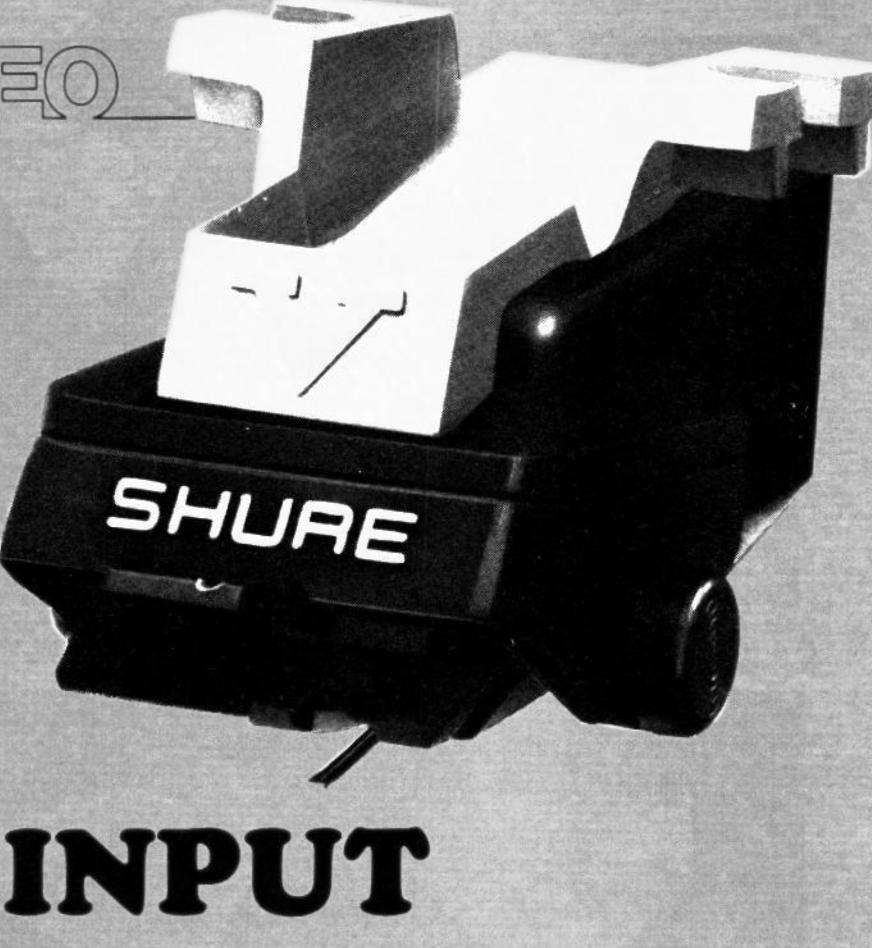

From STYLUS to PHONO INPUT

What you need to know about modern phono cartridges, plus how you can measure the frequency response of your cartridge, determine the proper load impedance and then alter the load impedance for maximum performance.

LEN FELDMAN

MOST OF US STILL RELY UPON THE PHONOgraph record for much of our music listening, and while futuristic promises of optical (laser) and digital discs seem close to realization, it will be many years before the vinyl analog LP record will be replaced to any significant degree. That means that we will be using phonograph cartridges as the first element in our home music systems for the foreseeable future. While volumes could be written about the design criteria for a "good" phono cartridge, we have chosen to concentrate on the input and output ends of this remarkable little device—the stylus assembly and the required load impedance of modern magnetic pickups. Much of the information for this discussion was derived from a series of technical papers assembled by the engineers at Shure Bros., and distributed during informative seminars. Shure held these seminars primarily for the purpose of informing audio enthusiasts as to what is involved in the design of high quality cartridges and secondarily, to educate the audio consumer regarding the importance of using only original manufacturer stylus replacements when it becomes necessary to replace a worn stylus in a high-fidelity cartridge.

Stylus tip design

The stylus tip provides the physical interface between the record groove and the rest of the phono cartridge. It must accurately translate the signal stored in the record grooves into an electrical signal that can be transmitted through the rest of the playback system. If the stylus assembly, excluding the tip, cannot cope with a given signal, the stylus will mistrack. Another important requirement is that a stylus must not cause additional noise while doing its job. Also, record and tip wear must be kept to a minimum.

