A High Accuracy Inverse RIAA Network

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READERS WILL BE AWARE of the recent correspondence between the two authors regarding RIAA equalization in phono preamplifiers[1,2]. This has led to a re-examination of many familiar circuits, and has shown the need for changes and corrections to many of these in order to improve their accuracy. Extremely high accuracy can indeed be achieved by careful design, such as in the Jung-White modification of the Dynaco PAT-5[3], and many readers may be interested in having available an inverse RIAA circuit of sufficient precision to enable them to measure the deviations of phono preamplifiers to a high order of accuracy, as well as to conduct critical listening tests.

TAA published in 1971[4] an inverse RIAA design by Reg Williamson, shown in *Fig. 1*. In original form this circuit is fairly accurate, and indeed is suitable for many requirements. However, it can be improved by changing R_1 from 910k to the theoretically ideal 883.333k, or 887k (nearest 1% value). But, even then the termination resistor R_3 slightly displaces the middle RIAA time constant T_2 (ideally $318\mu s$) from its desired value, because of the way in which the component values interact in determining the circuit's overall time constants. For a complete theoretical analysis of this see "On RIAA Equalization Networks"[5], copies of which are available, free of charge (while the supply lasts), from the first author at Dept. of Applied Mathematics, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada.

Ideally the frequency response of an inverse RIAA network should be as in *Fig. 2*. The corner at f_4 should not occur at all (i.e. $f_4 = \infty$Hz); in practice it is unavoidable. In general it should be placed as high in frequency as possible, so as to minimize deviations occurring in the audio frequency range of interest, namely to above 20kHz.

In considering an improved inverse RIAA circuit, taking into account all significant interactions (e.g., the effect of R_3 and driving source impedance), we originally felt that an active pre-emphasis circuit might be necessary. Such a design,
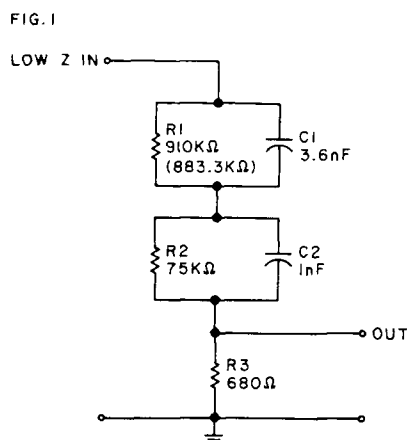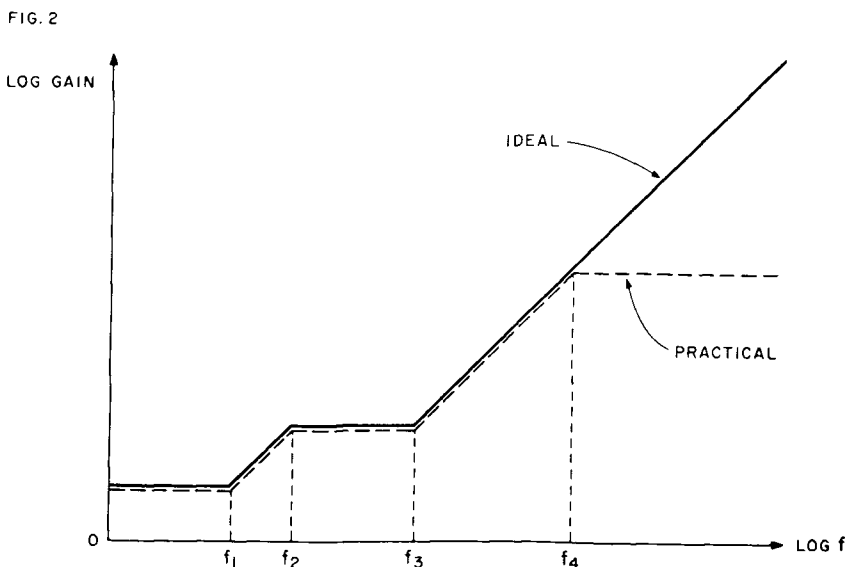

