THE JOHN HARDY CO.
SHIP 1728 Brummel St. Evanston, IL 60202 USA
MAIL P.O. Box AA631 Evanston, IL 60204 USA
Phone: (312) 864-8060

3-1-84

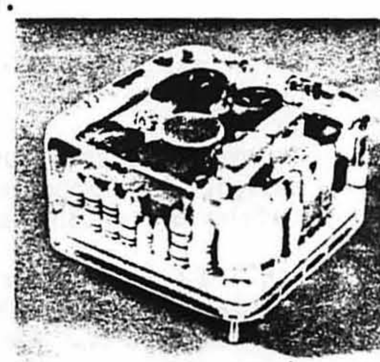
990 DISCRETE OPERATIONAL AMPLIFIER

Thank you for your interest in the 990 discrete operational amplifier. The 990 is a quality product of the Hardy Co.

Thousands of 990 op-amps are in use today in the most demanding audio applications. Leading recording studios, disc mastering facilities, TV and radio stations, manufacturers, etc., are using the 990 to improve their product. In addition to being available separately, the 990 is available from the Hardy Co. as part of a complete mic-preamp card, the MPC-500C. See the application notes later in this package for details. The MPC-500C is designed specifically to replace the stock cards in the MCI 500C/D series consoles, and is excellent for custom applications as well. For further information on this card, contact the Hardy Co. Additional products are under development and will be announced when ready.

CIRCUIT DESIGN: The original electronic design is by Deane Jensen of Jensen Transformers. For complete circuitry details, specifications, design theory, etc., please see the Jensen engineering report, enclosed.

PACKAGING & PRODUCTION DESIGN: The packaging and production design by John Hardy enables this 41-component circuit to be constructed on a circuit board 1" square, with final module dimensions after encapsulation of 1.125" square by .625" high. These dimensions and pin-outs conform to the API-2520 package, allowing direct replacement (Note 1).



APPLICATIONS: The 990 offers significant improvements in a variety of audio and instrumentation applications. When combined with the Jensen JE 16-A/B microphone input transformer, the result is a superb mic preamp. The two were designed for each other. This is the combination used on the MPC-500C mic preamp card. As a combining/-summing amp, the 990 offers significant reduction of bus noise. The 990 performs equally well as a phono preamp, tape-head preamp, line-output amp, in fact just about anywhere. Application notes are enclosed. The 990 sounds better too! The sensitivity and resolution of test and measurement equipment can often be increased with the 990.

RELIABILITY: To ensure reliability at time and temperature extremes, 1% ±100 ppm metal film resistors meeting RN55D (Mil-R-10509) specs are used. The capacitors in the signal path are ultra-stable (±30 ppm) monolithic ceramics, COG/NPO formulation. NOTE: please see the special report on ceramic capacitors (enclosed) for important information on this very special and superior formulation. All modules receive a total of 48 hours of active burn-in at 100°C (212°F). They are encapsulated in a special semi-rigid, clear, thermally conductive epoxy, to enhance reliability and promote thermal tracking of critical components.

MODELS: The 990 is now available in four standard versions:

MODEL #	APPLICATION
990-12V	Use with bi-polar 12-volt power supplies.
990-15V	Use with bi-polar 15-volt power supplies.
990-18V	Use with bi-polar 18-volt power supplies.
990-24V	Use with bi-polar 24-volt power supplies.

The 990 is also available in black epoxy without labels, for OEM applications. See note 1.

PRICES, DELIVERY, TERMS, WARRANTY: see separate sheet, enclosed.

If you have any questions or require applications assistance, please call. Thank you.

Sincerely,

John W. Hardy

John W. Hardy

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OTHER INFORMATION, COMPONENT UPGRADES, PACKAGING OPTIONS, ETC.

The Jensen engineering report lists components as specified by Deane Jensen. Many of these have been upgraded in the Hardy Co. 990 to ensure long-term reliability at temperature extremes:

R1 thru R14, listed as 1/4 watt 5% carbon film, have been replaced with 1% ±100 ppm metal film resistors meeting RN55D/Mil-R-10509 specs.

C1 thru C3 are ultra-stable monolithic ceramics (±30 ppm COG/NPO formulation). See the special report on ceramic capacitors, enclosed.

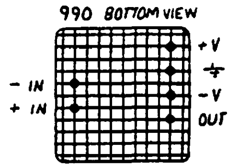
C4 & C5, listed as Y5V ceramics, are upgraded to the X7R formulation, offering much greater stability over a wider temperature range.

CR3 (1N914B diode), has been replaced with a diode-connected transistor (PN4250A) to provide better matching characteristics with Q3, which is also a PN4250A. See the engineering report for details.

Thermal coupling aids as listed are unnecessary. Thermal coupling is inherent in the package design. All components requiring thermal coupling are in direct contact with each other. The modules are encapsulated in a thermally conductive epoxy to complete the coupling process.

R15 & L3 are not part of the basic op-amp "triangle" and are not included in the modules as manufactured by the Hardy Co. They are available separately and their use is recommended for optimum results. See the engineering report. For prices, see "Output isolator", in price list.

Note 1: The standard clear 990 measures 1.125" square by .625" high. This is slightly higher than the API-2520, which measures .600 high. Where height is critical, the 990 is available encapsulated in black potting shells with black epoxy. Module height is .600. Electrical performance is the same. They can also be supplied without labels, for OEM applications.