As shown in Fig. 1, the dimensions of a standard record groove impose certain constraints upon stylus tip design. The groove is not a constant shape (unless it is unmodulated) but can become as narrow as 0.001 inch at the record surface. The tip, therefore, must be designed to accommodate this minimum groove width. And, since the bottom of the record groove is rounded (and not pointed) precautions must be taken to prevent the tip from contacting the bottom of the groove. Unwanted noise and mistracking will result if adequate clearance between the tip and the bottom of the record groove is not maintained.

For other than spherical tips, the entire contact area of the tip must not be tilted forward or backward with respect to the groove modulation. Such tilting would cause distortion and tips with longer contact areas are more sensitive to such misalignment than are tips with shorter contact areas. Other design constraints include the need for the stylus tip to accommodate a moderate amount of dust and lint, the ability of the tip to slide along the record material without modifying, damaging, or destroying the record groove, and finally, the tip must be capable of being manufactured precisely and consistently.

Possible tip shapes

Offhand, one might suppose that the ideal shape of the stylus tip would be the same as the shape of the cutting stylus that made the record groove in the first place. As we see from Fig. 2, however, that is not the case, since stylus tilt of

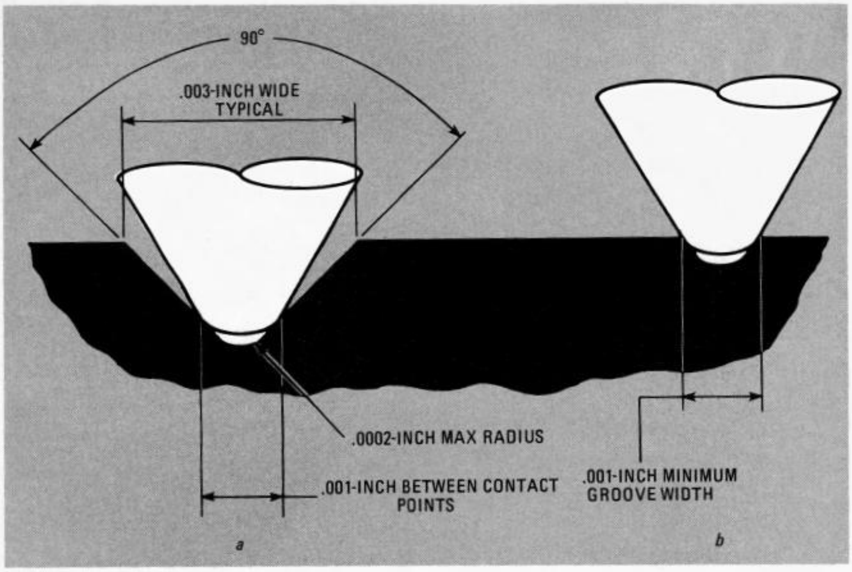

FIG. 1—GROOVE DIMENSIONS of standard lp record. The groove dimensions are constantly varying as a result of the modulation. The typical groove dimensions are shown in *a* while the minimum dimensions are shown in *b*.

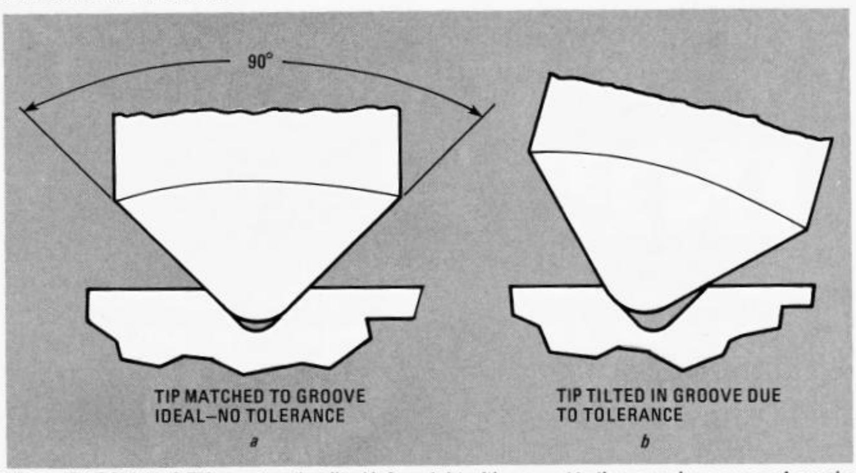

FIG. 2—THE STYLUS TIP must not be tilted left or right with respect to the record groove as shown in *a*. When stylus tip is tilted, proper contact with the record groove does not occur, as shown in *b*. This tilt angle is sometimes referred to as angular tolerance.

