Preamplifier design criteria

The design of high quality audio amplifier stages to cover a variety of signal sources from the fractions of mV generated by the moving coil cartridge to the 2 V reference 0 dB of the typical Compact Disc analog output provides a wide ranging challenge to the analog design engineer. There are a number of conflicting parameters which have to be assessed and addressed on the route to creating a state of the art audio preamplifier. The TAG McLaren Audio preamplifiers, either stand alone or as part of the highly regarded integrated amplifiers, set the standard by incorporating a number of unique and innovative design features.

Introduction

The primary function of the preamplifier is to act as the control centre of the audio system. The features and facilities that form the specification must provide a versatile array of inputs which can select between the increasing variety of different sources available today. These sources may be derived from audio material that has been stored and / or transmitted in either digital or analog formats. Although a CD transport will output the data in digital format it is still normal practice for this information to be converted to the analog domain, using a Digital to Analog Converter (DAC) prior to feeding to a preamplifier. The following paper will describe TAG McLaren Audio preamplifiers which process only analog signals.

Preamplifier topologies

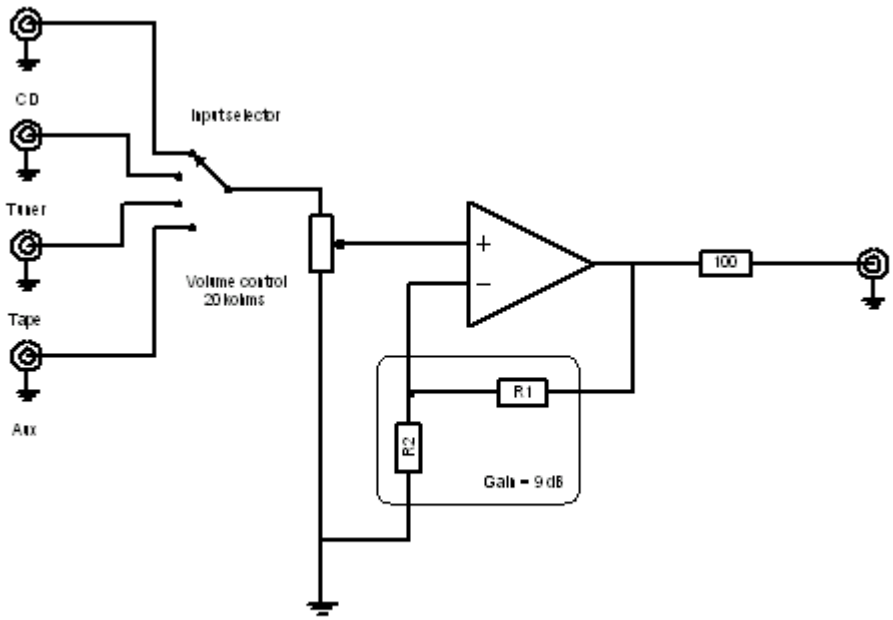
Analog audio signals are supplied from two sources and require different processing. The majority of sources are outputs from powered electronic items such as radio tuner, cassette deck, CD player. These signals typically have a level of the order of 1 volt rms for maximum output and have a 'flat' frequency response. These are frequently referred to as line level sources.

The alternative signal sources are those generated by transducers, typically used on the analog vinyl LP disc. In these cases the signal source consists of a voltage generated by a mechanical transducer either responding to displacement or velocity. The maximum level generated by these transducers are of the order of only 10s of millivolts. As the available dynamic range of the vinyl LP disc was significantly lower than that of the music to be recorded the technique of pre-emphasis during the recording process was employed to enhance this dynamic range. As a result the frequency spectrum of the signal source is not 'flat'. The recorded amplitude varies as a function of frequency in accordance with a specified mathematical function. One of the prime functions of a preamplifier with an input for analog LP disc replay is to provide both the gain to match the other 'line' level sources and the equalisation to convert the signal back to the original music spectrum. For the ultimate performance the analog LP amplifier may be designed as a stand alone unit which then feeds a preamplifier through a 'line' input. This unit is often described as a phono preamplifier and the TAG McLaren Audio PPA20 provides these comprehensive analog LP amplification facilities.

