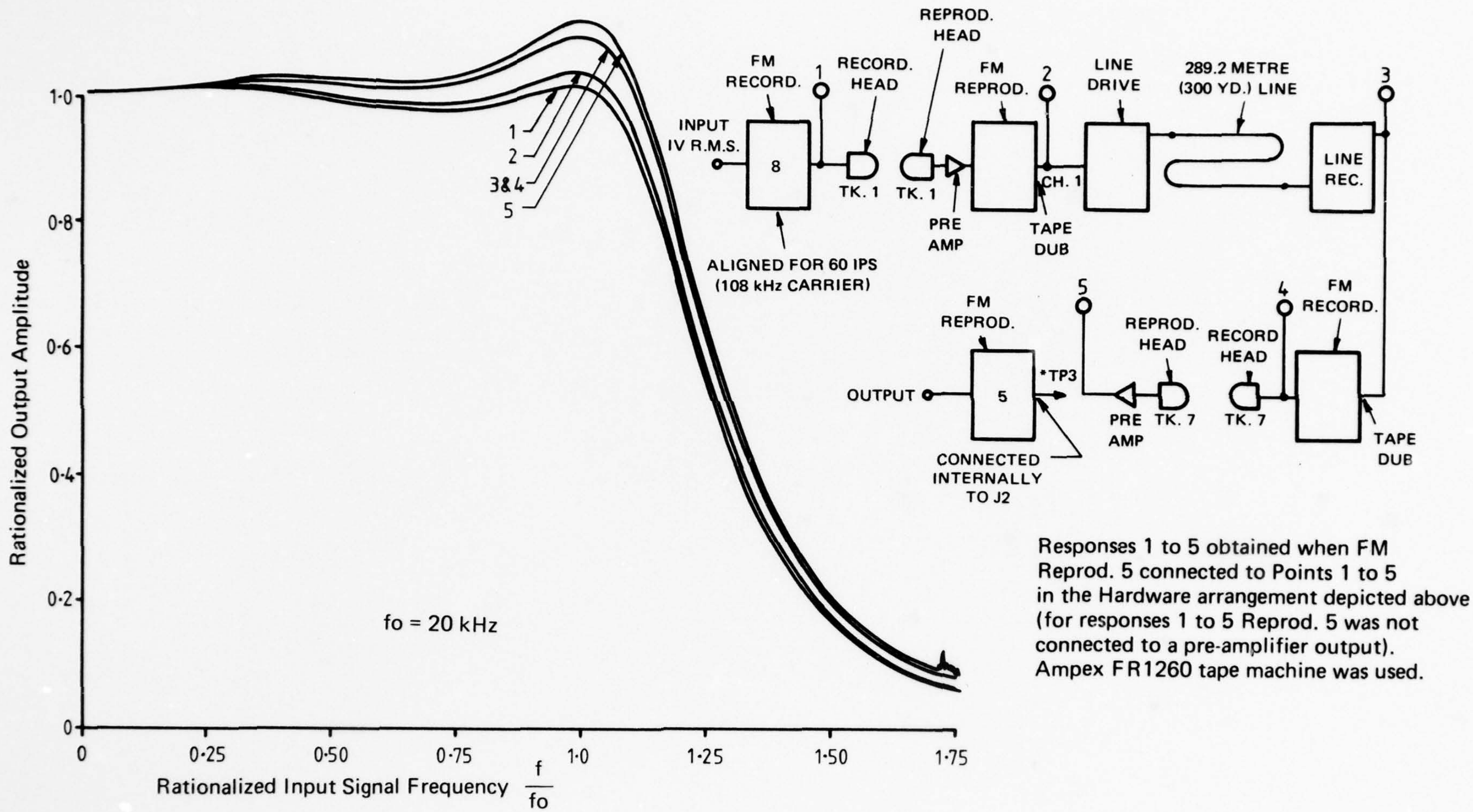


FIG. 36 EXTENT TO WHICH THE RECORDING PROCESS MODIFIES THE AMPLITUDE RESPONSE FOR 108 kHz CARRIER FM RECORDING AND COPYING

