

APPARATUS FOR PROVIDING AMPLIFICATION WITH MULTI-FEEDBACK PATH

1. TECHNICAL FIELD OF THE INVENTION

5 The present invention relates generally to the field of audio power amplifier and more particularly, to an apparatus for providing amplification with a multi-feedback path using vacuum tubes or solid state device series connected totem pole as push-pull output stage, or known as Single-Ended Push Pull (SEPP) amplifier in the art.

10 2. BACKGROUND OF THE INVENTION

Audio power amplifier using vacuum tubes series connected totem pole as push-pull output stage are known for quite some time and was believed first patented in 1950's (for example, US-A-2 802 907) by Peterson and Sinclair with successful release of Horizon™ series amplifiers. The solution solved distortion
15 problem caused by the transient of output transformer. Nevertheless, this type of amplifier is soon being phased out by Williamson and Ultra-linear™ type amplifier that also solves transient problem. However, as vacuum tube with higher current capability and solid state device appears later, the interest is renewed again as it is now possible to construct output transformer-less amplifier
20 using these devices.

Another reason why this type of amplifier is currently being sought after is that, there is no truly complementary device in the field. In practice, although we would indicate is as complementary, in actual fact, we would merely obtained a similar device. The reason being that NPN and PNP devices are different by
25 nature therefore true complementary NPN/PNP devices do not exist. Most manufacturers acknowledged this fact, and this can be gleaned from the data sheets where for a complementary pair one will note that there are differences,

from power bandwidth, to switching times. Although matching of non-complimentary device is equally troublesome, but it is easier and cheaper to deal with by additional circuitry.

5 For series connected output device, depending where the ground is connected to, typically the upper tube is a cathode or source follower where the lower device is a common grounded cathode or source amplifier. The device can be driven as such since both devices become a voltage follower (as in common cathode/source amplifier) or cathode/source follower. In either case the upper device required more signal drive compare to the lower device.

10 To convert both devices into voltage follower, one way is to drive the upper device using an inter-stage coupling transformer. This permits the upper device to become a true bootstrap cathode follower which has exactly the same gain as lower device. The balance drive can be accomplished in another way using bootstrap or positive feedback to the driver itself. Bootstrap is an acceptable
15 method where the gain of output device is low. As an example, Output Transformer-Less (OTL) amplifiers using positive feedback balanced method are quite many in the field, of which most popular is the Julius Futterman (United States Patent No. US-A-2 773 136 (1956), and US-A-3 123 780 (1965)) amplifier. The open-loop gain of Futterman's amplifier is way in excess of 5000,
20 and a global negative feedback of 40 dBs. However, stability with high open loop becoming is a concern when amplifier has to work with load of varying impedance due the amount of phase shift which is comparatively worse when bootstrapping the output device as compared to complimentary solid state counter part where no such design step is necessary.

25 In asymmetry SEPP amplifier, the output devices can be also be configured so that they both operate as cathode or source follower. In this case, the upper device is not bootstrapped, so that its gain is unchanged. As a cathode or source follower, the gain is less than unit due to negative feedback introduced by the load in its cathode path. For lower device, the gain is higher as the load is at the

plate or drain. If the gain is reduced by same amount as the negative feedback applied to upper device, both devices will operate as cathode follower. This implied 100% negative feedback to bottom device. The upper device is a true cathode follower, whereas the bottom device is considered as “emulated” cathode follower. True cathode follower generates a series of harmonic particularly harmonics of higher orders and this can impair signal when the output is high. It is believed that such problem is the main reason why it is rejected by some amplifier designers. Fortunately, as there is only one cathode follower to deal with, this problem may be solved by means of slightly bootstrapping the upper device directly (note this will not convert it to a voltage follower, as positive feedback is very minimal) so that the harmonics distortion contents are reduced. The bootstrap follower theory contributed by G. W. Short was published in WIRELESS Worlds January 1961.

It is noted most prior inventions configured output device as voltage follower that required larger amount of global negative feedback to reduce distortion and output impedance. This is true in the early day tube and transistor SEPP amplifier, especially so for solid state when there were no complementary device yet. Yet another example of recent OTL amplifier invention using bootstrap is mentioned in the United States Patent No. US-A-2 773 136 (1980), entitled “Audio Power Amplifier”, which used positive feedback to balance drive three out the six solid state amplifiers of his invention. There is no measurement about the harmonics distortion contents reduction is claimed however, but it’s known that the open loop distortion for field effect transistor or any other output device for that matter, is that in voltage follower modes the Total Harmonics Distortion (THD) figure is much higher than in drain follower mode and with the same amount of feedback. It is also noted that the feedback is taken directly from the output; hence the output impedance will be not a predetermined value. As it is also noted in order to have tube sound besides having triode characteristics, the output impedance should be higher since most tube amplifiers have generally higher output impedance. In general, the output impedance is proportional to the amount of global negative feedback designer applied, and the resultant value is

often small, and well below that of the critical damping of the speaker. On the other hand, if the amount of global feedback is reduced as in Takehara's amplifiers to maintain higher output impedance, the distortion will be higher.
5 This has become a dilemma, particularly when the positive feedback is adopted for balanced driving of the output devices.

3. SUMMARY OF THE INVENTION

The primary object of the present invention is to provide an audio power amplifier of high quality sound with reduced harmonic distortion components, as
10 well as harmonics of high orders (which normally greater than 7) while permitting the use of non complementary and high voltage device as output stage with optimal safety protection. Preferably, this is to be within and met the IEC standards.

Further, the object of the present invention is to provide an audio power
15 amplifier, in which a last-stage power amplifier is constructed with vacuum tube power triode while permitting the use of the same drive stage and front-end stage.