Amplifier module criteria

Line amplifier

This amplifier is designed to present a high input impedance so that it does not load the volume control potentiometer that immediately precedes it. This impedance has to be greater 200 kΩ in order that the logarithmic attenuation of the potentiometer is not altered. In turn the TAG McLaren Audio preamplifiers use 20 kΩ potentiometers which is the minimum value to define the input impedance to the preamplifier and in turn lowers the noise generation at 6 dB attenuation.



Line amplifier

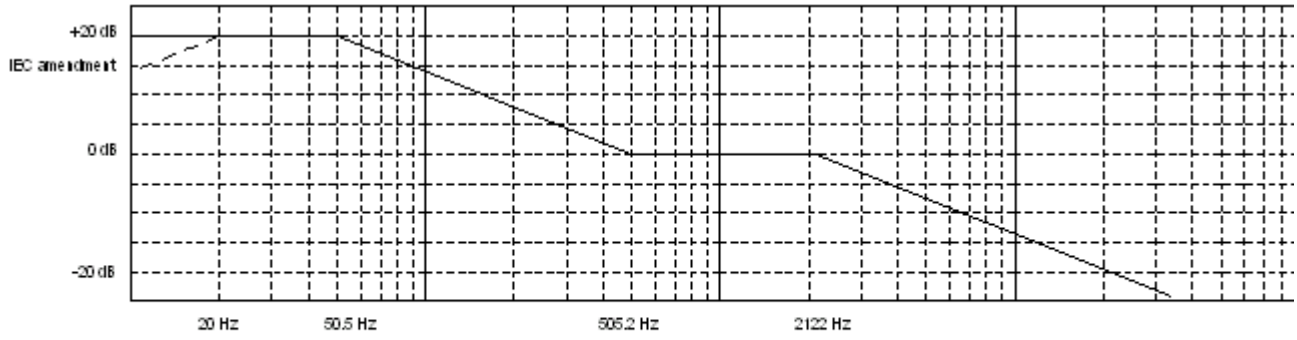
During the years since the arrival of the Compact Disc player with the output of 2 V for maximum signal level which is some 8 dB higher than what was the nominal output of tuners and tape recorders the required gain of the preamplifier has been reduced. The signal level outputs of tuners, cassette decks etc. have increased to come into line with CD sources. TAG McLaren Audio preamplifiers have now standardised on 9 dB of gain some 8 dB lower than their Audiolab predecessors. The top line preamplifier PA20R provides the added facility of gain switching in 3 dB steps which allows the user to match older sources precisely.

The ultimate system configurations are based on the use of multiple power amplifiers to drive the loudspeakers with the amplifiers located in close proximity to the speakers. For convenience the preamplifier will often be located at a distance from these power amplifiers. To minimise the interaction of cable capacitance and source impedance when driving long cable interconnects a low output impedance is required. The preamplifier stages of all the TAG McLaren Audio products are designed with this constraint in mind by defining a 100 Ω output impedance.

Analog LP disc amplifier

RIAA equalisation
Analog discs have always been recorded with pre-emphasis to enhance the signal to noise ratio and with it the dynamic range. A number of different 'laws' were presented and used until the arrival of the LP disc when the RIAA proposed a pre-emphasis which was adopted universally. This modification from the flat frequency spectrum is in two parts. At the low frequency, from 50 Hz to approximately 500 Hz the disc was cut with a constant amplitude characteristic. When this is traced by a velocity sensitive transducer the voltage generated rises at 6 dB per octave over this frequency range. The frequencies between 500 Hz and 2.1 kHz are recorded flat with constant velocity. Finally, with the objective of reducing the high frequency surface noise of the vinyl disc the frequencies above 2.1 kHz are pre-emphasised at 6 dB per octave.