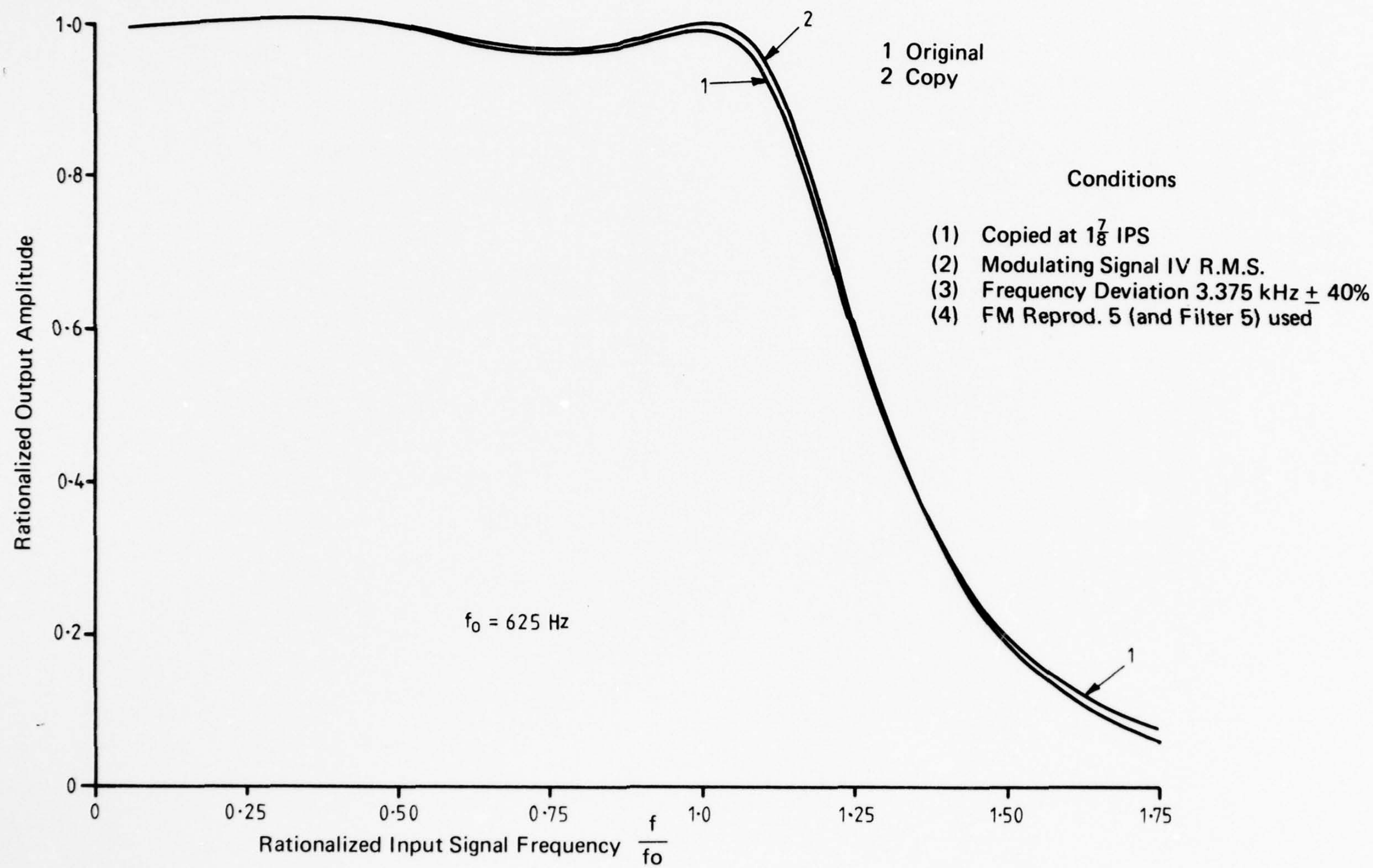


FIG. 37 EFFECT OF COPYING ON AMPLITUDE RESPONSE AT $1\frac{7}{8}$ IPS TAPE SPEED

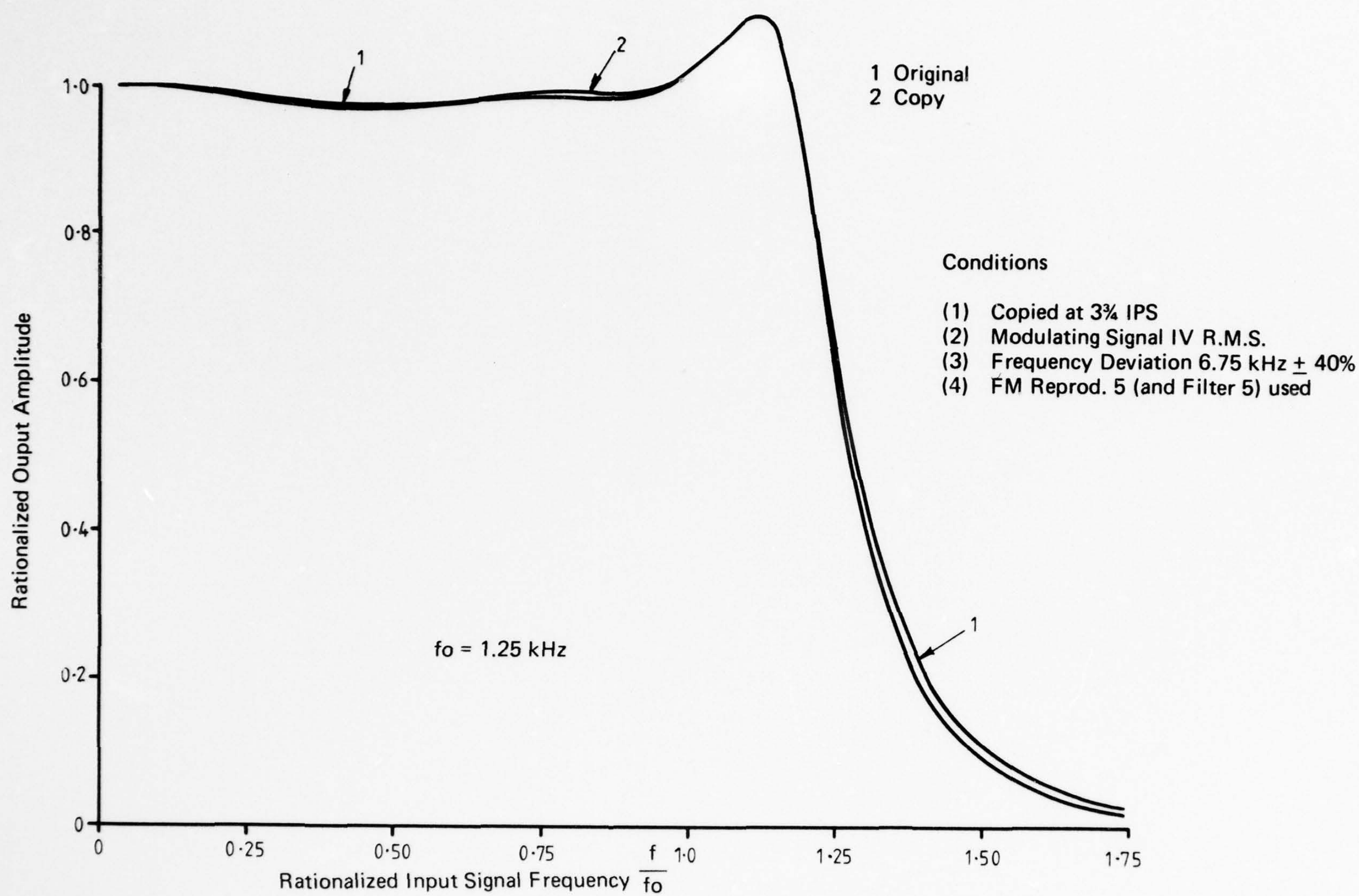


FIG. 38 EFFECT OF COPYING ON AMPLITUDE RESPONSE AT 3¾ IPS TAPE SPEED

