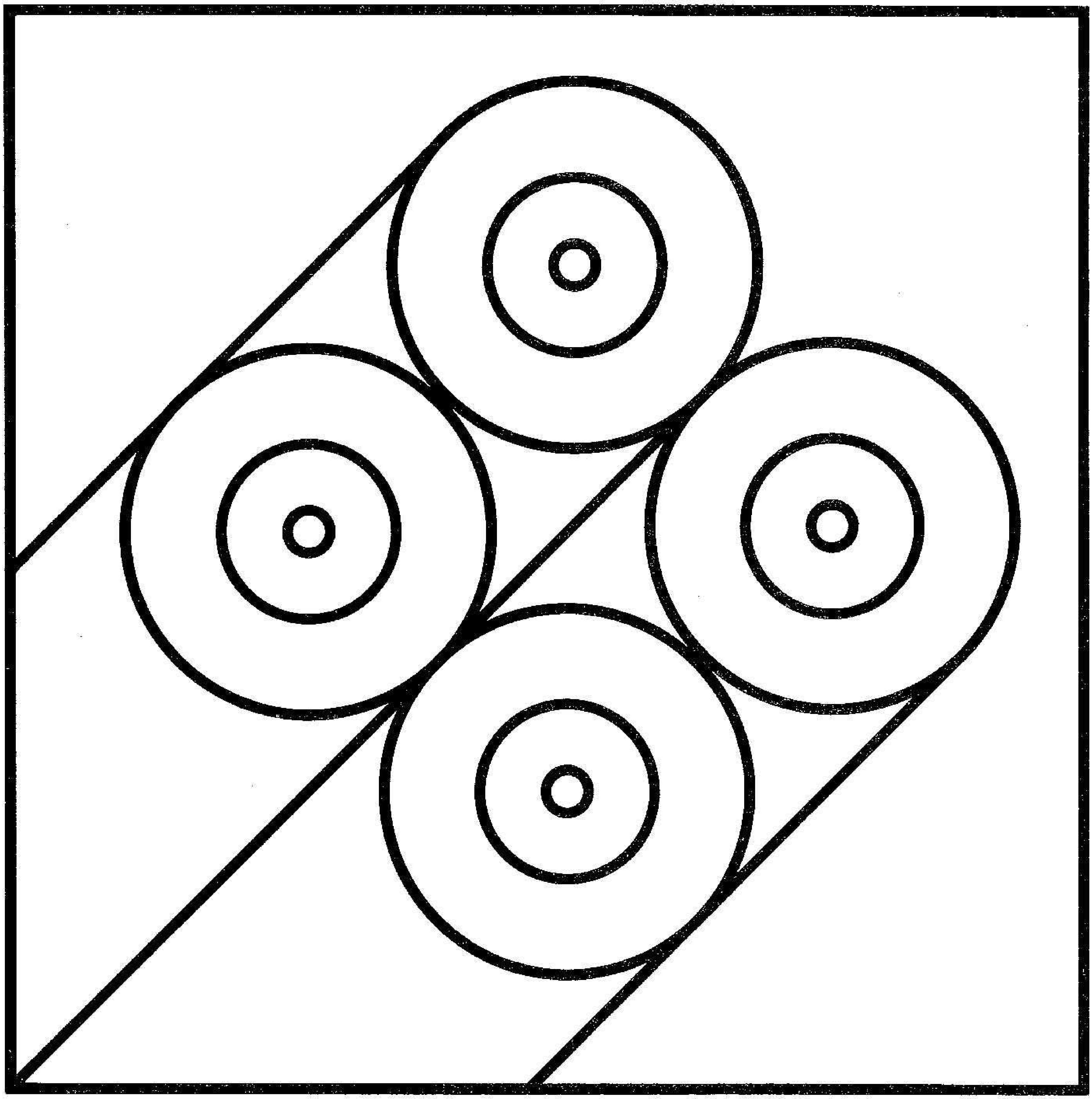


All You've Ever Wanted to Know about the CD-4 Disc System

CD-4

CONTENTS

Published to encourage a better understanding of the CD-4 discrete disc system, with compliments of JVC (Victor Company of Japan, Ltd.) and National Panasonic.

INTRODUCTION

In the heated debate about 4-channel stereo, the focus has at last shifted from the initial "whether or not" to the "how" or rather "which system". At least this is the case now in the U.S. and Japan and soon in Europe. By now, the frontiers have been redrawn much in the favor of quadrasonics. Hardware and software manufacturers, retailers as well as consumers seem for once to agree that the right 4-channel system is a definite improvement over 2-channel stereo.

Allow us, therefore, to refrain from rekindling the 2-against-4 dispute and to concentrate instead on the chief remaining question: Which 4-channel system is right? When you've come to the end of this pamphlet, you will realize that this, too, isn't a valid question any longer. At the risk of sounding biased, we believe there is one system that is right. The compatible discrete 4-channel disc system, CD-4 for short.

Although 4-channel sound entered into the listening rooms first via tape — 4-track, 4-channel discrete reels and 8-track 4-channel cartridges — the industry realized at an early date that quad sound could only have an important future if the phonograph disc could be adapted to it.

Among the firms that began looking into the various possibilities of 4-channel discs was Victor Company of Japan, Ltd. (JVC) which, from the very start in the sixties, set its sights quite high, insisting on a true discrete format. JVC engineers explored both the 12-inch 33 rpm LP and the 7-inch 45 rpm single and EP. Chiefly for reasons of repertory accommodation, our companies — and also RCA — have since concentrated on 4-channel LPs, but from a technical point of view there is no reason whatsoever that would prevent the manufacture of 45 rpm singles with 4-channel discrete sound.

As early as 1962, JVC foresaw the possibility of recording a supersonic carrier, even with then existing equipment. Successful completion of the world's first practicable discrete 4-channel disc system was announced and actually demonstrated by JVC in September of 1970. In October of 1970, JVC presented a technical paper introducing the CD-4 system at the 39th Convention of the Audio Engineering Society in New York. Only one year later, at the 41st Convention, JVC could already report a number of important engineering improvements. The CD-4 format had, in other words, already emerged from its infancy.

Then, in December of 1971, the Engineering Committee of the Japan Phonograph Record Association published a set of standards to be observed in the manufacture of CD-4 discs, paving the way for other manufacturers to join the growing CD-4 ranks. The fact that this set of standards, including charts and graphs, covers only 9 typewritten pages, already indicates that there is really nothing terribly complicated about CD-4 disc manufacture. In July of 1972, the Engineering Committee of the Electronic Industries Association of Japan set the standards for CD-4 hardware. While these actions certified the CD-4 system, this decision attests to the fact that the CD-4 system involves no great complexity. At the 43rd Convention of the Audio Engineering Society in September of 1972, JVC publicized the parameters of phono cartridge for CD-4 discs, thus opening the way for other cartridge manufacturers to develop CD-4 applicable pickups.

So much about acceptability to the manufacturers. What advantages, however, does CD-4 offer the record buying public?

Any quadrasonic disc system must be acceptable to the general recordbuying public as well as to the hi-fi enthusiast. It must be fully compatible with existing stereo and even mono playback equipment and must still yield every bit of musical information when reproduced over conventional pickups, turntables and amplifiers. Furthermore, any 4-channel disc should give full stereo separation when played in 2-channel fashion. More crucial, it must faithfully reproduce all four channels of the original sound field in all their undiluted and independent glory when played back on phonographs equipped with CD-4 demodulators.

It is this last point that has raised so many doubts about the various matrix disc systems. No existing matrix disc method allows the original four channels that the recording engineer had on his master tape to be retrieved without serious crosstalk and without a significant portion of some channel entering some other channel. The reason for this is easy to understand – all matrix systems have to blend the four original channels into only two channels, and no amount of electronic circuitry can completely separate them again. If encoding and decoding is done by the regular matrix (RM) method, for example, a signal originally present only in the front left channel will, upon decoding and playback, also be heard from the rear left and front right speakers. The CBS-SQ matrix system has good separation between the two front and between the two rear channels, but front-rear separation is a meager 3dB or, in laymen's terms, most of the front channel signal leaks into the rear channels, and vice versa. Complex logic circuits have been introduced to help this situation but they cannot fully solve it. These detect the (unwanted) presence of leaked-out front channel signals in the rear channels and boost the desired front while suppressing the unwanted rear portions so that the human ear will notice the front sound while masking the crosstalk in the back. Although they increase the cost of playback hardware considerably, these logic circuits do a fair job as long as a signal is present only in one of the four channels. If, however, signals of the same amplitude and phase orientation are present in both front and rear channels, the logic circuits are easily confused. Such matrix records played over a decoder with logic circuits thus have a tendency to sound jumpy and unstable. Viewed in this light, matrix 4-channel methods aren't really "4-channel" in the strict sense of the word.