The design engineers objective is to reverse this processing and deliver a tonally corrected electronic signal. The TAG McLaren Audio phono preamplifiers are designed to produce the precise inverse of the RIAA recording characteristic. This is achieved by creating a complex impedance feedback network which provides the precise 'mirror image' of the RIAA pre-emphasis.



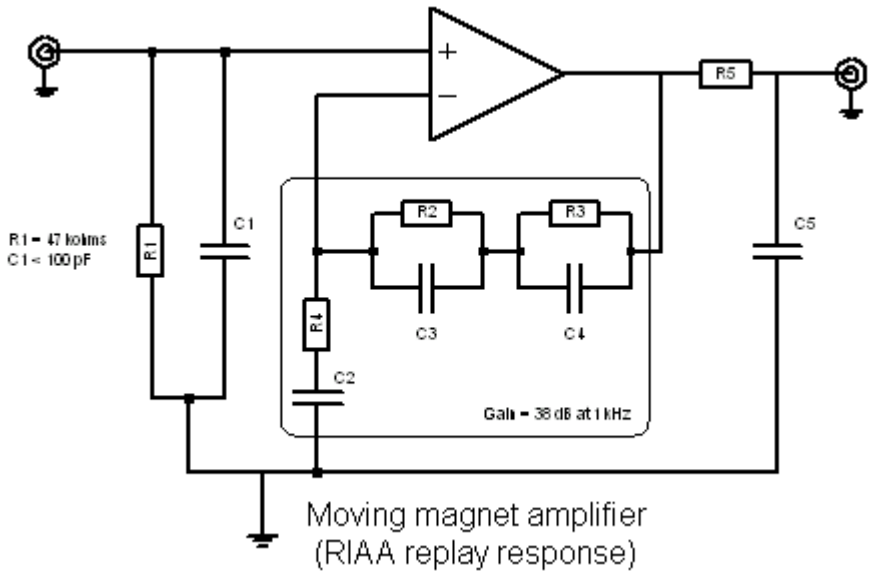
RIAA replay equalisation (solid line)
IEC amendment (dashed)

IEC amendment
This amendment to the RIAA replay characteristic introduces a high pass modification to the standard RIAA response. The requirement is for the response to be -3 dB at 20Hz then to roll off at 6 dB per octave below this frequency. For certain source material this has the advantage of attenuating sub audible artefacts which can result in audible intermodulation distortion products. The preamplifier PPA20 allows for this response to be switched in by the user should this provide an improvement.

Moving magnet transducers

Signal levels
Typical signal levels generated by a moving magnet transducer results in a peak level of some 30 mV. This is significantly below that of the 1 to 2 V level produced by line products such as CD players. Thus one of the functions is to boost the gain by 80x (38 dB) at the midband frequencies. In addition to this mid frequency gain the replay characteristics of the RIAA curve then adds an additional 20 dB at 20 Hz. Thus the designer faces the challenge of achieving close to 60 dB of closed loop gain at 20 Hz. Thus the normal levels of forward or open loop gain which provides the usual route to low distortion are not available. Extra attention to detail in the design process to create linear circuits has to be expended as normal levels of corrective feedback are unavailable. In the TAG McLaren Audio RIAA amplifiers all discrete Class A circuit topologies are used where the detail stage gain and linearity are totally under the control of the design engineer.

Source and load impedances
Most audio sources have a simple resistive source impedance of less than 600 Ω over the audio bandwith. This is not the case with the vast majority of moving magnet transducers. Close examination of the transducers impedance will result in a series resistor and inductor as a model of the source. Typical values for these components are 500 Ω and 500 mH. When this is combined with the input impedance of the amplifier which can be modelled as a parallel combination of resistor and capacitor a second order low pass passive filter is created. The conventional resistive termination for the moving magnet transducer is 47 kΩ. At first sight it would seem that the only requirement is for the designer to minimise the value of the parallel capacitance. However a number of cartridge manufacturers use an underdamped configuration of this second order filter to achieve a flat frequency response. Thus the cartridge designer will often specify the most appropriate terminating load for the cartridge. To assist in achieving this objective the TAG McLaren Audio phono amplifiers are designed to minimise the 'shunt' capacitance and then provide an additional phono socket connected in parallel with the cartridge input which allows passive components to be connected across the internal impedance and so tune the termination to the manufacturers requirement.