FIG. I

Fig. 1. The original Reg Williamson circuit[4] and its modification.

unfortunately, introduces as many problems as it circumvents. It was then decided that a slight modification to the

FIG. 2

Defining parameters (ideal case):
$f_1 = 50.05$ Hz; corresponding to time constant $T_1 = 3180 \ \mu s$.
$f_2 = 500.5$ Hz; $T_2 = 318 \ \mu s$.
$f_3 = 2122$ Hz; $T_3 = 75\mu s$.
$f_4 = \infty$ Hz; $T_4 = 0\mu s$.
Note: In practice $f_4 \neq \infty$; $T_4 > 0\mu s$.

Fig. 2. The frequency response of an inverse RIAA network in ideal and practical cases.

Williamson circuit would be most practical. The circuit is shown in *Fig. 3*. Present owners of previously purchased Old Colony Williamson networks can easily adapt them to the new values, if they so desire.

You will appreciate just how good this network really is if you examine the data in *Table 1*, which lists the relative accuracy of two of these networks for various test conditions. For some time Old Colony has been supplying the Williamson network with an ideal R_1 value of 883.3k and all 1% circuit components, as shown here. In the first column shown (listed as stock), this version of the network can be seen to offer better than ± 0.1dB accuracy, with sample number 1 being appreciably better (due to values which fall closer to theoretical).

These measurements were taken with a 600 ohm load resistor, the kit value supplied for R_3. However, as noted above, the presence of R_3 not only places f_4 at

338kHz: it also alters mid-band response. Fortunately, the mid-band error can be compensated for rather easily by minor adjustment of two network values, R_2 and C_2 being convenient for this purpose (as described in[5]).
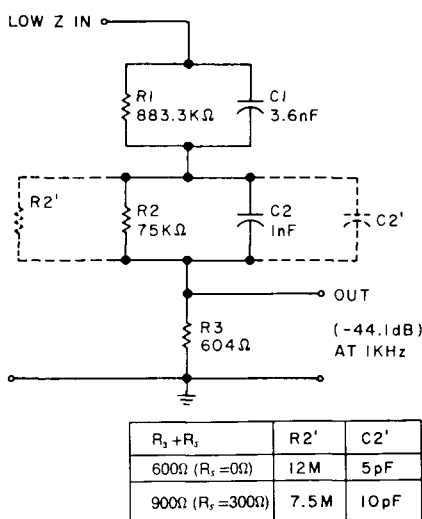
With an R_3 termination resistance of 600 ohms, R_2 and C_2 should be altered by shunting with the R_2' and C_2' values (noted as dotted). This yields the (compensated) responses shown in the R_2', C_2' columns for the two sample networks. As you can easily note, this version is much better for either case over the entire band. In both, the response drops above 20kHz, due to R_3. Network #1's accuracy is notable, and network #2 is just in excess of ±0.05dB.

The result of a source resistance R_s of 300 ohms is shown in the third columns, and results in some deterioration. Notice that here the high frequency (hf) rolloff begins at a lower frequency (as expected), and also that mid-band response is not as even. The latter problem is because R_2' and C_2' are not the optimum value for this source resistance, having been calculated for only the $R_3 = 600$ ohm resistance. The corresponding values of R_2' and C_2' for a 300 ohm source resistance should be 7.5 meg and 10pF, respectively.

You will also note that the most serious error which occurs with the additional source resistance is in the hf rolloff, as for example in network #2. Therefore the network's best performance will be realized when it is driven from a low impedance (100 ohms or less) source, with the 600 ohm termination used, and R_2' and C_2' added. If you must use a 300 ohm source resistance, you can then employ the alternate R_2'/C_2' values.