What's worse, at least in the eyes and ears of artists and recording engineers, is the incurable habit of all matrix systems to condemn certain signal combinations in certain spatial and phase relationships to death – these are cancelled out, never to be retrieved again. To quote Walter Carlos, a prominent US composer and recording engineer: . . . "We investigated the cause of the mysterious missing parts for Switched-On Bach. It turns out, and this has never been in print before, that every matrix quad system has an infinite number of signal combinations which cancel out when the matrix master is encoded, and can never again be recovered. To prove this important point, we produced several quadrasonic (matrix) mixes which vanished when encoded, leaving only a very soft sputtering! The SQ was by far the most tricky matrix to find such complete examples for, but it too, succumbed. Imagine never knowing just what part of a meticulous mix will be lopped off, or severely attenuated, by the time it gets to disc". Additional cancellations may occur in mono playback, which is not exactly a recommendation for the matrix discs' mono compatibility, either.

This is not the case in CD-4 discrete four channel discs. Without neglecting any of the demands stated above – compatibility with existing stereo and mono hardware, economy – CD-4 maintains full "channel fidelity" with theoretically infinite separation between all four channels. Thus, all sound sources can be distinctly localized in the sound field, can move in any desired direction and along any conceivable line within the 4-channel quadrangle. CD-4 gives total freedom to the composer or performing artist to make unrestricted use of any stationary or in motion effect. (In the matrix system, it is next to impossible to localize a sound source at the center between the rear speakers, or to move it along a diagonal line in the sound field.) In regard to channel separation, the CD-4 system offers the same basic quality as discrete 4-channel tape formats. CD-4 is the only true 4-channel disc system!

The third common hi-fi medium, FM broadcasting, can be expected to follow records into the 4-channel age very soon. Four-channel FM broadcasting would not be very meaningful unless it offered true discrete sound. All the various systems now under consideration by the National Quadraphonic Radio Committee of the EIA are such discrete systems as developed by RCA, GE and QSI. All indications are that the FCC will adopt a discrete 4-channel process. In step with this tendency in the U.S., the Electronic Industries Association of Japan is now conducting a series of studies. We expect 4-channel discrete FM broadcasting on an experimental basis to begin quite soon in Japan. Technically, the same solutions would also be valid for European countries.

A BRIEF OVERVIEW OF CD-4 BASICS

The basic function of the CD-4 system will be easy enough to understand if you recall what happens in FM multiplex broadcasting. In both, a carrier is employed to convey the additional information needed to separate the channels in playback. In FM MPX, the main carrier wave contains the Left + Right sum signal, and the subcarrier is modulated with the Left – Right difference signal. In a CD-4 disc, the same process is applied to each wall of the groove: the inner groove wall carries undulations which represent the Front Left + Rear Left channels, and additionally there is a 30kHz carrier which contains the frequency-modulated Front Left – Rear Left signal. Correspondingly, the outer groove wall carries the FR + RR signal in its basic undulations, while the FR – RR signal is conveyed by the 30kHz carrier. The CD-4 playback demodulator connected between turntable and amplifier does basically the same job as the MPX decoding circuits in an FM stereo tuner – by a simple series of mathematical operations, it retrieves the original four signals, to be amplified and reproduced over four speaker systems.

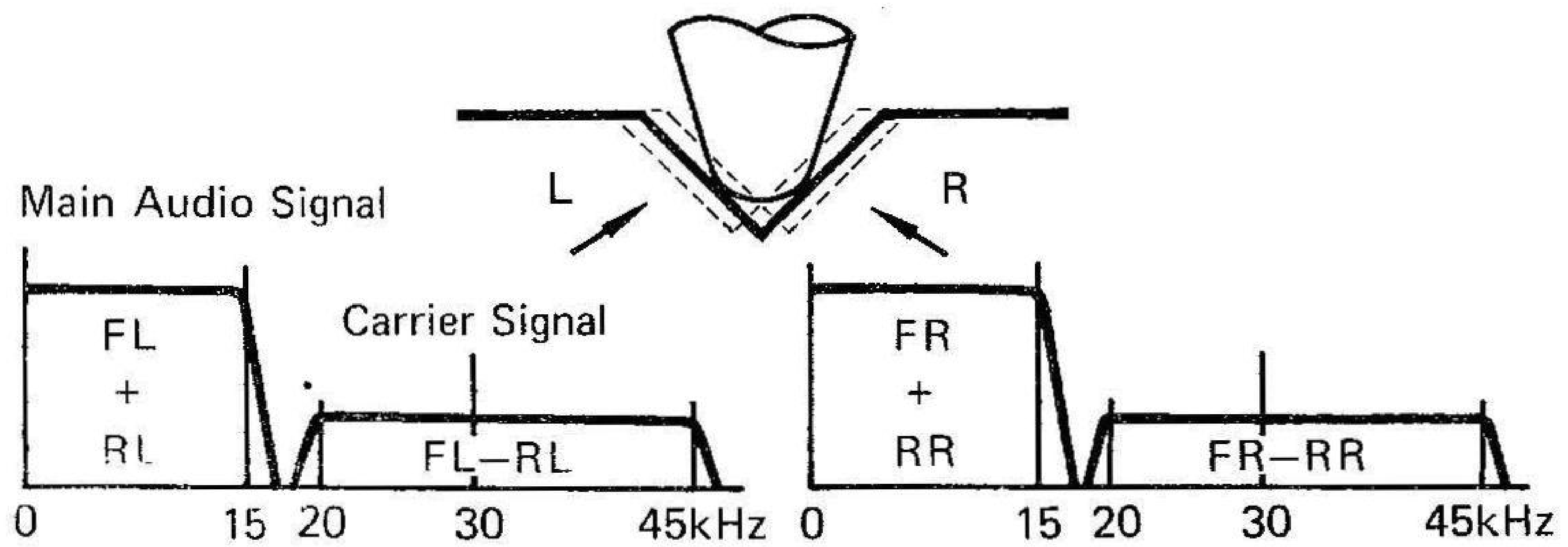
This brief outline already clears up a misconception often encountered in discussions of the discrete 4-channel disc, namely: "When playing a CD-4 disc on 2-channel stereo equipment, isn't all the musical information contained in the rear channels lost?". The answer is definitely no. Two-channel phonographs will pick up and reproduce both basic wall undulations, in other words the FL + RL and FR + RR signals. Note the plus signs – all musical information will be retrieved; the left speaker will reproduce everything that was recorded on the left, the right speaker, everything on the right. By logical extension, monophonic playback of a CD-4 record will reproduce the sum of all four channels.

A CD-4 disc is, in other words, fully compatible with both stereo and mono playback equipment, and there can be no question of existing equipment being outmoded or mass market interests being disregarded.

Before we enter into a more detailed step-by-step analysis of the CD-4 chain of transmission, let us deal with another question often asked, that of software availability. RCA and Warner-Elektra and Atlantic are now committed to the CD-4 system with new releases of discrete 4-channel discs already scheduled and in production. In Japan, JVC (Victor Company of Japan), Nippon Polydor, Teichiku and Nippon Phonogram have made more than 150 CD-4 LPs available with a repertory spanning the range from Bach to Elvis.

Other major record companies are soon expected to join the CD-4 ranks. RCA has announced that within 1 or 2 years most of its new releases will be 4-channel discrete. To the prospective buyer of a CD-4 playback system, he actually needs only a few additions to his existing stereo or 4-channel rig, so that there's no valid reason for "waiting it out" any longer. CD-4 is now progressing to its final, universally accepted stage.

