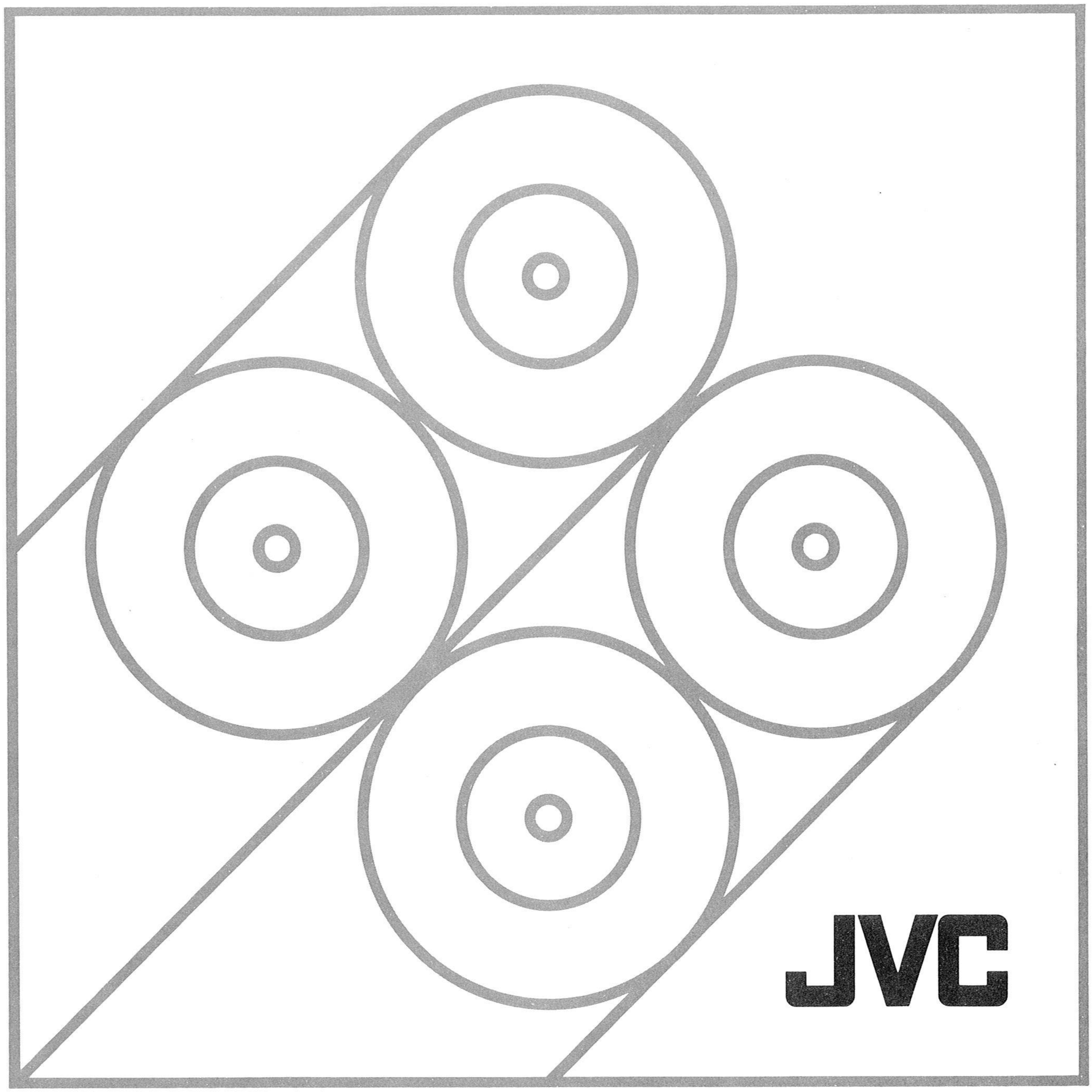


For a Better Understanding of CD-4

Principles of Discrete 4-Channel CD-4 System

1. Preface

The aim of 4-channel stereo is fuller and more accurate reproduction of the original sound field in order to improve Hi-Fi results in playback. This system greatly increases the sense of presence and dynamic force and makes possible minute separation of musical sounds, resulting in marked qualitative improvement in listening effect. The system has also opened up new possibilities for the creation of new musical art in the 4-channel sound field.

Since the essence of 4-channel reproduction, as stated above, involves reproduction of the original sound field, improvement of its sound quality, and enhanced possibilities of musical art creation, it follows that all four channels should be high-quality, crosstalk-free transmitting systems.

A 4-channel system composed of four independent transmitting channels is called a discrete 4-channel system. Systems using two transmitting channels and four speakers to achieve a 4-channel effect are called matrix systems.

2. Development of The CD-4 Disc

Discrete 4-channel reproduction was first made possible by open-reel tapes and was popularized through quad-8 tapes; however, 4-channel discs were eagerly awaited because of the economic and operational advantages.

The discrete 4-channel disc, which may be considered the "ace card" in the development of 4-channel reproduction, was developed on the basis of the following principles;

1) High-fidelity: that the channels faithfully transmit the original sound field.
2) Discrete: that adequate interchannel separation be maintained.
3) Compatibility: that 4-channel discs be playable on conventional stereo devices and that conventional stereo discs be playable with the new devices.
4) Economy: that both the hardware and software be low in cost but high in operational capability.
5) Standardization: that the system be standardized worldwide for interchangeability.

Taking C from "compatible", D from "discrete", and 4 from "4-channel", the disc was designated "CD-4".

CD-4 discs and reproduction units were put on the market in Japan in July, 1971. Today, more than 100 albums are catalogued. The CD-4 disc has been specified as the standard discrete disc by the Technical Section of the Japan Record Industrial Association, and a number of major labels are preparing to put CD-4 records on sale in the near future.

3. Principles of the CD-4 System

4-Channel signals are converted into sum signals and difference signals. As shown in Figs. 1, 2 and 3, the sum signals of CH1 + CH2, and CH3 + CH4 are recorded in a conventional 45-45 groove. The difference signals CH1 – CH2, and CH3 – CH4 are frequency modulated and superimposed in the same groove. In reproduction, the modulated difference signal is detected, after which the

$$\tfrac{1}{2}\,[(CH1 + CH2) + (CH1 - CH2)] = CH1$$
$$\tfrac{1}{2}\,[(CH1 + CH2) - (CH1 - CH2)] = CH2$$
$$\tfrac{1}{2}\,[(CH3 + CH4) + (CH3 - CH4)] = CH3$$
$$\tfrac{1}{2}\,[(CH3 + CH4) - (CH3 - CH4)] = CH4$$

computation is done, and the four original signals come out independently. As each channel is thus identically related to the direct signal and the carrier signal, the four reproduced signals are equal in quality, which is the distinctive feature of the system. When a CD-4 disc is played on a conventional stereo player, only the sum signal of the audio frequency range is reproduced, making it possible to reproduce all the information without any loss.

There may be some concern about the possibility of damaging the groove if a conical stylus with a high stylus pressure is used, because the modulated signal has a very short wavelength. However, even after hundreds of trackings with a conical stylus with 5.5 gr. pressure, the loss in the modulated signal is very slight, which means satisfactory reproduction of 4-channel stereo. Under the circumstances, no problem will be encountered if the disc material is made harder and a demodulator of higher sensitivity is developed. The CD-4 is an excellent system having both musical and mechanical compatibility.

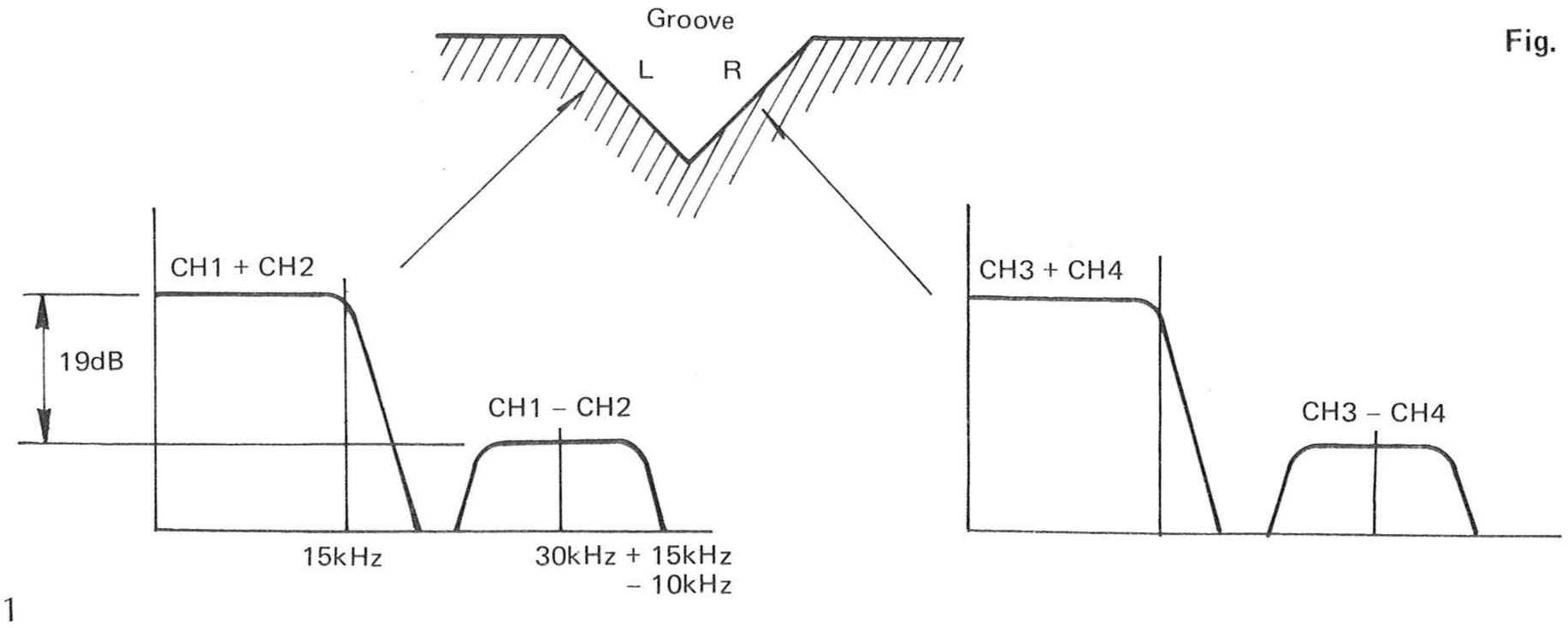


Fig. 1 CD-4 Disc

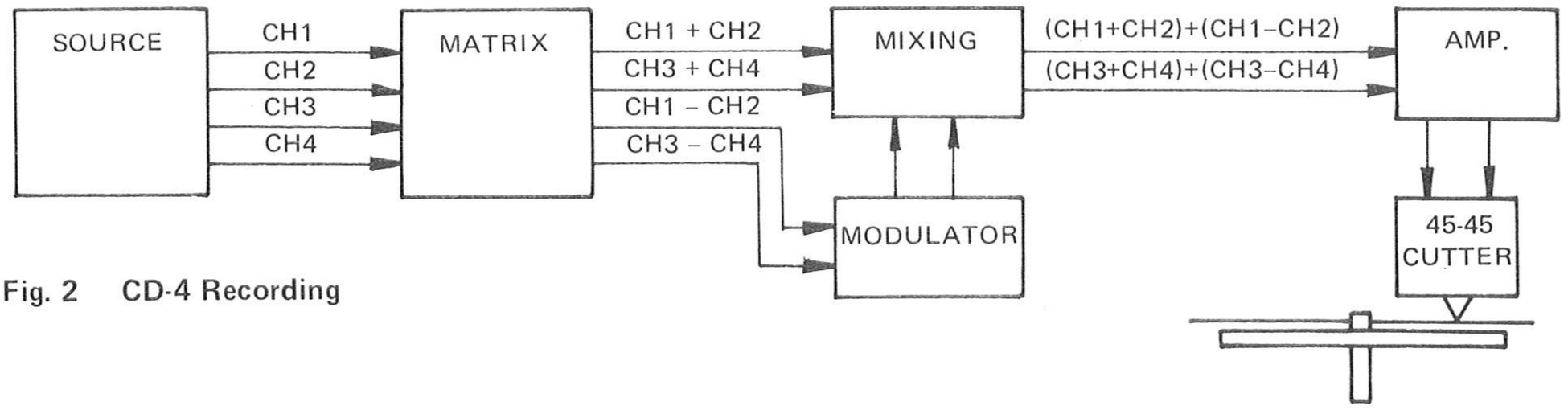


Fig. 2 CD-4 Recording

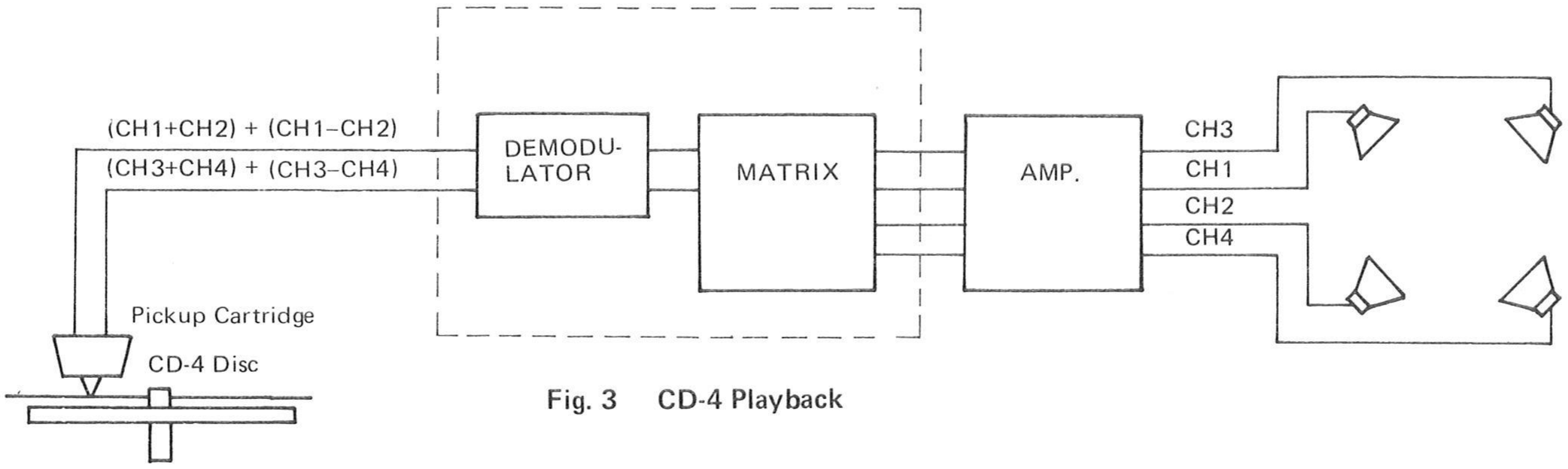


Fig. 3 CD-4 Playback

4. Recording Characteristics of the CD-4 Disc

The most significant technical point about CD-4 is that the 30kHz carrier is modulated by the difference signal.