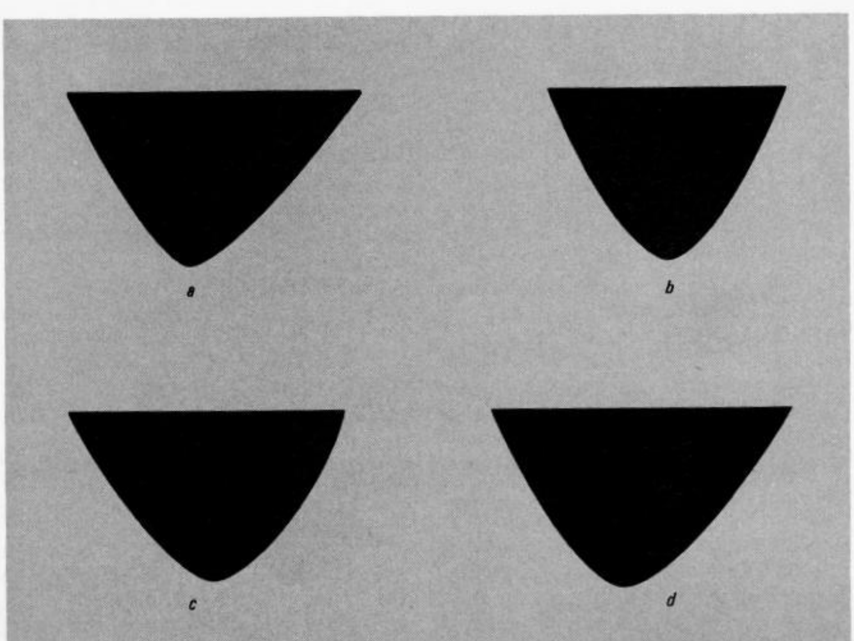

FIG. 4—BIRADIAL TIPS include several different shapes. The Shibata tip is shown in *a*, the Pramanik is shown in *b*, the quandrahedral is shown in *c*, and the hyperbolic is shown in *d*.

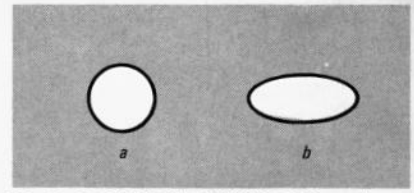

FIG. 3—SPHERICAL STYLUS TIPS produce a circular contact area with the record groove, as shown in *a*. Biradial tips produce an oval contact area as shown in *b*.

even a few degrees would lead to almost complete mistracking. Other possible tip design shapes include spherical tips, having circular cross sections and biradial tips having oval cross sections. These cross sections are shown in Fig. 3.

While the front profiles of a spherical tip and a biradial tip of equal major radius are the same, the advantage of the biradial tip is its smaller tracing radius that yields significantly lower tracing distortion. A class of tips having an elongated contact region evolved during the early and mid-1970's, when CD-4 quadraphonic records were being issued. As shown in Fig. 4, this classification now includes such tip shapes as Shibata, Pramanik, quadrahedral, hyperbolic, etc. The chief difference between these and the biradial tip is the front profile, but we cannot tell from these views about the contact radius. In fact, all of the tips just named in this category have approximately the same average tracing radii as the typical biradial tip—0.0003 to 0.0035-inch.

Carefully controlled tests are necessary to evaluate tip performance. Such tests must not be limited to one kind of measurement, but must include distortion, noise, and wear tests. The results of the tests have shown that biradial and long contact tips with the same tracing radius yield about the same average distortion as expected from theory. All of these geometries will reproduce roughly the same amount of surface noise provided that they have adequate clearance to the bottom of the groove.

Record and stylus tip wear tests conducted over the years by Shure Bros. have yielded some results worth noting. For example, their data shows that diamond tips have a significantly longer life than sapphire, as shown in the plotted curves of Fig. 5. Another test revealed the increased abrasive action of playing a stylus continuously on the same record as opposed to a limited number of plays (20) on several different records. Downward tracking force is also a major factor of tip life, regardless of stylus tip shape, as shown in Fig. 6. These tests show a trend toward a faster rate of wear as tracking force increases.