Fig. 1 Signal Configuration of CD-4 Disc



STEP-BY-STEP DESCRIPTION

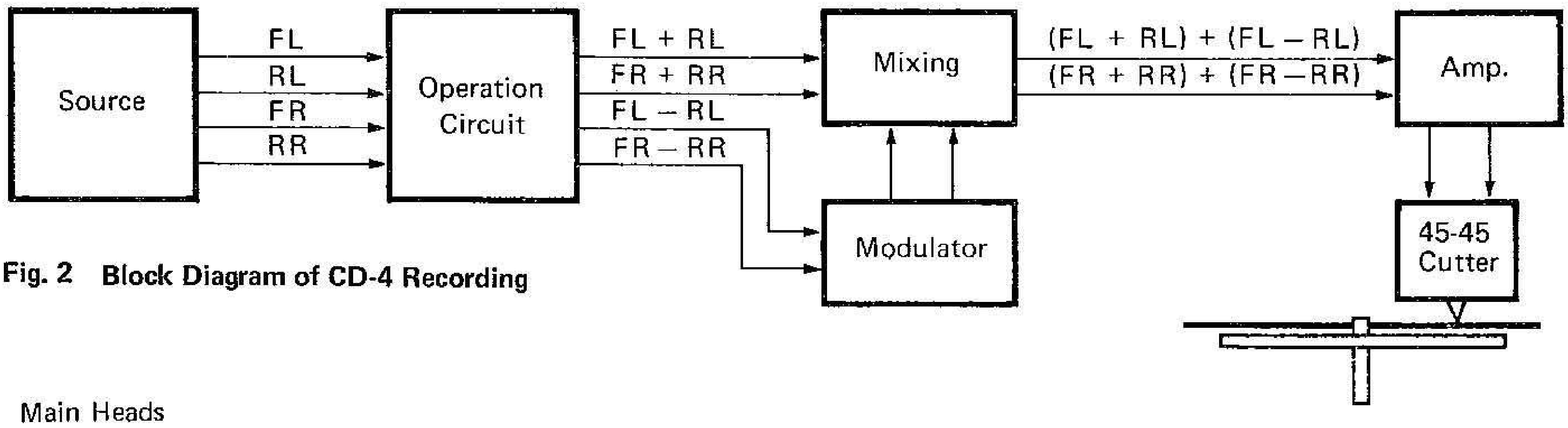


Fig. 2 Block Diagram of CD-4 Recording

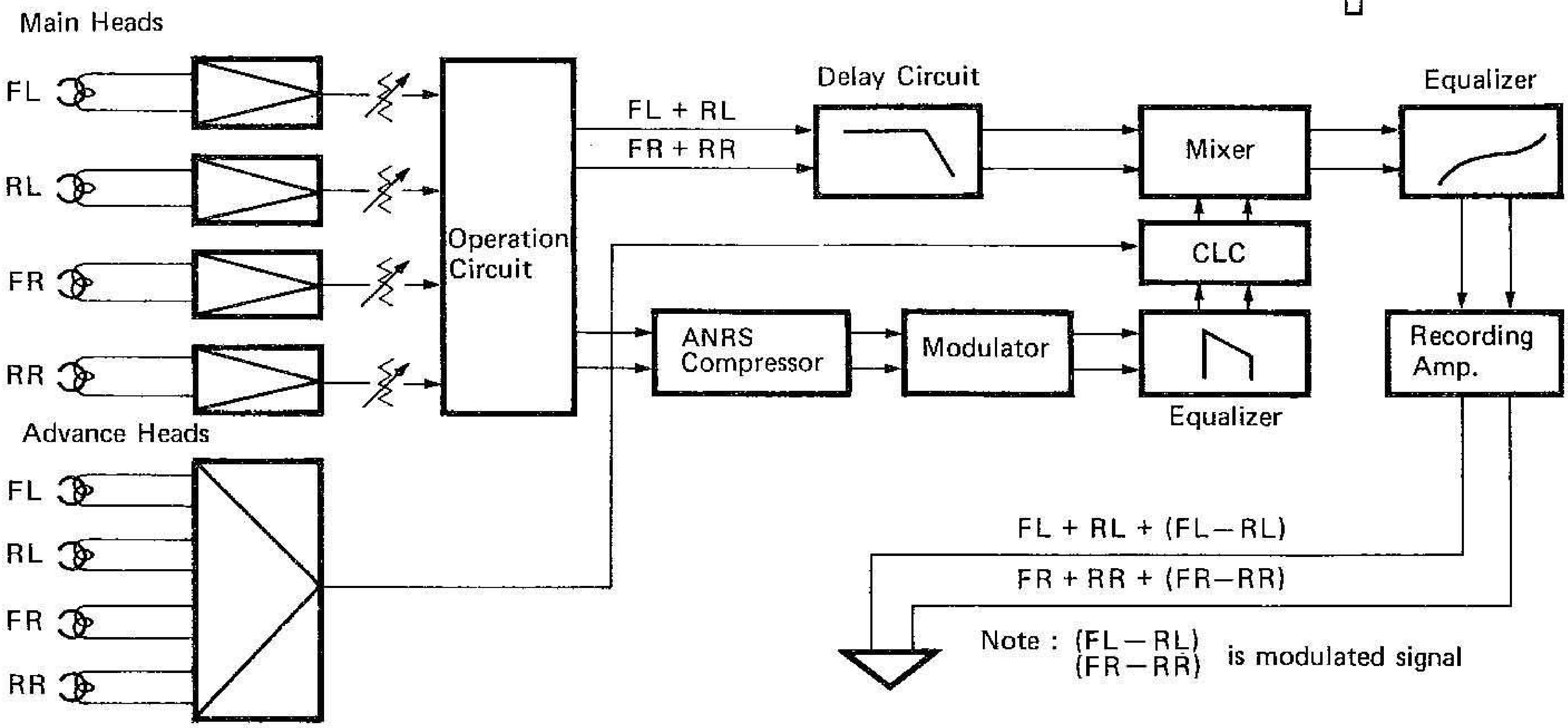
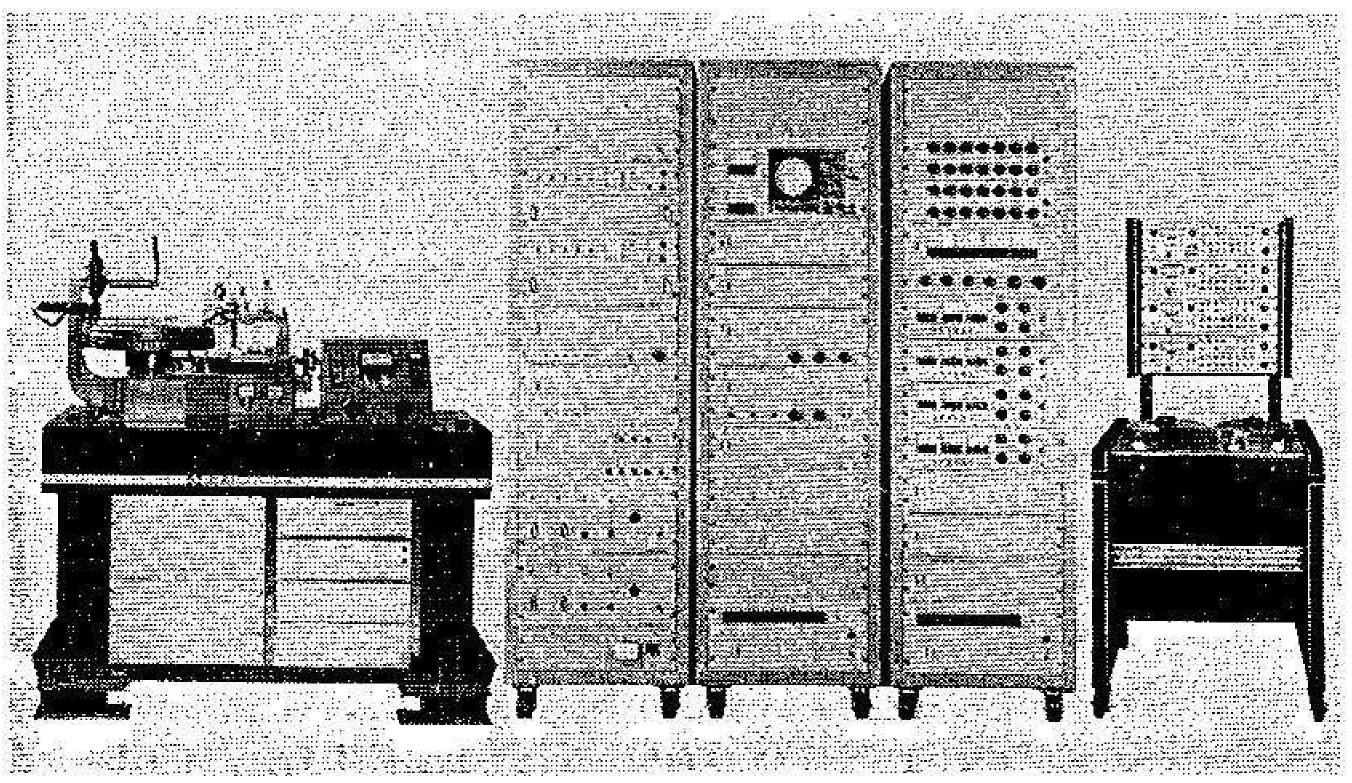


Fig. 3 Block Diagram of Cutting System

1. Recording, Modulation, Cutting

For producers and recording engineers, there are no special precautions to observe when making a quadrasonic master tape for release as a CD-4 disc. Unlike all matrix formats, CD-4 being a discrete method, does not impose any limitations on the composer's, performer's, producer's or recording engineer's imagination. The master tape can make use of all conceivable 4-channel effects.