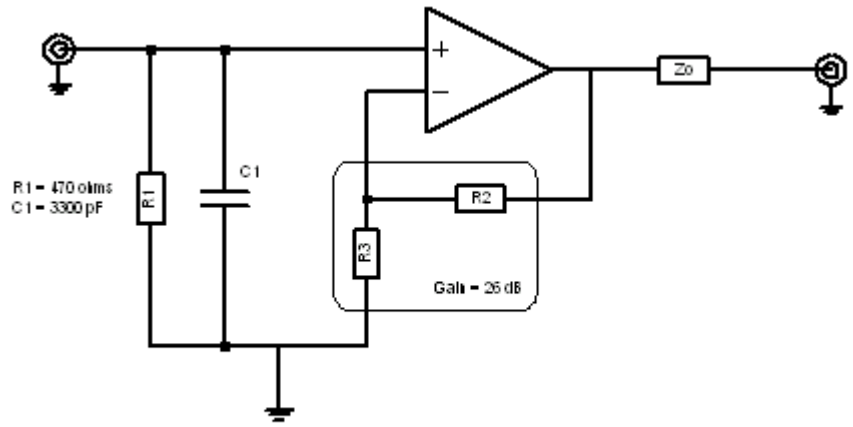


Noise
The typical cartridge described above presents a a source impedance of the order of 5 to 10 kohms as a result of the inductive component. The amplifier input circuit has to be designed to complement this source. Again the use of the discrete component design provides the ability to select the first amplifying device in combination with the quiescent current in order that the best signal to noise ratio can be achieved.

Moving coil transducers

Signal levels
Compared with the above, the moving coil cartridge presents a quite different source. Usually the impedance will be of a few 10s of ohms with a negligible inductive component. However the signal output is lower still and results in the requirement for an additional gain of between 20 and 30 dB over and above that demanded by a moving magnet transducer. A moving coil cartridge requires between 60 and 70 dB of gain at 1 kHz or 80 to 90 dB at 20 Hz before it is ready to pass to the preamplifier volume control and line amplifier. As some 40 dB of gain and the RIAA replay equalisation has already been provided for a moving magnet cartridge then the ideal topology for moving coil amplification is to concentrate on providing 20 or 30 dB of gain with the optimum design of matching to the source impedance.