Naturally, the degree to which you really need to observe these ground rules depends upon your final intended use of the network. If you are measuring by reading the preamp output on an AC VTVM, for example, and confine measurements to 20kHz and below, any of these conditions is more than adequate because in such a case you will not be able to resolve differences much below 0.2dB. The frequency reponse of your oscillator can also be a limitation, as its error is equivalent to either a network error or preamp error. Therefore, unless you go to the trouble to validate your own individual network and have a more sophisticated oscillator/detector system, you should not expect much below ±0.2dB in terms of believable error measurements. In all cases keep the capacitive loading on the output of the network to a minimum (by using short lengths of low capacitance cable and
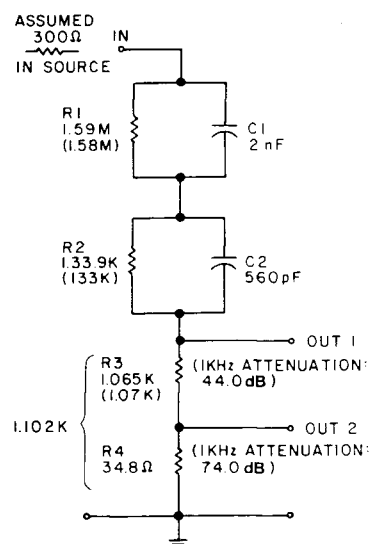
FIG. 3

LOW Z IN

R1 883.3KΩ C1 3.6nF

R2' R2 75KΩ C2 1nF C2'

OUT

R3 604Ω (−44.1dB) AT 1KHz

$R_1 + R_3$	R2'	C2'
600Ω ($R_s = 0Ω$)	12M	5pF
900Ω ($R_s = 300Ω$)	7.5M	10pF

NOTES:
ALL RESISTORS METAL FILM, 1%
ALL CAPACITORS 1% POLYSTYRENE OR MICA

Fig. 3. Modification to Williamson network for greater accuracy.

FIG. 4

ASSUMED 300Ω IN
IN SOURCE

R1 1.59M (1.58M) C1 2 nF

R2 133.9K (133K) C2 560pF

R3 1.065K (1.07K) OUT 1 (1KHz ATTENUATION 44.0 dB)

1.102K

R4 34.8Ω OUT 2 (1KHz ATTENUATION 74.0 dB)

Fig. 4. An alternative inverse network suggested in the Lipshitz JAES article[5]. Values shown are ideal; closest 1% values are in parentheses. Output 1 is for a moving magnet cartridge; Output 2: moving coil.

defeating any preamp loading capacitors, if switchable) for greatest hf response accuracy.

The measured data listed in *Table 1* were derived from a sophisticated wide band comparator system, which measures only input-output deviations and uses a DVM for readout of relative dB. It is not a true absolute measuring system (in spite of the high resolution), so the data should be interpreted in *relative* terms only.

An alternative inverse RIAA network as described in[5] is shown in *Fig. 4*. As you can see this design uses the same general network form but has a higher impedance and is thus easier to drive. It is designed to be driven from 300 ohm sources (as noted) with network values optimized for minimum error for such conditions. The circuit of *Fig. 4* is the closest one can come to meeting these conditions with standard available capacitor values for C_1 and C_2. With R_3 and R_4 connected as shown, a second output is available. This is suitable for equalized moving-coil phono preamplifiers, and will exhibit frequency response properties similar to the basic output.

Both these networks can be driven adequately from most preamplifier outputs. A stereo version is thus suitable for conducting listening tests on phono preamplifiers, by feeding them with a musical signal from your audio system via the network. This enables one to perform a bypass test on the phono stage of a preamplifier by comparing the input signal to the network with the output of the phono stage (after matching gain and polarity).However, if you want to do this, take some special precautions. You must use network components appropriate for listening use. Mica capacitors, while entirely adequate for steady state bench