From the quadrasonic master tape, the lacquer disc is cut via a chain of simple mathematical operations, modulator, mixer and amplifier. An easy to understand block diagram is shown in Fig. 2 while Fig. 3 gives more details of the cutting process.



From the main tape reproduce heads, the signal enters the operation circuit where the sum and difference signals are obtained. This must not be confused with those operations employed in the various matrix 4-channel systems – note that it produces four output signals, not two.

Photo 1: CD-4 Cutting System

The FL + RL and FR + RR sum signals then pass through a 40 μsec delay line. This is needed to facilitate synchronizing of the sum signals with the carrier-modulated signals at playback. (In general, all the complex techniques needed for multiplex cutting of base bands and FM-modulated carrier have been incorporated in the recording and cutting system, with the effect that playback hardware, i.e. the demodulator, can be kept as simple and economical as possible.)

The difference signals from the operation circuit are fed into a compressor of the ANRS (Automatic Noise Reduction System), the first in a series of stages that deal with reduction of noise and distortion. This ANRS operates by frequency-selective compression (in the recording process) and expansion (in the playback process). Medium and high ranges are treated separately, with a resultant compression of 10dB in the midrange and 15dB at 10kHz.

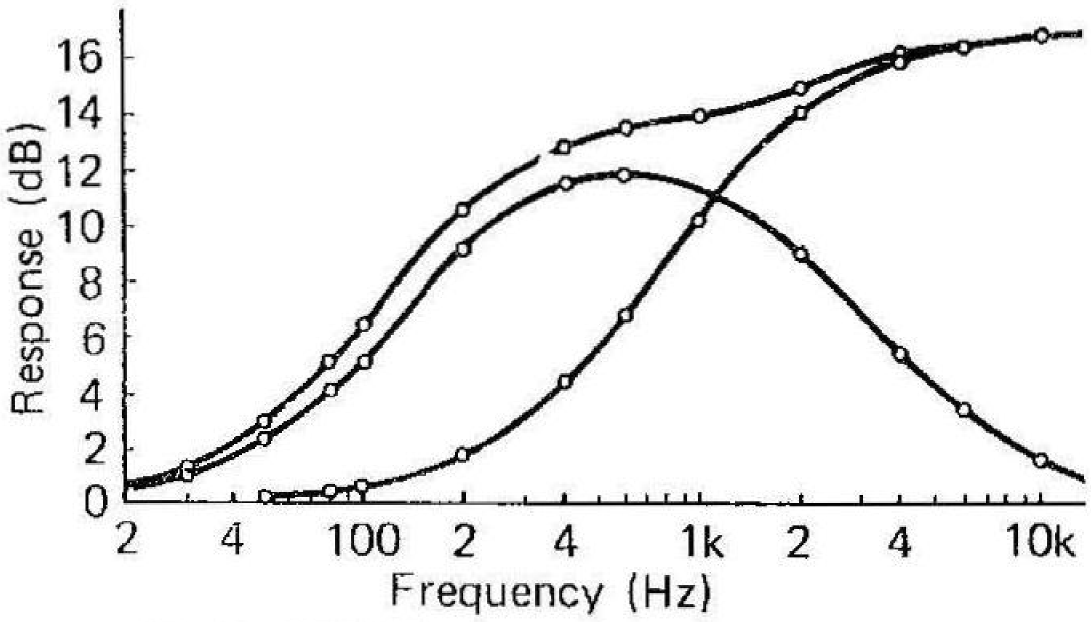


Fig. 4 **ANRS Compressor Characteristics**

Please note that this noise reduction is applied only to the difference signals. In the base bands, ANRS is not needed and its inclusion would cause compatibility problems on playback over conventional 2-channel equipment. In the difference signal, ANRS not only reduces noise in the high frequencies, but also minimizes crosstalk in the midrange band. Such crosstalk distortion tends to concentrate in the 700Hz range, and that's why midrange compression-expansion is provided along with the high range treatment. Fig. 5 illustrates the ANRS process while Fig. 6 shows its compression-expansion characteristics.

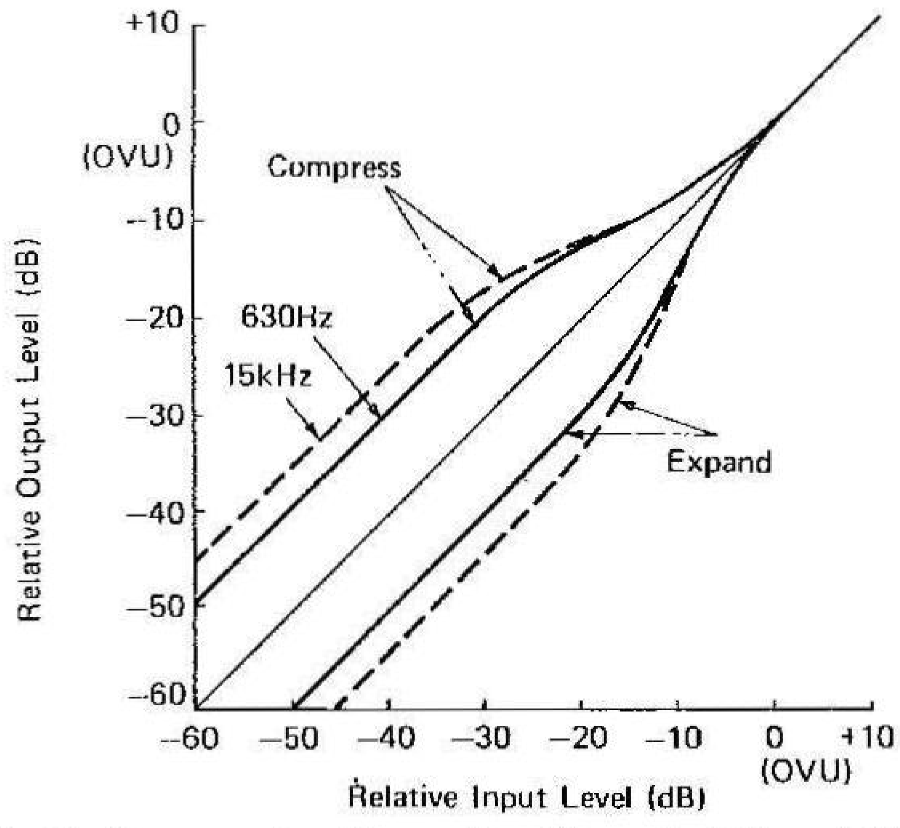


Fig. 6 Compression-Expansion Characteristics of ANRS

In the next stage, the difference signals are used to modulate the 30kHz carriers (which are derived from a single master oscillator to preclude the occurrence of "beat"). Modulation, although usually referred to as FM, is actually a combination of FM and PM taking advantage of the merits of both methods. Below 800Hz, frequency modulation is used, phase modulation takes over from 800 to 6,000Hz, to be replaced again by FM above 6kHz. This combination of modulations in fact offers the advantage of achieving even wider dynamic range.

We must now discuss the distribution of signal bandwidths over the audio and carrier bands, and the reasons that led to the adoption of this particular band pattern. Starting from the top: 45kHz, the upper limit of the modulated carrier, represents the highest frequency that a newly developed phono cartridge can trace or that present cutting techniques, even with reduced cutting speeds, can engrave. The lower end of the carrier band has been set at 20kHz, 5kHz above the upper end of the base band. This 5kHz gap is needed to permit high and low pass filters in the demodulator to separate the bands without making too great and costly demands on the filters' cutoff characteristics. The basic audio information occupies the 30Hz to 15kHz band.