Yet, another object of the present invention is to provide an audio power amplifier, in which a last-stage power amplifier is constructed with power metal
20 oxide field-effect transistors (hereinafter referred to as power MOSFET) having triode characteristics, while permitting the use of the same drive stage and front-end stage.

A further object of the present invention is to provide an audio power amplifier, with predetermined output impedance, and to derive differential negative
25 feedback port from upper and lower device feedback path.

Yet another object of the present invention is to provide an audio power amplifier which comprises a phase inversion stage with high voltage drive level for the vacuum output stage and high current drive for solid state output state.

5 Still, another object of the present invention is to provide an audio power amplifier which comprises of multiple output devices with separate bias adjustment and circuitry and drive path for each output device and permitting minimal distortion components of output stage.

Yet, another object of the present invention is to provide an audio power amplifier which comprises of dual power transformer to derive multiple DC
10 supplies that permits power output regulation and minimal signal interferences.

Other objects and advantages of the present invention will become apparent from the following descriptions, taken in connection with the accompanying drawings, wherein, by way of illustration and example, the preferred embodiment of the present invention is disclosed.

15 In accordance with the preferred embodiment of the invention, there is disclosed an apparatus for amplification comprising :- a front-end input stage having multi-feedback port, a front-end, a driver stage with fixed DC bias control and improved signal coupling, a phase inversion stage with improved signal coupling, distributed negative feedback, an output stage with asymmetry output
20 device, a balanced equalisation method for asymmetry output device using negative feedback, an output stage capable of providing negative multiple feedback, an output stage having a predetermined output impedance value, an output stage having separated bias control and signal drive for each of the output device, a power supply with dual power transformers, and a compensated bias for
25 output device to obtain maximum power output possible.

These and other objects of the present invention are accomplished by providing,

An apparatus adapted for amplification characterized in that said apparatus includes:-

a front-end input stage (110) having multiple feedback port (102);

a distributed negative feedback means (300);

5 a non bootstrapped phase inversion stage (130) for connection with an output stage (150) having asymmetry output device (152);

a balanced equalization method for asymmetry output device using negative feedback; and

10 said output stage (150) capable of providing multiplicity of negative feedback.

Preferably, the front-end input stage includes a drive module.

Also preferable, the output stage having a predetermined output impedance value. The output stages also have separated bias control and signal drive module.

15 Also preferable, the power supply requirement of the apparatus includes use of dual power transformer power supply.

Also preferable, the apparatus includes means to increase slew rate, means to distribute multiple negative feedback, means to reduce phase shift, means to bootstrap to an upper output device to reduce odd and/or higher order harmonics,
20 means to provide multi-path negative using differential potentiometer adjustment for the phase inversion stage and the front-end stage, means to provide high voltage and high current drive signal from the phase inversion stage, means to provide negative feedback from the output device; and means to provide high

tension and bias voltage to said front-end input stage and said non bootstrapped phase inversion stage.

Yet is also preferable that the output stage is provided with a short circuit protection means, and devices connected is separately fused having indication
5 means to indicate faulty device. Also preferable, the output stage is provided with over-voltage protection circuitry.

4. BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the invention will now be described, by way of example only. The drawings constitute a part of this specification and include exemplary
10 embodiments to the invention, which may be embodied in various forms. It is to be understood that in some instances various aspects of the invention may be shown exaggerated or enlarged to facilitate an understanding of the invention.

Fig. 1 is a circuit diagram illustrating prior art driver stage of an amplifier;

Fig. 2 is a circuit diagram illustrating another prior art driver stage of an
15 amplifier;

Fig. 3A is circuit diagram illustrating vacuum tube state phase inversion stage of the present invention;

Fig. 3B is circuit diagram illustrating solid state phase inversion stage of the present invention;

Fig. 4A is circuit diagram illustrating vacuum front-end and driver stage of the
20 present invention;

Fig. 4B is circuit diagram illustrating solid state front-end and driver stage of the present invention;

Fig. 5 is circuit diagram illustrating the vacuum tube state output stage of the present invention;

Fig. 6 is circuit diagram illustrating the solid state output stage of the present invention;

5 Fig. 7 is a circuit diagram illustrating an example of audio power amplifier incorporating the preferred embodiment of the present invention;

Fig. 8 is a block diagram illustrating an example of the audio power amplifier incorporating the preferred embodiment of the present invention;

10 Fig. 9 is a circuit diagram illustrating another example of audio power amplifier and its key element incorporating the preferred embodiment of the present invention;

Fig. 10 is a circuit diagram illustrating another example of audio power amplifier and its key element incorporating the preferred embodiment of the present invention;

15 Fig. 11 is a circuit diagram illustrating yet another example of audio power amplifier and its key element embodying the preferred embodiment of the present invention;

Fig. 12 is comparison table of multi-port distributed feedback and single route feedback against expected distortion; and

20 Fig. 13 is comparison table that shows the drive level requirement and gain/NFB calculation for vacuum tube state and solid state output devices as the output is connected to different load impedance.

5. DETAILED DESCRIPTION OF THE DRAWINGS

Referring now to Fig. 1 and Fig. 2, there are shown prior arts for the present invention. For asymmetry output stage, the drive signal requires the top and bottom tube to be different and usually require an equalisation means. Fig. 1 is a driver for the upper tube of asymmetry amplifier of the prior art. Signal S1 enters VT1 through grid (2), and output with a same phase as S2 appears at cathode but with more current drive than S1. The inverted signal is decoupled via Zener diodes (10, 12, 14) while they provide voltage regulation. The output voltage, V_o is added to the bottom of cathode resistor, thus increasing S2 by the same amount. However due the 100% feedback voltage, V_o on cathode means increased input impedance, hence the output will not increase without increasing input signal S1. This ends up the same function as conventional cathode follower stage while Zener only acts as voltage stabiliser.

