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INITIAL DESIGN OF THE CELLO AUDIO PALETTE

Richard S. Burwen, March 3, 1984

The accompanying schematic, description, and tentative specifications and features were submitted to Mark Levinson's Cello Ltd. and became the basis of the Cello Audio Palette tone control system. This design used a large number of integrated circuit op amps. Cello wanted to achieve the best possible performance and avoid any possible criticism of its op amps. They replaced the important signal processing op amps with their own proprietary discrete component opamps, greatly increasing the manufacturing cost. The final production circuit, aside from the op amp design, was simplified somewhat in order to use fewer op amps. Cello's Audio Palette was a remarkable success and manufactured for many years.

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PROGRAM EQUALIZER

TENTATIVE CHARACTERISTICS AND FEATURES 3/1/84

LEFT-RIGHT MATCHING	±.2 dB at any setting ±.1 dB, flat
DIFFERENTIAL INPUT	1M each side to ground
Common mode rejection	40 dB min.
ROTARY SWITCHES	Requires specially developed 59 position, 2 gang attenuators with stops
EQUALIZERS	ON-OFF (6 equalizer controls plus 2 input level controls)
15 Hz control	±29 dB @ 15 Hz in 1 dB steps
120 Hz control	±14.5 dB @ 15 Hz in .5 dB steps
500 Hz control	±6 dB @ 500 Hz in .25 dB steps
2,000 Hz control	±6 dB @ 2,000 Hz in .25 dB steps
5,000 Hz control	±12 dB @ 25 kHz in .5 dB steps
25,000 Hz control	±24 dB @ 25 kHz in 1 dB steps
Interaction	Control action is independent and additive in dB
PHASE SWITCH	0, 180°
INPUT LEVEL CONTROLS	Left, right -24 to +5 dB in .5 dB steps
OUTPUT LEVEL CONTROL	+10 to -40 dB in 1 dB steps, -42, -44, -46, -48, -50, -55, -60, OFF
DISTORTION	
Flat, unity gain, 7.8 V into 2K	.02%, 20 Hz-20 kHz
FREQUENCY RESPONSE	
Flat, unity gain	±.1 dB, 15 Hz-25 kHz
OUTPUT MUTING	Electronic
LOW FREQUENCY BLENDER	ON-OFF Monophonic at 25 Hz

PROGRAM EQUALIZER
TENTATIVE CHARACTERISTICS AND FEATURES

NOISE

Unity gain, controls flat	-90 dBm, 20 Hz-20 kHz
Equalizer out, unity gain	-96 dBm, 20 Hz-20 kHz

POWER SUPPLY

Separate unit delivers ±18 V regulated
POWER ON-OFF
POWER LED on front panel
POWER LED on supply

PROGRAM EQUALIZER

CIRCUIT DESCRIPTION

The schematic of the Program Equalizer is divided into three sections: left channel, power supply, and right channel. The parts in the power supply section are numbered from 1 while parts in the left channel are numbered starting at 100. The parts in the right channel are shown as a block and numbered in the 300s and are identical to the corresponding parts in the left channel. To achieve accurate gains and matching between channels necessary for transparency, some parts within the left channel are matched to one another while others are matched to the corresponding parts in the right channel. Both the left channel and the right channel are operated from ±22 V @ .5 A average, 1 A peak, which is closely regulated in the power supply section. The power supply section also contains a voltage sequencing circuit and timer which control the supply voltages and inputs to the output amplifiers for the purposes of muting the output during the first five seconds after power is applied. The mute circuit is necessary to prevent a large turn-on transient.

CUSTOMER CONNECTIONS

In the professional model, four XLR style connectors are provided for the channel inputs and outputs. Power comes in through a four pin XLR style connector from an external ±28 V regulated power supply unit. In addition, the power and all inputs and outputs are available at a 16 pin round connector to which a long single cable can be connected when remote operation is desired. The far end of the remote cable is plugged into a junction box which provides XLR style input and output connectors plus a four pin XLR style power supply connector. An alternate consumer type junction box provides phono connectors for inputs and outputs and, additionally, provides a pair of input follower amplifiers to prevent the cable capacitance from loading the customer's equipment.

In the professional model, a genuine differential input is provided having an impedance of 1 M from each side to ground. When used with a single-ended source the minus input should be grounded. The output amplifier is also a differential type which permits its ground to be at the far end of a long cable. A ground connection must be provided at pin 2 of each of the output connectors, either at the far end of the cable if used, at the Program Equalizer chassis, or the customer's equipment. Pin 2 cannot be left open and, therefore, specially modified output cables are required if XLR style connectors are to be used. The use of the remote junction box automatically provides this ground at the far end of the remote cable.