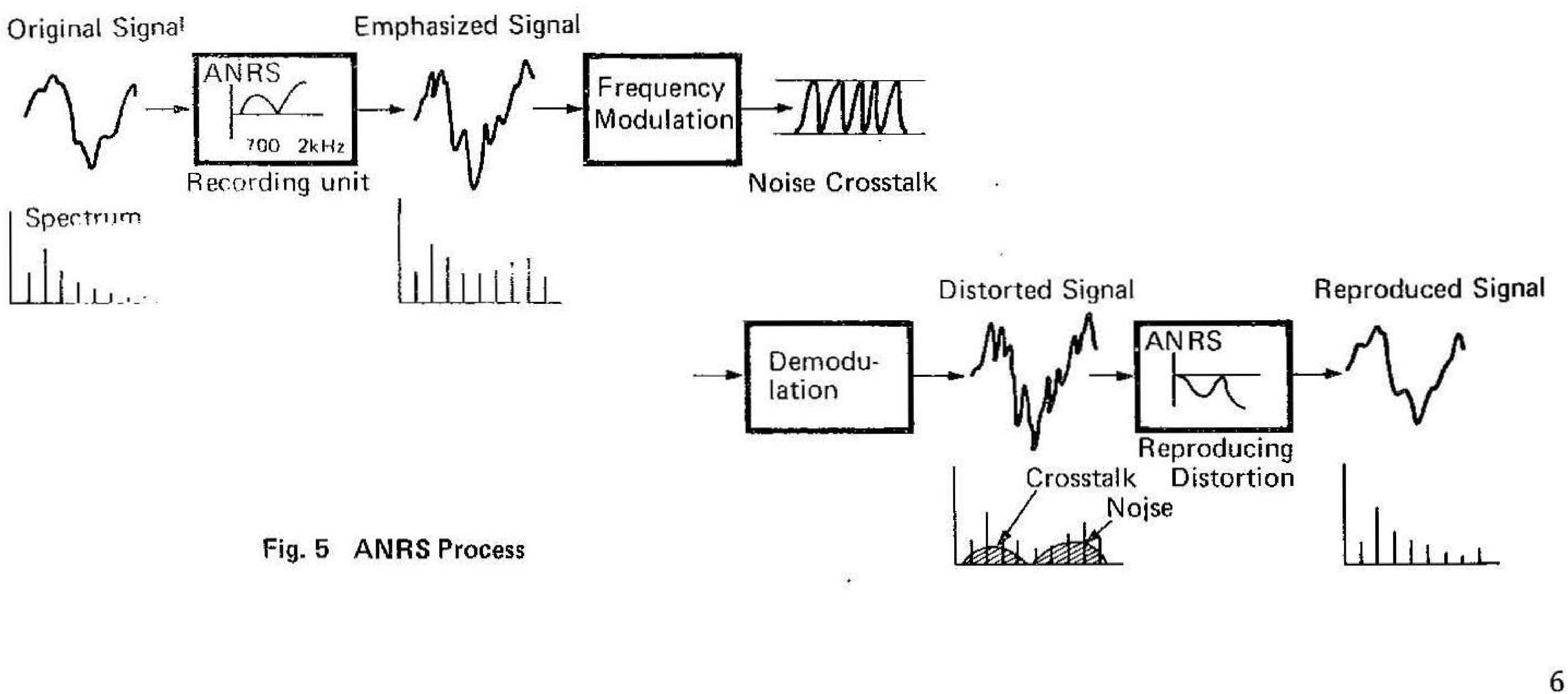


Fig. 5 ANRS Process

The signals emerging from the modulator pass through an equalizer with high-end roll-off, and then re-join the base band sum signals in the mixer, but not before having passed through a carrier level controller (CLC). Obtaining advance information directly from the master tape via advance heads, the CLC correlates the base band signal level with carrier level, boosting the latter during high passages of the former. Its effect is fourfold: (1) Interference of the base band signals on the carrier during playback is reduced to maintain high quality of the difference signals. (2) S/N ratio in the difference signals is improved. (3) The carrier becomes more resistant to abrasion in playback. (4) The task of the playback cartridge is made easier, so that cartridge and especially stylus tolerances can be kept broader. A detailed discussion of CLC circuits would be beyond the scope of this article. Suffice it to say that it detects the maximum envelope in the base band signals obtained from the advance heads, and controls carrier level accordingly, with a time constant of 150 msec and a maximum amplitude variation of 6dB.

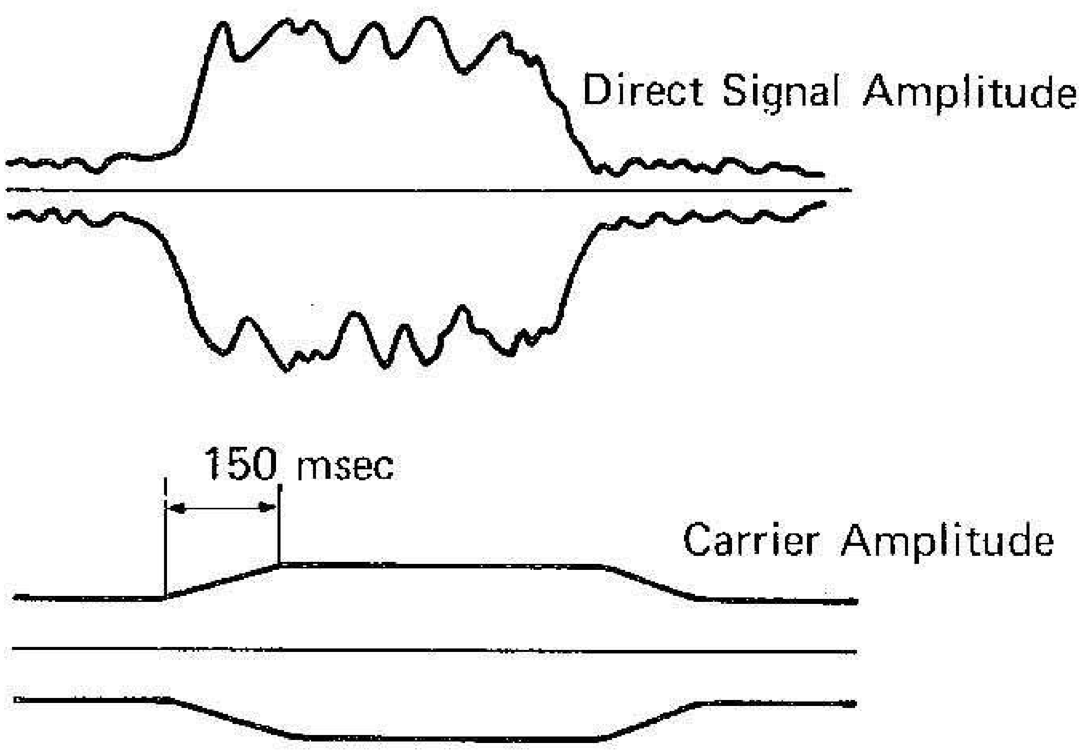


Fig. 7 Variation of Carrier Level by CLC

Yet another measure is taken to lighten the burden on the playback cartridge in tracking base and carrier undulations at the same time. Called Neutrex, this system compensates the groove waveform in advance to avoid or at least minimize tracking errors in playback. Without such compensation, a stylus of standard dimensions might bounce along an imaginary waveform resulting from influence of the direct signal upon the carrier, and vice versa, resulting in distortion and mixing of both. Neutrex is chiefly of interest to the cutting engineer, but it should be mentioned here that its cutting parameters have been set to give optimum tracking with styli of 7 μ side radius. Comparative listening tests against the master tapes have shown a substantial improvement in sound quality achieved by this cutting compensation.