When broken down to basics, the main modulating systems are AM, FM and PM. These systems are compared as to suitability for discs in Table 1.

AM is not suitable, and both FM and PM have certain disadvantages, so CD-4 uses a modulating system that takes advantage of the merits of both FM and PM. In the CD-4 system, studies were made of the dynamic range, etc., of various frequencies of modulating signals, and the modulation curve shown in Fig. 4 was adopted.

A serrasoid modulator is used, and a dynamic range of about 90dB is obtained.

Recording characteristics include RIAA characteristics for direct signals and a standard level of 22.3mm/sec for compatibility with conventional stereo discs. Recording velocity is constant at a modulated signal level 19dB below that of the direct signals, thus facilitating stylus tracking during reproduction. The carrier level is set at 35.4mm/sec. The recording characteristics are as shown in Fig. 5. As stated before, these values have been standardized by the Technical Section of the Japan Record Industrial Association.

	FM	PM	AM
Minimum Necessary Frequency Range	20 kHz – 50 kHz	20 kHz – 50 kHz	20 kHz – 50 kHz
S/N	Good at low frequency	Good at high frequency	Bad
Utility of Frequency Range	Good	Bad at low frequency	Fair
Effect of PU Crosstalk	Distorted crosstalk at medium tone	No effect at suitable modulation range	Unstable crosstalk of distortion and level
Playback level Fluctuation	None	None	Depends on PU but generally large
Effect of Direct Signal	Slight	Slight	Severe
Effect of Dust and Scratches on the surface of disc	Slight	Slight	Severe
Life	Long when level of FM modulation is correctly selected.		Very short as modulation signal varies considerably.

Table 1 Comparison Chart between Modulation Methods

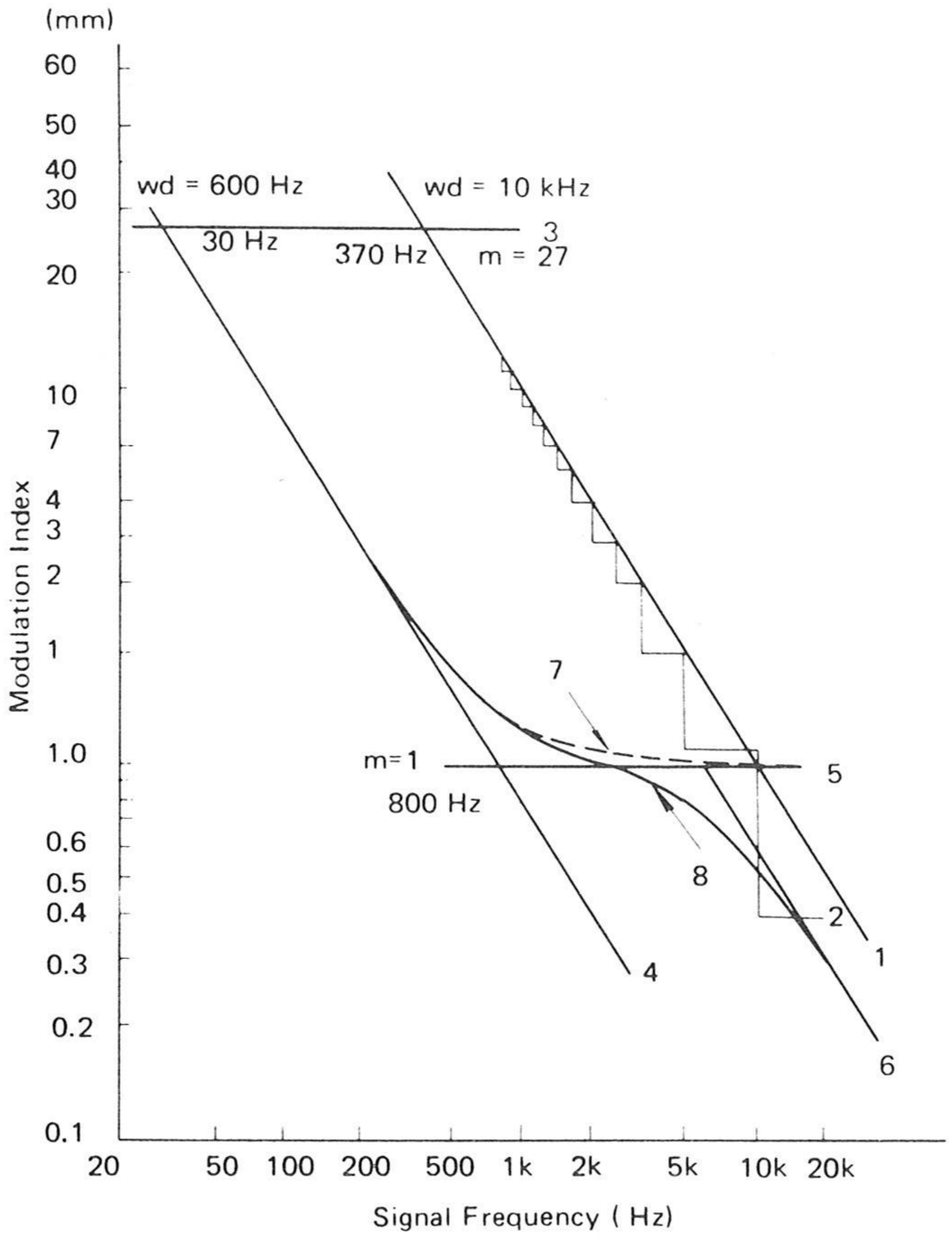


Fig. 4

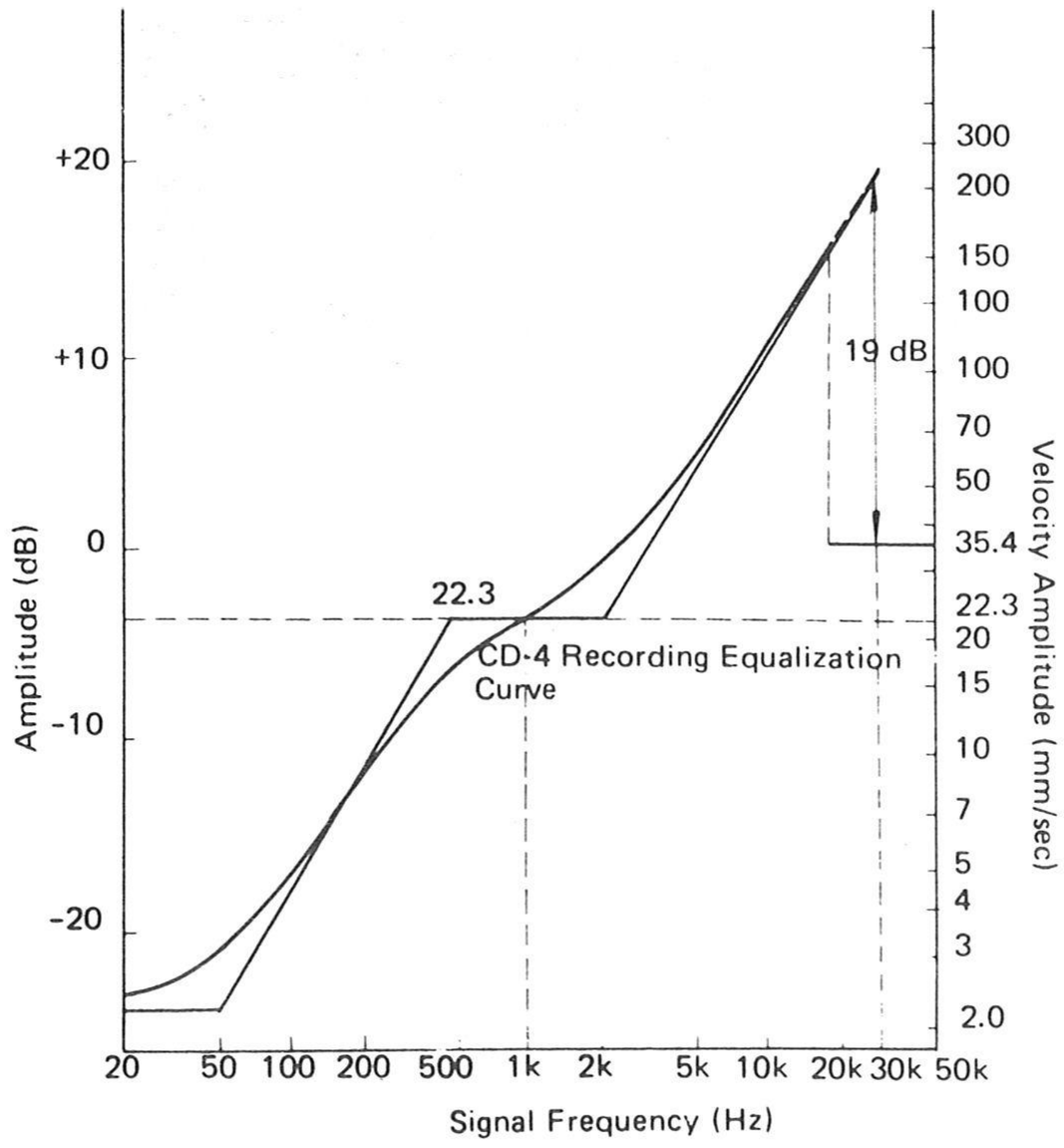


Fig. 5 CD-4 Recording Equalization Curve

5. Cutting of the CD-4 Disc

Advanced techniques are employed in cutting to lighten the burden on the reproduction system so that discs and demodulators can be widely marketed at reasonable prices.

The following are the essential points in cutting:

1) Beat is not generated because of modulated signal recording with a single master oscillator.
2) A 40μsec delay line is inserted into the direct signal line to facilitate timing of the direct signal with the modulated signal in playback.
3) To ease the burden on the pickup cartridge, a Neutrex which compensates for distortion arising from the carrier level controller (CLC) and waveform compensator, and an automatic noise reduction system (ANRS) have been adopted, thereby obtaining sound quality equal to or better than conventional 2-channel stereo.

The CD-4 record requires frequency response of up to 45kHz in the cutting. However, in consideration of cutter head capability, reduced cutting speed is applied. With further improvements of the cutter head performance, normal cutting speed will be possible for the disc in the future.

Fig. 6 is a block diagram of the cutting system. Fig. 7 is a photograph of the entire system. Incidentally, the process of making the record is identical with the existing process from the lacquer disc through to the finished disc.

CLC and Neutrex were developed for the purpose of stabilizing pickup cartridge tracing, thus achieving high-fidelity reproduction. As seen in the block diagram in Fig. 6, CLC detects the signal level by means of the advance head and controls the carrier level automatically so that automatic carrier level cutting will be optimum in line with variations in the direct signal level. When the modulated signal is reproduced, the direct signal and the modulated signal may be distorted and, at the same time, the modulated signal may be modulated by the direct signal, as shown in Fig. 7. In order to solve this problem and obtain a normal pickup waveform, the Neutrex corrects the composite signal and the modulation in advance.

With CD-4, a modulated signal wavelength shorter than that of the conventional record requires that precautions be taken against noise as well as for reduction of demodulated signal crosstalk distortion arising from pickup cartridge crosstalk. An automatic noise reduction system (ANRS) was adopted to take care of this problem. The noise spectrum at the time of modulated signal reproduction is shown in Fig. 8. FM noise rises in the high range and PM noise flattens out, and the values actually measured show the effect of this. Consequently, it is necessary to improve the S/N ratio above 2kHz.