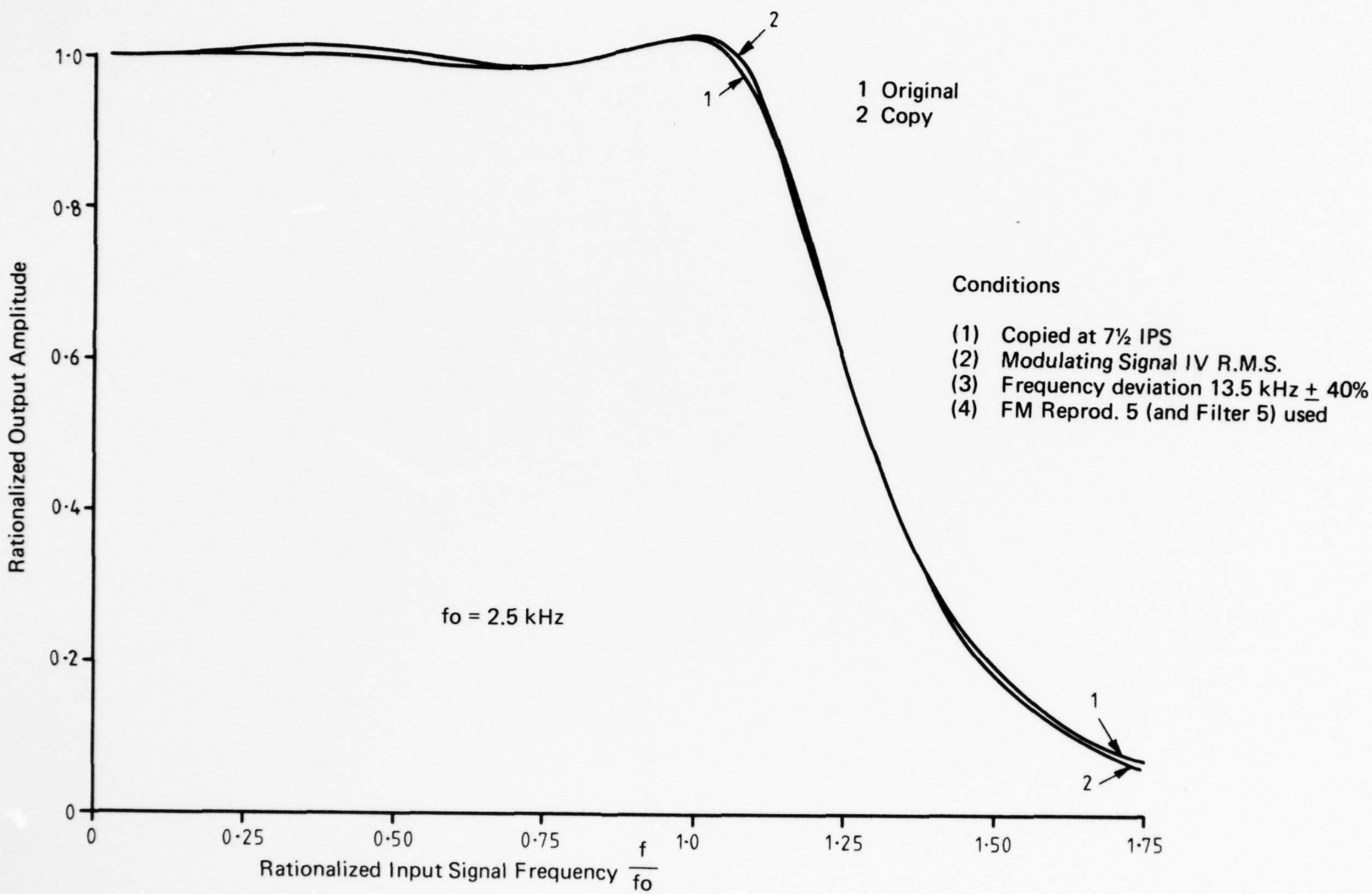


FIG. 39 EFFECT OF COPYING ON AMPLITUDE RESPONSE AT 7½ IPS TAPE SPEED

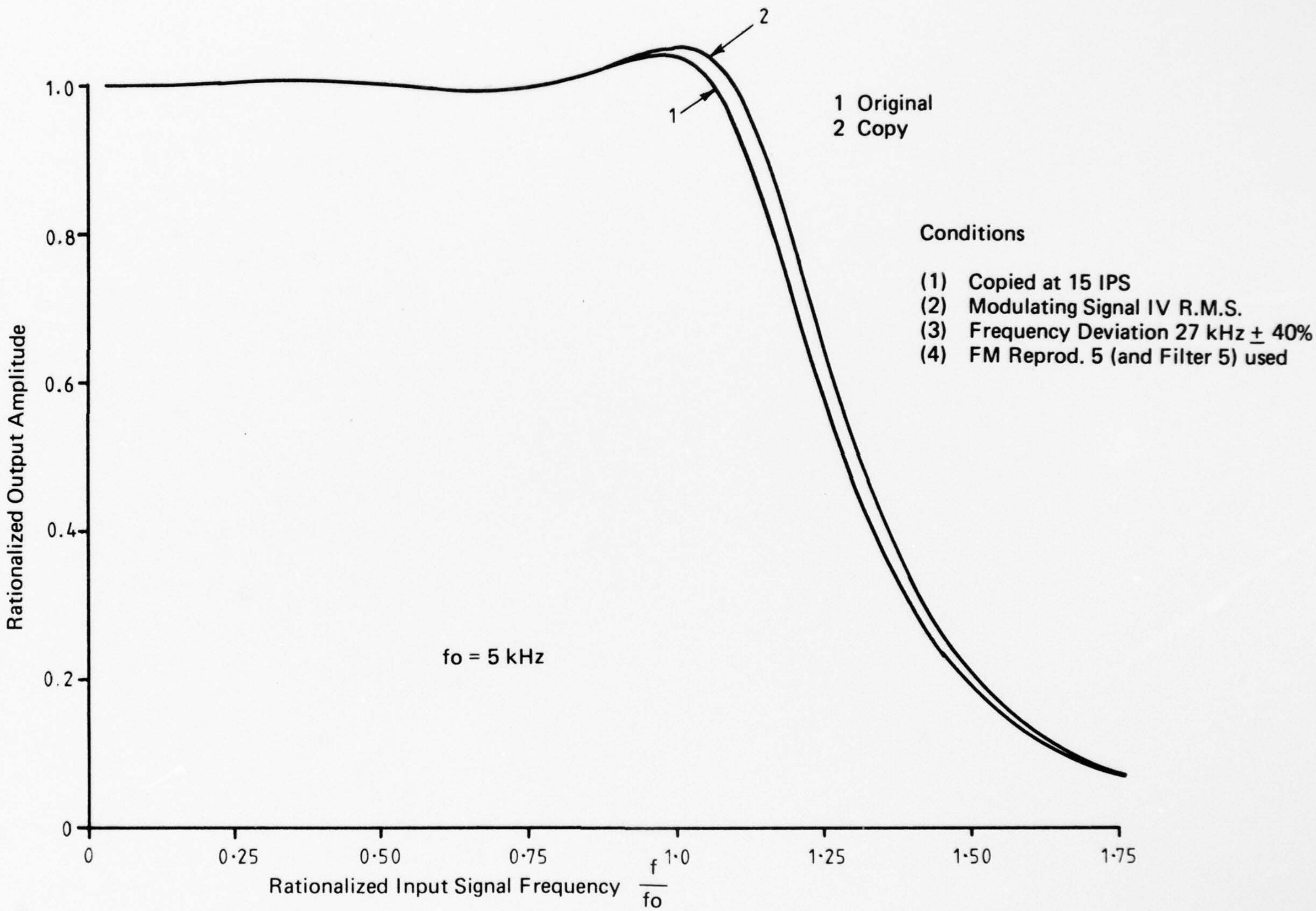


FIG. 40 EFFECT OF COPYING ON AMPLITUDE RESPONSE AT 15 IPS TAPE SPEED