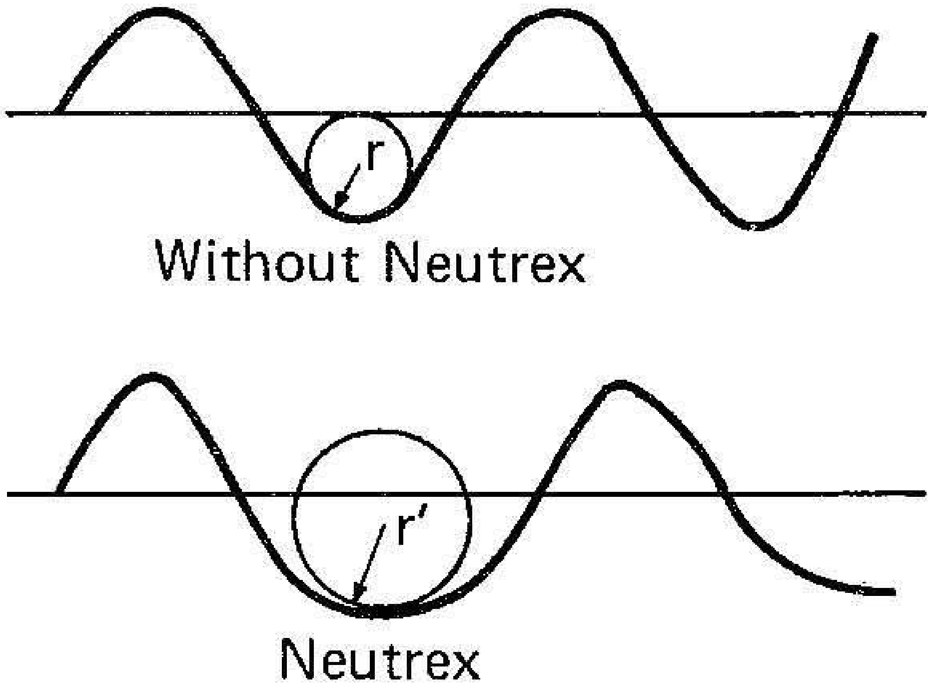


Fig. 8 Effect of Neutrex (r, r' : Stylus Radius)

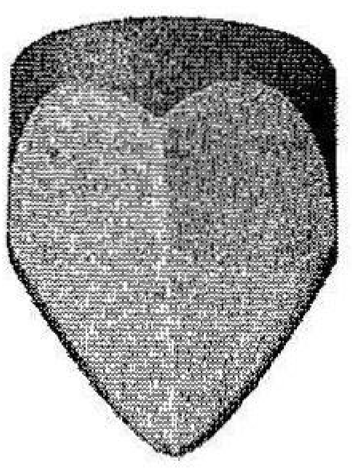
At present, cutting speed has already been raised to one half of rated record rpm due to an improvement in cutting head design. Further advances will eventually make it possible to cut CD-4 masters at full speed, once cutting heads are perfected to reach up to 50kHz. Until that day, cutting is being done at half speed, which poses no great problem, however, because master tape equipment and cutting lathes are already capable of being switched to half speed operation.

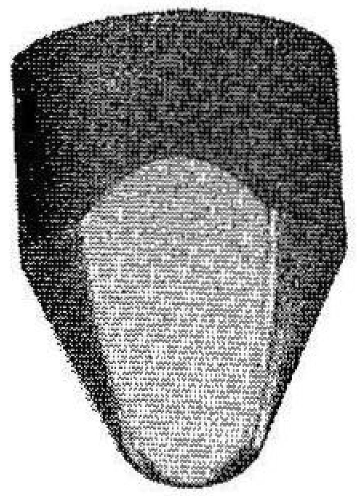
At present, CD-4 LPs can accommodate over 25 minutes per side, and eventually 30 minutes per side is distinctly feasible. The record manufacture and resin mix are practically identical with those of conventional LPs; nevertheless, it has been experimentally proven that a CD-4 disc still retained its carrier after over one hundred cycles of playing with a 0.7 mil conical stylus at a tracking force of 5 grams far in excess of normal LP usage.

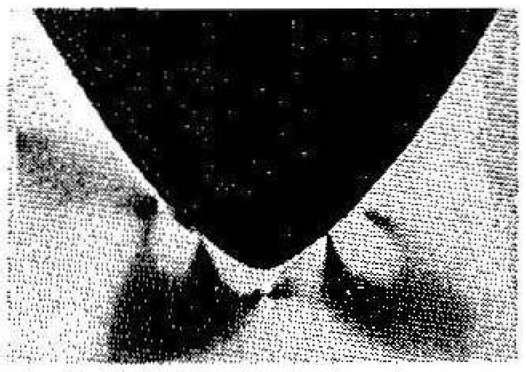
2. Playback Functions, JVC and National Panasonic Playback Equipment

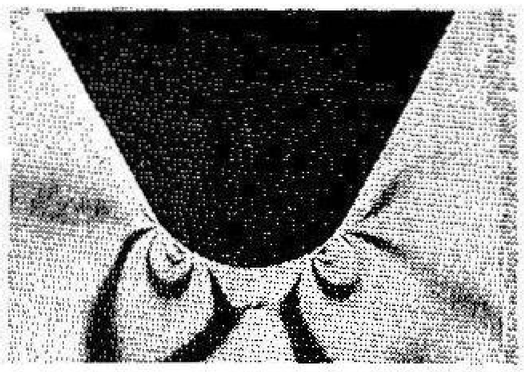
Now we finally come to the part that will interest potential 4-channel buyers most, the cost of playback equipment. It is not, repeat not, higher than that of the more elaborate matrix systems with gain riding logic. The CD-4 demodulator with a supplied 4-channel cartridge bears a moderate pricetag. And that's all you need (plus, of course, the usual 4-channel amplifier-speaker system required for any 4-channel installation).

The single most important invention in playback hardware that brought CD-4 within easy reach of the general public is the Shibata stylus, named after its inventor, Mr. Shibata of Victor Company of Japan, Ltd. As shown in the accompanying micrographs (1 and 2), the Shibata stylus is different in shape from the conventional elliptical stylus. It is shaped in such a way that its contact area with the record groove is four times greater than that of elliptical stylus. This feature is of great importance in tracking of the CD-4 supersonic carrier: the Shibata stylus makes a much smaller indentation in the record groove. It behaves as if the record material had been considerably strengthened. This raises the mechanical resonance frequency of the pickup system twofold, giving a corresponding improvement in high-end frequency response.









Micrograph 1
Shape of Shibata Stylus

Micrograph 2
Shape of Conventional Elliptical Stylus

Micrograph 3
Tension Upon the Disc Surface by Shibata Stylus (2 g)

Micrograph 4
Tension Upon the Disc Surface by Elliptical Stylus (2 g)

The larger area of stylus-to-groove contact, of course, helps prolong the life of the record (see micrographs 3 and 4) and of the stylus itself. Indirectly, the reduction in groove deformation leads to an improvement in signal-to-noise ratio in discs that have been played over and over again. Directly related to the shape of the stylus is the higher reproduction fidelity, as the ideally dimensioned radius helps to eliminate wave and phase distortions. Needless to say, the Shibata stylus brings most of its advantages into play when tracing conventional stereo records, too.

JVC is now marketing a moving magnet type cartridge (model 4MD-20X) equipped with the Shibata stylus and excellent for CD-4 tracking. JVC builds such cartridges also into a variety of console or near-console modular stereo systems with built-in CD-4 demodulators. These CD-4 "package deals" are meant chiefly for the Japanese market and the styling is directed to Japanese tastes.