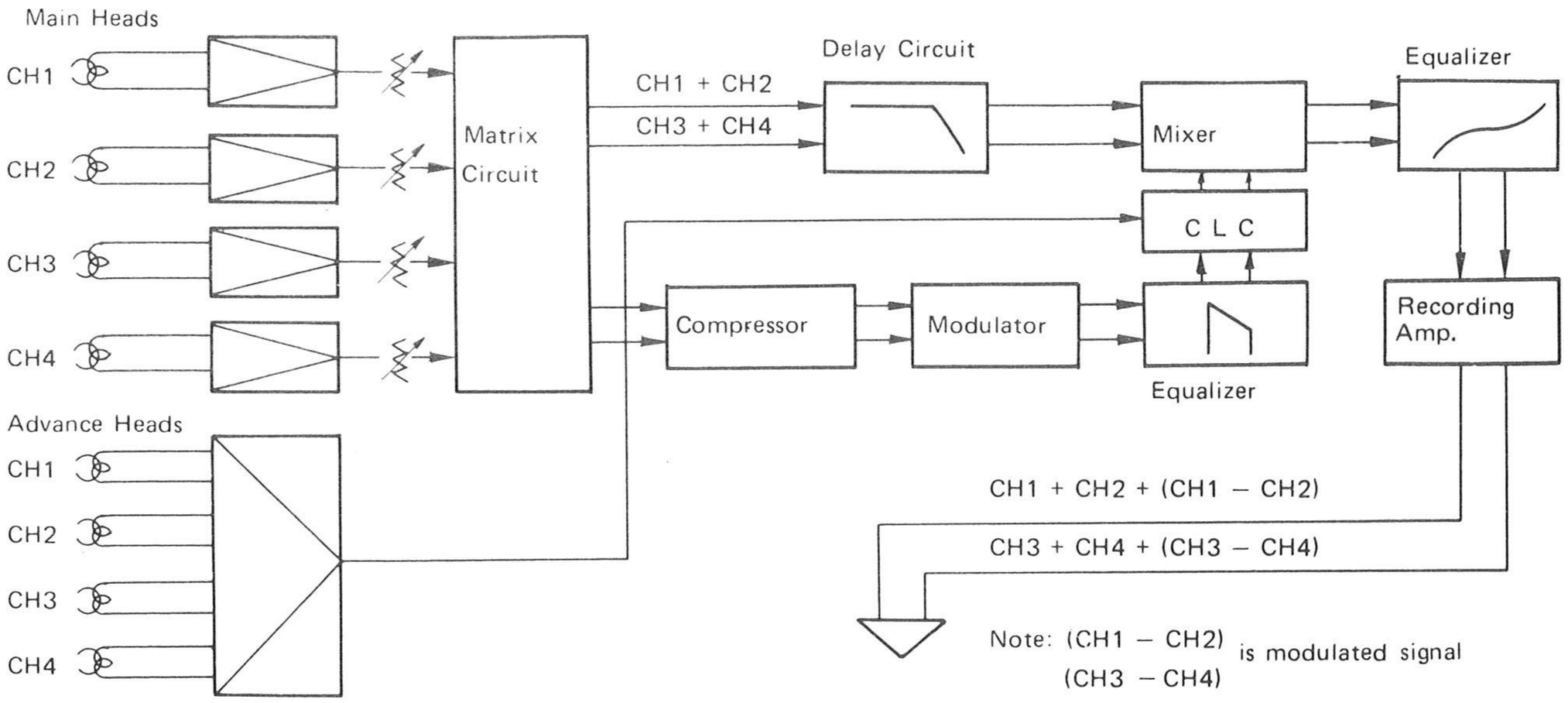


Fig. 6 Block Diagram of Cutting System

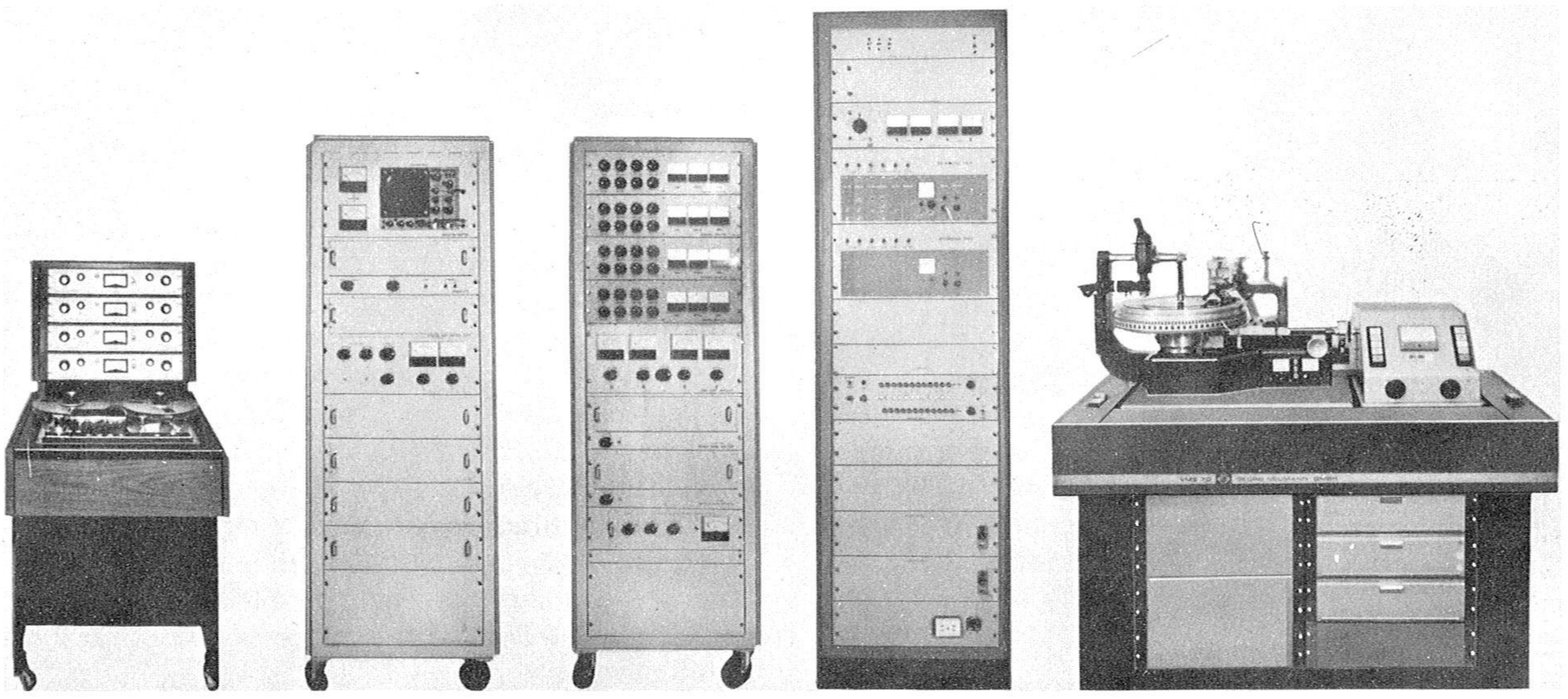


Photo 1 CD-4 Cutting System

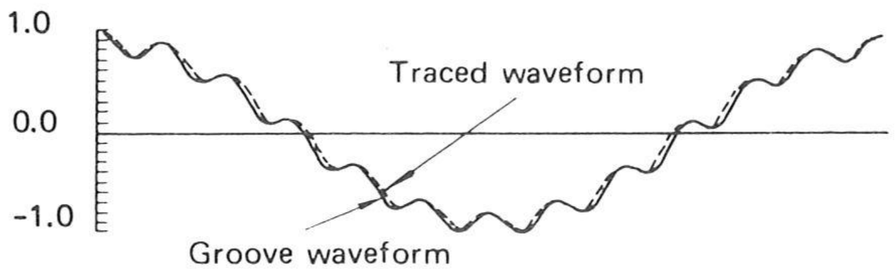


Fig. 7 Groove Waveform and Traced Waveform

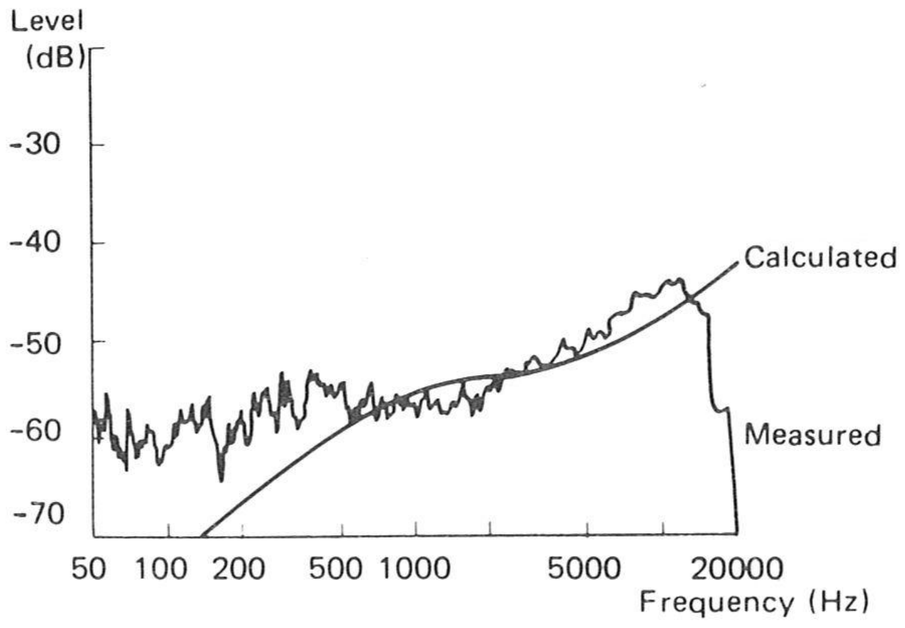


Fig. 8 Noise Spectrum of CD-4

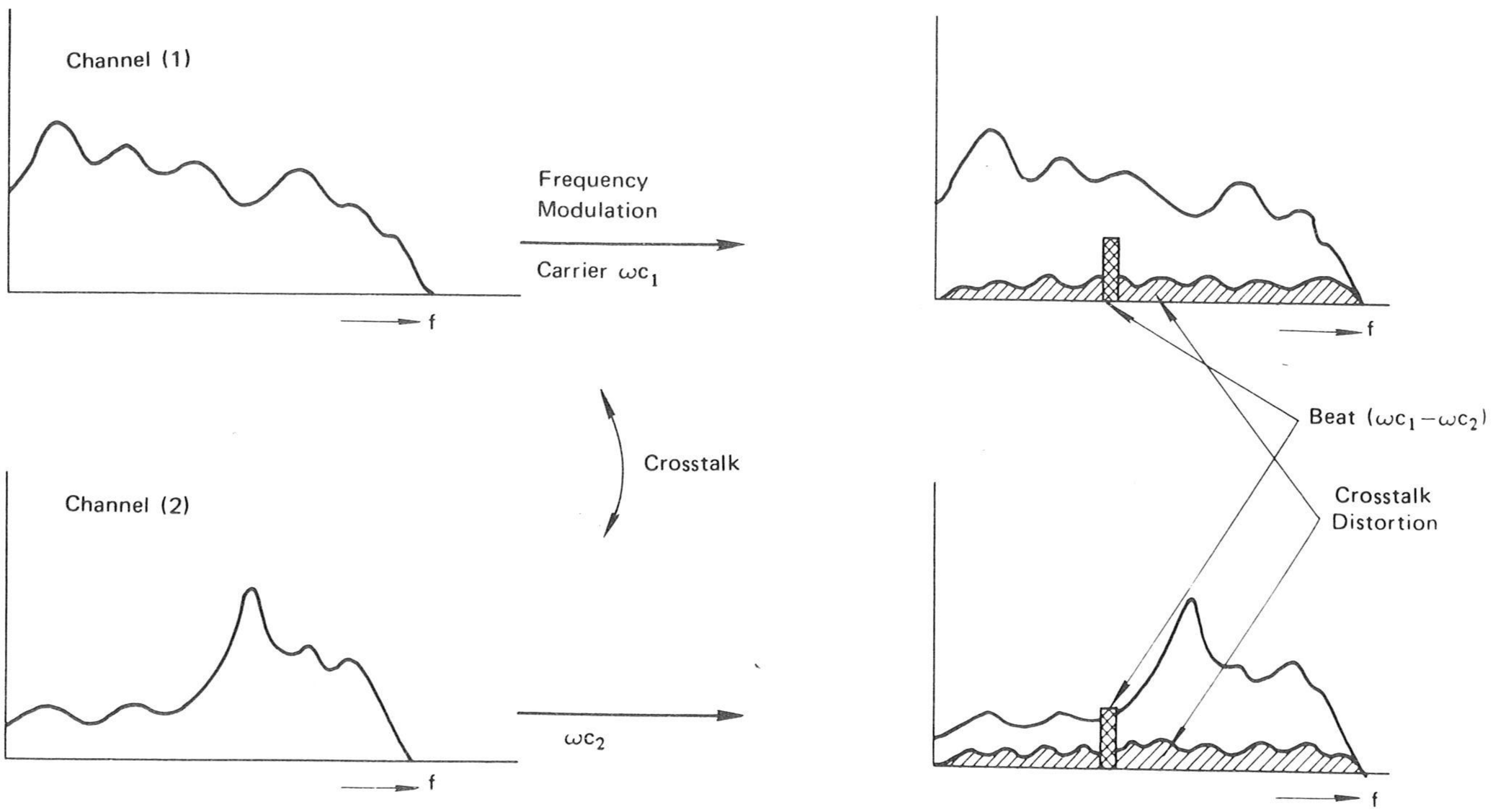
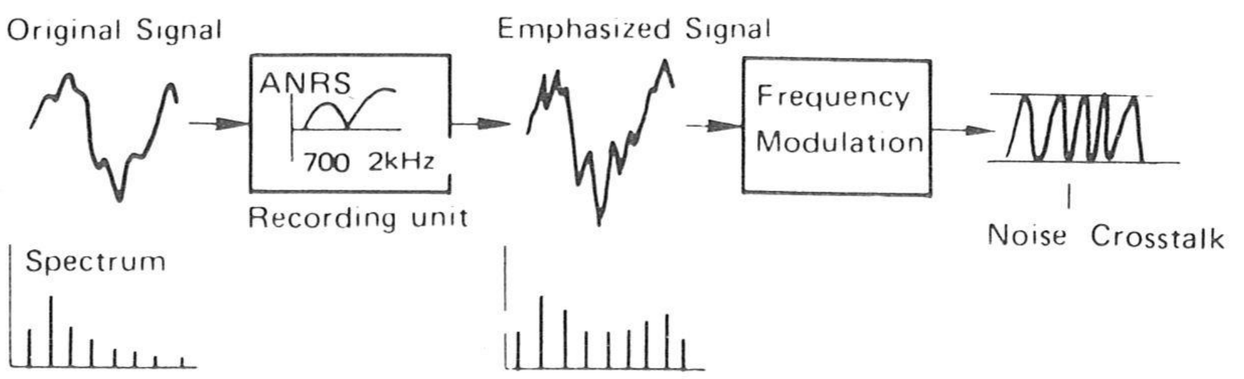


Fig. 9 Effects of FM Crosstalk

Distortion caused by crosstalk develops as shown in Fig. 9. According to theoretical computations, some differences are evident depending on modulation conditions, but there is a tendency for distortion to concentrate near 700Hz. A pickup cartridge with 30dB crosstalk would be required to reduce this to a level undetectable in practical operation. ANRS was developed so that Hi-Fi reproduction would be possible at a low range of FM noise (as mentioned previously) using a normal cartridge with crosstalk 15dB or so.