Fig. 2 is a cathodyne phase splitter driver of a prior art. The function is generally the same as Fig. 1, except the drive signal for the bottom output device is taken from anode of this driver. Resistor (6) and resistor (8) are of equal value and the output voltage V_o is added to S2. This raises the impedance of the cathode arm. The ratio of upper to lower arm is thus altered such that $S3 = S2 - V_o$. It may be noted that drive signal tracking is tight over entire output ranges. Disadvantages of the priors arts are as follows:-

One of the main deficiency of the prior arts is that the design does not have provision to cater for varying output impedance as the driver used output as reference, the drive balance will be lost when a higher or a lower load than design value is presented since 100% tracking of upper and lower drive signal call for 100% matching of both devices over the entire working voltage and power output range. Matching under varying load is clearly not possible as trans-conductance of the devices change as current drawn is varied. Here is some of drawback of these prior arts:

- 1) In Fig. 1, the driver is intended to bootstrap the upper device but it is not a true bootstrap follower. A true bootstrap follower is a cathode follower with either (1) an inter-stage coupling transformer while the input signal is reference to ground through primary winding and secondary winding is connected to grid/gate and cathode/source or, (2) bootstrap applied to anode driver circuit.
- 2) As positive feedback is applied to cathode, this increases driver input impedance and increase driver output impedance. This driver required just as much drive as a conventional cathode follower.
- 3) The use of Zener diode still will not make it a bootstrapped cathode follower.

Prior art as shown in Fig. 2 shared the above mentioned disadvantages and in addition to the following disadvantages:-

- (1) The driver output will be limited to HT, permitting a maximum of +500V, and no provision for going negative.
- (2) Any back electromotive force (EMF) from speaker is directly amplified by both output devices.
- (3) It is an indirect or long winding method to reduce gain of upper tube.
- (4) There is a sonic penalty as damping and speed or timing (slow down) of lower frequency suffers due to 100% bootstrapping of the cathode driver causing varying output impedance and time differences between the upper and lower drive signal. This creates unnecessary lower frequency boom and sound quality degrading.

Fig. 1 and Fig. 2 also shared the following disadvantages:

- 1) It's a shock hazard as the driver current flows through the load, high voltage of the driver may appear on output terminal unless suitable protection circuit is in place.
- 2) No advantages in converting upper device a voltage follower.

In the present invention, the output stage is configured as cathode/source follower, which requires a lesser amount of negative feedback to reduce distortion and output impedance. To successfully applied negative feedback, the open loop distortion should be kept low, as expected amplifier distortion is roughly the open loop distortion divided by the amount of feedback. The open loop distortion for voltage follower is about 10% where it is less than 1% for cathode / source follower. To obtain the same distortion level, 10 times more negative feedback is required. The maximum amount of negative feedback possible is determined by the slew rate of the front-end device, and if exceeded, it can cause additional higher order harmonics distortion which can impair sound quality since these higher harmonics although inaudible to the ear but their existence can modulate the noise floor which will impair the sound quality. The slew rate requirement of the front-end stage and driver was first analysed by Dr. Matti Ojala in 1970's "Transient Distortion in Transistor Audio Power Amplifiers" where he clearly shows that the slew rate of the front-end stage must exceed the signal bandwidth. Otherwise it can cause Transient Inter-modulation Distortion (TIM). This type of distortion is created when the output voltage is required to change faster than the amplifier can cope; it is also called 'slew rate' distortion, and produces a complex high order of harmonics which the feedback mechanism is too slow to remove. That is to say if the signal bandwidth is 20 KHZ then the amplifier should have bandwidth of 20 KHZ at least in the open loop otherwise the maximum power output at top frequency will reduce. Slew rate is not the same as low pass band filter as the determining factor is really the current limitation of the whole amplifier. In real world circuit, one has to

consider the effects of the resistances, capacitances and inductances to determine the maximum current demand and this current demand is frequency dependent. In addition, when come to negative feedback, poor slew rate causes phase error in the front-end and driver as they try to advance the phase angles in attempt to correct the error. This invention solves the problem by implementing distributed multi-port feedback scheme in the front-end stage, so that the amount of feedback at each port is such that speed of negative feedback is faster than the slew rate and means to keep the phase shift error to very low level. The result of this application is stated in Table 2 where it shows that multi-port feedback outperforms single port feedback. The example amplifier can deliver 16V p-p into 8 ohms load at 150 KHz, implied S_r of 15V/mS in close loop, the calculation below it shows the example amplifier output power rating (subject to the number of output tube being implemented).

Slew rating and power output calculation

$f_{\max} = S_r / 2\pi V_p$, where $f_{\max}$ is the maximum frequency in KHz, S_r is slew rate in V/mS, and V_p is peak output voltage, P_o is the output power into 8 ohms load impedance.

	S_r	V_p	P_o	$f_{\max}$	S_r	V_p	P_o	$f_{\max}$
20	15	8	1	298	1	8	1	20
	15	16	4	149	2	16	4	20
	15	32	16	75	4	32	16	20
	15	64	64	37	8	64	64	20
	15	96	144	25	12	96	144	20
25	15	114	203	21	14	114	200	20
	15	128	256	19	16	128	256	20

Referring now to Fig. 3A and Fig.3B, where phase splitter that overcomes all of the above disadvantages is illustrated. The functions of the components are described as follows:-

Legends: J - Jack, R - Resistor, C capacitor, Z - Zener, D - Diode, S - Signal, P - Preset trimmer, VT - Vacuum Tube, Q - Solid State transistor