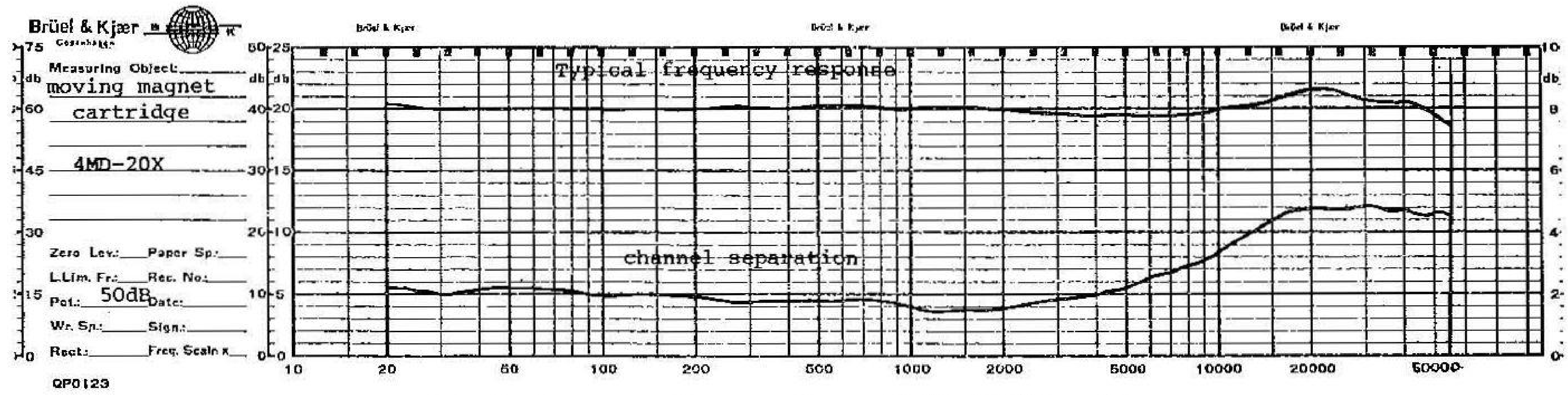


Fig. 9 Frequency Response Curve of 4MD-20X Cartridge

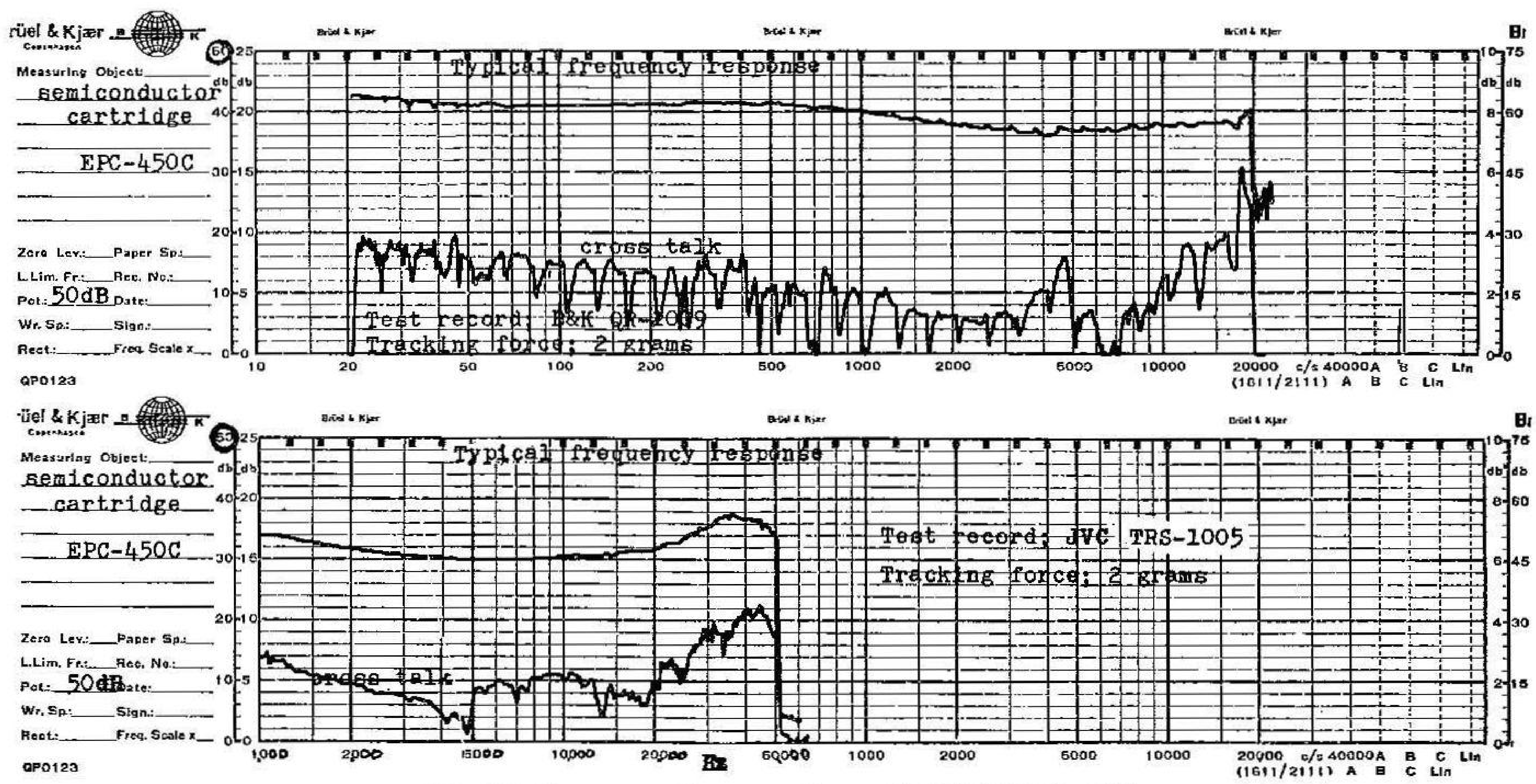


Fig. 10 Frequency Response Curve of EPC-450C Cartridge

The Shibata stylus is also found in the light tracking force version (model EPC-450C) of two semiconductor phono cartridges made by National Panasonic for CD-4 playing, with a frequency response from DC to 50,000Hz. The chief design effort was, of course, to obtain this fabulous range, which led to the adoption of the Shibata stylus discussed above, and the semiconductor principle. A tiny piezo-electric element, supplied with a DC bias voltage from the demodulator, produces resistance changes as varying pressure is exerted upon it by the armature of the stylus-cantilever assembly. The cantilever is very thin and consists of super-strong titanium.

The heavy tracking force version of this semiconductor cartridge manufactured by National Panasonic is the model EPC-460C with a super-duralmin cantilever and a specially polished diamond stylus. The coupling system in the model EPC-460C is somewhat different, as a micro-coupler has been adopted instead of the standard armature.

In addition to extremely wide frequency response, the CD-4 system makes several other demands upon cartridge performance: sharp channel separation, high phase accuracy, relatively high output voltage and the ability to track faithfully at supersonic frequencies. The JVC and National Panasonic cartridges discussed above match all of these demands perfectly.

Other Japanese manufacturers have brought out cartridges suitable for CD-4 tracing — Audio Technica, Fidelity Research, Grace, Micro Seiki and Satin.

After our rather detailed discussion of the recording and modulating process, the functions of the CD-4 demodulator should be easy enough to understand. Its block diagram is shown in Fig. 11.

The composite signal from the cartridge first undergoes RIAA equalization, but only in the lower part of the frequency spectrum and only if a magnetic cartridge is used, as the semiconductor cartridge is self-equalizing in the low range. The signal is then split into its base band and carrier by low pass and bandpass filters respectively. The low 30 to 15,000Hz portion (the sum signal) passes through a potentiometer which is linked to the separation control screw, then undergoes RIAA equalization in its upper range.

Presence of the carrier signal activates the 4-channel CD-4 radar with its indicator lamp on the front panel, while its absence causes a muting circuit to cut off all signal flow in the carrier demodulation strip. The difference signal is retrieved in the FM detector, passes through an FM/PM equalizer and then through a low pass filter which eliminates any remaining traces of carrier frequency. After expansion in the ANRS expander (the playback portion of CD-4's automatic noise reduction system; see Fig. 5 and 6), the difference signal enters the operation circuit where, in a series of algebraic operations, the four discrete channel signals are retrieved. This brief outline already mentions some of the numerous performance features of the CD-4 demodulator.

In operation the presence of a CD-4 carrier can be confirmed at a glance by the "4-ch radar" eye. If the selector on the demodulator is set at "4-ch" but a 2-channel disc is played, the sound will be "stereo times two" — the front and rear left-hand speakers will reproduce the left signal, both right-hand speakers the right channel signal.

The separation control, a pair of semi-fixed screws, actually act upon the level of the sum signals to bring them into line with the difference signal levels so that the adding and subtracting operations will produce undiluted discrete signals without "leftovers". Adjustment will be required only once as long as you keep using the same phono cartridge, and we supply a test record with adjustment instructions.

In regard to circuit design, the most important feature in the demodulator is no doubt the phase lock loop circuit included in the FM detector stage.