MODULE DIMENSIONS:
1.125" SQ x .625" H
PIN LENGTH = .233
PIN DIAMETER = .040
PINS CONFORM TO 0.1" GRID

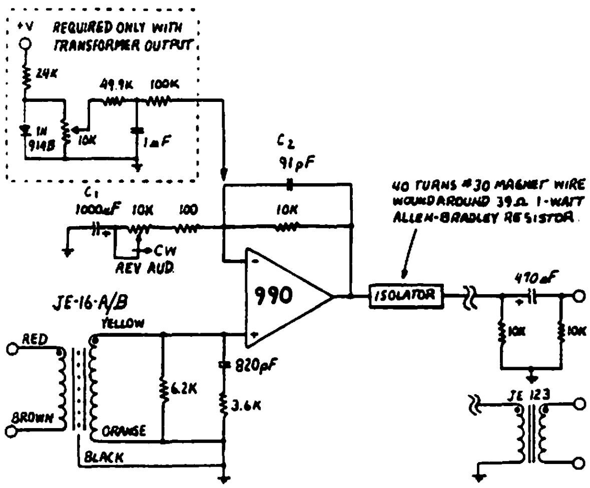
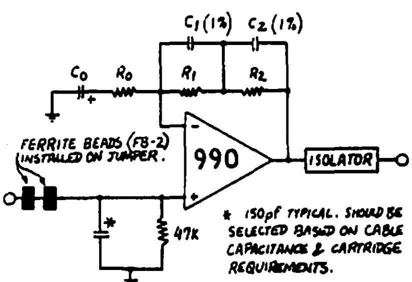


FIGURE 1: MICROPHONE PREAMPLIFIER



* 150pF TYPICAL. SHOULD BE SELECTED BASED ON CABLE CAPACITANCE & CARTRIDGE REQUIREMENTS.

ALL RESISTORS = ±1%

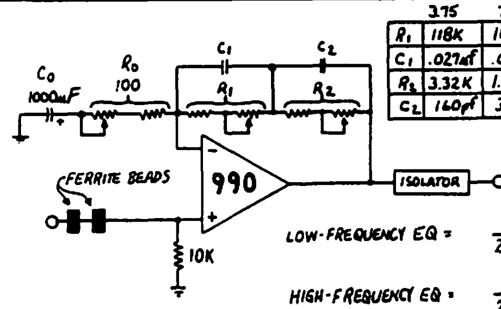
	CALCULATED VALUES	NEAREST 1% RESISTOR	CALCULATED VALUES (SCALED)	NEAREST 1% RESISTOR (SCALED)
R_0	1.402k	(1.40k)	140.2	(140)
C_0	100uF		1000uF	
R_1	1.590M	(1.58M)	159.0k	(158k)
C_1	2000pF		.020uF	
R_2	133.9k	(133k)	13.39k	(13.3k)
C_2	560pF		5600pF	

RIAA Response

(Hz)	(dB)
10	+19.743
20	+19.274
30	+18.593
40	+17.792
50	+16.946
70	+15.283
100	+13.088
200	+ 8.219
400	+ 3.784
500	+ 2.648
700	+ 1.234
1k	0.000
2k	- 2.589
3k	- 4.740
5k	- 8.210
7k	-10.816
10k	-13.734
15k	-17.157
20k	-19.620
30k	-23.117
40k	-25.607
50k	-27.541

FIGURE 2: PHONO PREAMPLIFIER

	3.75	7.5
R_1	118K	118K
C_1	.027uF	.027uF
R_2	3.32K	1.87K
C_2	160pF	300pF



LOW-FREQUENCY EQ = $\frac{1}{2\pi R_1 C_1}$

HIGH-FREQUENCY EQ = $\frac{1}{2\pi R_2 C_1}$

PHASE-LEAD COMPENSATION = $\frac{1}{2\pi R_2 C_2}$

LOW-FREQUENCY CUT-OFF = $\frac{1}{2\pi R_0 C_0}$

$f = \frac{1}{2\pi t}$

SPEED	t_2	DESCRIPTION
1.875	120uS	CASSETTE, NORMAL
1.875	70uS	CASSETTE, HI-PERF
3.75	90uS	N.A.B
7.5/15	50uS	N.A.B.
30	17.5uS	N.A.B.

USE t_2 FOR HIGH-FREQUENCY EQ

USE t_1 FOR LOW-FREQUENCY EQ.

t_1 IS NORMALLY = 3183uS = 50 Hz

FIGURE 3: TAPE-HEAD PREAMPLIFIER

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APPLICATION NOTES

FOLLOWING ARE SEVERAL CIRCUITS FOR USE WITH THE 990 DISCRETE OPERATIONAL AMPLIFIER. WITH THE PROPER ATTENTION TO DETAIL, YOU SHOULD ACHIEVE EXCELLENT RESULTS.

MICROPHONE PREAMPLIFIER

Figure 1 shows a traditional transformer-input microphone preamplifier. The composite circuit is adjustable from 11.6 to 45.6 dB of gain, including the transformer step-up of 5.6 dB, with a bandwidth of 120 kHz (-3 dB). The Jensen JE 16-A/B mic-input transformer was designed specifically for the 990.