TABLE I: OLD COLONY INVERSE RIAA NETWORK RESPONSE: VARIOUS CONDITIONS

Freq (Hz)	NTWK #1			NTWK #2		
	Stock	W/ R_2',C_2' (12Meg, 5pF)	W/ 300Ω R_s	Stock	W/R_2', C_2' (12Meg, 5pF)	W/ 300Ω R_s
10	+0.020	−0.006	+0.005	+0.069	+0.040	+0.056
20	+0.024	−0.003	+0.010	+0.064	+0.036	+0.050
50	+0.028	+0.005	+0.014	+0.044	+0.015	+0.030
100	+0.036	+0.008	+0.023	+0.024	−0.004	+0.007
200	+0.031	+0.007	+0.021	+0.017	−0.012	0.000
500	+0.010	+0.002	+0.006	+0.005	−0.005	+0.003
1k(REF)	0	0	0	0	0	0
2k	+0.001	+0.008	+0.007	−0.016	−0.012	−0.011
5k	+0.015	+0.016	+0.015	−0.045	−0.035	−0.037
10k	+0.011	+0.015	+0.006	−0.055	−0.050	−0.054
20k	−0.003	0.000	−0.020	−0.070	−0.067	−0.086
30k	−0.023	−0.021	−0.065	−0.092	−0.090	−0.125
40k	−0.050	−0.050	−0.120	−0.121	−0.121	−0.185
50k	−0.091	−0.090	−0.200	−0.161	−0.161	−0.260

Conditions of test: Through JW-33(A) phono card with equalization values as per TAA letters 3/78. R_3 termination 600 ohms, network driven from low impedance buffer, except as noted. Measured @ TAPE OUT JACK @ 1VRMS level. All values in dB relative to 1kHz. Levels are not necessarily absolute—see text.

WHAT IS
AN INVERSE RIAA NETWORK?

THE PHONOGRAPH DISC as a reproduction medium has physical limitations which are offset by altering the bass and treble portions of the spectrum in material to be recorded. In short, the frequencies below 500Hz are cut so they will not take excessive room, and those above 1kHz are boosted because they are too small to make a good groove.

This cut/boost pattern is standardized into what is known as the RIAA curve, fostered by The Recording Industries Association of America.

The material on your records is supposedly cut to this curve. If you wish to test how well your preamp does the job of restoring the recorded signal to normal and don't have anything but an oscillator which puts out signals in volts, you will have a hard time deciding just how much less bass you should be putting into the preamp at 30Hz to correspond to what the RIAA curve calls for. What you need is a device that does to your oscillator's output what the record maker's RIAA networks do to the signals going onto his recordings.

The inverse RIAA network goes between your oscillator and your phono preamp. If the oscillator puts out the same level at all frequencies (they do not, usually) then if your preamp is correctly equalized, you should get the same output at all frequencies—adding the amplification which the phono preamp supplies, of course.