	Ref. No.	Type	Functional Description
5	30	D	This diode is used for grid over voltage protection for VT2A when power is first turn-on by shunting the high voltage away from the grid into the cathode. When the device is fully operating, the voltage at the cathode is higher than the grid. This reverse biased the diode so normal function continued.
10	38	R	This resistor is the anode resistor arm of the cathodyne phase splitter.
	40	R	This resistor is cathode resistor arm of cathodyne phase splitter.
15	42	R	This resistor is the decoupling resistor, corresponding to coupling resistor 46.
	44	C	This film capacitor is used for decoupling unwanted feedback signal.
	46	C	This capacitor is a bypass electrolytic capacitor for negative supply.
20	48	R	This resistor is a voltage dropper, so that the negative voltage is between -45 to -100V.
	50	R	This resistor is the feedback resistor divider.
	52	C	This capacitor is the feedback voltage coupling capacitor.
25		C-40V-175V	This is negative supply for VT2A / Q4.
		NFB1	This is negative feedback source 1. This feedback is connected to feedback port at cathode of V1B/Q1 and feedback port at anode of VT1A.

	NFB2	This is negative feedback source 2. The feedback is connected to anode / drain resistor arm of cathodyne phase splitter VT2A/Q4 and feedback port at V2B/Q3 grid / gate.
5	S1	This is input source signal.
	S2	This normal driver output signal.
	S3	This inverted driver output signal, equalised.
	Vo	This is the normal amplifier output voltage.
15	B+500V	This is primary high tension for the phase splitter, ripple has been filtered.
	Q4 Q	N channel MOSFET (Metal Oxide-Silicon Field Effect Transistor)
	V2A V	Vacuum tube, medium Mu triode

There are 2 distinct differences compared to the prior art, (1) negative feedback is applied to anode resistor arm of upper tube directly, and (2) the driver is ground referenced, instead of output reference. In addition, the driver has the following advantages:-

- (1) Differential negative feedbacks (NFB1 & NFB2) are tapped across resistor (72) of the upper device cathode and resistor (74) of the lower device anode. This voltage is similar to voltage at output but they are better immune to the back EMF created by output device. The back EMF has to buck against resistor (72) and (74) before reaching the feedback circuit.
- 2) Differential negative feedbacks permit feedback to be fine tuned so that harmonics distortion contents can be reduced to minimum. In normal output signal there is always some Large Signal Nonlinearity (LSN) which causes large harmonics distortion. This implied some differences in forward gain for signal travelling through upper and lower device. This

can be solved by applying a differential negative feedback amount to increase the gain of the half that is lower gain and to reduce the gain of the half that is higher gain.

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- (3) The circuitry path at which NFB2 is derived is the same circuit of a local feedback loop for the lower output device. This local feedback mechanism can greatly enhance the stability of the solid state output device where the gain is much higher than the vacuum tube counter part as local NFB comes into instant action without waiting for the vacuum tube to heat up. The open loop distortion is lower as both devices now
- 10
- operated as cathode follower.
- (4) Negative feedback for the driver reduces the output impedance of the phase splitter tube. The lower device has higher gain and therefore higher input capacitance due to miller effect than the upper device. This low impedance helps to drive the lower device by providing more current
- 15
- capability.
- (5) The output level of the cathode arm is not affected since any corresponding level increased at the cathode arm will be decoupled by electrolytic capacitor (44).
- (6) High driver output level is possible by applying negative voltage rather
- 20
- than further increasing high tension voltage.
- (7) The input impedance of the cathodyne phase splitter is high as high value grid resistor is being used. This has resulted very little phase shift at the lower freq due to minimal signal loading. Frequency phase shift at 10 Hz is <0.5 degree.

Thus the phase splitter has solved the problems of the prior arts, as well offering other advantages as mentioned above.

Referring now to Fig. 4A and 4B, they show circuit diagrams illustrating the front-end stage (110) and driver module (120) of the present invention. The followings are the functional description for each component used.

Legends: J - Jack, R - Resistor, C capacitor, Z - Zener, D - Diode, S - Signal, P - Preset trimmer, VT- Vacuum Tube, Q - Solid State Transistor

	Ref. No.	Type	Functional Description
10	2	J	Signal input jack, RCA type to accept input
	3	C	Input signal coupling capacitor and provide DC isolation for fixed biasing.
	4	R	This is input filter resistor, part of input filter.
15	5	R	Fixed bias resistor VT1B/Q1. Fixed bias does away with the self bias resistor and electrolytic capacitor which can have undesirable sonic effect of the signal and thus can be avoided.
	6	R	This is grid resistor which also is part of input impedance.
20	8	C	This is input filter capacitor, part of input. Together these two components prevent high frequency oscillation say beyond 2 MHz.
25	9	P	This is bias trimmer. It is adjusted so that the voltage on pin 6 VT1B plate is about +120V (when ECC83is used).

	12	R	This is NFB divider to accept negative feedback. It is also known as port 1 of distributed feedback.
	13	R	This resistor value determines the part of the amount of negative feedback.
5	14	C	This provides the ground path for input drive signal, as it is decoupled to ground and provide filtering for bias voltage supply.
10	15	C	This capacitor works in conjunction with resistor (13), as it reduces the overshoot or ringing due phase lags when NFB is applied. This will permit the system to stabilise.
	16	R	This is grid resistor for VT2B/Q3 and load resistor for the front end stage. Higher resistance value can be used for the fix bias scheme being used.
15	18	P	This trimmer provides the initial bias for VT2B/Q3. Additional negative can be provided by the rectified action of VT2B/Q3 as the signal drive is increased.
	20	R	This is the cathode resistor of VT1A. The voltage drops across it forms the bias voltage for VT1A.
20	21	R	This is summing resistor, which combines input signal and NFB2 signal. This resulted in error correction signal output to the grid of VT2B.
	22	D	Green LED provides 1.85V DC bias supply voltage.
	25	C	This film capacitor is for signal coupling.
25	23	R	This is negative feedback resistor at grid VT2B. The feedback source is NFB2, which is taken from the slider side of differential feedback pot. (94).