C_1 is used to keep the DC offset of the 990 constant by AC-coupling the gain-adjust pot. Without this capacitor, the DC offset would change as the gain-adjust pot were adjusted, because the inverting input would see a changing DC resistance to ground while the non-inverting input saw a fixed resistance. Small DC voltages develop at op-amp inputs as the input bias currents flow through whatever DC resistance path is available (voltage = current x resistance). If both inputs see identical DC resistances, they will develop the same voltages. With identical voltages at the inputs there will be no DC offset at the output, since the output of an op-amp is determined by the difference between the two inputs. With different DC resistances at the inputs, a DC offset would appear at the output. If C_1 were jumpered, not only would the DC resistance at the inverting input change (causing the DC offset to change), but the circuit would now have DC voltage gain of 100 at maximum gain (instead of unity gain at DC regardless of gain-pot setting, with C_1). A difference of only a couple millivolts at the inputs would turn into a couple HUNDRED millivolts at the output of the op-amp.

Also shown is optional offset compensation. The diode regulator and filter circuit supplies a current into the inverting input which compensates for the unequal DC resistances seen at the inputs. The offset voltage at each input is found by multiplying the input bias current (2.2 uA) by the DC resistance seen at that input. For the non-inverting input, the DC resistance is the mic-transformer secondary resistance paralleled by the 6.2K load resistor. For the inverting input, the 10K feedback resistor is the only DC path. Since the closed-loop DC gain of the amplifier is unity, the DC offset at the output is equal to the difference of the offset voltages at the two inputs. The compensating current required into the inverting input is the offset voltage divided by the feedback resistance (10K). This DC offset compensation will significantly reduce the DC offset at the output for those applications without an output coupling capacitor.

C_2 provides the proper phase-lead compensation with a high-frequency cut-off of 175 kHz.

The use of a capacitor in series with the gain-pot as a means of controlling DC offset is traditional. So too is the use of an output capacitor. For a different and superior approach that eliminates these capacitors, please see the app-note entitled "MICROPHONE PREAMPLIFIER WITH SERVO CONTROL OF DC OFFSET", found later in these notes.

PHONO PREAMPLIFIER

Figure 2 shows a phono preamplifier with related component values and theoretical RIAA response figures. The circuit will result in extremely accurate RIAA response, typically better than ±0.1 dB, provided the values and tolerances are maintained. The values are taken from a paper by Lipshitz [1] which thoroughly covers RIAA equalization networks and their proper design. For specific design information, formulas, etc., refer to that paper.

Column 1 shows the exact calculated resistor and capacitor values as listed in the paper, with the closest 1% resistor values shown in parenthesis. Column 2 shows these values scaled by a factor of 10, to take advantage of the improved noise figure of the 990 at lower source impedances.

C_0 AC-couples the op-amp causing DC gain to be unity. It could be eliminated if offset compensation were performed. See "MICROPHONE PREAMPLIFIER" for one technique.

The ferrite beads at the input are optional to reduce RFI.

The circuit gain is approximately 41.7 dB at 1 kHz. Any changes in component values should be carefully evaluated based on the Lipshitz paper.

REFERENCES

1. Lipshitz, S., "On RIAA Equalization Networks", Journal, Audio Engineering Society, Vol. 27, #6, 6/79, pp. 458-481.

TAPE HEAD PREAMPLIFIER

Figure 3 shows a tape head preamplifier. Component values for 3.75 and 7.5 i.p.s. NAB equalization and a gain of 50 dB are listed. Other gains and equalizations are easily achieved using the formulas provided. Tape head specifications and characteristics vary widely, so the values listed will probably require trimming, and the final results should be carefully examined for any irregularities.

Tape heads with extremely low output levels will require additional gain, and a 2nd op-amp should be considered for that purpose. The 2nd op-amp should have flat response, and each op-amp should be set for equal gain at high frequencies (20 kHz).

This circuit is very similar to the RIAA phono preamp, except that this one is tuneable, and the R_2C_2 network is out at 300 kHz performing the phase-lead compensation rather than the critical RIAA equalization function. See "PHONO PREAMPLIFIER" for comments on C_0 and ferrite beads.