The record wear tests demonstrate the importance of proper tracking and low stylus mass in preventing groove damage. In other record wear tests, re-

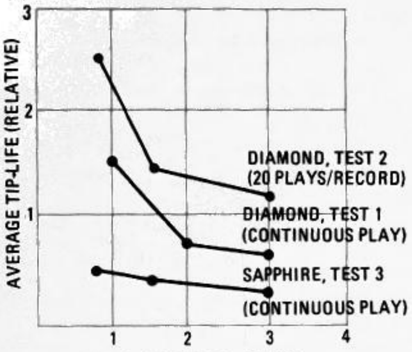

FIG. 5—TIP WEAR depends on the tip material and the tracking force.

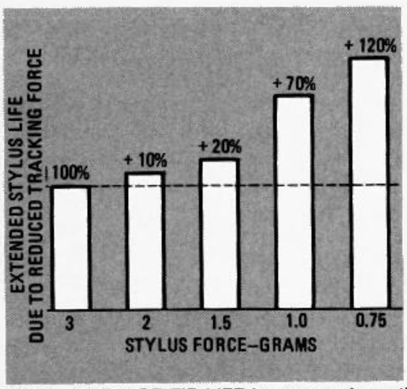

FIG. 6—AVERAGE TIP LIFE increases dramatically as the tracking force is reduced.

sults indicate some advantage to long contact tips, but the advantage is dependent on the groove modulation level and the tracking force. Low stylus mass (i.e. high trackability) and low tracking force are far more beneficial in achieving long record and tip life.

Proper cartridge loading

It is unfortunate that after dedicated engineering departments go to all the trouble that they do to create pickups that are capable of uniform frequency response, high trackability, and long life, so many users pay little or no attention to the proper mounting and impedance requirements of the cartridge. The subject of proper cartridge mounting is, in itself, a complicated one and requires a complete discussion on its own which would be too lengthy to include here. However, a few notes concerning proper cartridge loading are in order. The subject is not inordinately complex, but it is nevertheless often ignored.

Read any cartridge specification sheet or owner's manual supplied with a modern cartridge and you will find a specification called "load impedance". That specification consists of two parts, one resistance and the other capacitance. More often than not, the resistance component of that load impedance is specified as 47 kilohms, and you need do nothing about it since just about every phono preamp input presents that resistance. Some preamplifiers even have a choice of resistance values, from around 22 kilohms to 100 kilohms (the latter value was often recommended for CD-4 quadraphonic cartridges when those were common a few years ago, but but is hardly ever called for in a modern cartridge). What may or may not be listed under the general heading of impedance, however, is the required value of load capacitance, given in pF when it is listed.

Both the load resistance and the load capacitance are extremely important if "flat" frequency response is desired. If the load impedance presented to the cartridge is far removed from the recommended values, the high-frequency portion of the response will be altered. To show how the response is altered, Shure Bros. provided us with a response curve of their *V15 Type IV* cartridge when it was loaded with 47 kilohms of resistance and 250 pF of capacitance per channel. This response curve is shown in Fig. 7. Note that there is no resonant peak within the frequency range from 40 Hz to 20 kHz.

To show the effects of proper and improper cartridge loading, we mounted a lower cost magnetic cartridge into our turntable; one known to have a resonant peak within the audio spectrum. The

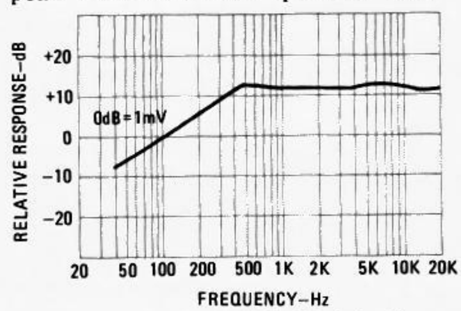

FIG. 7—FREQUENCY RESPONSE of the Shure V15 Type IV cartridge with a 47-kilohm 250-pF load impedance. The sloping response below 500 Hz is a result of the test record (see text.)