The improvement realized with ANRS is shown in Fig. 10. Incidentally, the problem of beat, as stated before, has been solved by using one master oscillator. The ANRS, as shown in Fig. 11, is of block construction and the circuit configuration is of a well known type. The basic characteristics of ANRS are as shown in Fig. 12. While FM noise and crosstalk distortion have been markedly improved by using ANRS, there is no deterioration of characteristics since the input and output are equal. And, since ANRS is applied only to the modulated signals, no difficulties are encountered when CD-4 discs are played on conventional 2-channel stereo devices.



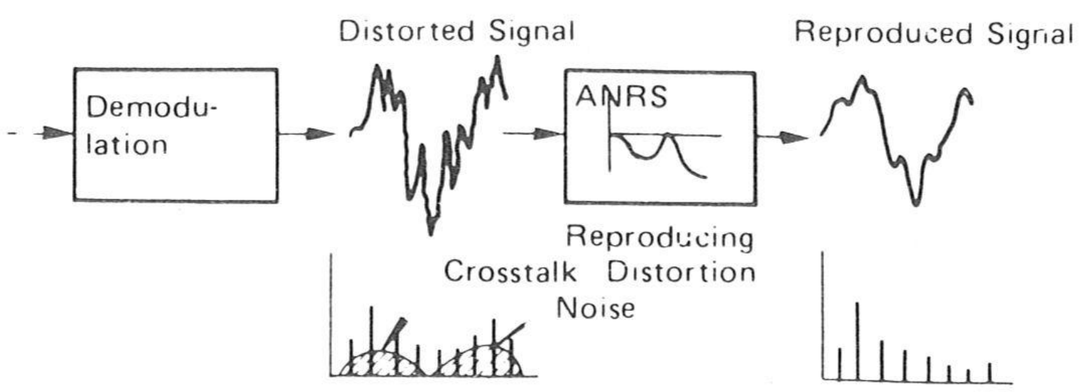
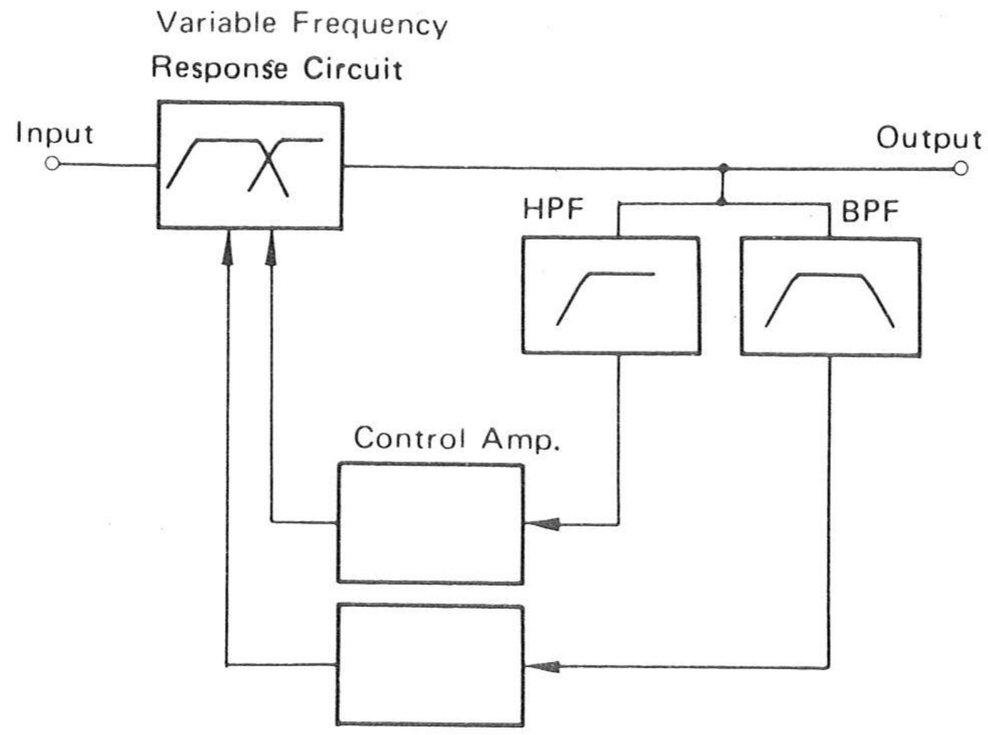
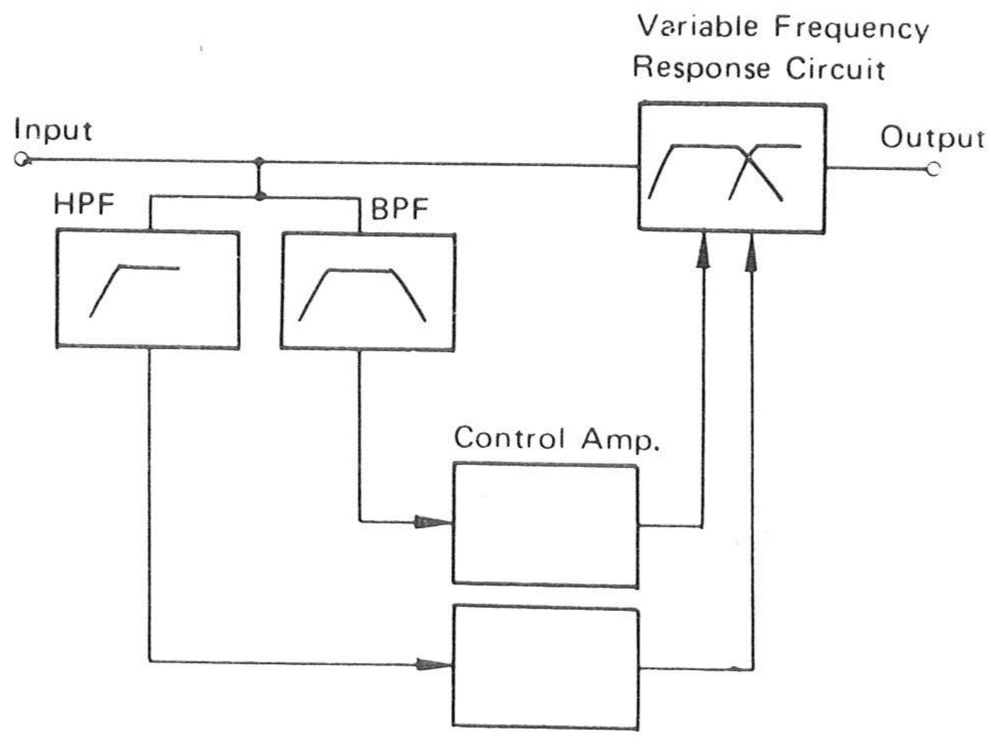


Fig. 10 ANRS Process



(Compressor Block Diagram)



(Expander Block Diagram)

Fig. 11 Actual Block Diagram of ANRS

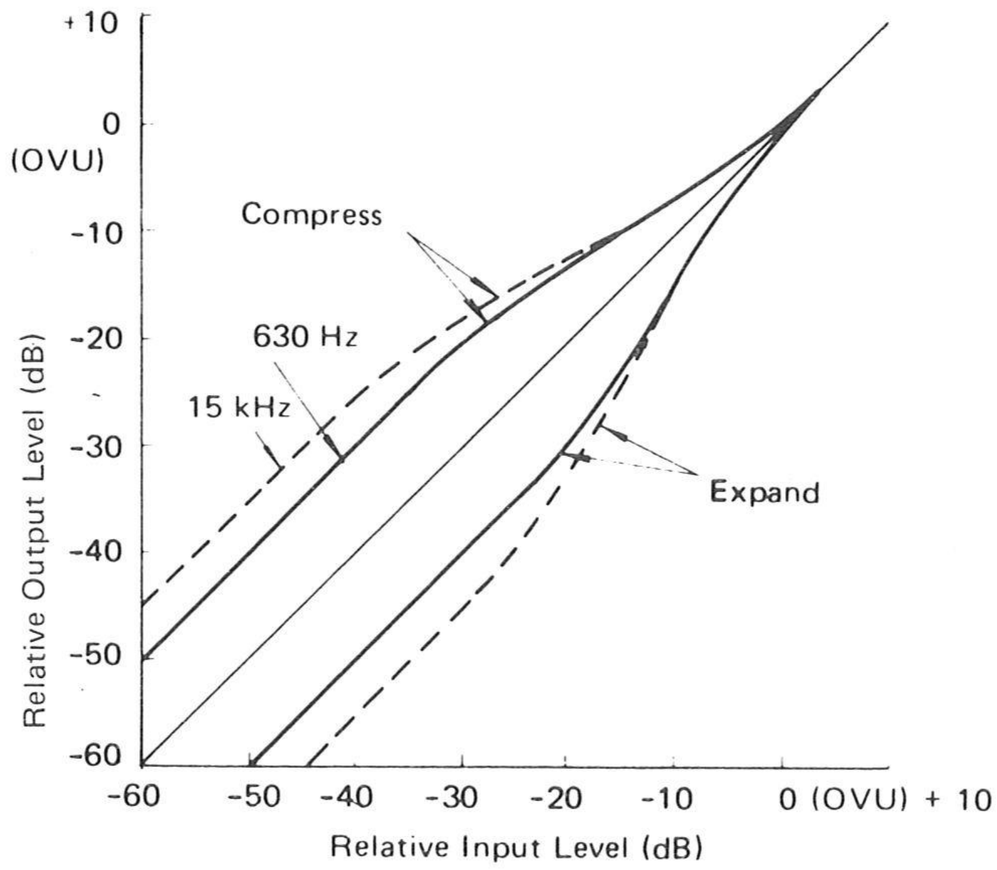


Fig. 12 Level Response of ANRS

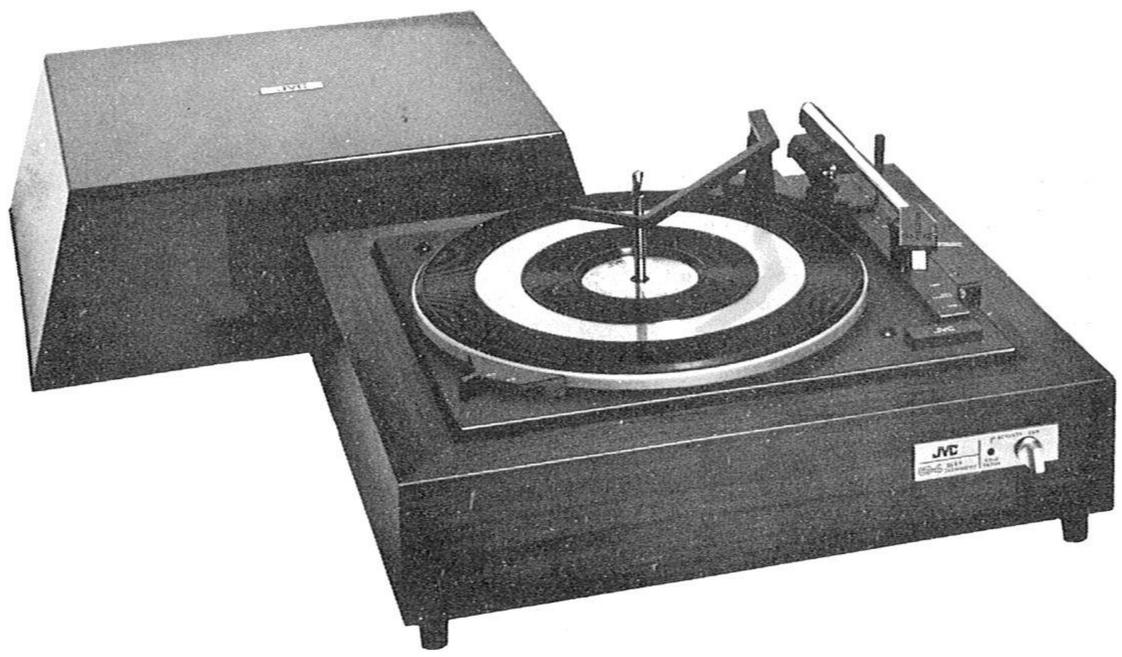


Photo 2 4VC-5244
4-Channel Turntable with
Built-In Demodulator

6. CD-4 Disc Reproduction

Fig. 13 is a block diagram of the CD-4 playback system. The most important parts of the system are the pickup cartridge and the modulated signal detector.

Ideally, the playback stylus should be identical to the recording stylus. In general an elliptical stylus is used for Hi-Fi reproduction; however, the Shibata stylus, with a large contact area against the record groove and outstanding capability for accurate pickup of modulated signals, has been developed.

Fig. 14 shows a comparison of the frequency response of the Shibata stylus with that of a conventional elliptical stylus. The use of the Shibata stylus increases the area of contact with the groove by about four times, and the pressure per unit area is reduced to one-fourth. For this reason, the disc material apparently becomes harder, the frequency response becomes flat up to a higher frequency, and the service life of the disc is prolonged.

While the conventional conical and elliptical styluses are both practical for CD-4 disc reproduction, the Shibata stylus gives better Hi-Fi reproduction.

Advanced circuits were recently developed for detection of FM signals. It is possible with these to pick up the signals even when the carrier level drops by as much as 20 to 30dB. Namely, 4-channel playback can be adequate even with a cartridge without sufficient high range capability, or even with damaged discs. This is the result of angular modulation of higher frequency recording. In other words, CD-4 discs can be handled in the same way as conventional stereo discs.