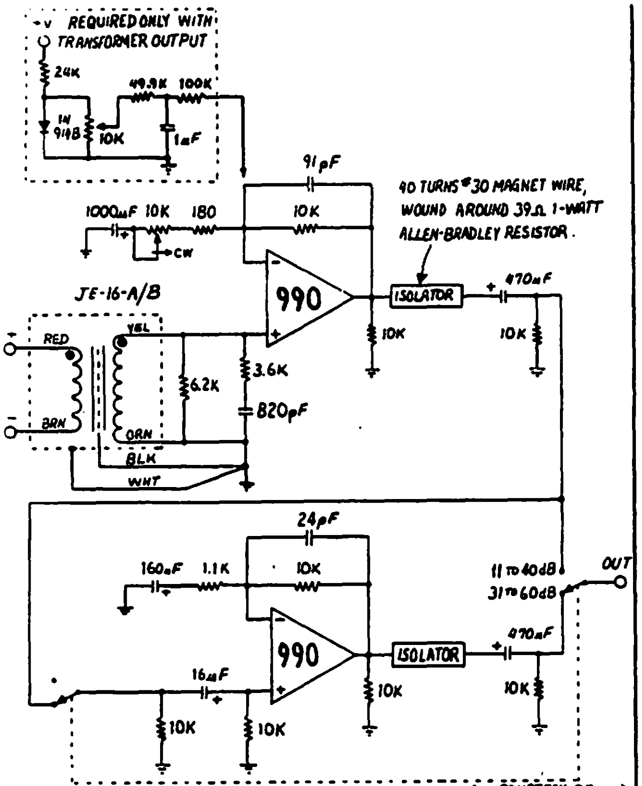
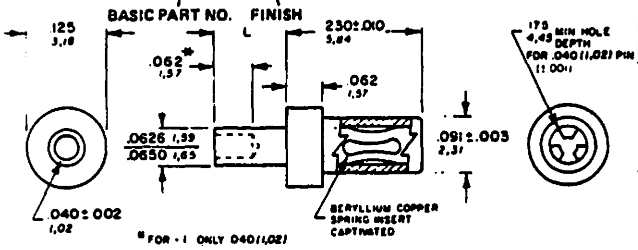


FIGURE 4: TWO-STAGE MICROPHONE PREAMPLIFIER (COURTESY OF JENSEN TRANSFORMERS)

09-9035-X-XX P.C. JACK FOR .040 PIN



*FOR -1 ONLY .040(1,02)

ACCEPTS .040(1,02) PIN

PART NO	L	BOARD THICKNESS
09-9035-1	.062 (1,57)	1/32 (0,79)
09-9035-2	.094 (2,39)	1/16 (1,59)
09-9035-3	.125 (3,18)	3/32 (2,38)
09-9035-4	.156 (3,96)	1/8 (3,18)

COMPONENT FINISH

PART NO	BODY (BRASS)	SPRING (BERYLLIUM COPPER)
09-9035-X-03	GOLD/COPPER	GOLD/COPPER
04	ELECTRO-TIN/COPPER	ELECTRO-TIN/COPPER
06	ELECTRO-TIN/COPPER	GOLD/COPPER

FIGURE 5: SOCKET FOR .040 D PIN

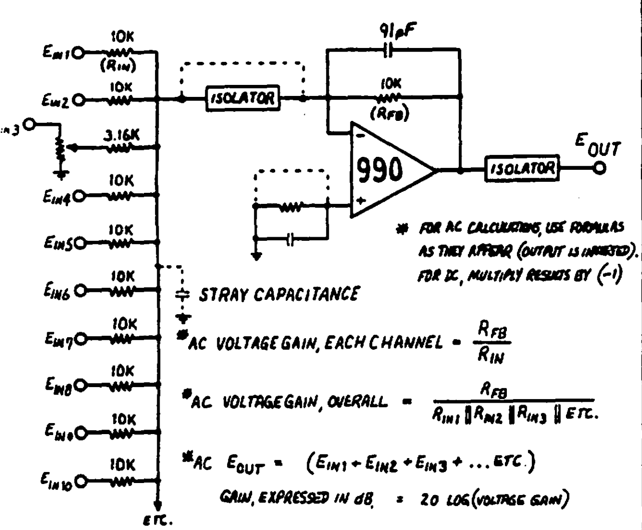


FIGURE 6: SUMMING AMPLIFIER (INVERTING)

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TWO STAGE MICROPHONE PREAMPLIFIER

Figure 4 shows a two-stage transformer coupled microphone preamplifier. It is recommended for situations where extremely high gain is required. The 1st stage is essentially that of the single-stage preamp of figure 1, except the maximum gain is about 5 dB lower. A switchable 2nd stage with 20 dB of gain enables a choice of single-stage operation up to 40 dB of gain (including transformer step-up) or two-stage operation with up to 60 dB of total gain. The 2nd stage could be changed from fixed to adjustable gain. Ideally, each stage would have the same amount of gain in the high-gain applications, and a variable 2nd stage would allow gain matching at any overall gain.

Offset voltage compensation can be performed on the 1st stage, as described in the single-stage preamp text. Note that the 2nd stage will have a low V_{OS} because the inverting and non-inverting inputs see identical DC source resistances (10k).

SOCKETS

Many types of sockets are available from several manufacturers. A common socket is shown in figure 5, reprinted from the Concord catalog. The same part is available from Cambion as well. This socket is available from stock from the Hardy Co. (see the price list).

This particular socket may be soldered in place, or swaged (special tool required).

CONCORD ELECTRONICS CORP. (212) 777-6571
30 Great Jones St.
New York, NY 10012 Part #09-9035-2-03

CAMBION (617) 491-5400
445 Concord Ave.
Cambridge, MA 02238 Part #450-3756-02-03

A good selection of sockets is also available from:

ROBINSON NUGENT INC. (812) 945-0211
800 E. 8th St.
New Albany, IN 47150

SUMMING AMPLIFIER

Figure 6 shows a summing amp with several optional features. Some applications require signals to be combined at unity gain, others require different gains. For example, the signal of channel 3 is attenuated by a potentiometer (typically 10 dB of attenuation) just before it enters the summing circuit. To restore the 10 dB lost through the pot, a lower value is used for R_{IN}, in this case 3.16k (see formulas). With many channels being summed simultaneously, the overall composite signal at the output of the summing amp could become excessive, resulting in insufficient headroom. The final value for R_{IN} would therefore be chosen based on the number of channels, signal levels, pot settings, etc.

