A HIGH PERFORMANCE, HIGH EFFICIENCY AUDIO SUBSYSTEM FOR CAR RADIO

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1. INTRODUCTION

An electronic module designed for locally powered loudspeakers in OEM autosound applications has evolved from a circuit that employed small scale off-the-shelf ICs and many discrete components, though a revision utilizing semi-custom ICs and fewer discretes, to an advanced realization that capitalizes on the benefits of full custom integration. This paper first considers the unique requirements placed on high fidelity music systems by automotive application, and describes a particular system solution that specifies a compact electronic circuit. Implementation of the circuit functions with the full custom ICs is then discussed, followed by a presentation of the measured performance of the circuit.

2. CONSTRAINTS

Although automobile manufacturers have provided factory installed radio receivers since the 1930's, it has only been within the last decade that they have chosen to offer systems having or exceeding the music reproduction capabilities achieved by the home Hi-Fi industry. Thus, the engineering advances driven by the particular constraints of sound reproduction in cars have occurred largely in isolation from the evolution of home music system design. Efforts to deliver high fidelity music reproduction from OEM autosound systems have revealed constraints peculiar to the automotive environment.

Perhaps surprisingly, the automobile makes extreme demands on those parameters most often associated with high fidelity performance. The car places the listener within one meter of loudspeaker drivers in a space lacking the size and modal complexity of the living room. This contributes to a remarkable sensitivity to waveform distortions, frequency response anomolies and clipping of program peaks. In addition, the proximity of listeners to the loudspeakers (typically three meters for rear seat occupants) requires extremely low self noise while the vehicle's widely varying ambient noise level and spectrum require wide dynamic range and well behaved large signal characteristics.

Other requirements of the OEM auto application are new to the "high end" audio equipment manufacturer. The most obvious must be the need to conform the system mechanical package(s) to the car. This becomes quite challenging as the vendor is called upon to supply systems for a broad spectrum of car models. Interior space is a precious commodity in present day automobiles. This often precludes devices or models that occupy any more space than that traditionally given to the radio receiver and the loudspeakers. Also, different vehicles require different acoustical approaches; an "infinite baffle" system placed in a package shelf cannot be installed in a sports car having no package shelf ! These constraints suggest the need for a variety of loudspeaker designs, each fitted with a miniaturized local electronics module for signal and power processing. Each vehicle type will offer its own unique frequency aberrations to acoustical radiation from any given point to the listener's locale. Therefore, a necessary feature of the module is the implementation of a frequency response that, when convolved with those of the specific speaker and speaker placement in a given automobile, delivers a properly balanced spectrum of acoustic power to the listener.

The abusive environment of the automobile is well known. Ambient temperatures routinely vary from -40°C to in excess of 100°C. Regular exposure to moisture and windblown particles accompanies constant shock and vibration. The automobile manufacturer must employ components which can withstand these conditions and continue to function reliably for the life of the vehicle.

In addition to posing system-wide reliability problems, temperature extremes present a particular challenge to the power circuit designer. The common 'under glass' package shelf placement of speakers exposes the unit to temperatures far in excess of those experienced by the car's occupants. The power amp attached to those speakers must perform without compromise at the temperature extremes. Limited space, elevated ambient temperature, cost targets and the industry's emphasis on mass reduction preclude the use of large heatsinks. This requires highly efficient power processing circuits.

Production volumes required by the OEM customer place new demands on the premium audio system manufacturer . Control of costs is essential, both for manufacture and to support a network of thousands of sales and service locations. Proliferation of component types, while seemingly required by a growing variety of different vehicle applications, is expressly discouraged. And once an acceptable design is submitted the automobile manufacturer will demand levels of quality, consistency and manufacturing process controls seldom encountered in consumer electronics.

A music system meeting all of the above criteria went into production in spring 1982 [3]. The electronics modules, measuring 26mm x 100mm x 150mm, each contained 8 integrated circuits, 37 discrete active components and 192 passive components. A revised circuit introduced in 1983 utilized two semi-custom integrated circuits [1]. Containing 3 ICs, 36 other active components and 127 passive components on a circuit board of the same size as the discrete implementation, this new design increased the capacity of the manufacturing facility. Since then demand has continued to increase and we have seen the introduction of automobile designs that cannot accomodate the size of the existing module. Loudspeaker enclosure volumes have also been compromised by these new car designs, requiring increased electrical power for equivalent radiated acoustical power at low frequencies. This in turn has implied even higher conversion efficiency of the power amplifier.

These new constraints have been met through the design and application of two custom integrated circuits on a board

Fig.1. A comparison of the original, revised and current versions of the subsystem.

utilizing surface mounted components. The resulting 22mm x 80mm x 78mm module occupies one-third the volume of the previous realization and contains the two custom integrated circuits, four NMOS power transistors, 27 leaded passive components and 65 surface mounted resistors and capacitors. (The photograph, Fig.1, compares this solution with its predecessors.) This design exploits the opportunity accorded by custom system integration to achieve precision signal and power processing through circuit complexity, with a greatly reduced component count for low cost and high reliability.