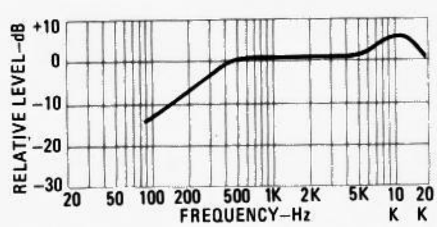

FIG. 8—FREQUENCY RESPONSE of a low-cost magnetic cartridge with a 100-kilohm 100-pF load impedance. Note the large resonant peak at 12 kHz.

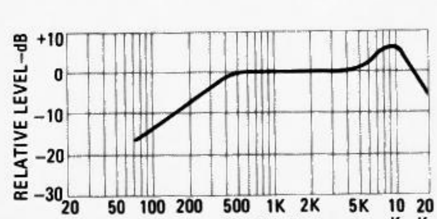

FIG. 9—INCREASING THE LOAD CAPACITANCE to 300 pF lowered the frequency of the resonant peak to 10.5 kHz. The load resistance is 100 kilohms.

make and model number are not important, but suffice it to say that it was not a cartridge from one of the better known, high-quality cartridge manufacturers. Two response curves were made each with a different load impedance. Results are shown in Figs. 8 and 9. Incidentally, in Figs. 7 through 9, the sloping response up to 500 Hz is a function of the test record (CBS STR-100), which is recorded with a constant amplitude below 500 Hz and with a constant velocity above that frequency. Since we were concerned only with the high-frequency end of the response as a function of load impedance, we did not pass the output of the cartridge through any equalization process to yield a horizontal line below 500 Hz.

In Fig. 8, we loaded the cartridge with 100 kilohms instead of 47 kilohms and added no loading capacitance other than that supplied by the connecting audio cables (about 100 pF for each channel). The resonant peak occurred at 12.0 kHz with a 6.3 dB rise in amplitude.

Next we added an additional 300 pF of capacitance across the cartridge output terminals, but left the higher-than-normal resistance of 100K ohms in the circuit. Results are shown in Fig. 9. Here, the resonant peak is shifted down in frequency to 10.5 kHz, but its amplitude has increased to +7.5-dB relative to our 0-dB point at 1 kHz.

From these response curves it should be clear that proper (or improper) cartridge loading can have a much greater effect upon the way a cartridge sounds when reproducing music than some of the more subtle, and often insignificant design elements promoted by some cartridge manufacturers. After you have selected a cartridge that can track your records properly, has low distortion, and will not wear out your records or its own stylus tip after a short time, it's still up to you to install it into a pickup arm that can work well with it and to load it with the recommended values of resistance and capacitance. Let's take a look at some tests you can perform in your home for determining whether your cartridge is loaded properly and what you can do if it isn't.

User tests

Often, a phono cartridge is installed by the manufacturer of the turntable system or by the dealer from whom the turntable and cartridge were purchased. Under those circumstances it is difficult to know whether or not the matter of proper cartridge loading has been properly taken care of. Furthermore, the instruction pamphlet supplied with most phono pickups is usually discarded when the cartridge is installed, so that you have no easy way of determining what the proper loading capacitance is for the cartridge in question.

In such case, proper loading of a cart-

TABLE 1-TEST RECORDS

Record catalog number	Source
STR-130	CBS Technology Center 227 High Ridge Road Stamford, CT 06905
STR-100	CBS Technology Center 227 High Ridge Road Stamford, CT 06905
AT-6606	Audio-Technica U.S., Inc. 1221 Commerce Drive Stow, OH 48224
QR-2011	B&K Instruments, Inc. 5111 W. 164th Street Cleveland, OH 44142
XG-7001	Denon America, Inc. P.O. Box 1139 West Caldwell, NJ 07006

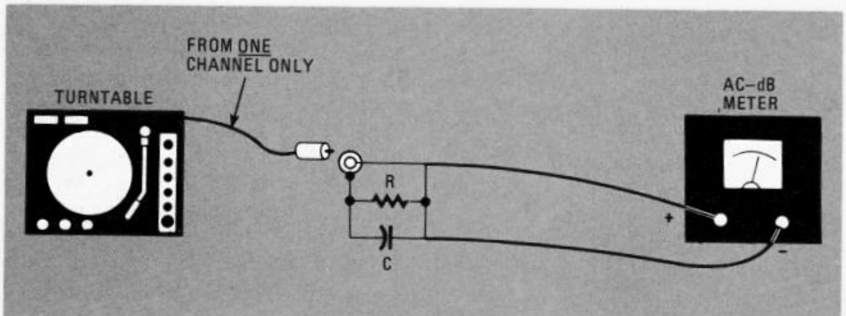

FIG. 10—TEST SETUP for measuring the frequency response of a phono cartridge at the output of the cartridge. The R-C load impedance network is connected across the output terminals of the cartridge.