The non-inverting input may be grounded directly, or through a resistor. The value of the resistor should equal the DC source resistance seen by the inverting input, which is the parallel resistance of all the input resistors and the feedback resistor (R_{IN} and R_{FB}). With both inputs of the 990 seeing identical DC source resistances, the output offset voltage will be the lowest. This resistor can result in increased noise when compared to a directly terminated input. This problem can be overcome by adding a capacitor in parallel with this termination resistor. The capacitor has infinite impedance at DC, so the terminating resistor is the only factor as far as DC specs are concerned. The impedance of the capacitor becomes much lower than that of the terminating resistor above DC, so the noise performance of the 990 is not significantly compromised. The value of the capacitor will depend on the noise performance of the type of op-amp being used, number of channels being summed, noise limitations of the channels being summed, etc. A value of 0.1 uF would be a place to start.

Note that the actual termination point or location for the non-inverting input is critical: In larger consoles with many inputs, there can be much noise appearing on the ground bus, since even a heavy ground bus will have a small but measureable resistance, with voltages appearing across the resistance. These voltages can be in the form of power-supply noise, return currents (thus voltages) from other modules, etc. Although each input of the summing amp may be at unity gain, the overall gain of the summing amp is determined by using the parallel resistance of all the input resistors for the value of R_{IN} in the gain formula. For example, 24 inputs with R_{IN} of 10k results in a final parallel resistance of 417 ohms, for a voltage gain of 24 (27.6 dB). That is how much the ground bus noise would be amplified if the non-inverting input were terminated far from the signal sources being summed. Grounding is critical!

Longer summing busses cause increasing amounts of stray capacitance to appear at the inverting input. This capacitance causes phase-shift in the feedback signal, and in sufficient quantities, can cause oscillation. Additional capacitance can be used in the feedback loop to compensate. Also an isolator (normally used at the output of the 990) could be inserted between the summing bus and the inverting input, with the isolator as close to the inverting input as possible. The isolator has an impedance of 0.2 ohms at DC, rising to only 5 ohms at 20 kHz, so the audio bandwidth passes through relatively unaffected. Above 155 kHz, the impedance is 39 ohms, reducing the effects of the stray capacitance.

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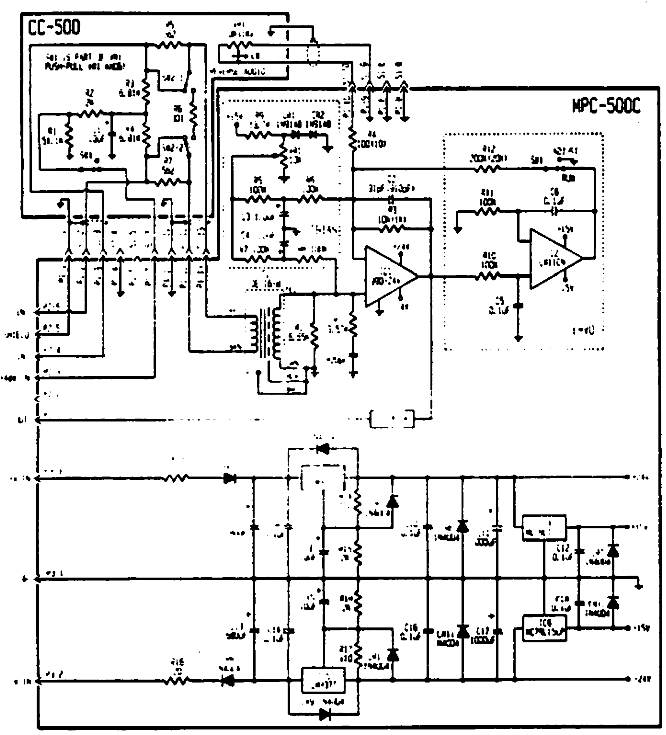

FIGURE 7: MPC-500C Mic-Preamp Card & CC-500 Control Card

MICROPHONE PREAMPLIFIER WITH SERVO CONTROL OF DC OFFSET

Figure 7 shows a single stage microphone preamplifier with a special servo circuit, input bias current compensation circuit, and related power supplies. The circuit is similar to the preamp shown in figure 1, however the servo and input bias current compensation circuits now control the DC performance of the circuit, making it possible to eliminate the gain-pot capacitor and output capacitor. This results in a substantial improvement in audio quality since even the best film capacitors are a compromise.

As discussed in the earlier application note "SINGLE STAGE MICROPHONE PREAMPLIFIER", gain-pot adjustments without the use of a gain-pot capacitor (C_1 in figure 1) would cause changes in the DC offset of any op-amp. Other offsets result from drift due to time and temperature. A capacitor in series with the output is often used to keep these various offsets from reaching the outside world.

With the servo approach, the LM11CN op-amp monitors the output of the 990 for the presence of any DC offset and provides a corrective voltage to the inverting input of the 990, nulling the DC offset of the 990 to within the DC offset limits of the LM11CN itself.