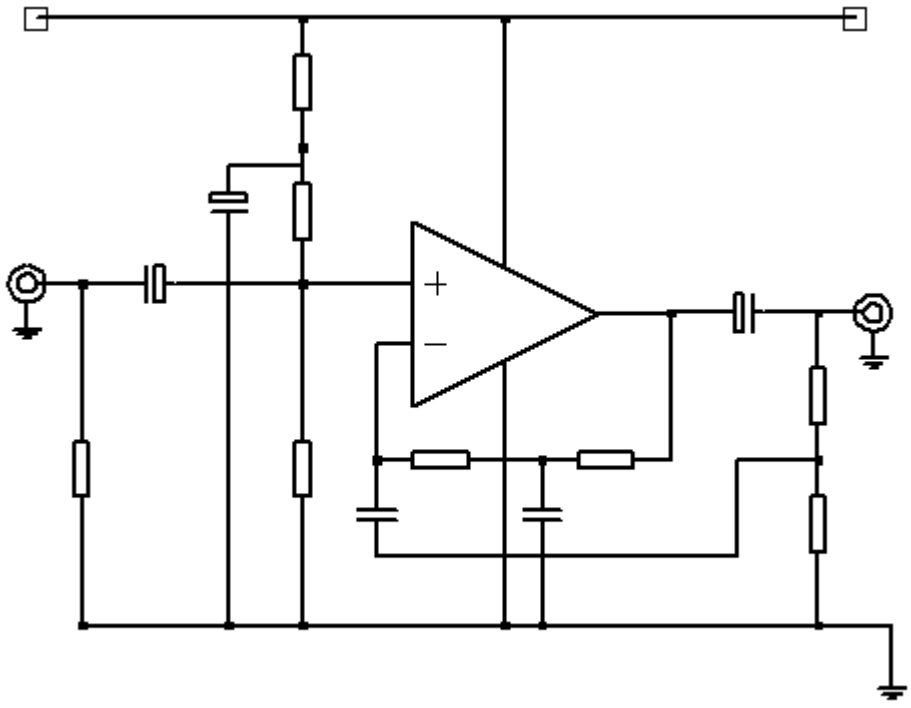
Source and load impedance
As a low resistance source with minuscule inductive component the optimum design for the moving coil cartridge differs significantly from that required by the moving coil transducer as described above. As the impedance lies in the 10s of ohms the optimum match requires many milliamps quiescent current flowing in the active devices. Integrated circuits do not lend themselves to optimising a low source impedance transducer as does a discrete component design. As TAG McLaren Audio uses the optimum discrete semiconductor design it has been possible to use the PNP transistor in place of the slightly poorer NPN complimentary device where the best possible noise figure is demanded.



Moving coil amplifier

Circuit designs

Dual feedback path
To achieve the objective of extending the low frequency bandwidth while retaining the coupling capacitors to block unwanted and potentially harmful DC potentials a design was developed and refined to use two feedback loops. Although the large values of capacitors required for the extended bandwidth resulted in the use of electrolytics these were extensively tested for low parasitic inductance and Equivalent Series Resistance (ESR). Final selection was then made from the technically best candidates using carefully controlled auditioning tests.



Dual feedback path

The output coupling capacitor, although generously biased, has been included within the feedback loop by using separate DC and audio frequency feedback paths. The DC stabilisation is performed by a path which is decoupled at audio frequencies while the audio frequency signals are coupled through high quality plastic film items which are in turn bypassed with low inductance polypropylene components.