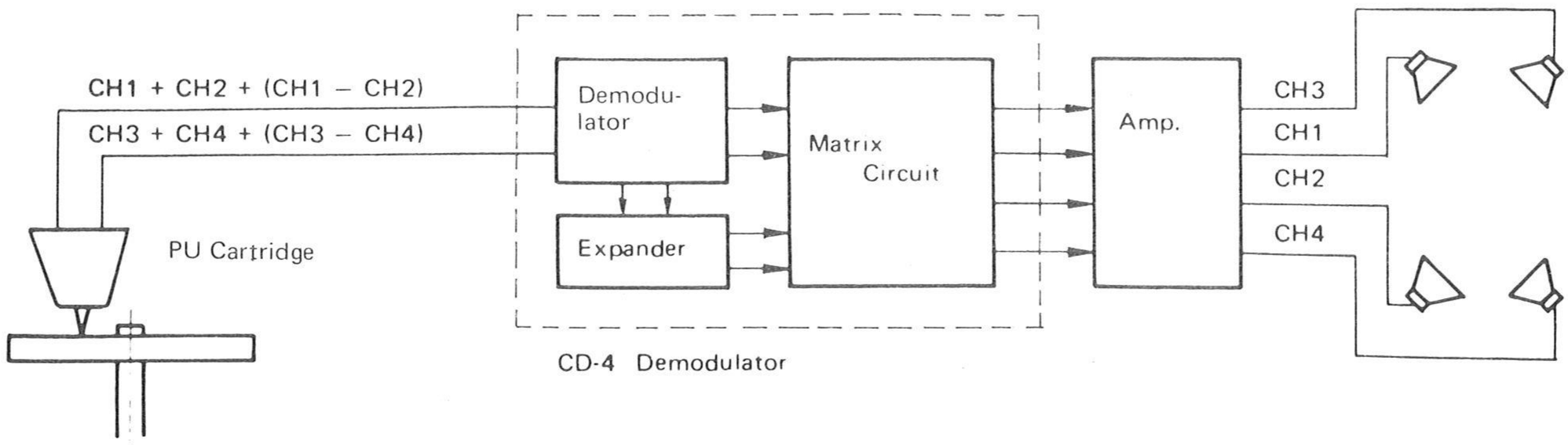


Fig. 13 Block Diagram of Playback System

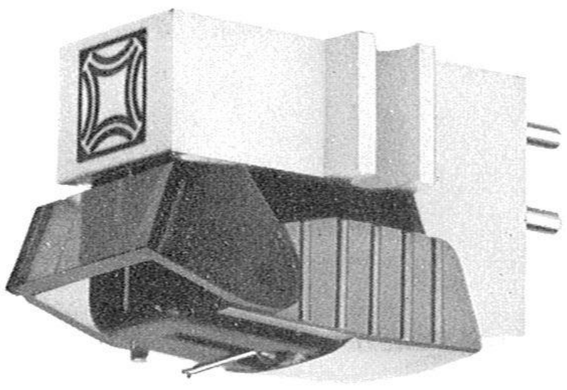


Photo 3 4MD-20X
4-Channel Cartridge
with Shibata Stylus

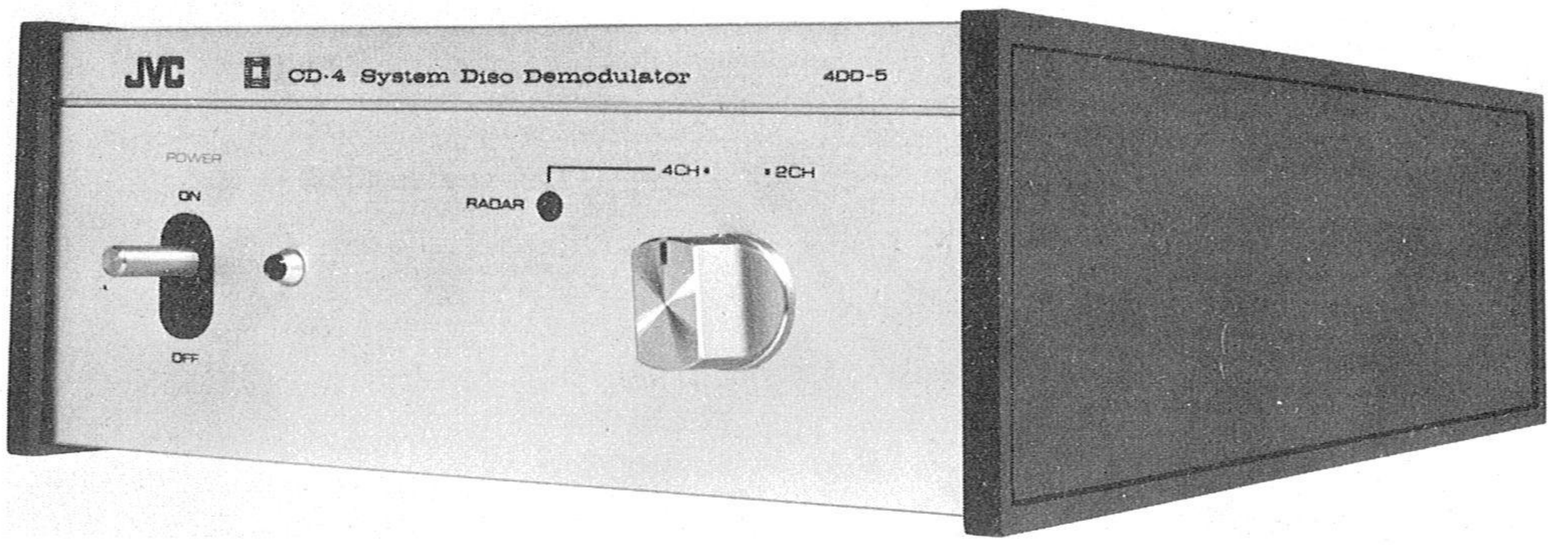


Photo 4 4DD-5
CD-4 Disc Demodulator

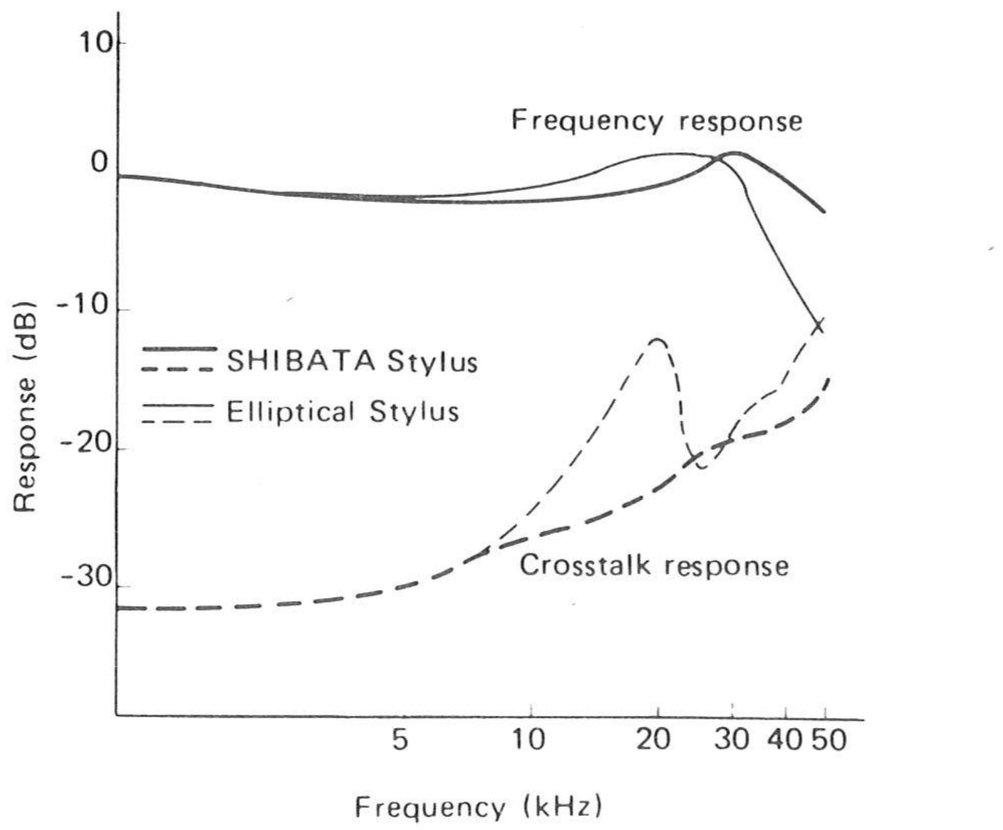


Fig. 14 Frequency Response of Shibata Stylus and Elliptical Stylus: CD-4 Cartridge

7. Conclusion

Victor Company of Japan started marketing CD-4 discs, demodulators and Shibata styluses in Japan in July, 1971. As a result, notable changes have occurred in the Japanese market. Specifically, the appearance of a discrete 4-channel system has made the enjoyment of 4-channel music generally available, and the difference between the discrete system and the matrix system has become recognized. In particular, audio and music critics, whose opinions are influential, have called attention to such features of the discrete system as minute separation of music sources, a rich sound field, and pleasant sound that does not tire the listener. True 4-channel reproduction, which aims at hi-fi reproduction superior to that of conventional 2-channel reproduction, can be obtained economically only with the CD-4 discrete system.

As is well known, the matrix system has lately become more complex and expensive because of alleged improvements in phase-amplitude matrix and apparent reduction of crosstalk by logic. However, it is clear that this system cannot become ideal as long as it employs only two transmitting channels. The discrete system, on the other hand, starts with the ideal state in 4-channel reproduction and is following a normal course of development by reducing costs while maintaining a high level of performance. The discrete system is ready to enter the stage of mass-marketing.

Recording of CD-4 Disc

Four-Channel Recording System

Various systems have been developed in an effort to realize the full possibilities of 4-channel reproduction from records. 4-Channel systems are now being marketed in the United States, Europe and Japan. Of the various systems, the one considered most promising by the music industry is the CD-4 disc, the only discrete system, which is being marketed in Japan and by RCA in the US. Victor Company of Japan and Nihon Polydor have already put on the market about a hundred different titles for the CD-4. With the likelihood of increases in the future, 4-channel recording has now become almost a daily routine. The 4-channel source recording and CD-4 cutting systems will be introduced and described in this section.

Studio Recording System for CD-4

1. The Effect of the 4-Channel System

The development from monaural to 2-channel stereo was a step toward greater high-fidelity reproduction. The improvement is considered to be due to the psychological influence of the sound field rather than to the improvement of physical parameters, such as frequency response, non-linear distortion, signal-to-noise ratio, etc. Similar observations could be made of 4-channel stereo, for the following are cited as the significant characteristics of 4-channel reproduction:

1) Concert hall effect (ambiance).
2) New sound, new music.
3) Greater enrichment of sound.

2. Studio Recording System

A comprehensive multi-microphone and multi-track recording system has been adopted in the recording studio of Victor Company of Japan. The reasons for this are:

1) Efficient studio operation.
2) Creation of better sound.

The mixing console has microphone inputs for 24 channels and output of 8 or 16 channels. The reverberation time of the studio was designed at 0.6 second.

3. Mastering System

The following functions are provided for tracking down the original tape recorded in the studio:

1) Reverberation control.
2) Delay effect.
3) Equalization.
4) Limiting.

In the process, considerations of musicality and sound quality are studied carefully by the artists (composer, arranger, performers), producer and the mixing engineer before the master tape is completed.

1) Problems of Discrete and Matrix Systems in 4-Channel Mastering

In the discrete system, no technical restrictions are imposed in tracking down from the original tape (8ch or 16ch) to the 4-channel system, making 4-channel mastering possible exactly in accordance with the desires of the musicians and the arrangers. In particular, since four discrete signals can be accurately cut, CD-4 discs succeed in conveying the original mastering ideas and sound quality without any subsequent reprocessing.

In the matrix system, on the other hand, the existence of phase difference between tape recorder tracks gives rise to serious technical restrictions during encoding. For this reason,

(1) there have been a number of cases where difficulties have been encountered in tracking down original multi-track (8ch – 16ch) tapes prepared in the past and stocked.
(2) the phase differences between master tape recorders preclude interchangeability of tape recorders.
These problems pose serious impediments in preparing program sources.