There are two capacitors (polypropylene) in the servo circuit, but the only signal that is affected by these capacitors is the ultra-low frequency and DC components. These capacitors are working with their respective resistors as ultra-low frequency low-pass networks. Essentially, the only signal that passes through the servo circuit is the DC offset of the 990. The audio bandwidth is completely unaffected. The servo keeps the DC offset of the preamp circuit well below 1 mV under normal conditions.

The LM11CN was chosen as the servo amp because it has exceptional DC characteristics, with a typical offset voltage of 0.2 mV and a drift of .002 mV per degree centigrade of temperature change. Since the servo op-amp only sees extremely low frequency signals, it does not need a high slew rate.

An input bias current compensation circuit is also shown. It performs two important functions. First, it nulls the small DC voltages that appear at the inputs of the 990 due to the normal flow of input bias current. This eliminates the noise that sometimes occurs during gain pot adjustment, caused by DC voltage across the pot. Second, since the input bias current is compensated for and the DC voltages at the inputs are nulled, the DC offset of the 990 will no longer change as the gain pot is moved. Without this circuit, the offset of the 990 could shift as much as 120 mV during extreme changes of gain (max. to min. or vice versa), the exact amount depending on the specific input bias current and DC offset of the individual 990. Smaller gain changes would cause smaller offset shifts. It is important to note that the servo circuit would still reduce the largest shifts to less than 1 mV in just a few seconds, but the bias compensation circuitry eliminates these shifts and corrections. The servo circuit's only task then is to deal with the inherent DC offset of the 990. The complete adjustment procedure for the input bias compensation circuit is shown below. The pair of 1N914B diodes provides a reference voltage of 1.2 volts. The 10K trimmer adjusts this voltage and applies it to the inputs of the 990 as a current through the 100K resistors. The 1.0uF polycarbonate capacitors act as low-pass filters to remove noise from the compensation circuit.

Figure 7 shows the complete circuitry of the MPC-500C mic preamp card and the CC-500 control card, retrofits for the MCI 500C/D series consoles. Both cards are available from The Hardy Co. The MPC-500C shows two sets of values for some of the parts. The first values shown are those used in the stock MPC-500C card, and are chosen for compatability with the 10K gain-adjust pot in the MCI consoles. The values in parenthesis are preferred because they will provide a 1 to 2 dB improvement in S/N ratio. A low noise version of the MPC-500C is available. The CC-500 control card is available in MCI-compatible and low noise versions, making conversion of the MCI consoles possible. The higher resistor values of the stock MPC-500C (and the preamp of figure 1) are a necessary compromise to keep the value, size and cost of the conventional gain-pot capacitor from becoming too great. Elimination of this capacitor removes these restrictions, making the lower noise version possible.

The complete power supply as shown on the MPC-500C card is excellent for any audio application. There are actually two sets of regulators. The first set (LM317 and LM337) brings the ±32 volt supplies of the MCI consoles down to the ±24 volts required by the 990-24V op-amp. The 2nd set (78L15 and 79L15) provides a lower supply voltage for the LM11CN, which is rated at a maximum of ±20 volts. The 2nd set of regulators could be eliminated by using the 990-15V or 990-18V and setting the main regulators at the appropriate lower voltage. However, headroom would be reduced by as much as 4 dB due to the reduced supply voltage (±15 volt supplies).

The power supply as shown requires a minimum of ±30 volts for proper operation due to the input/output differential spec of the 317/337 regulators and the voltage drop of the 20 ohm resistors (R13 and R16). These resistors provide more effective filtering, but can blow if either supply is shorted to ground. Alternatively, they can be eliminated.

The LM317/337 regulators are similar to the conventional 7800/-7900 or 340/320 three-terminal regulators, but offer improved performance in a number of areas. There are several diodes used in the circuit. The input diodes protect the regulators from reverse polarities. The balance of the diodes protect the regulators and op-amps from various possible destructive modes. These diodes are absolutely required! For complete details on the diodes, complete part numbers, etc., consult the manufacturer's data sheets.

The LM317 and LM337 regulators are available from National Semiconductor and Texas Instruments. The 78L15 and 79L15 are common items available from several different manufacturers. The LM11CN op-amp is available from National Semiconductor and Motorola.

The servo concept can be applied to virtually any audio circuit. There are many variations. For complete details, a good reference is an article by Brian Clark in The Audio Amateur, issue 3/1982. Contact The Audio Amateur, P.O. Box 576, Peterborough NH 03458.

ADJUSTMENT PROCEDURE: A DC voltmeter with 0.1 mV resolution or better is required. NOTE: The trim-pot is a precision 25-turn device.

1. Allow the MPC-500C to warm up (15 minutes minimum).
2. Move the slide switch (SW1) on the MPC-500C to the "ADJ" (ADJUST) position.
3. Connect the DC voltmeter to the output of 990, at the output connector.
4. Measure and record the DC offset of the 990 with the gain adjusted to MAXIMUM, then MINIMUM.
5. If the bias compensation trimmer is correctly adjusted, the two measurements you just made will be equal (within 1 mV of each other). The measurements could be as much as 100 mV or more, as long as they are equal. Adjust the trimmer and repeat steps 4 and 5 until the measurements are equal. When they are, the input bias current of the 990 has been completely nulled.
6. Move the slide switch to the "RUN" position. The LM11CN will quickly null the remaining DC offset to less than 1 mV, and the offset will remain there even during extreme adjustments of the gain pot. If the compensation trimmer were out of adjustment, the DC offset of the 990 could temporarily go as high as 120 mV during extreme gain adjustments (maximum to minimum, or vice versa). Even then, the LM11CN would null that offset to less than 1 mV in a couple of seconds.