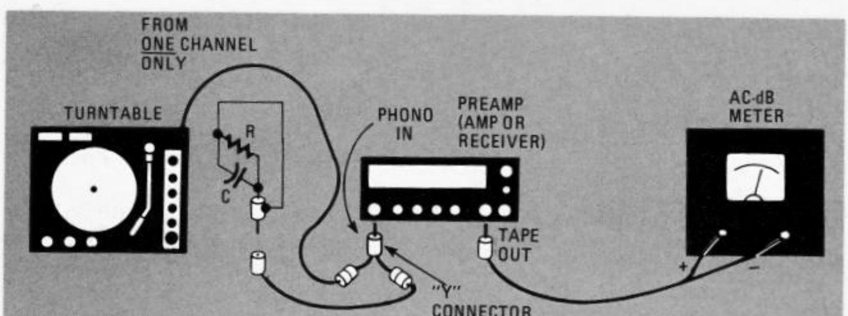

FIG. 11—TEST SETUP for measuring the frequency response of a cartridge with the cartridge connected to a preamplifier. In this case, the load impedance is the impedance of the phono input of the preamplifier. A "Y" connector is used to connect an R-C circuit across the output terminals of the cartridge if the load impedance needs to be altered.

ridge can be verified by direct measurement of frequency response, using any of a number of available test records, all of which contain tones on a one-at-a-time basis rather than on a continuous sweep basis that requires the use of a synchronized X-Y response plotter. A partial list of such test records will be found in Table 1, along with the names and addresses of the organizations from whom the record can be obtained.

The STR-100, ST-130, and AT-6606 test records contain single-tone frequencies, while the remaining two contain third-octave pink-noise bands rather than single frequencies. Either type may be used to obtain a frequency response plot of your phono pickup, and the only other piece of test equipment required is an AC voltmeter that has a flat response (preferably to within +1 dB or better) over the range from 20 Hz to 20 kHz. As for meter sensitivity, if you plan to measure the response of the cartridge with no intermediary electronics (such as a preamplifier) and you are dealing with typical moving-magnet cartridges, the meter's most sensitive full-scale reading should be around 5 millivolts or lower. If you do not have access to such a sensitive AC voltmeter, you may prefer to measure cartridge response including the amplification and equalization characteristics of your associated preamp. In that case, sensitivity need be no lower than 0.5 volts full-scale for the AC voltmeter you intend to use.

TABLE 2

Frequency Hz	Meter Reading-dB
1000	0.0
20,000 to 500	0.0
400	−2.0
300	−4.4
200	−8.0
100	−14.0
80	−16.0
60	−18.4
50	−20.0
40	−22.0
30	−24.4
25	−26.0
20	−28.0

To obtain the response curves, the cartridge output (via the connecting audio cables) would be connected directly to the voltmeter as shown in Fig. 10. Of course, for a stereo cartridge, the response of each channel would be measured separately. A terminal strip could be used for convenience, so that various values of capacitance and resistance could be used to terminate the cartridge output. Because the STR-100 record is recorded at constant amplitude below 500 Hz and at constant velocity above that frequency, the ideal response from a perfectly loaded and perfectly designed phono cartridge at the spot frequencies would have the output levels listed in Table 2 if we assume an arbitrary 0 dB at 1000 Hz.

Using the direct-hookup method shown in Fig. 10, the readings are likely to be very low in voltage and unless cable lengths are kept quite short, readings might be influenced by stray hum fields that could lead to erroneous results. Still, this method is worthwhile because only the cartridge performance is involved. There are no intermediate electronic circuits, with their possible frequency response errors, to detract from the accuracy of the measurements being made.