5	30	D	This diode is used for power first turned on protection for VT2A by shunting the high voltage away into the cathode. When the device is fully operating, the voltage at the cathode is higher than the grid, this reversed bias the diode so normal function is continued.
	32	R	VT2B plate load resistor. The other end of resistor is connected to regulated HT+350V
	35	R	Grid resistor for VT2A.
10	36	C	This signal coupling has identical function as capacitor (25).
	56	Z	Zener diode, voltage regulator +150V
	58	Z	Zener diode, voltage regulator +150V, series together with Zener diode (56) to provide HT +300V to front-end.
15	60	Z	Zener diode, voltage regulator, series with Zener diode (56, 58) to provide HT +350V to driver
	62	C	This is the filtering capacitor. This e-cap also filters out any hissing noise introduced by the Zener diodes.
	64	R	This resistor discharges any reminding voltage in e-cap 62 after power down.
20	66	R	This is voltage dropper.
	Q1		N channel FET (Field Effect Transistor)
	VT1A		Vacuum tube, medium Mu triode
25	VT1B		Vacuum tube, high Mu triode
	VT2B		Vacuum tube, high Mu triode
	Q1		N channel JFET (Junction Field Effect Transistor)
25	Q2		N channel JFET (Junction Field Effect Transistor)
	Q3		N channel JFET (Junction Field Effect Transistor)
	S0		Normal input signal source
	S1		Normal output signal source

	S2	Inverted output signal source
	B+300V	This is regulated supply for front-end
	B+350V	This is regulated supply for driver.
5	B+380-500V	H.T. supply, filtered. +500V for vacuum tube state output stage, +380V for solid state output stage.

Overall description of active front-end and driver components (taking vacuum tube state and solid state devices into account) as depicted in Fig. 4A and 4B:

- 10 (1) This circuit uses multiple distributed NFB to reduce odd harmonic distortion since odd harmonic contents would be higher in a single path with large amount of negative feedback. A single loop negative feedback of large amount puts on greater demand on slew rate of the preamp and driver stage. If the slew rate is exceeded, then more odd harmonics will be generated since NFB is not fast enough to clear the errors.
- 15 (2) This circuit use DC fix bias control in the front end diver and phase splitter. In the RC constant, R is large and C is small, and hence together with fixed biasing scheme it can provide extend low frequency response with little phase shift and less sonic penalty as no cathode bypassed capacitor is required.
- 20 (3) The vacuum tube base output stage requires more feedback due to higher output impedance. It also required higher driver level at the output stage due lower cathode efficiency and lower trans-conductance. It has less distortion and odd harmonic due to triode characteristics. So high gain, high voltage driver will be demanded.
- 25 (4) On the other hand, the source follower has better efficiency than cathode follower but higher distortion initially than tube base, and so it requires more current and less voltage drive but fairly high gain demanded.

	Ref. No.	Type	Functional Description
5	VT1B	V	This is vacuum tube preamplifier for small signal amplification tube. The gain of this tube is about 55 when ECC83 (1/2 12DW7/ECC83) or similar tube with Mu 100 is used. Preset trimmer (9) is adjusted so that the voltage at pin 6 is about +120V. Input signal enters RCA jack (2), and to grid (7) via filter resistor. NFB1 is applied to cathode of V1B, and this is PORT 1 of distributed feedback. The amplified output signal is taken from cathode pin 3. The output from this source is better as the square response shows less ringing and harmonics.
10			
15	VT1A	V	This device acts as plate load for VT1B and by itself is a cathode follower where output signal is connected to next stage. Value of resistor 20 is larger when ECC82 is used (1/2 12DW7/ECC832) and the value is chosen so that it has about 1/2 the supply across it. The plate current is about 0.8mA. The top plate is connected to B+300V via resistor (70). NFB is applied to the top plate via film capacitor (68) and this forms PORT 2 of distributed feedback route.
20			
25	VT2B	V	This vacuum tube is for further signal amplification and to drive the phase splitter. For vacuum tube output stage 12DW7 or ECC83 section is used and the gain is 70 fully bypassed. For solid output stage ECC99 or 6N30P is used and the gain is about 15, either device can provide the high current drive for solid state output stage. V2B is fixed bias and the initial bias is adjusted by trimmer so the grid voltage -1.0V, plate voltage
30			

at this time is +150V with about 0.3mA current flows. The driver in this operating mode, ECC83 delivers 200V p-p output with < 5% distortion. When the signal drive becomes large, the additional bias voltage is provided due to grid leak action and provides stable amplification and hence they will less abrupt clipping at peak output. NFB2 is applied via resistor (23) and it's merged with summing resistor (21). This resulted in error correction signal output to the grid of V2B and this forms PORT 3 of distributed feedback route. Resistor (23) also prevented oscillation at very low frequency and increases the stability of the system.

VT2A V This is vacuum tube based cathodyne phase splitter. The plate is connected to 500V via resistor (50) and (38) and cathode is connected to negative supply of about -100V via resistor (40, 42 and 48). This is a total of 600V. For tube base output stage, the tube used is ECC82 section of 12DW7. The actual anode to cathode voltage is not more the 300V. The high voltage is necessary as at least 200V p-p output is required from each arm of phase splitter. This grid is self biased to about -15V and this is about 4.5 mA current flows through resistor (40), which is enough to drive the vacuum tube output stage. When ECC99 or 6H30P is used, the current will be 15-20mA, which is enough to drive the solid state output stage. Resistors (50) and (38) forms voltage divider so that this permits 100% negative feedback via NFB2 differential feedback port.