The inverse network supplied by Old Colony is passive and has the advantage of not distorting, but it also uses up quite a lot of the energy put out by your oscillator (see *Figs. 3, 4*), which is a very good thing. The signal your phono preamp wants is very small indeed and your oscillator will do a better job putting out a larger signal, too.   THE EDITOR
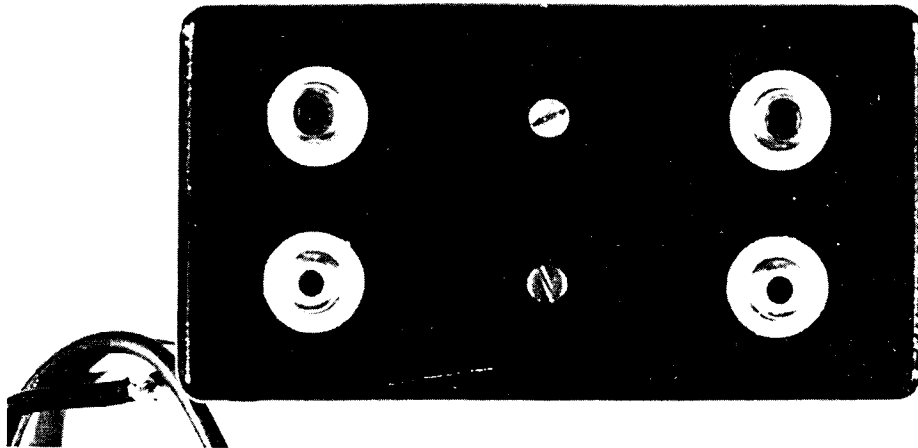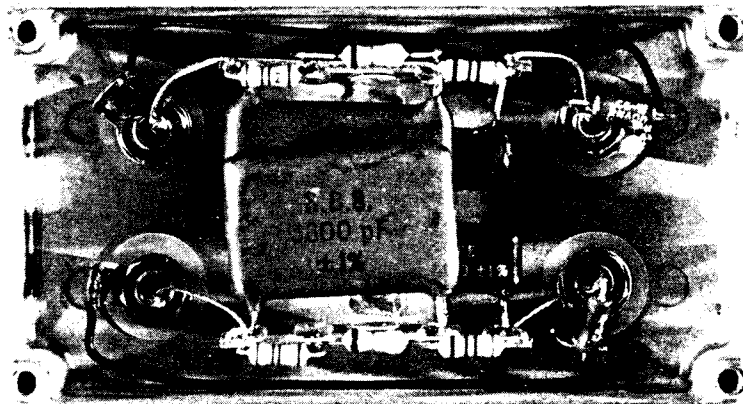

Fig. 6. Jung's stereo prototype network is housed in a cast aluminum box with gold input jacks, isolated from the chassis by plastic washers. The box is connected to ground by a separate flying lead attached to one of the cover mounting screws.
*Fig. 7. Interior view of the prototype.*

tests, have some dielectric absorption which is undesirable for auditioning tests. Polystyrene capacitors are preferable for listening, as are metal film resistors. Input-output connections should be of the highest quality, as should be the cabling used. Finally, you must provide some means of level matching if you intend to use a direct A-B switch. Do not adjust R_3 for this purpose, as it will alter frequency response! Of course all of this assumes a top quality line level source, such as a master tape.

Fig. 5 shows a suggested physical construction method for either network. Leave the shields of the input and output jacks floating within the case. The box is best grounded via a flying lead to its case, which gives maximum flexibility in avoiding noise pickup. Such an enclosure will easily accommodate two networks for stereo use, as you can see from the photos in *Figs. 6* and *7*.

Old Colony is making available a parts kit of suitable accuracy for building a stereo version of the circuit, based on the Williamson design. It will include a cast aluminum box/w. cover, gold input/output jacks, jack insulators, two four-lug terminal strips and all *Fig. 3* parts, including

R_2'/C_2' for both 600Ω and 900Ω ($R_3 + R_s$). Components are ±1% or ±2% tolerance; capacitors will be polystyrene. Retrofit kits will also be available for earlier versions of the kit.

As a parting word, don't be too surprised if you measure (and hear) quite significant frequency response deviations on even very expensive phono preamplifiers. Many of the designs currently on the market are deficient in this regard.   ☐

REFERENCES

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3. W. G. Jung and D. White: *"A PAT-5 Modification"* *Audio Amateur*, Vol. 9, No. 1, 1978, pp. 7-22; see also issue 3/79, p. 24.
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FIG. 5
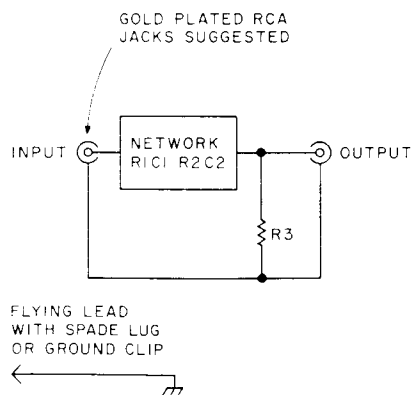
Fig. 5. Physical mounting arrangement.