If this same test record (STR-100) is used to test cartridges that are already connected to the preamplifier, then the setup shown in Fig. 11 would be used. The "Y" connector, readily available from electronics parts stores, permits parallel connection of various load resistors and capacitors, each wired to a blank phono-tip plug. With this setup, the phono pickup itself remains connected to the preamplifier of the system. The voltmeter should then be connected to the TAPE OUT (sometimes identified as REC OUT) jack on the rear of the preamplifier (or integrated amp, or receiver) being used. Since RIAA equalization is being provided by the preamp-equalizer of the system, a perfectly loaded ideal cartridge would yield the readings listed in Table 3 (again, re-

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ferred to a 0-dB reference level at 1000 Hz).

After the spot frequency levels at the output of the preamp are noted in dB terms, they can be compared with the RIAA related readings listed in Table 2 and any differences between the two can be plotted on graph paper. Since cartridge loading primarily affects the high frequency response of a cartridge, it is not really necessary to plot frequencies below 1000 Hz. Omitting frequencies below 1000 Hz greatly reduces the time it takes to complete a single plot and, since several plots will probably be required until you have optimized the cartridge load for your system, you may want to simply concentrate on the upper part of the audio spectrum where changes in capacitance and resistive loads have their greatest effect.

The CBS test record, STR-130, is recorded using RIAA equalization in the first place. Therefore, when playing back the spot frequencies available from this record through a preamplifier, the perfectly-loaded ideal phono cartridge should deliver equal amplitude outputs at all of the available test frequencies. Any deviation from equal amplitude outputs indicates an inferior cartridge design or improper cartridge loading.

Modifying the load impedance

The results of the frequency-response tests will reveal much about the correct load impedance for the cartridge. High-end resonance peaks are usually tamed by increasing the capacitance across the cartridge terminals, by reducing the resistive load across the cartridge terminals, or by using a combination of both methods.

Generally speaking, the total load-resistance should be maintained at 47 kilohms and should only be changed if the overall response of a cartridge cannot be brought into line by changing the overall value of capacitance. Even then, the total load-resistance should not go below 27 kilohms or higher than 100 kilohms.

To increase the effective capacitance across the cartridge terminals and/or decrease the resistive load across the cartridge terminals it is necessary to use a parallel R-C circuit. Figures 10 and 11 show circuit examples. To increase the capacitance, a capacitor, C, may be connected in parallel with the cartridge output. I have found that it is best to experiment in steps of approximately 50 pF, increasing the capacitance until the desired results are obtained.

To decrease the resistive load, a resistor, R, may be connected in parallel with the output of the cartridge. If it is necessary to further decrease the resistive load, a smaller value resistor should be used.

TABLE 3

Frequency Hz	Meter Reading-dB
20000	−19.5
18000	−18.8
16000	−17.7
14000	−16.6
12000	−15.3
10000	−13.7
8000	−11.9
6000	−9.6
5000	−8.2
4000	−6.6
3000	−4.8
2000	−2.6
1500	−1.5
1000	0
800	+0.7
600	+1.8
500	+2.6
400	+1.9
300	+1.1
200	+0.2
150	−0.6
100	−0.9
80	−1.3
60	−2.3
50	−3.0
40	−4.2
30	−5.8
25	−7.0
20	−8.6

A new frequency response test should be done each time the load impedance is altered to determine the best response and, therefore, the best load impedance for the cartridge. If the cartridge is a stereo cartridge, the response tests will have to be repeated to determine the best load impedance for the other stereo channel.

After the tests are completed, you will have two R-C networks, one for each stereo channel. There are two options for incorporating the two R-C networks into your stereo system. The first is to connect the resistor and capacitor to a male phono plug for use with a "Y" connector. The parallel R-C network is soldered between the "hot" (center) and "ground" (outer) terminal. When completed, the male phono plug with the R-C circuit is plugged into the "Y" connector. The cable from the turntable is plugged into the other jack on the "Y" connector and, finally, the "Y" connector is plugged into the input of the phono preamplifier, as shown in Fig. 15. Of course, two "Y" connectors and two R-C networks will be necessary for stereo systems.

The other alternative is to house the R-C circuit in a small metal box. In addition to the small metal box you'll need two jacks (one will be the input, the other the output) and a length of shielded cable (four jacks and two lengths of shielded cable for stereo. Connect the box in series with the audio cables from the turntable. **R-E**