LEFT CHANNEL

An input differential amplifier is used to provide common mode rejection and unity gain, together with a high input impedance of 1 M from each side to ground. Two types of operational amplifiers are used. The LF412ACN is used to provide picoamp input currents together with a low offset of only 1 mV. However, these amplifiers are noisy (2.7 uV referred to the input over a 20 Hz to 20 kHz bandwidth) and distort at the high frequencies when driving a low impedance load. Distortion is very low at a load impedance of 5 to 10 K. The second type, the NE5532AN, is a transistor input amplifier which provides very low noise, equivalent to about 1,500 ohms source resistance (.7 uV in the 20 Hz to 20 kHz bandwidth) and has a very good output stage capable of delivering ±20 mA. Each amplifier is operated from ±22 V highly regulated supplies in order to handle signal levels of +24 dBm.

The system design is intended to produce a very low noise output of less than 10 uV rms in a 20 to 20 kHz bandwidth. With the large number of operational amplifiers used, every microvolt in every stage counts. Therefore, to achieve the low noise and distortion desired, each input follower consists of four halves of the LF412ACN whose outputs are added in parallel. Since the signals add faster than the noise, the signal-to-noise ratio is improved by 6 dB.

Because operational amplifiers invert phase and cause large spikes when an input is overdriven, each input is initially clipped at ±19.6 V. Amplifiers A101A and A101B act as ±19 V reference supplies capable of delivering output currents in either direction. At the positive input, the input signal first passes through a 499 ohm resistor R10 after which it is clamped at the reference voltages by diodes D102 and D104. The signal is then ac coupled by C106 to the followers A104A, A104B, A105A, and A105B. Two stage low-pass filtering, consisting of R113, R114, C107, and C108, together with the FET inputs of the operational amplifiers, prevents radio frequency signals from becoming rectified and causing a noise output. Because of the large coupling time constant of 2 seconds, practically no signal voltage is developed across the coupling capacitor and dielectric absorption becomes unimportant. The negative input is similar to the positive input and the difference between the two inputs is amplified by A106A.

All amplifiers from this point on used directly in the signal path are the low-noise NE5532AN. Because this amplifier contains diodes across its input which can charge an input coupling capacitor during overload, ac coupling is effectively accomplished instead by using an integrating amplifier A107A to feed back any output offset. This arrangement eliminates the output offset of A106A and the preceeding amplifiers and holds the output within the ±1 mV offset of A107A. During clipping, the capacitors associated with A107A can become charged but only rather slowly and the offset at the output of A106A that can be produced by even a full output from A107A is only ±.5 V. Since A107A does not amplify high frequency signals it cannot produce any appreciable distortion. This system provides small signal response similar to ac coupling with a 5 second time constant. As a result of using two different time constants, C111 X R128 and C110 X R127 corner peaking of .2 dB is produced at .1 Hz and the response is flat at 15 Hz.

The output of A106A can swing over a ±20 V range. At this point it feeds the phase inverter A106B which is switchable to either inverting or non-inverting. A logic controlled high voltage MOSFET switch, U101A (shown in its on position), selects the phase of A106B. With the switch in the position shown, the input signal is fed to the positive input as well as to R129 and A106B produces a gain of +1. If pin 16 of U101A is grounded, the switch grounds pin 5 of A106B turning it into an inverting amplifier. Matched resistors R129 and R130 provide accurate gain in either condition. Switching spikes are minimized by utilizing a make-before-break switch having an overlap time of .5 us.

The system provides for the future addition of a separate signal processing board such as a volume expander to be inserted next in the system. The output of A106B feeds the input of the expander. Electronic switch U101B which feeds the follower A108A, then connects the input of this follower amplifier either to the output from the expander, as shown in its on position, or to the output of A106B. The logic signal which operates U101B comes from the Schmitt trigger inverting amplifier U1C in the power supply section which is normally biased positive at its input so as to produce a zero output. Switching the junction of R16 and R17 to ground would insert the expander in the system.

It is important that offsets throughout the system be very small so the switching will be silent in the absence of a signal. Therefore, an integrating follower amplifier A107B, which is half of an LF412ACN, is used to zero the output of A108A to within ±1 mV. The integrator A107B acts as a unity gain follower at high frequencies and may produce a very small amount of distortion. However, only 1/20 of its output is fed into the input of A108A and so this distortion becomes negligible.

The output from follower A108A then goes through another switch, U102A, to follower A108B which feeds the equalizer system with its input level control. A high input impedance amplifier is used after each switch to eliminate distortion due to the 10 ohm resistance variation of the switch over the ±20 V signal swing.