CERAMIC CAPACITORS

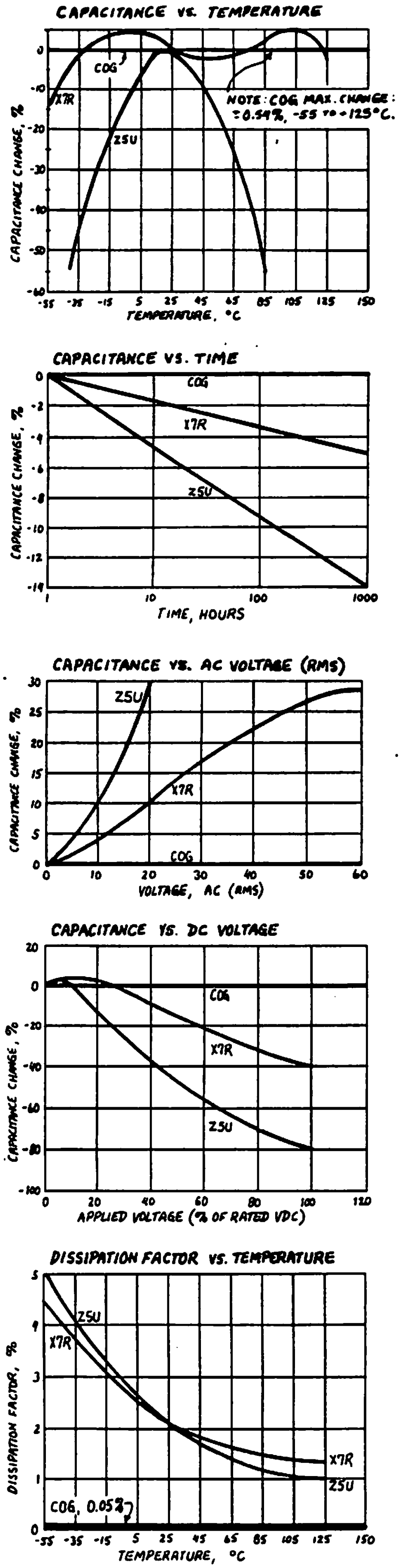

FIG. 1: TYPICAL CHARACTERISTIC CURVES

Ceramic capacitors have a bad reputation in audio circles. It is only partially deserved. Many engineers are unaware that there are several distinctly different formulations of ceramics, each having its own unique set of properties. The three most common E.I.A. [1] types are:

1. Ultra-stable, **COG** dielectric (also called **NPO** [2]).
2. Stable, **X7R** dielectric.
3. General purpose, **Z5U** dielectric.

The COG dielectric stands apart from the others as a vastly superior performer. It is also more expensive, particularly in values above a few hundred picofarads, and is usually dismissed as cost-prohibitive. A common mistake is to shop by price alone and buy the cheaper ceramic dielectrics, not realizing the serious performance compromises. The engineer then condemns ALL ceramics based on the limited experience with only the inferior types. TOO BAD! Examination of the performance graphs of figure 1 reveals some of the significant differences between the dielectrics.* In each case...capacitance vs. temperature, capacitance vs. time (aging), capacitance vs. applied A.C. voltage, capacitance vs. D.C. stress, and dissipation vs. temperature, the X7R and Z5U dielectrics show significant compromises when compared to the COG formulation.

The X7R and Z5U formulations trade off electrical performance for increased volumetric efficiency. To achieve this, a ferroelectric material is used. Ferroelectric behavior is very complex. An excellent text by Centre Engineering [3] provides a comprehensive discussion of this and other ceramic properties, and is recommended reading. Essentially, ferroelectricity causes capacitance to change as the applied voltage to the capacitor is changed. In audio applications, the AC voltage passing through a ferroelectric dielectric would modulate the capacitance. In resistor/capacitor networks such as found in equalizers, crossovers and AC coupling circuits, this modulation effect causes distortion which increases as the signal frequency approaches the cut-off frequency of the RC network.

Tests were conducted with three ceramic dielectrics: COG, X7R, and Y5V (Y5V is similar to the Z5U formulation) to measure total harmonic distortion vs. frequency when used as high-pass and low-pass filters. Figure 2 shows the specific HP and LP filter circuits and the test results. The X7R and Y5V formulations show significant amounts of distortion, but the COG formulation, being non-ferroelectric, shows distortion figures at or very near the residual of the measuring equipment.

An article by Jung and Marsh [4] presented the same test, but with the X7R dielectric only, providing a rather pessimistic view of ceramic capacitors. The balance of the article is extremely enlightening and is recommended reading, as it enters into relatively unexplored areas of capacitors in audio applications.

The COG ceramics were chosen for use in the signal path of the 990 as manufactured by the Hardy Co. for several reasons. First, their performance is exceptional, as noted. Second, though the higher values are considered cost-prohibitive, the low values used in the 990 (62pF, 91pF, 150pF) are cost-competitive. Third, they are physically the smallest capacitors available, extremely important when 41 components must be packaged on a 1" square p.c. board.