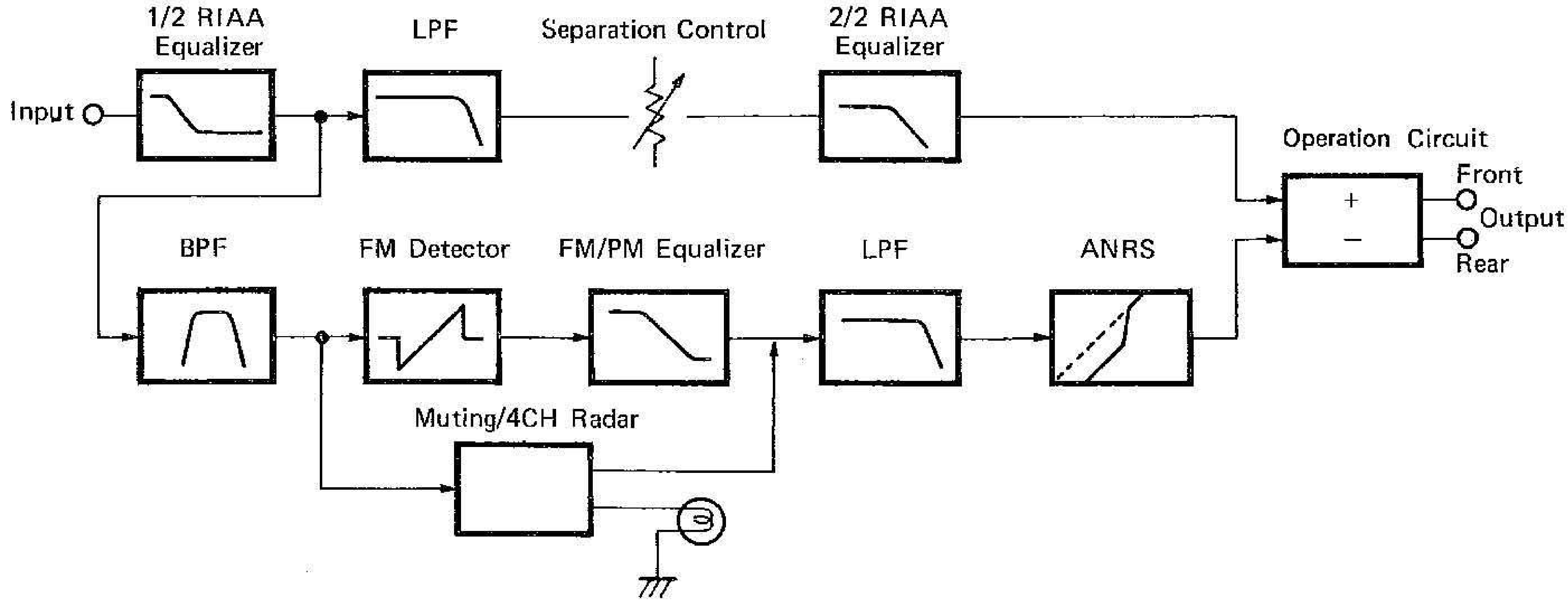


Fig. 11 Block Diagram of CD-4 Demodulator

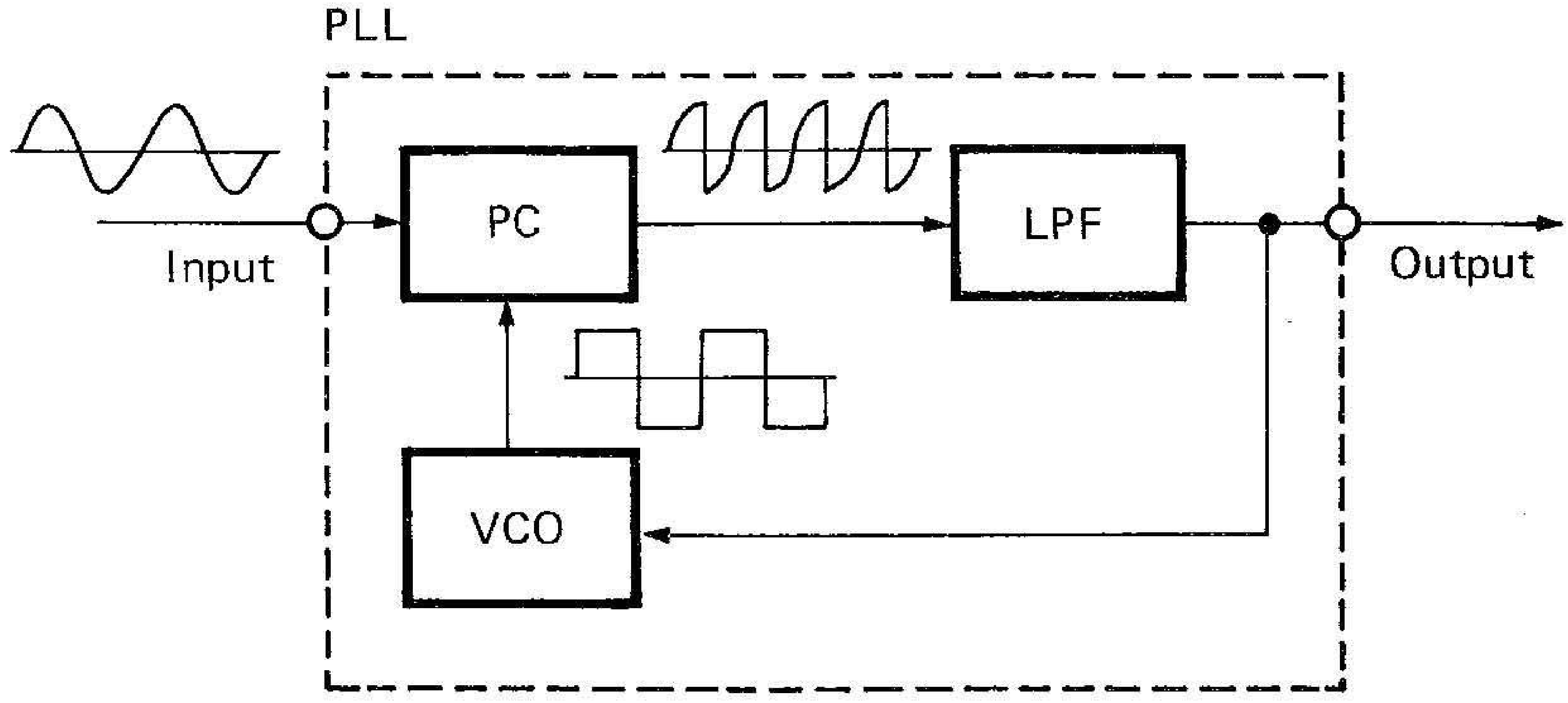


Fig. 12 Block Diagram of Phase Lock Loop

As shown in the block diagram, the phase lock loop circuit consists of three blocks, a voltage controlled oscillator (VCO), a phase comparator (PC) and a low pass filter (LPF). The VCO is a sort of square wave generator whose frequency is controlled by the applied voltage in a linear relationship. The PC compares the phases of the input signal and VCO output and produces a signal with a DC component corresponding to the detected phase difference. This signal passes through the LPF where only the DC component is isolated, which is then returned to the VCO input to control VCO frequency.

As long as VCO output frequency and phase are identical with those of the input signal, the PC produces no DC component. If input signal frequency increases and phase advances, a phase difference between VCO output and signal is caused, whereupon the PC generates a DC component which in turn raises VCO frequency. In this way, VCO phase and frequency are always locked to the input signal. The PLL can be understood as a "phase feedback technique" which constantly keeps the VCO frequency identical with the signal through all frequency deviations. The control voltage applied to the VCO, being dependent on signal frequency, can be looked upon as the result of an FM detection process. In other words, the PLL functions as an FM detector.

A peculiarity of this FM detection by PLL is that detection bandwidth varies in relation to input signal level and load. As long as input level remains above a certain value, detection bandwidth will stay practically constant.

An FET, which functions as a variable resistance element, is connected to the output of the PLL circuit. If the carrier level from a CD-4 disc drops below a certain point, indicating excessive record wear or carrier drop-out caused by dust in the grooves, the dynamic impedance of the FET also drops, whereby the PLL circuit's FM detection bandwidth is automatically and instantaneously narrowed and irritating noise is consequently suppressed. This ingenious circuit design is very effective in dealing with noise and distortion problems in the difference signal configuration of CD-4 records. An added advantage is that the phase lock loop also suppresses the effects of phase deviations caused by turntable flutter.

The FM/PM equalizer in the carrier stretch is the counterpart of recording equalization discussed previously. Comparable to the cycles of pre-emphasis and de-emphasis in FM broadcasting, this equalization helps to improve signal-to-noise ratio and to maintain constant dynamic range.

The CD-4 demodulator is largely equipped with ICs, which helps to explain its compact size, light weight and high reliability. Latest production models now have a carrier level sensitivity control for easy matching to the carrier pickup characteristics of any good 4-channel cartridge.

After you have read this article, you will understand why we are so convinced that the CD-4 discrete disc system is the truly superior 4-channel medium. Because of the many (and successful) precautions taken to assure high fidelity sound as good as any you've ever heard in 2-channel. And because of a superb job done by JVC and National Panasonic in designing the hardware.

CD-4

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