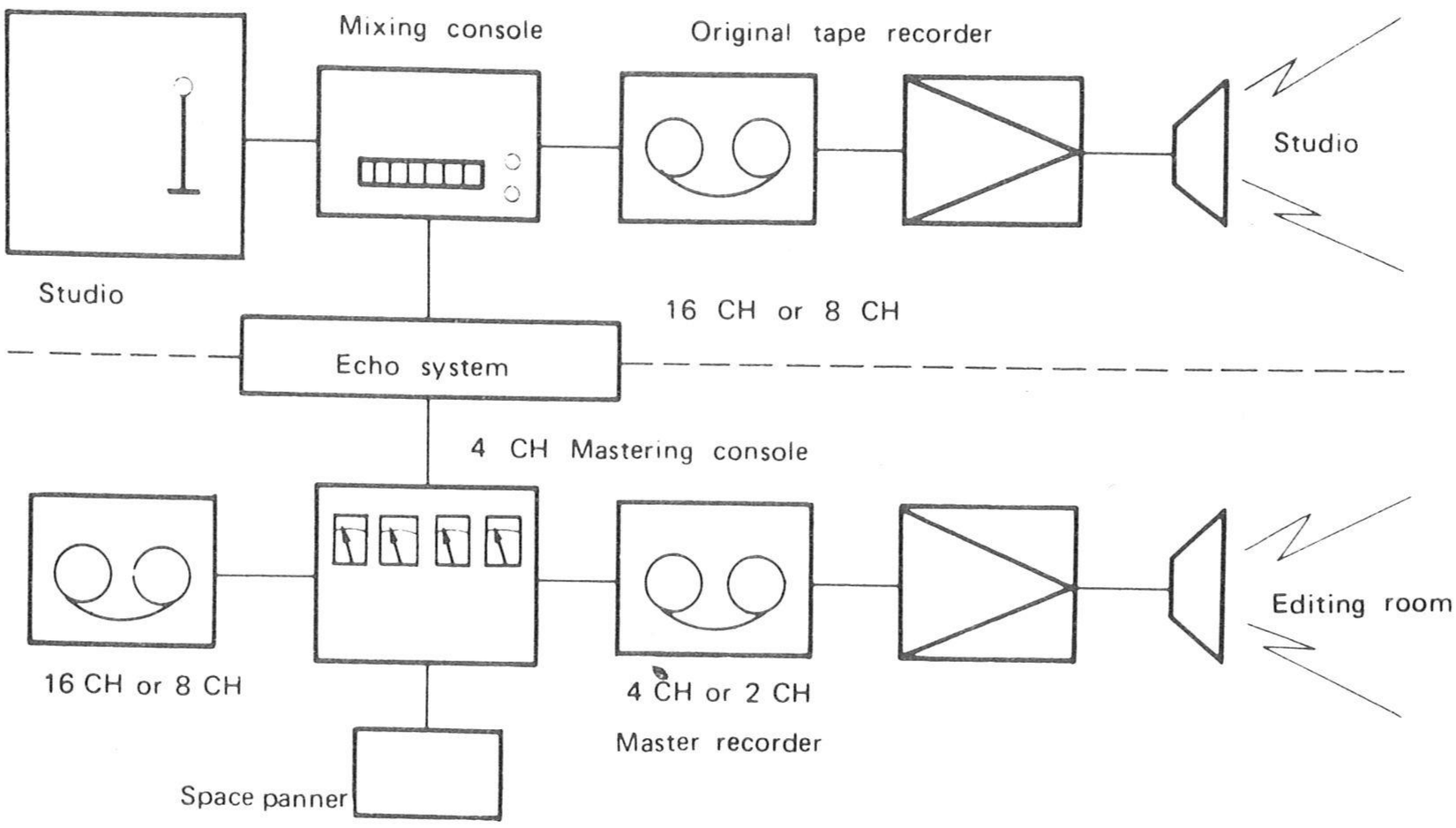


Fig. 15 Program Source Recording System

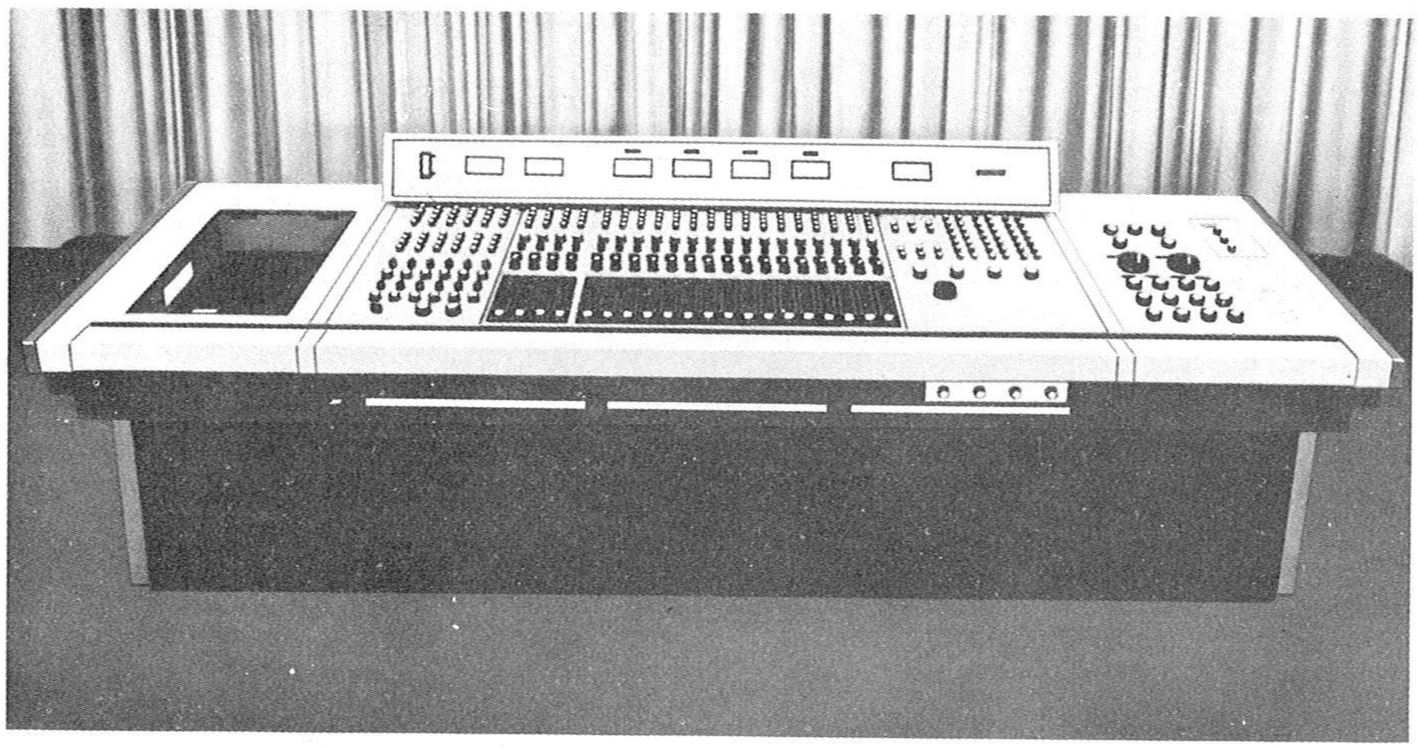


Photo 5 4-Channel Mastering Console

2) Problems of 2-Channel/4-Channel Compatibility

In tracking down to the 4-channel system, mastering is done with 2-channel monitors with added front and rear. For this reason, problems do not arise when a 4-channel source is played on a 2-channel system.

The equipment employed in the mastering system is as follows:

(1) 4-Channel Mastering Console
This console is used exclusively for tracking down 4-channel stereo. Its principal functions are performed with:
(i) direction selector (10 positions) (see Fig. 16),
(ii) round pan-pot,
(iii) 4-channel echo system.

(2) Space Panner
This panner gives optional localization; it can be operated with one finger by means of a joy stick. A diagram for one input is shown in Fig. 17. This device localizes sound by shifting smoothly, greatly increasing the freedom of musical expression.

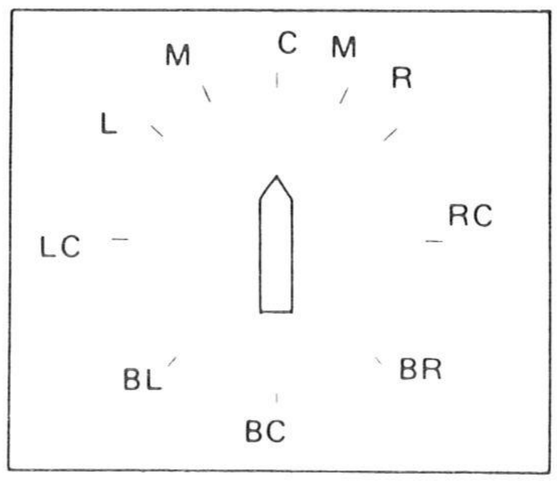


Fig. 16 Direction Selector

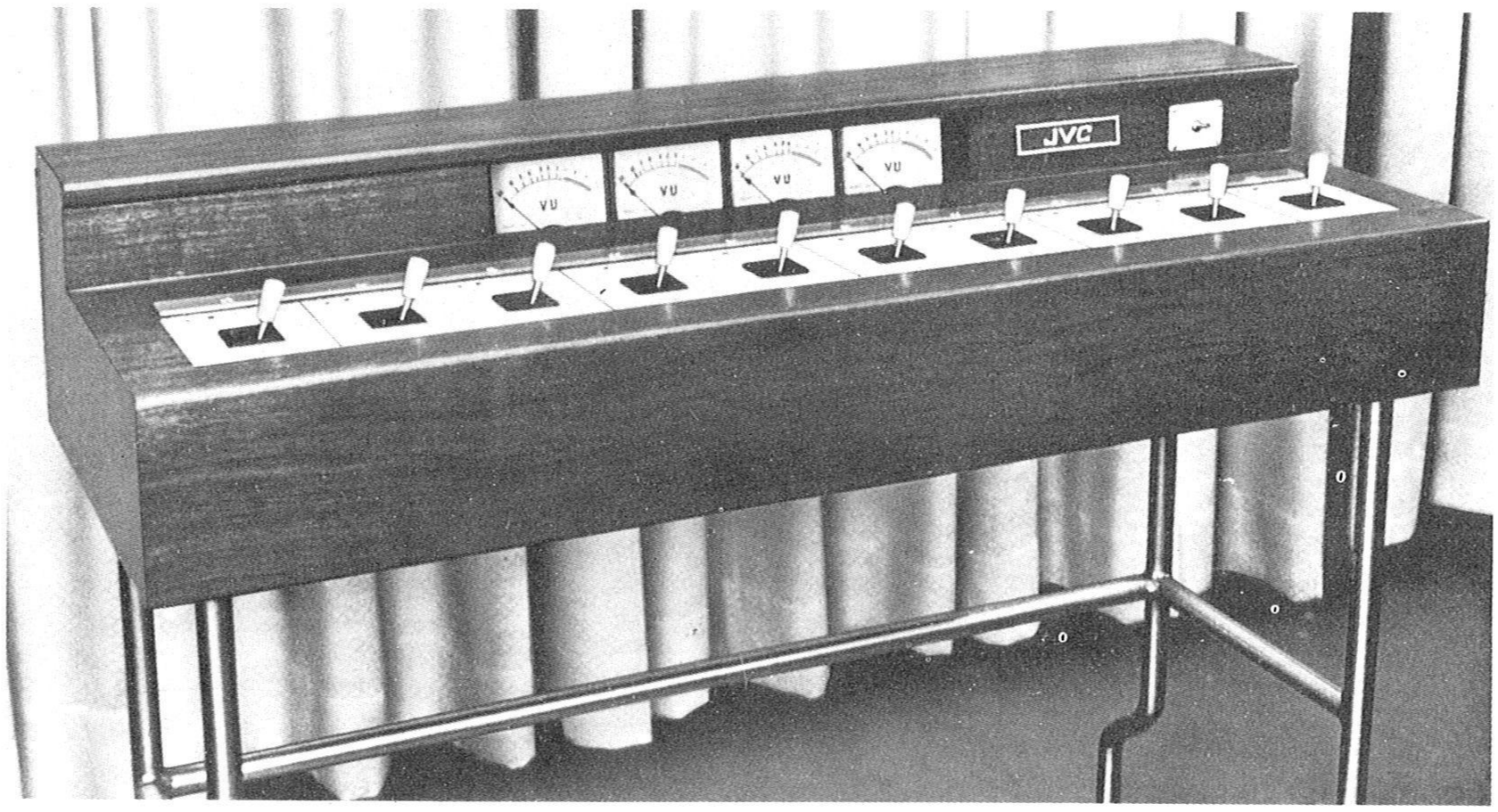


Photo 6 Space Panner

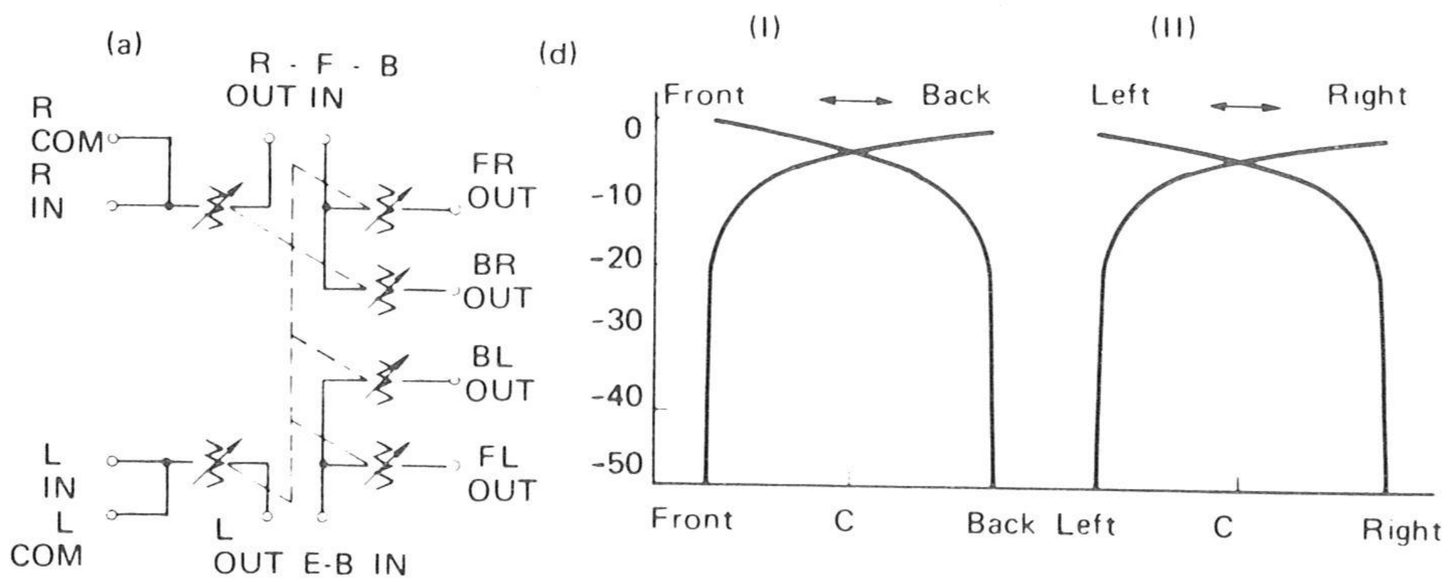


Fig. 17 Space Panner Block Diagram

4. Popular Music

Novel effects are frequently produced in popular music through composing and arranging techniques, and such music has already been produced for 4-channel stereo. Lately, music using the lesely machine, jet machine, music synthesizer, etc., has become popular with the younger generation and in the 4-channel system, too, some entirely new sound fields are being created and some significant results have been achieved.

Here the "Drum Battle" recorded by our company is illustrated. Fig. 18 shows the microphone arrangement. This is a comprehensive multi-recording system using a 16-channel recorder.