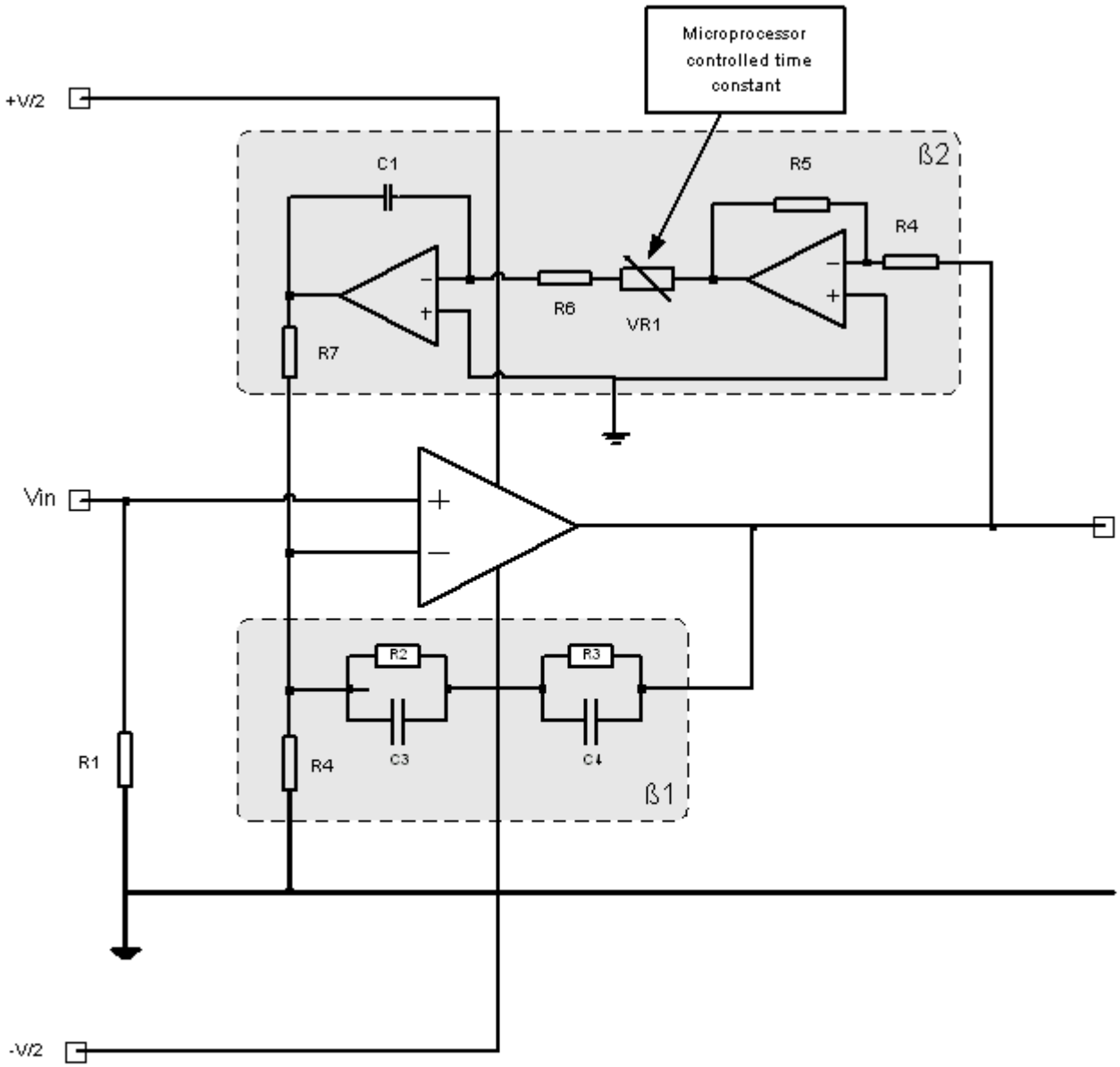
Straight line SL concept
The dual feedback path configuration from the preamplifiers used in the integrated 60i, 60iRv and preamplifier PA10 was the inspiration for the development which led to the straight line SL concept with the direct coupled forward and feedback paths.

The culmination of this design work is best described in the RIAA stage amplifier of the PPA20. It is here that the concepts of direct coupling around an amplifier of 58 dB gain at 20 Hz complete with rapid settling time whilst still retaining the ultra low 0.1 Hz low frequency breakpoint have been realised using a development of the dual feedback topology. Low DC offset output is guaranteed by the servo integrator $\beta 1$ feedback path which is totally separate from the audio gain defining $\beta 2$ feedback path which uses the precision polypropylene capacitors and Vishay resistors which define the RIAA characteristic with extreme accuracy.

The means whereby an amplifier with a low frequency -3 dB point at 0.1 Hz can be constructed without excessive waiting times for transient settling is contained in the additional functional capability of the $\beta 1$ servo path. The low frequency breakpoint of the passband is defined by an RC time constant which is made sufficiently large to achieve the target bandwidth. A fast settling time is simply achieved using a small value RC time constant. As both time constants are not required at the same instant all that is required is to switch between them and the this function is carried out under microprocessor control whenever the status or configuration is altered.

Conclusion

The combination of discrete component Class A amplifier modules using novel and innovative circuit topologies is at the core of the sophisticated preamplifier circuit designs used across the range of TAG McLaren F3 series products. After the technical development of the designs to satisfy the target specifications the final realisation of a production amplifier only comes about after extensive auditioning which ensures that the ultimate sound quality is delivered by the F3 preamplifier.



Input impedance = R1
Gain (audio bandwidth) 38 dB at 1 kHz frequency

'sl' RIAA amplifier with time constant switching