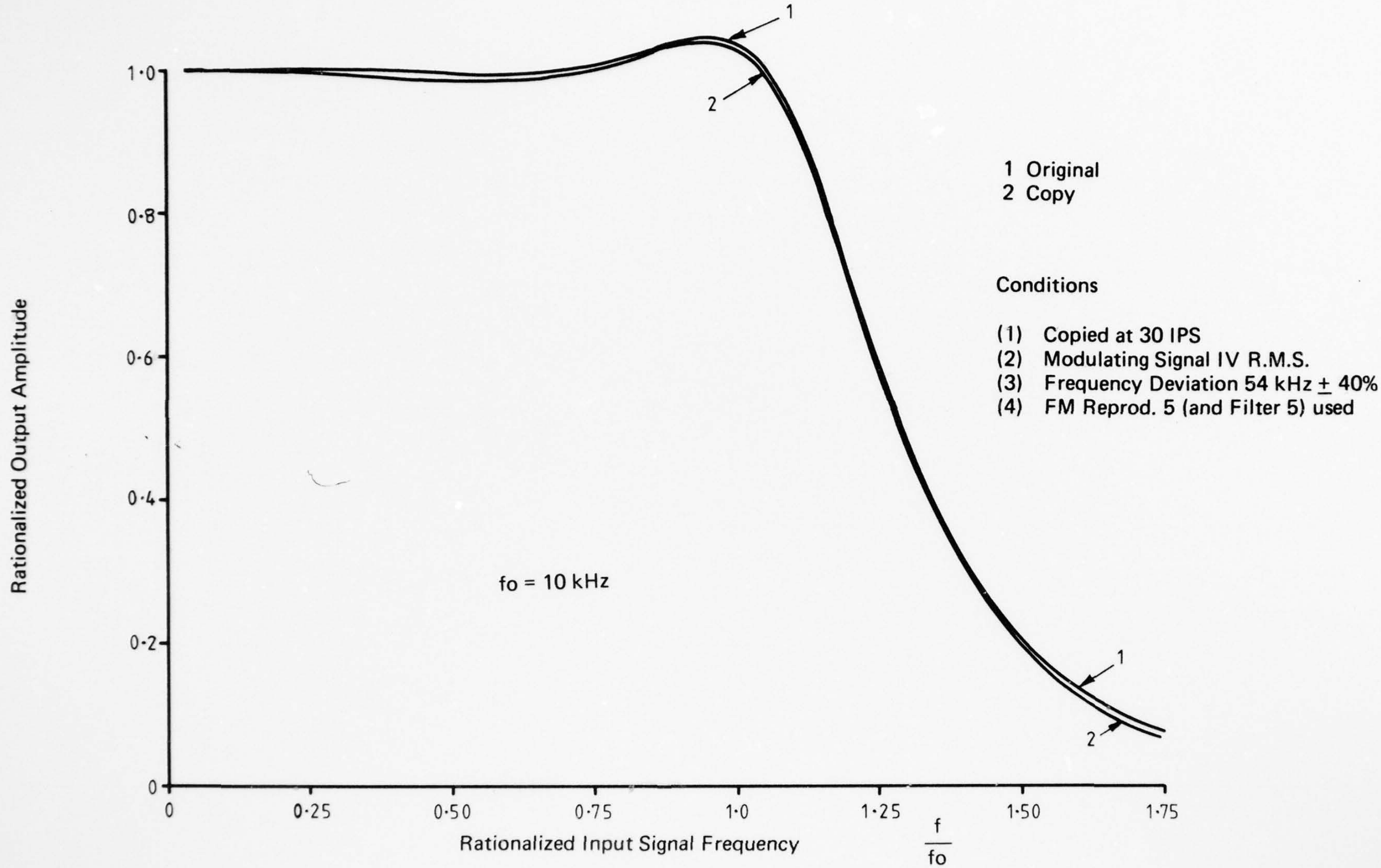


FIG. 41 EFFECT OF COPYING ON AMPLITUDE RESPONSE AT 30 IPS TAPE SPEED

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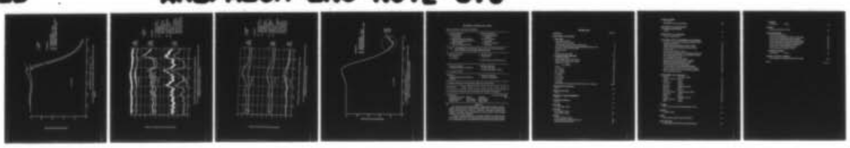

END
DATE
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9-79
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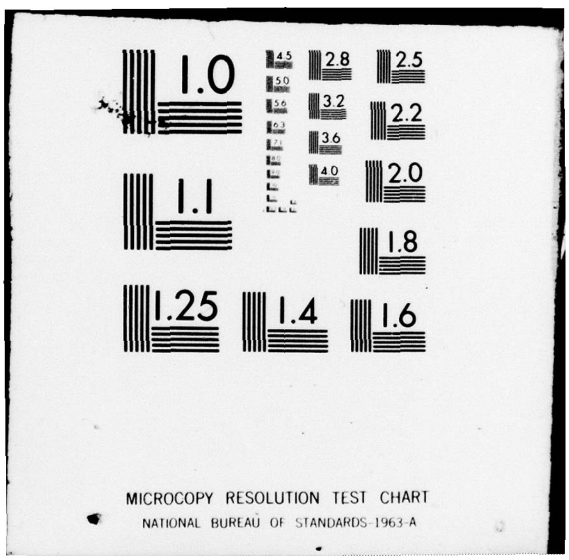
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