Overall description of front-end and driver components (all solid state devices) as depicted in Fig. 3B and 4B:

	Ref. No.	Type	Functional Description
5	Q1	Q	This is solid state preamplifier for small signal amplification tube. The gain of this is about 55 and reduced to about 5 after 20dB of negative feedback. Preset trimmer (9) is adjusted so that the voltage at upper JFET source is about $\frac{1}{2}$ the +B3 voltage. Input
10			signal enters RCA jack 2, and to gate 2 via filter resistor. NFB1 is applied to source of Q1, and this is PORT 1 of distributed feedback.
	Q2	Q	This device acts as plate load for Q1. Value of resistor (20) is chosen so that about $\frac{1}{2}$ the supply across it. The
15			current is about 2-3mA. The top drain is connected to +B3 via resistor 70. NFB1 is applied to the top drain via film capacitor (68) and this forms PORT 2 of distributed feedback route.
	Q3	Q	This JFET is for further signal amplification and to drive the phase splitter. The gain is about 30. It is fixed
20			DC bias controls by trimmer (18) and resistor (16). The driver needs to supply about 50V p-p output. NFB2 is applied via resistor 23 and it's merged with summing
			resistor (21). This resulted in error correction signal input to the gate of Q3 and this forms PORT 3 of distributed feedback route.
25			
	Q4	Q	This is solid state based cathodyne phase splitter. The drain is connected to +B1 40V via resistor 50 and 38 and source is connected to negative supply of about -
30			40V via resistors (40, 42, 48). This is a total of 80V and

about 40V p-p output is required from each arm of phase splitter. Voltage drop resistors are used to bias the phase splitter. This device is self biased, the current is about 20mA flows through resistor (40), which is enough to drive solid output stage. MOSFET can be IRF series with drain to source of 150V or more, but the input capacitance should be low enough so it can be driven by driver Q3. Resistors (50 and 38) form voltage divider so that this permits 100% negative feedback via NFB2 differential feedback port.

10	54	Z	Zener diode to protect MOSFET from overload and transients.
	56	Z	Zener diode to protect MOSFET from overload and transients.

15 Referring now to FIG. 12 (TABLE 1), Comparison figure of multi-port distributed feedback and single route feedback against expected distortion. Output = 16V p-p into Load=8 ohms. THD figures are based on Hameg 8027 Distortion Meter and HM8037 Oscillator. From the figures, it is noted that:-

- 1) A single path feedback of large amount at Port 1 does not achieve best distortion figures.
- 2) When all ports are used, it can achieve best distortion figure.

Reference is now made to Fig. 5 and Fig. 6. Fig. 5 is circuit diagram illustrating the vacuum tube state output stage of the invention, and Fig. 6 is circuit diagram illustrating the solid state output stage of the invention.

25 Functional description of components as in Fig. 5 and Fig. 6

	Ref. No.	Type	Functional Description
5	2	C	signal coupling
	4	C	signal coupling
	6	C	signal coupling
	8	C	signal coupling
10	10	R	bias voltage divider
	11	R	bias voltage divider
	12	R	bias voltage divider
	13	R	bias voltage divider
	14	P	bias voltage trimmer
	16	P	bias voltage trimmer
15	18	P	bias voltage trimmer
	20	P	bias voltage trimmer
	22	R	grid / gate supply resistor
	24	R	grid / gate supply resistor
	26	R	grid / gate supply resistor
	28	R	grid / gate supply resistor
20	30	R	grid / gate resistor
	32	R	grid / gate resistor
	34	R	grid / gate resistor
	36	R	grid / gate resistor
	38	C	Decoupling / bootstrap
	40	C	Decoupling / bootstrap
25	42	C	Decoupling
	44	C	Decoupling
	46	R	grid / gate stopper
	48	R	grid / gate stopper
30	50	R	grid / gate stopper
	52	R	grid / gate stopper

	56	R	short circuit current limiter
	58	R	short circuit current limiter
	60	R	short circuit current limiter
	62	R	short circuit current limiter
5	64	F	fuse, normal, output device fault protection
	66	F	fuse, normal output device fault protection
	68	F	fuse, normal output device fault protection
	70	F	fuse, normal output device fault protection
	72	R	Feedback resistor, upper half
10	74	R	Feedback resistor, lower half
	76	F	Fuse, overload / speaker protection, fast acting
	78	R	open loop resistor
	80	C	Snubbed cap, prevent high freq oscillation
	82	R	Snubbed resistor, prevent high freq oscillation
15	84	Z	Zener, faulty DC output protection
	86	Z	Zener, faulty DC output protection
	88	C	Decoupling
	90	C	Decoupling
	92	P	Preset trimmer, differential feedback pot. NFB1
20	94	R	Preset trimmer, differential feedback pot. NFB2
	100-	Z	Zeners to protect MOSFET from signal overload, and
	112		transients
	VT1	V	Vacuum tube Power output device
	VTn	V	Vacuum Power output device, where n is multiple of 2 up
25			50.
	TR1	V	Solid state Power output device
	VTn	V	Solid Power output device, where n is multiple of 2 up to
			8.