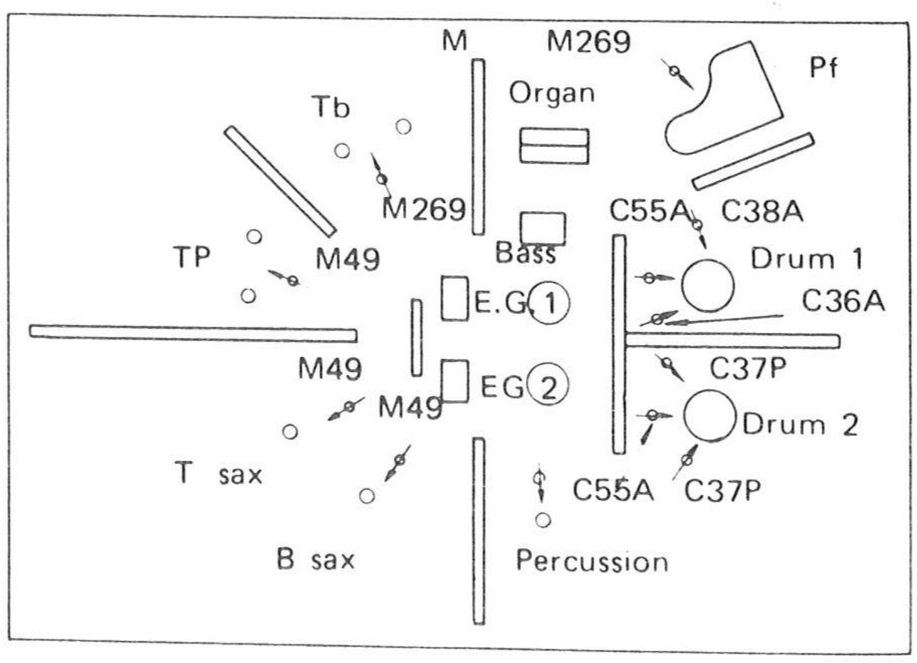


Fig. 18 "Drum Battle" Microphone Arrangement

5. Classical Music

Unlike popular music, classical music is largely intended for concert hall performance. For this reason, "hall presence" and "perspective" are essential points in the 4-channel system. The microphone arrangement, therefore, is largely of the off-set type, and auxiliary on-set microphones are provided for instruments with low output. Recording of hall reverberations becomes highly significant and an engineer with a good grasp of the characteristics of the orchestra and of the hall is required.

Photo 7 Symphony Recording

CD-4 Cutting System

In frequency modulated recording, complex techniques are mostly included in the recording system so that the reproduction equipment can be composed of the simplest circuits possible.

CD-4 disc recording techniques in general consist of the following:

1) Techniques for stabilized cutting of multiplexed signals with three times the frequency range of conventional recording.
2) Techniques for improving the quality of reproduction.

To achieve these, the following important techniques have been adopted:

1) Low-speed cutting.
2) Automatic noise reduction system (ANRS).
3) Carrier level control (CLC).
4) Neutrex.

Fig. 19 is a block diagram of the recording system, and the various techniques employed are as follows:

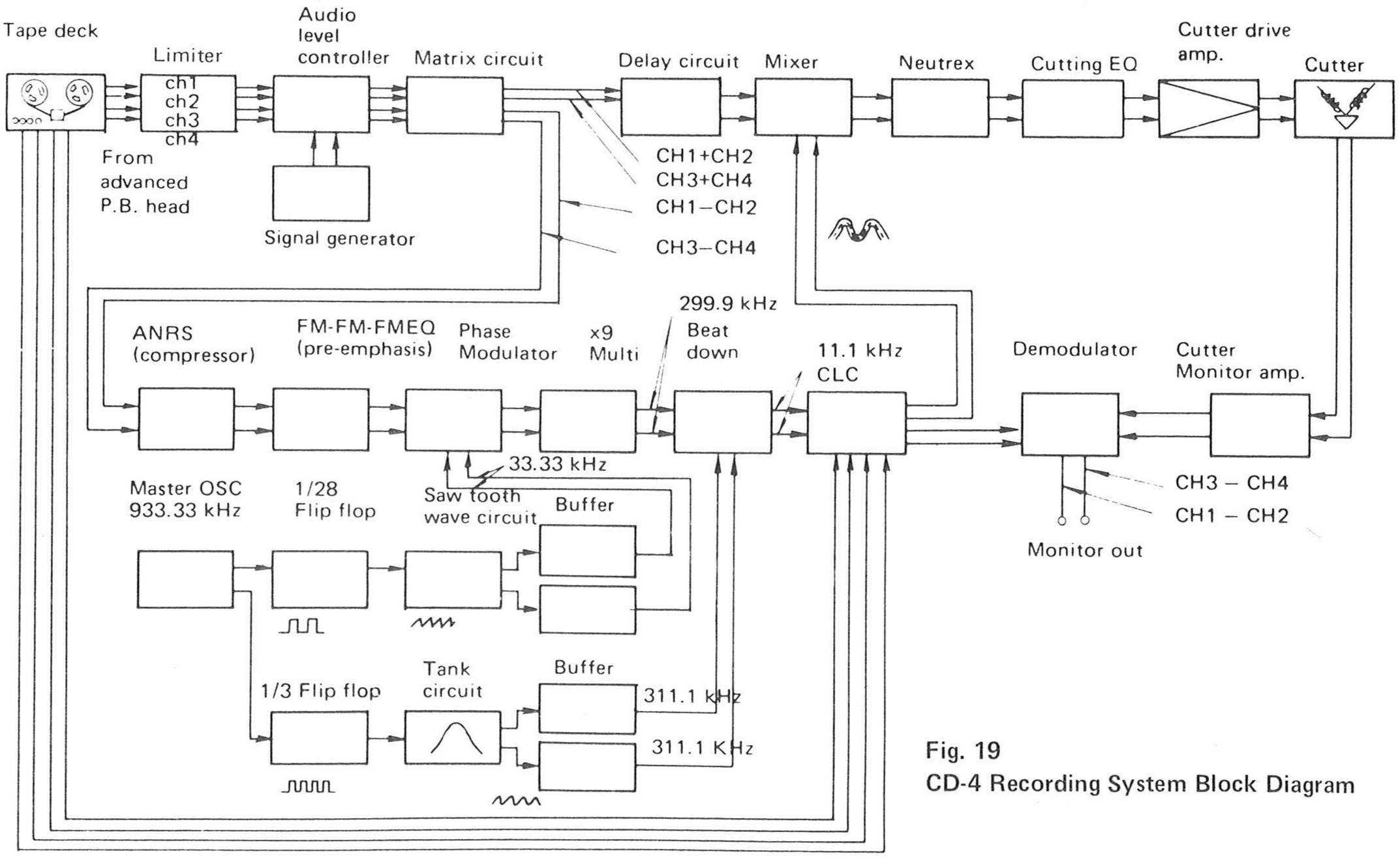


Fig. 19
CD-4 Recording System Block Diagram

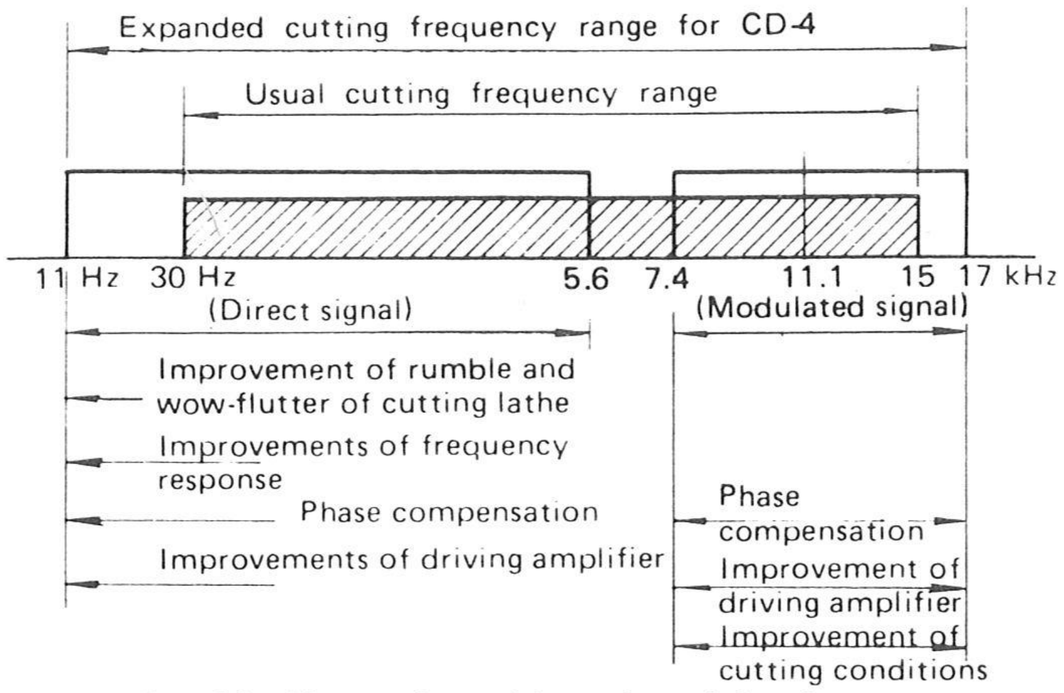


Fig. 20 Illustration of Low Speed Cutting

1. Low-Speed Cutting

The frequency range of the currently employed cutter is 30Hz to 15kHz, so some means must be applied to cut over the wide frequency range (30Hz to 45kHz) needed for CD-4. For this reason, cutting is done at 1/2.7 of normal speed and the direct signal and modulated signal bands are expanded to 11Hz to 16.6kHz, as shown in Fig. 20. Because of this, the various compensation measures shown in the figure have been implemented. Compensation items can be summed up as follows:

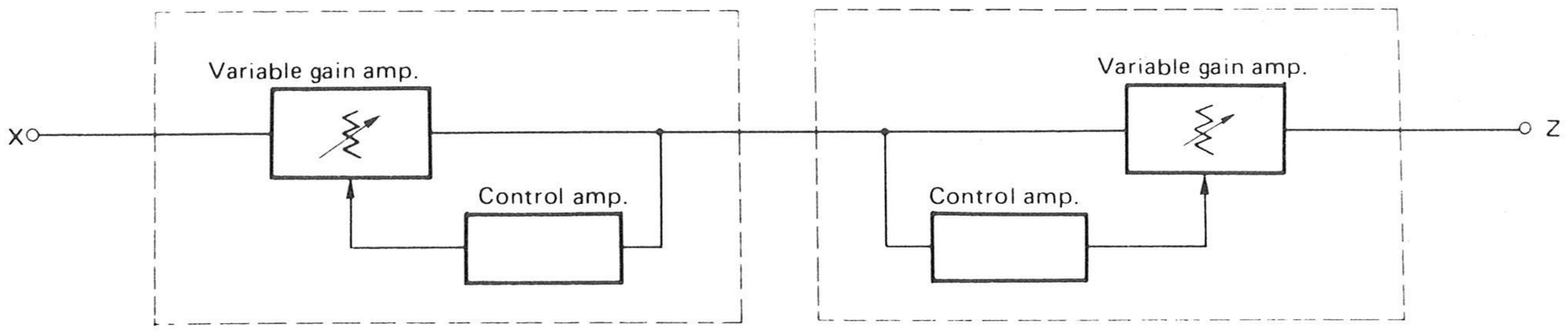
1) Low rumble, wow and flutter of the recording machine.
2) Use of a cutter disc amplifier with compensated frequency and phase characteristics.

2. Automatic Noise Reduction System (ANRS)

In the CD-4 system, the difference signals (CH1 – CH2), (CH3 – CH4) are recorded in the frequency range from 20kHz to 45kHz, so the wavelength is less than that of conventional discs. Naturally, precautions have to be taken against noise. ANRS consists of a compressor in the cutting system and an expander in the demodulator. This ANRS was developed for the purpose of eliminating noise generated in the difference signal path. (Fig. 21)

The system has the following features:

1) As shown in Fig. 22, the mid-range and high range are controlled separately; compression is 10dB in the mid-range and 15dB in the high range.
2) In setting the attack time and the recovery time, repeated hearing tests are made, in addition to theoretical analysis, for every program source. By this means, sound quality deterioration due to modulated noise has been completely eliminated.
3) Equality of input and output signals is most essential.
4) Distortion caused by crosstalk that develops in the transmitting system (pickup, demodulator, etc.) is also reduced to one-third.



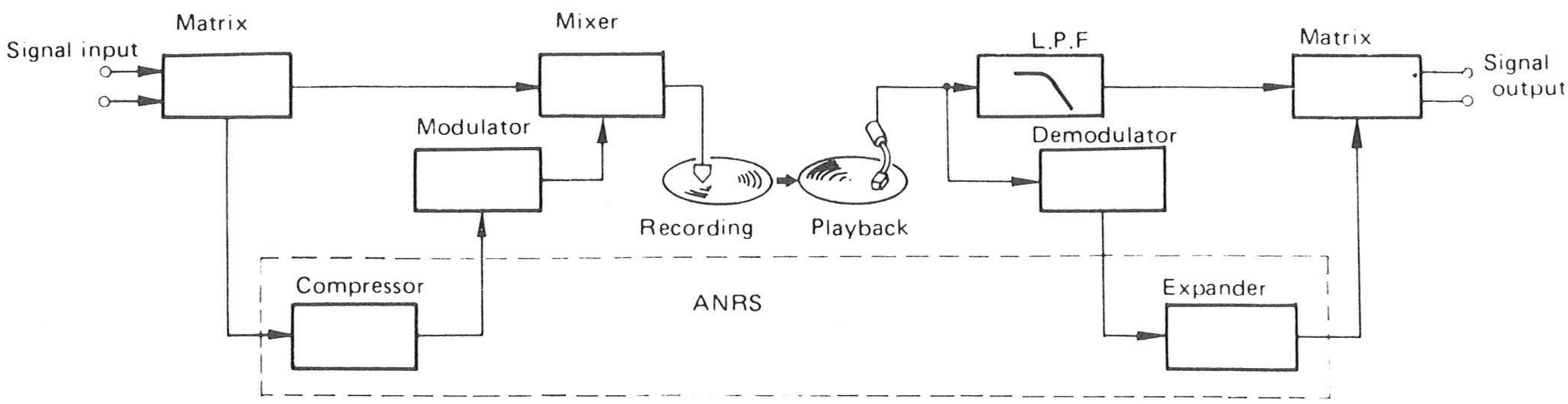


Fig. 21 Block Diagram of Automatic Noise Reduction System

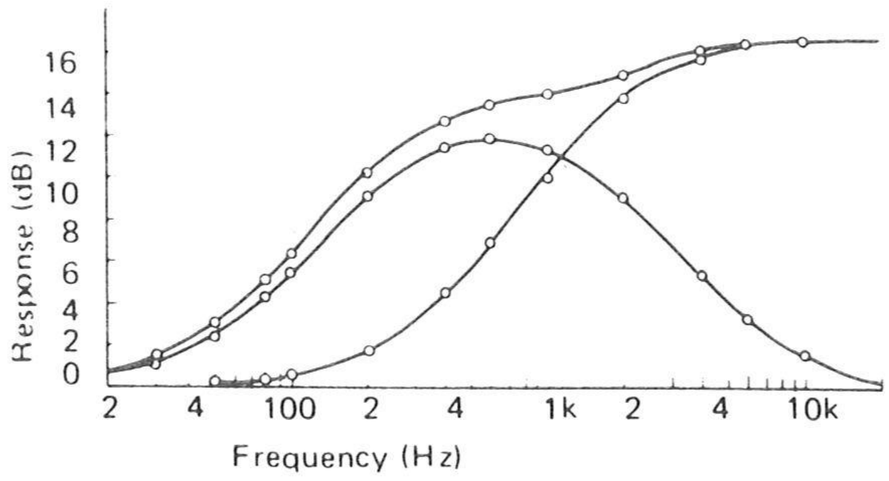


Fig. 22 ANRS Compressor Characteristics

Fig. 22shows the frequency response of the compressor. The mid-range characteristics are formed by the series resonance circuit of LCR, and the resonance frequency is boosted by 12dB at 60Hz. The high range characteristics are formed by HPF of CR. It rises from 283Hz, becomes flat above 2kHz and the boost in the higher range is 17dB. Since 2dB compensation is provided to prevent distortion in the control circuit, compression of 10dB is achieved in the mid-range and 15dB in the higher range.