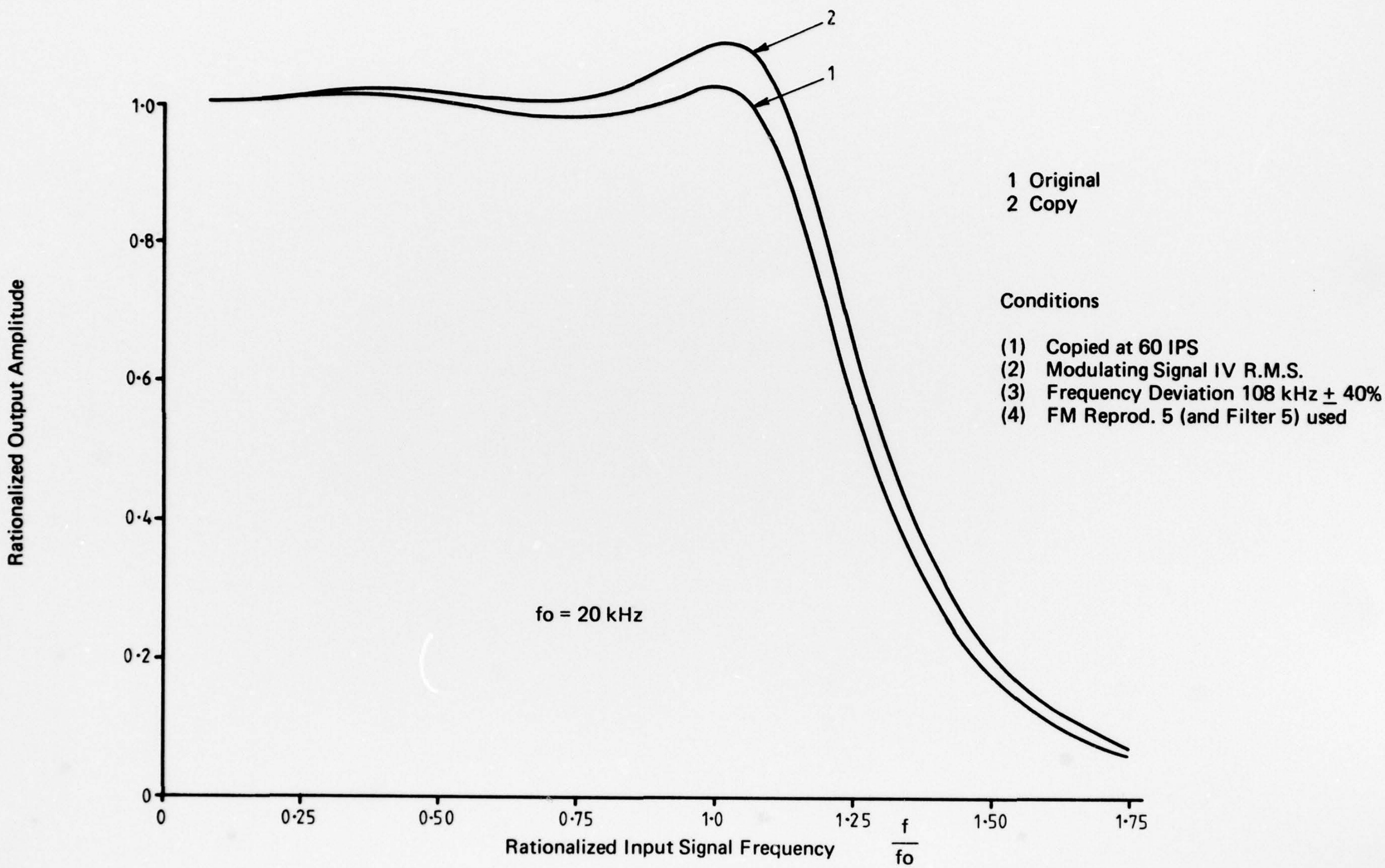

FIG. 42 EFFECT OF COPYING ON AMPLITUDE RESPONSE AT 60 IPS TAPE SPEED

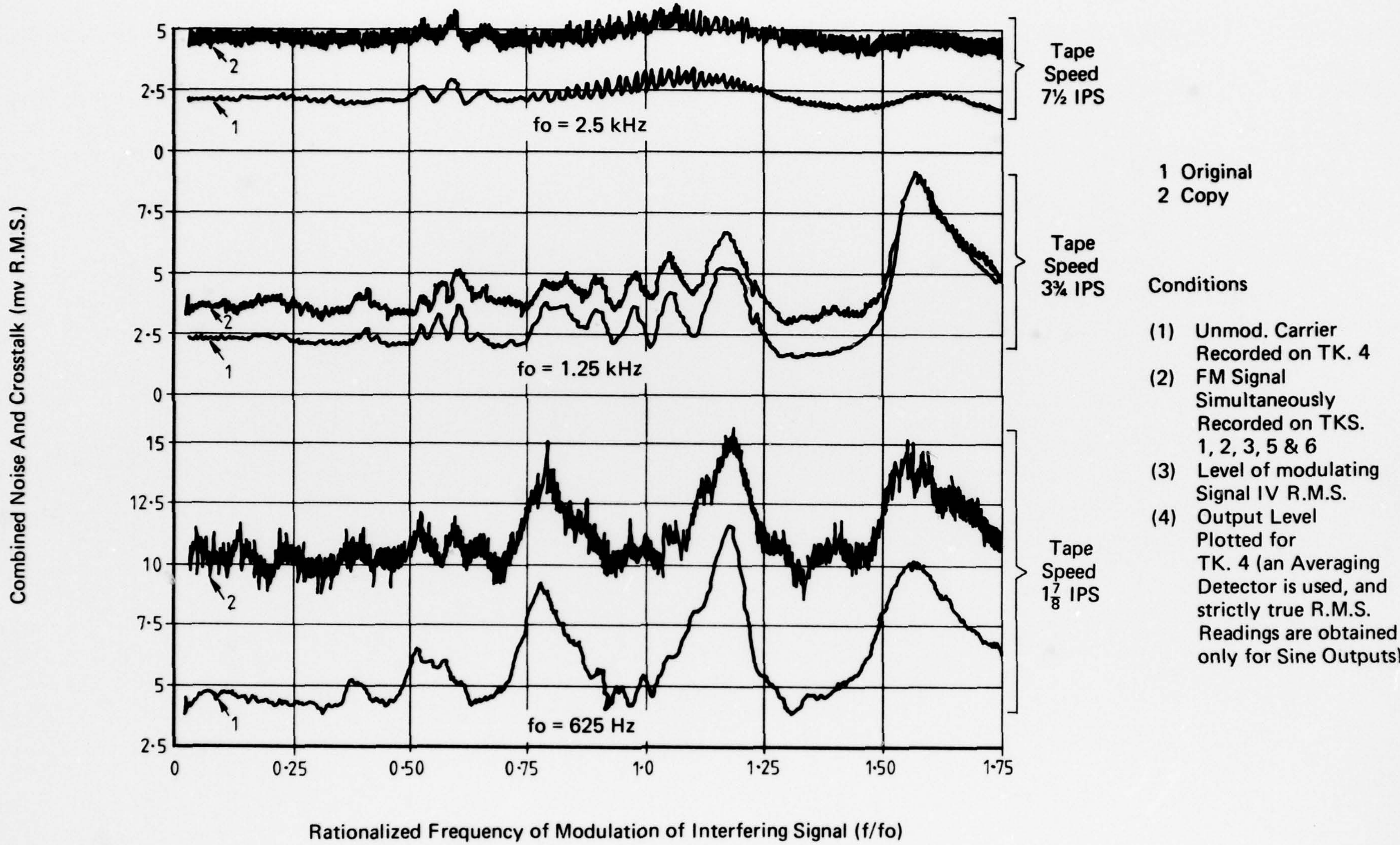

FIG. 43 COMBINED NOISE AND CROSSTALK INTRODUCED BY COPYING PROCESS FOR LOWER TAPE SPEEDS

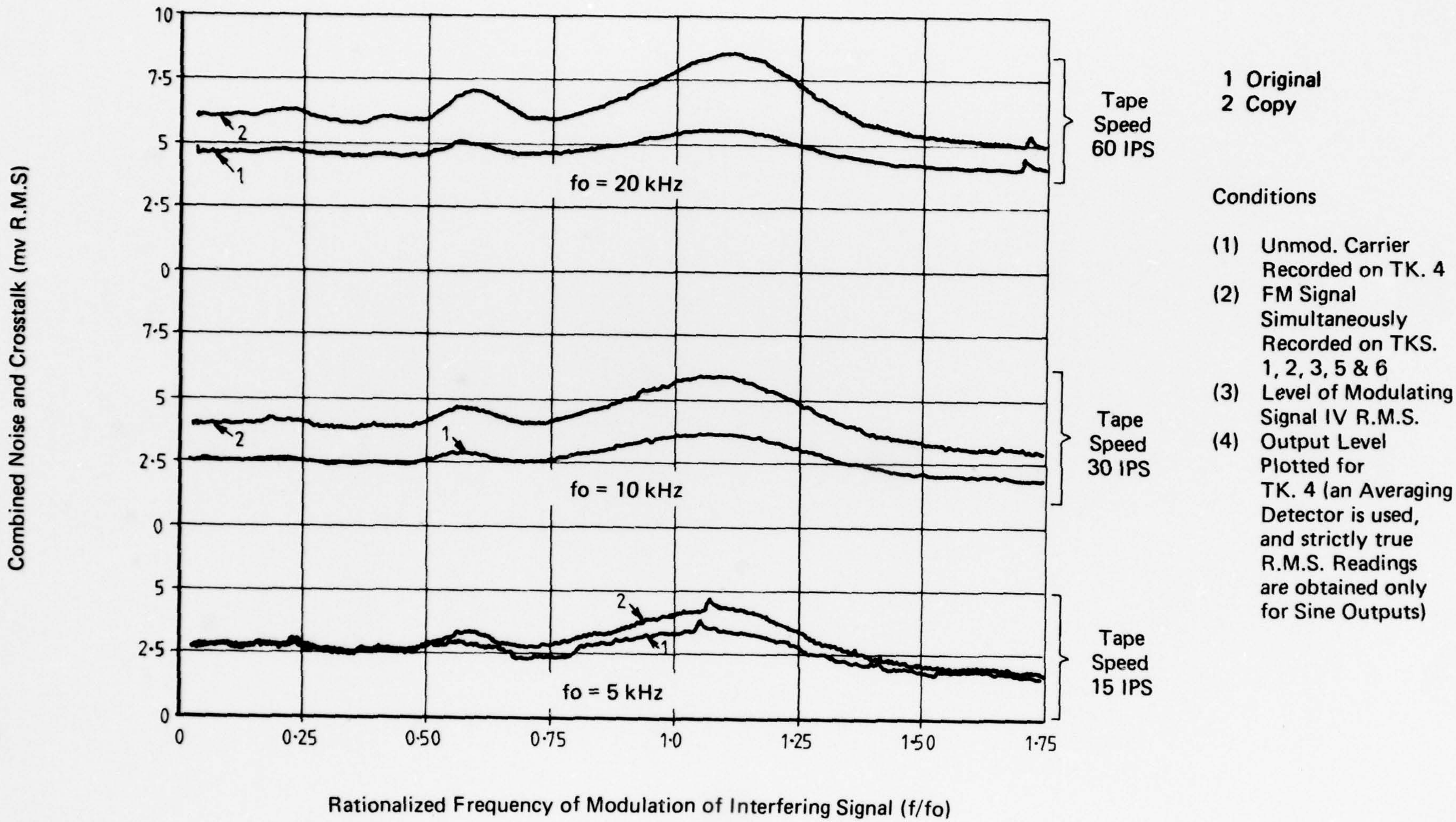

FIG. 44 COMBINED NOISE AND CROSSTALK INTRODUCED BY COPYING PROCESS FOR HIGHER TAPE SPEEDS

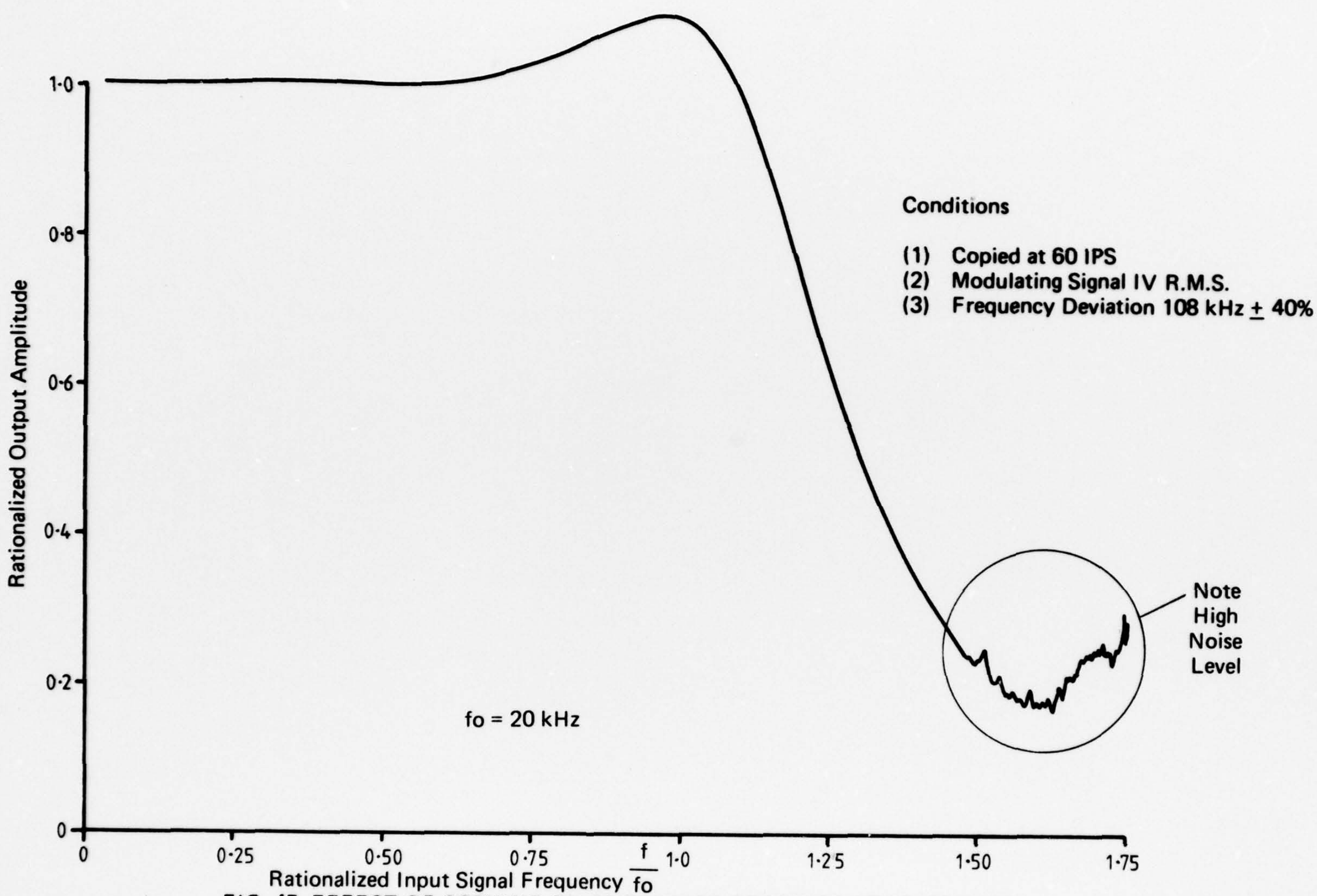

FIG. 45 EFFECT OF COPYING ON AMPLITUDE RESPONSE AT 60 IPS TAPE SPEED FOR NOISY TRANSMISSION CHANNEL

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Magnetic tape	Tape recorders	Digital signals

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    1403

16. *ABSTRACT*

The techniques described enable analogue or digital signals reproduced using one magnetic tape machine to be transmitted via land line cable and copied using another machine situated remotely (at least up to 270 metres). Also signals, generated using transducers for example, may be transmitted from a remote location to a tape recording machine or other receiving equipment.

A frequency divider in conjunction with standard magnetic tape reproducer hardware provides a simple means of low pass filtering of data recorded in frequency modulated form. Consideration is given to the production of an intermediate tape with filtered data.

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