Overall description of vacuum tube state and solid state output stage as in Fig. 5 and Fig. 6 are as follows:-

This is a series connected totem pole output stage. The vacuum tube stage operates from a $\pm 175\text{V}$ bipolar DC supply and has separate bias supply while the solid state operate from $\pm 45\text{V}$ and the bias supply is bias voltage is taken from bipolar supply. The ground is at the centre of bipolar supply, and upper half has load in the path of cathode, and for lower half, it's in the path of anode or source of lower device. In the ground position as shown, the upper half is cathode or source follower and bottom half is cathode or source grounded amplifier, and in lower half the load is at the anode or drain. The upper cathode (source) follower required higher drive signal or 30% higher than the bottom device due to the 100% degeneration or negative feedback on its cathode (source). The bottom tube has a gain of about 3 when the load is very light or open circuit, and gain drops as load is increased. The gain is only slightly greater than the upper cathode follower as the load is increased. The bottom MOSFET has a gain of about 30 when the load is very light or open circuit, and gain drops as load is increased. More details of the gain calculation can be found in Table 1 (Fig. 12). It's noted MOSFET has far more gain in common source mode than source follower mode. For modular design, every module consists of 2 x 6C33C or 10 x 6C19P. For modular design, every module consists of 2 x MOSFET. To double the power output, the output of the modules is combined, and is driven by one single driver module. The output device needs not be perfectly matched but 20% matching is desirable. This ensures peak power output is not prematurely clipped by under power device. Although MOSFET has better match than tube, 20% match is preferred. The bias of each device is separately adjusted so that the DC offset is not offset by different idle current. In fault condition, DC higher than 50V of either polarity will cause the two Zener diodes connected back to back to conduct current and the fuse will be blown. Hence there will be no DC higher than 50V appears in output terminal. The Zener diode arrangement permits 100V p-p audio signal to pass. This is about 90W RMS into 16 ohms load.

There are fuses to protect against hazard when the tubes are overloaded or when fault condition. The current due to this fault need not necessary go out through the load. For example when both tubes are overloaded due to a bias problem, both tubes will draw just about the same current. In this case there is little current
5 flow through the speaker. Hence, fuse (64 to 72) can be normal fuse or even slow blow. The advantage is to prevent unnecessary fuse blown out due momentary signal overload where no DC appears or DC is below safe level at the output. All fuses for MOSFET protection are fast acting. But fuse (72) must be fast acting to protect again any abnormal condition such serve signal overload or faulty output
10 stage that is causing DC to rise above safe level at the output terminal. Speaker cut out is implemented for added safety. The cut off relay will be triggered to isolate output terminal if more than 1V appears at the output terminal. Trimmer (92) is the differential preset trimmer for negative feedback. The advantages are:-

- 1) Negative feedback can be fine tuned to a point where distortion is lowest.
- 15 2) Negative feedback is taped on top of feedback resistor of each output device. This better represents the output waveform needs correction as it's not heavily loaded.
- 3) The feedback circuit are more isolated from the output and thus better immured against the back EMF of the load impedance.

20 Trimmer (94) is the differential feedback NFB2. It is used to control the gain of lower output device so that the gain is the same as the upper output device. The advantages are same as 92 mentioned above. Film capacitors (38 and 40) are connected to output, so there is a small amount of positive feedback to resistor (30 and 34). Advantages are:

- 25 1) Permits smaller value with higher quality film to be used
- 2) Reduced loading effect of input stage, and hence reduce distortion

- 3) Reduced harmonics distortion contents of the upper device of which the harmonics contents are higher due cathode follower operation.

Resistors (22 to 28) are in series with bias supply of the output device, and they are connected to decouple / bootstrap film at one end. These are part of the grid / gate resistors. The value of capacitor is small so they formed a large reactance at lower frequency. The advantages are; 1) Permitting higher value of grid / gate resistor to be used, since part of grid / gate current will be supplied by shunt film capacitor 38-44 without running into risk of thermal run away, and 2) Permitting better lower frequency response.

Trimmer (14 to 20+ are bias preset potential-meters so that bias voltage for each output device can be separately adjusted. The advantages are; 1) Permitting unmatched device to be used (although 20% match is recommendation), and 2) Permitting smaller value of coupling capacitor to be used as input resistor is higher.

Resistors (72 and 74) are NFB resistors. Provide differential feedback for front-end as well to the phase splitter. These resistors also determine the limit of the output impedance. This permits output impedance to be predetermined to match the critical damping of the speaker. In the conventional feedback amplifier, output impedance is a by product as it varies by the amount of feedback and it can be reduced to very small value with large feedback amount. This can cause over damping, which reduces bass response. In this invention, minimal output impedance is equal to these two resistors in parallel. This minimal output impedance is necessary for solid state device to have tube like sound.

Reference is now made to FIG. 13 (Table 2) that shows the drive level requirement and gain / NFB calculation for vacuum tube state and solid stage output devices as the output is connected to different load impedance.

Fig. 7 is a circuit diagram illustrating an example of audio power amplifier of the invention, some descriptions as follows:

A4T1 is a toroidal power transformer. In the positive phase, it supplies 120V AC to the rectifiers of bipolar supply and charges the capacitors in positive rail.

5 In the next negative phase, it charges the capacitor in negative rail. The voltage is lower in solid state output.

1) It supplies the bias supply circuit that is required to bias the output device. In solid state, the bias supply is not necessary as it derive the bias supply directly from bipolar rail.

10 2) It supplies the heater power to the power tube of one channel.

3) It supplies the heater power for the front end driver tube of one channel.

A4T2 is another toroidal power transformer. The phase is the inverse of A4T1, so it provides AC 120V to bipolar rectifiers so that it charges the capacitors at the opposite rail, I.E. when A4T1 is charging the capacitors in positive rail, this
15 A4T2 is charging the capacitor in negative rail and via-versa. The voltage is lower in solid state output. Thus together with A4T1, it's a full wave rectifier, much like a centre tap power transformer.

1) It supplies power to the high tension supply circuit that is required by front end stage.

20 2) It supplies the heater power to the power tube of one channel.

3) It supplies the heater power for the front end driver tube of one channel.

4) It supplies the 24V supply for speaker relay cut out and cooling fan.