3. Carrier Level Controller (CLC)

Since, in the CD-4 system, the direct signal and the carrier signal are recorded in four superpositions, the state of modulated carrier reproduction is affected by the direct signal during playback. If the level of the direct signal is very high, the reproduction of the modulated carrier signal deteriorates and may result in poor sound quality. The CLC is designed to enhance stabilized reproduction of the carrier signal. The principle consists of varying the modulated carrier level in accordance with the direct signal level, and has the following effects:

1) Interference by the direct signal is eliminated during reproduction, and deterioration of sound quality of the difference signal is prevented.
2) Signal-to-noise ratio in the differential signal system is improved.
3) Abrasion resistance during playback is improved.
4) Pickup cartridge tolerance is broadly improved.

Fig. 23 is a block diagram of the CLC. The control signal is detected by the advance head of the master tape recorder and, with constant detection of the levels of the four signals that form the basis for the direct signal, carrier signal amplitude control is automatic. Furthermore, the use of the advance head permits optimum timing of the control operation. An outline of the operation is shown in Fig. 24. The time constant of carrier amplitude rise and fall in the CLC operation is 150 msec and the maximum amplitude variation is 6dB; therefore, generation of a spurious sideband through amplitude variation can be ignored since it does not influence sound quality.

The process shown in Fig. 25 is explained as follows. The reproduction signal level for channels 1 to 4 is detected with the advance head. This passes through the OR gate circuit, the wave-shaping circuit and the mirror integrating circuit to become the control signal. The control signal is supplied to the CLC control circuit and the carrier signal level is compensated. Consequently, since the compensated carrier signal is put through cutting, differential signal stabilization, especially internally stabilized reproduction, becomes possible.

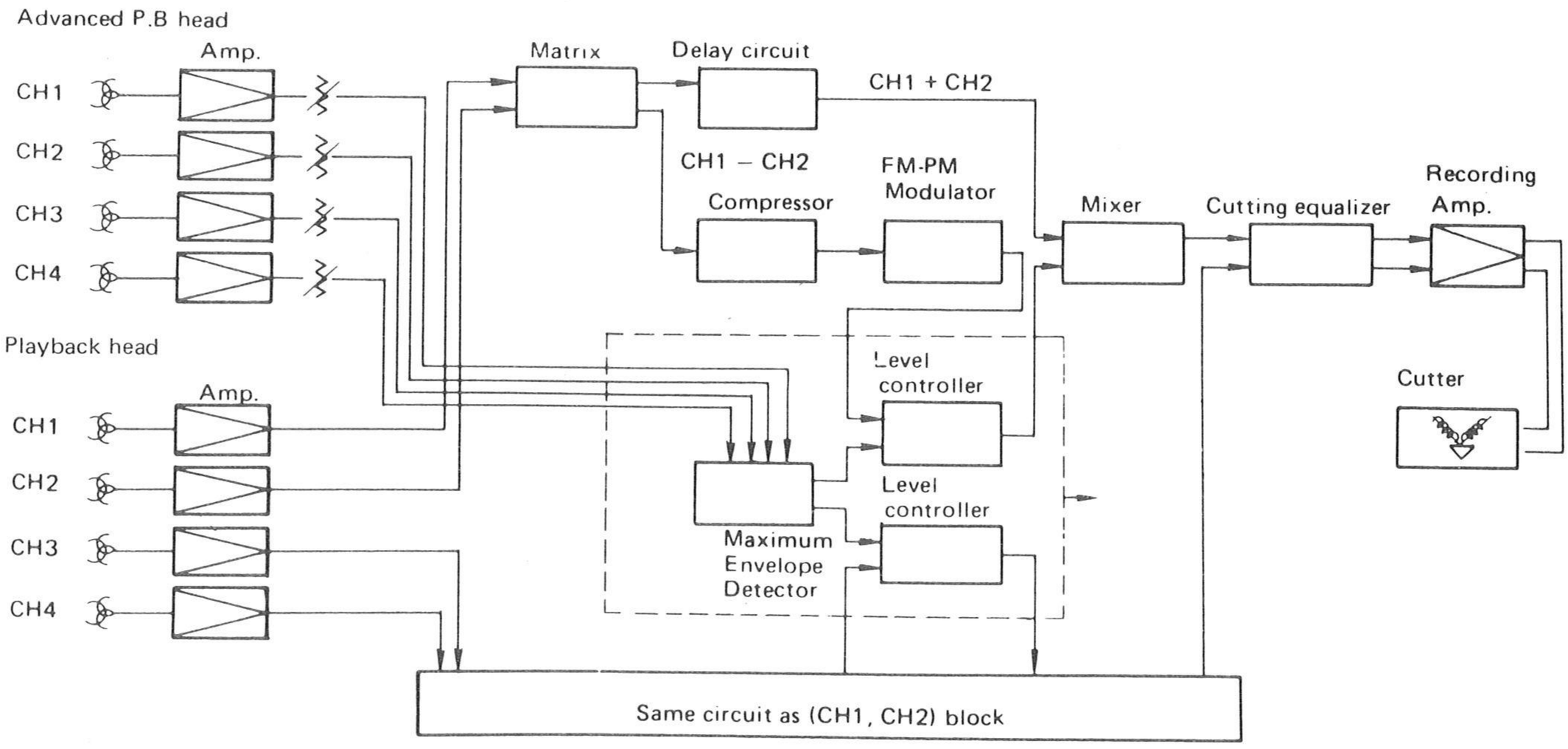


Fig. 23 Block Diagram of Carrier Level Controller

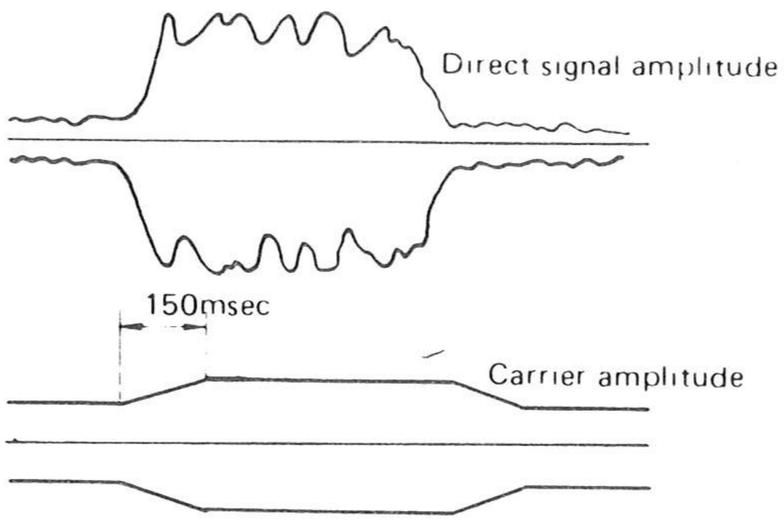


Fig. 24 CLC: Variation of Carrier Level

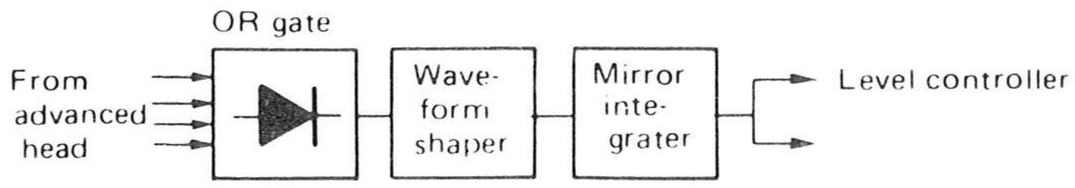


Fig. 25 Maximum Envelope Detector

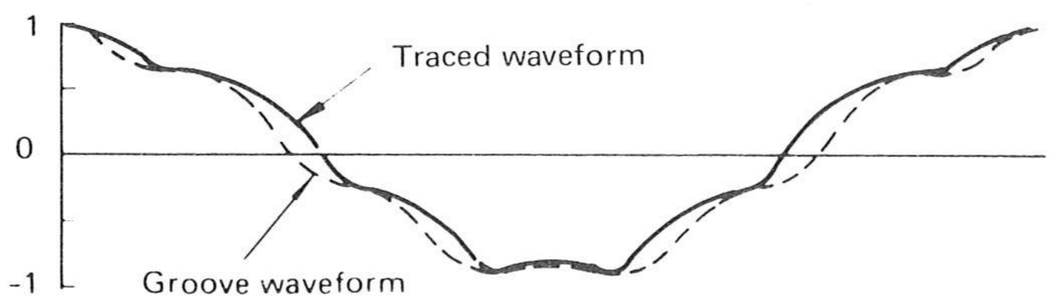


Fig. 26 Traced Waveform

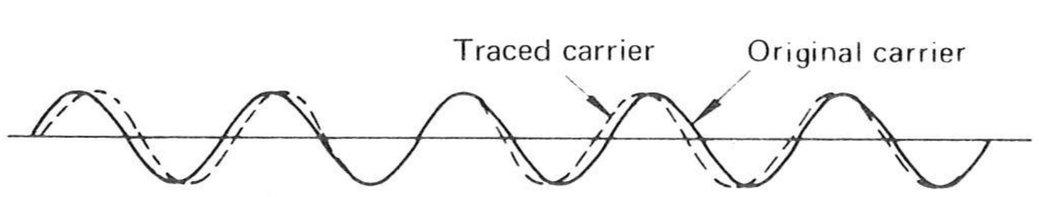


Fig. 27 Carrier Waveform

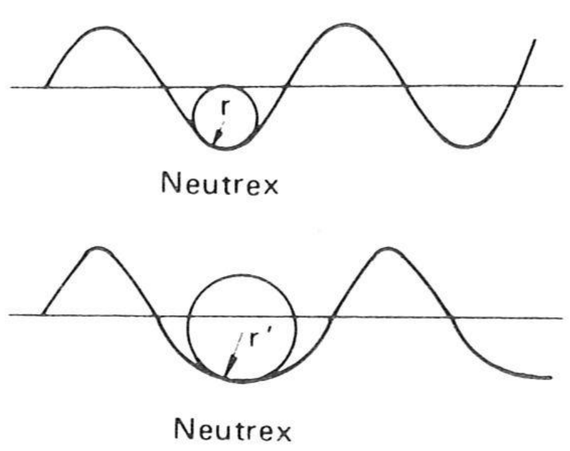


Fig. 28 Effect of Neutrex
(r, r' ; Stylus radius)

4. Neutrex

Tracking distortion arising from a pickup deteriorates the sound quality. Various measures to cope with this problem have been proposed and developed to the stage of practical application. In the CD-4 system, in which the direct signal and the modulated carrier are recorded simultaneously, this phenomenon disturbs the modulated state of the carrier and causes distortion and noise to develop. Fig. 26 shows the groove waveform resulting from simultaneous recording of the direct signal and the modulated carrier (a non-modulated carrier is shown in the figure), and the waveform when the groove is tracked by a pickup. The figure clearly shows the effect of the direct signal on the carrier. Fig. 27 shows when only carrier variation is considered. As the carrier is further modulated by the direct signal, the following are detected by the demodulator:

1) The signal that should be detected is distorted.
2) Distorted direct signal is mixed with the detected signal.

The higher the direct signal amplitude and the higher the frequency, the more pronounced these effects become.

To avoid such difficulties, the groove waveform has been compensated for in advance so that proper tracking waveform will be obtained. It is clearly evident that the use of Neutrex has reduced the interference between the direct signal and the modulated carrier, and there is also a marked improvement in direct signal sound quality that should not be overlooked. This is the result of cutting in the frequency range where distortion is minimum, since the middle to high ranges, which determine the details of sound, are converted to 1kHz – 5kHz by low-speed cutting. It is also the result of a marked reduction in distortion by the use of Neutrex. Despite the fact that the high-frequency limit of the direct signal is 15kHz, comparative listening tests against master tapes at record frequency show no deterioration in sound quality, thus making high-fidelity recording possible.

There is also an improvement in tracking limit with the Neutrex. As shown in Fig. 28, the adoption of Neutrex has allowed a higher substantial curvature limit even at identical record wavelengths. Neutrex is now designed to match the 7μ playback stylus.

Conclusion

The basic objective of the CD-4 recording system described herein is to provide music of any type without distortion.

Progress made in the 4-channel system will probably give rise to music of new types. The intentions of the composer and arranger must be conveyed to the listener without the slightest distortion. High-fidelity reproduction apart from such musical considerations has no justification, and faithful reproduction becomes possible only when the software and hardware techniques are integrated.

We are confident that CD-4 is a system that satisfies these requirements.

CD-4

JVC

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Aug., 1972
Printed in Japan