It is hoped that this information will provide a better understanding of ceramic capacitors. Each of the formulations has its proper place, and for audio frequency applications, the COG dielectric is by far the best choice.

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REFERENCES:

1. E.I.A. = Electronic Industries Association.
2. NPO = Negative-Positive-Zero, indicating a temperature coeffecient of capacitance that is neither plus nor minus, but is very close to zero. Tempco = 0 ±30 parts per million per degree centigrade), -55 to +125 degrees centigrade.
3. "TECHNICAL INFORMATION, Ceramic Capacitors". Capacitor catalog, Centre Eng., 2820 E. College Ave., State College, PA 16801
4. Jung, W., Marsh, R., "Picking Capacitors - Part 1" Audio, 2/80; "Picking Capacitors - Part 2" Audio, 3/80.

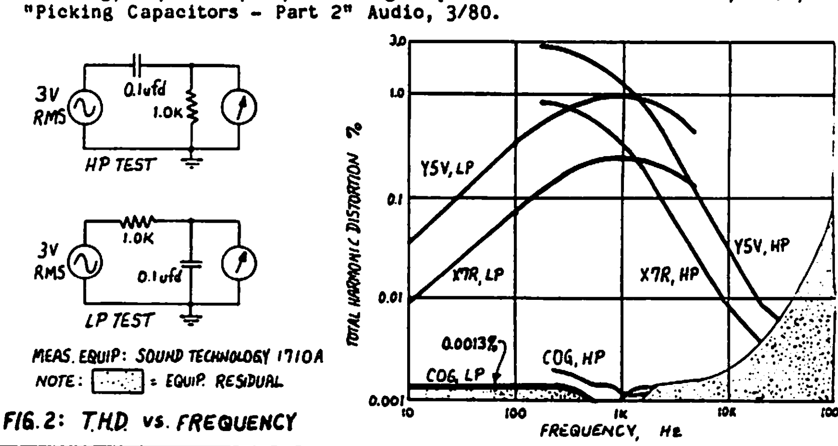

FIG. 2: T.H.D. vs. FREQUENCY

PRICES, DELIVERY, TERMS, WARRANTY.

ITEM		1-9	10-24	25-99	100-999	1000-up
990-12V,15V,18V,24V		$ 46.95	--	$ 43.95	$ 41.95	$ 39.95
Output isolator (R15 & L3)		2.91	--	2.55	1.95	1.52
Sockets (six req. per 990)		.79	--	.75	.69	.65
FB-2 ferrite beads (100/bag)		5.25/bag				
MPC-500C		195.00	175.00	165.00	159.00	155.00
opt. 1 (gold conn.)	**ADD:**	5.00	4.00	3.50	3.00	2.50
opt. 2 (1K gain pot)	**ADD:**	--	--	--	--	--
MPC-500C ACCESSORIES:						
CC-500 gain-control card		30.00	27.00	25.00	24.50	24.00
opt. 1 (1K gain pot)	**ADD:**	--	--	--	--	--
opt. 2 (gold conn.)	**ADD:**	1.00	.90	.81	.75	.70
opt. 3 (gold switch)	**ADD:**	2.00	1.80	1.50	1.37	1.25
Potentiometer, 10K rev. audio		6.00	5.50	4.95	4.75	4.25
Potentiometer, 1K rev. audio		6.00	5.50	4.95	4.75	4.25
Connector, 3x.156 Female, tin		.38	.34	.31	.29	.27
Connector, 3x.156 Female, gold		.60	.54	.49	.45	.43
Connector, 6x.156 Female, tin		.56	.50	.46	.42	.40
Connector, 6x.156 Female, gold		1.50	1.35	1.22	1.13	1.07
Connector, 8x.100 Female, tin		.90	.81	.73	.68	.64
Connector, 8x.100 Female, gold		2.26	2.03	1.84	1.70	1.60
Standoff, 4-40 thread, .25Dx.625H		.20	.18	.16	.15	.14

PRICES SUBJECT TO CHANGE. CONTACT THE HARDY CO. FOR CURRENT PRICES.

ADDITIONAL CHARGES: There is a $5.00 shipping and handling charge on each order. Orders are shipped via UPS Blue label ("2nd-Day Air") where available. C.O.D. orders add $1.65 for UPS COD fee. Illinois orders please add 7% State sales tax. Out of state orders: Any applicable sales or use taxes for your state are your responsibility.

FOREIGN ORDERS: There is a $5.00 shipping and handling charge on each order. Import duties are the responsibility of the purchaser. All orders shipped via Air Mail.

DELIVERY: Generally from stock. Contact the Hardy Co. for current delivery information.

TERMS: Prepaid and C.O.D. orders are accepted. Net-30 is available with approved credit.

If you have any questions or require applications assistance, please call. Thank you.

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WARRANTY: The 990 operational amplifier, the MPC-500C microphone preamplifier card and the CC-500 control card are warranted against defects in materials and workmanship for a period of one year from date of shipment. The Hardy Co. will replace defective product under this warranty if factory inspection reveals evidence of such defects. Product must be returned to the factory for inspection, shipped prepaid. No other warranty is expressed and/or implied.

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