Advantages of this arrangement are:

- 1) The power fluctuation of one transformer does affect this other and hence ensure signal integrity.
- 2) Regulation is not necessary as the bias supply is derived from the same transformer as bipolar supply. The bias supply and bipolar supply will fluctuate in the same manner.
- 3) The HT is derived from the same supply as the bipolar supply using voltage doublers and it is added to positive rail of bipolar to obtain a total of +500V required by the front end. The hazard is reduced as the use of dangerous high voltage transformer is avoided.

A3RL1 is a relay and its associate circuitry will operate so that the speaker is disconnected when there is more 1V DC appears on the output terminal. The acting time is enhanced by using the released timing which is normal faster than make time. This is about 3 mS. Advantages:

- 1) To avoid DC output at the speaker terminal that can destroy the speaker.
- 2) To disconnect speaker due to distortion that causes DC output at the output terminal.
- 3) To mute the amplifier during heating up.

A3DZ1 to A3DZ4 are power Zeners connected back to back. The rating is 50V each and hence it permits DC protection up to 50V and audio signal up to 100V p-p to pass with no loss or degrading of sound quality.

Advantages:

- 1) To prevent high voltage appears at the output terminal
- 2) Zener is more reliable than relay cut out, so it is a fall back safety device necessary for securing protection.

5 A2DL1 to A2DL10 are the LEDs (Light Emitting Diode) that indicate the condition of fuses A2F1 to A2F10. These LEDs light will go off if the fuses are blown and thereby provide indication of the problem devices.

Reference is now made to FIG. 8 where the overall block diagram representation of the amplification apparatus as disclosed in the preferred embodiment of the present application is illustrated. The apparatus includes front-end input stage
10 (110), a distributed negative feedback means (300), a non bootstrapped phase inversion stage (130), an output stage (150) having asymmetry output device (152), a balanced equalization method for asymmetry output device using negative feedback. The input stage comprises of a multiple feedback port (102),
15 summing network (105) and a driver module (120). The output stage (150) is capable of providing multiplicity of negative feedback to be as feedback to the different stages in the front-end input stage (110) and the phase inversion stage (130). Output stage (150) is shown comprises of bias drive network (140), output device (152), differential negative feedback network (155) and short
20 circuit protection means (160). The short circuit protection means (16) includes used of Zener diodes. The power supply requirement of the apparatus is being met by used a power supply means (250) that include used of dual transformer AC power supply (230) providing high voltage power supply (220) to the front-end stage (110) and the non bootstrapped inversion stage (130), bias power
25 supply (210) to the output stage (150), bipolar power supply (200) to the output device (152) and direct current supply (190) to a speaker cut out circuitry (170). The output stage (150) capable of providing multiplicity of negative feedback as mentioned earlier.

The implementation of the preferred embodiment of the present invention is depicted in FIG. 9, 10 and 11. Discussion on the basic building block of the amplification apparatus of the present invention has been discussed earlier; therefore it will not be repeated again. Suffice to say that the key elements within
5 the circuits of the building blocks work together to provide much improved amplification apparatus that met the objects of the invention.

While the invention has been described in connection with a preferred embodiment, it is not intended to limit the scope of the invention to the particular form set forth, but on the contrary, it is intended to cover such alternatives,
10 modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

WHAT IS CLAIMED IS:

1. An apparatus adapted for amplification characterized in that said apparatus includes:-

a front-end input stage (110) having multiple feedback port (102);

a distributed negative feedback means (300);

- 5 a non bootstrapped phase inversion stage (130) for connection with an output stage (150) having asymmetry output device (152);

a balanced equalization method for asymmetry output device using negative feedback; and

- 10 said output stage (150) capable of providing multiplicity of negative feedback.

2. An apparatus as claimed in claim 1, further characterized in that said front-end input stage (110) includes a driver module (120) for electrical connection with said non bootstrapped inversion stage (130).

- 15 3. An apparatus as claimed in claim 1, further characterized in that said output stage (150) having a predetermined output impedance value.

4. An apparatus as claimed in claim 3, further characterized in that said output stage (150) having separated bias control and signal drive module (140).

- 20 5. An apparatus as claimed in claim 1, further characterized in that said apparatus includes a power supply means (230) having dual power transformers, said power supply means providing high voltage (220) power

supply to said front-end stage (110) and said non bootstrapped inversion stage (130), bias power supply (210) to said output stage (150), bipolar power supply (200) to said output device (152) and direct current supply (190) to a speaker cut out circuitry (170).

5 6. An apparatus as claimed in claim 4 further characterized in that said apparatus includes a compensated bias means for said output device so as to obtain a maximum possible output power.

7. An apparatus as claimed in claim 1, further characterized in that said apparatus includes :-

10 means to increase slew rate;

 means for distributing multiple negative feedback;

 means to reduce phase shift;

 means to bootstrap to an upper output device to reduce odd and/or higher order harmonics;

15 means to provide multi-path negative using differential potentiometer adjustment for said phase inversion stage (130) and said front-end stage (110);

 means to provide high voltage and high current drive signal from said phase inversion stage (130);

20 means to provide negative feedback from said output device (152);

 means to provide high tension and bias voltage to said front-end input stage (110) and said non bootstrapped phase inversion stage (130).

8. An apparatus as claimed in claim 7, further characterized in that said output stage (150) is provided with short circuit protection means, each of devices connected thereto is separately fused and indication means to indicate faulty device and said output stage (150) is further protected by an over voltage protection circuitry (160).
- 5
9. An apparatus as claimed in claim 7, further characterized in that said front-end input stage (110) and said inversion stage (130) having vacuum tube device element whereas said output stage (150) having solid state device element.
- 10
10. An apparatus as claimed in claim 7 further characterized in that said front-end stage (110), said inversion stage (130) and said output stage having solid stage device element.
11. An apparatus as claimed in claim 7 further characterized in that said front-end stage (110), said inversion stage (130) and said output stage (150) having vacuum tube state device element.
- 15