A 59 position attenuator switch, RS1, is used for input level adjustment in steps of .5 dB. This is the only attenuator switch which has a single section. All the others use two sections to control both the left and right channels simultaneously. At the 0 dB setting of RS1, it has an attenuation of 5 dB which is made up by the amplifier A109B. Trim resistors R136 and R137 can be added if necessary to provide gain accurate within .1 dB. The output of A109B then feeds the unity gain inverting amplifier A112B which utilizes the integrator A116A to zero its output. The tone control signals are actually summed into the plus input of A112B. Because the impedances throughout the system are kept very low to prevent noise generation in the resistors, the tone controls require more signal current than A109B can deliver. Therefore, two additional followers, A109A and A115B, are used to drive portions of the load. As a rule, the load on each NE5532AN is kept to a minimum of 1,000 ohms. At ±20 V output this means the signal current is ±20 mA which is all the amplifier can deliver at extremely low distortion.

The 25 kHz control is the most critical with respect to noise and distortion. The control RS2A has a resistance of only 3,000 ohms and is connected from the output of follower A109A which produces the input signal to the output of follower A117A which produces a feedback signal equal to the output of A112B. At the mid-point of RS2A the signal voltage is 0 and no signal is added into the positive input pin 5 of A112B to alter the flat response. For low noise RS2A is buffered by a pair of followers A110A and A110B whose outputs are added into a bandpass amplifier A112A designed to peak at 28 kHz. A112A inverts phase and produces negative feedback when its output is added into pin 5 of A112B. When RS2A is turned clockwise, more input signal at high frequencies is added in at A112B to boost the highs. In the counter clockwise direction the high frequency feedback is increased so as to attempt the highs. The 15 Hz control operates similarly but is driven by separate followers A115B and A117B. This control feeds a follower amplifier A113A which in turn drives a bandpass amplifier A113B which peaks at 13 Hz. To produce flat response at the centers of each of the 25 kHz and the 15 kHz controls, it is desirable to use matched resistors for each half of each control.

The 500 Hz control operates similarly from the same signals as the 15 Hz control. The arm of the 500 Hz control feeds the follower A114A and the 500 Hz bandpass amplifier A114B whose output is summed into pin 5 of A112B. Because only 6 dB of boost and attenuation are available, noise due to this control and its amplifiers is small and it is practical to use a control whose center tap is grounded. With this arrangement perfectly flat response is produced at the center position since there is no signal fed to A112B. The 2,000 Hz control operates similarly and feeds the follower A111A and the bandpass amplifier A111B whose output is summed at pin 5 of A112B. The center frequencies of these controls are far enough apart so that there is negligible interaction among them.

The output of A112B then feeds another unity gain inverter, A119B, into whose inputs are summed the outputs of the 120 Hz and 5,000 Hz controls. As the 5,000 Hz control has only 3,000 ohms resistance in order to maintain low noise, separate follower amplifiers, A118A and A118B, are used to feed it. A118A delivers a signal which is the same as the output of A112B while follower A118B delivers a signal which is the same as the output from A119B. No buffer amplifier is used after the 5,000 Hz control because the variations in its output impedance are needed to maintain the control action in the same frequency range from one end of the control to another. The 120 Hz control, on the other hand, has a grounded center tap and feeds a follower amplifier A115A and then a low-pass amplifier A115B. Since A115B inverts, its output after attenuation by R161 and R162 is fed to the non-inverting input pin 5 of A119B. The 5,000 Hz control, which has no buffer amplifier, feeds directly via R164 and C142 to the inverting input pin 6 of A119B. Amplifier A116B acts as an integrator to produce low frequency feedback around A119B so as to zero its output. The entire system of tone controls, together with the input level control, can be switched in or out using the electronic switch U102B which feeds the follower amplifier A120A. Switch U102B selects either the output of A119B or the output of A108A. If the parts in the equalizer system are well matched so as to produce truly flat response at the center positions of the controls, the tone control system will be quite transparent at its flat position.

The output of the follower A120A then feeds the low frequency blender system. The blender utilizes a bridge connected summing amplifier A119A which produces unity gain for a signal received from A120A. Added into ints negative input is a zeroing signal from the integrator A122A connected to the output of A119A and a 20 Hz bandpass signal received via R173 from the right channel. This bandpass signal has unity gain at

20 Hz. At the same time, the output of A120A feeds the inverting bandpass amplifier A120B centered at 120 Hz and which feeds its signal to the right channel. If a signal were fed into the left channel only, it would appear at the output of A119A with unity gain and the low frequency components of the signal would appear at the output of the right channel with unity gain at 20 Hz. Thus, in the vicinity of 20 Hz the loudspeakers can operate in unison, thereby producing greater efficiency on a more solid bass. The effect on a stereo signal is to boost the bass about 4 dB and on a monophonic signal the bass is boosted 6 dB @ 20 Hz. At 300 Hz, the signal fed to the opposite channel is down 20 dB.

The low frequency blender can be switched in or out by CMOS switch U103A which selects either the output from A120A or the output from A119A to feed into the follower A121B.

Next the signal goes through the output level control RS8A, which at its 0 dB position produces an attenuation of 10 dB. The 59 steps on this control are at 1 dB intervals except at large attenuations. Following this control the signal is amplified 10 dB by A121A and rezeroed by the integrator A122B. The signal can then be muted by the electronic switch U103B together with FET Q101 which grounds the input of the follower A123A. For the first 5 seconds after power is applied, the input to A123A is grounded, thereby preventing the input signal transient from reaching A123A. This does not solve the entire muting problem, however, as the application of power to A123A and the amplifiers its feeds can cause an output transient if the supplies are not properly sequenced. The follower A123A feeds a unity gain differential amplifier A124A which in turn drives parallel followers A123B and A124B. Two followers are used so the system can drive a high capacitance cable and a 600 ohm load. Feedback to A124A comes from the outputs of the followers which are summed by resistors R193 and R194. These resistors are used to balance the output currents of the two followers in a manner similar to that of the emitter degeneration in the parallel transistor output stage. Summed into the positive input of A124A is a ground voltage which may be derived from the far end of a long output cable. This arrangement effectively refers the output signal to the distant ground thereby eliminating common mode noise between the distant ground and the Program Equalizer chassis. It is very important, however, that pin 2 of the output connector P2 be grounded preferably at the remote location.

Experiments show that if the negative supply voltage for the NE5532AN operational amplifier is at least -2 V whenever there is any appreciable positive supply voltage, even millivolts, then the output will follow a grounded input with only a small offset even when there is insufficient positive supply voltage to operate the amplifier. This is the essence of the muting system. A voltage sensor circuit in the power supply section operates the power MOSFET Q102 which acts as a switch in series with the positive supply for A123 and A124. This transistor cannot be turned on unless the negative supply is already on.

POWER SUPPLY SECTION

The timer and voltage sensor for the muting circuit utilizes an integrated circuit transistor package Q2 powered from the -28 V bus V12. The sum of the +22 V supply voltage, V1, and the -27 V regulated voltage, V12, is applied to the series circuit consisting of a 33 V zener diode and resistor R19. Whenever the sum of these voltages exceeds 33 V, then transistor Q2A is turned on causing transistor Q2B to be turned off. Capacitor C16 can then charge via R23 connected to the +22 V supply V1. When the voltage across C16 reaches 1.1 V, the Darlington transistor Q2C and Q2D turns on and cuts off the FET Q101 which was shorting the input of A123A to ground. As the voltage at the collector Q2D rises, it eventually switches the logic inverter U1F, a high speed CMOS Schmitt trigger inverter, and its output turns on the system input signal via the electronic switch U103B. The time delay produced by C16 and R23 is about 5 seconds. If the sum of the supply voltages drops below 33 V, Q2A cuts off thereby turning on Q2B to short C16. This causes Q2C and Q2D to cut off operating Q103B and Q101 both of which ground the input of A123A. FET Q101 is needed because a MOSFET will not remain on in the absence of power.

Another voltage sensor, Q1, in conjunction with the 10 V zener diode D7, determines when the -22 V supply exceeds -11 V. At this point the collector output of Q1, which is connected to R196, operates the power MOSFET Q102 to apply positive supply voltage to the output amplifiers A123 and A124.

All the electronic switches are operated by front panel manual switches which when closed insert the appropriate system functions. For example, the equalizer switch S3 grounds the input to the Schmitt trigger inverter U1D and operates the MOSFET U102B to utilize the output from the equalizer and, at the same time, operates U102A to permit the input signal to pass to the equalizer system. Resistor R18 and capacitor C15 together eliminate the effects of switch contact bounce by causing the input to U1D to rise slowly.

Power can come in either via the 4 pin XRL style connector P3 or via the remote cable connector P4. The +28 V is regulated down to +22 V using the integrated circuit regulator A2. Because this regulator is too noisy for such a low noise system, additional feedback via the operational amplifier A1B is used to eliminate its noise and to provide a much higher degree of regulation at frequencies up to 200 kHz. To avoid potentiometers, a separate 10 V precision reference A6 is used and this feeds via a low-pass noise filter R1 and C5 the follower A1A. The +10 V low-noise output from A1A is then used as a reference for both the positive regulator system and for the negative regulator system. The negative regulator consists of A4 with additional feedback around it provided by the operational amplifier A1A. Separate power supply buses for the various parts of the system emanate from the sense points of these regulators where the output impedance is in the microohms.