3. SYSTEM CONFIGURATION

The music system block diagram as realized by this latest design is identical to the previous version [1] and is shown here as Fig.2. The components of this system are as follows:

A high performance electronically tuned receiver provides AM, FM, stereo and cassette tape as program sources. The receiver features automatic loudness compensation, full time single-ended noise reduction for all programs, a popular complementary noise reduction system for tape playback and a frequency selective front-rear balance control that allows the listener to adjust the spatial characteristics of the musical presentation to taste, while maintaining the ability to deliver maximum acoustical power at all frequencies of interest. The mechanical package of the receiver has been completely redesigned for application in new cars; the constituent parts (tuner and signal processing circuitry, tape drive and control head) can be separated for flexibility of placement. This allows the designer to effectively utilize space in the car, and also provides the opportunity for enhanced ergonomics. Four low level outputs which achieve a signal-to-noise ratio of 100dB provide stereo program information to the rest of the system.

A broad selection of full range, high efficiency loudspeaker drivers, mounting hardware and injection moulded vented enclosures (custom tooled for each car body type) have been designed to permit placement of sound sources for correct spatial perspective in automobiles. Depth of these drivers ranges from 150mm to 35mm and nominal impedances of each can be tailored to the particular application while maintaining efficiency. Typical minimum passband impedance magnitudes range from 0.4 to 2.0 ohms. Each enclosure or mounting system is designed to secure an electronic module to the loudspeaker.

The block diagram of the electronic

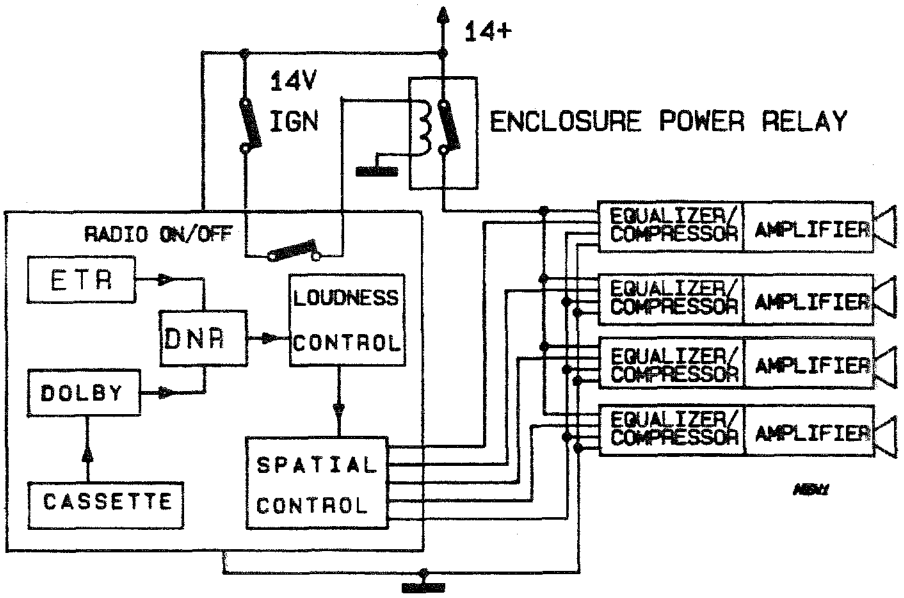

Fig.2. System block diagram.

module (Fig.2) has evolved since the semi-custom design discussed above, but the major functions remain the same. A differential input stage precedes a variable gain compressor/limiter which mitigates the audible effects of system overload. A series of up to four second order active filter stages provides custom equalization for proper radiated acoustic power spectrum from the loudspeakers. The equalizer is followed by an efficient switch-mode power amplifier operating at 115kHz. Also contained in this unit are power supply conditioning, noiseless muting and protection circuits. The circuit is packaged in a metal shield can measuring roughly 1" x 3" x 3" and is fitted with a small "pigtail" terminated with connectors for the speaker and vehicle harness.

The music system components are connected by a car body wiring harness that uses single or double runs (depending on specific module power requirements) of AWG No 16 copperwire for power supply to the modules and shielded twisted pairs for signal distribution.

4. ELECTRONICS MODULE FUNCTIONS & ORGANIZATION

The functions of the module fall into three categories: low noise, low distortion, wideband audio signal processing, power amplification and "housekeeping" functions such as power supply conditioning, muting and fault protection. The first task in the custom integration of a system is to define partitions for the circuitry to be integrated. The obvious choice was to design one low noise 20-pin IC to implement the input diff amp, compressor and uncommitted op amps for the active equalizer. Another 20-pin device was specified to accomplish as much of the power amp circuitry as could be economically integrated. The audio signal must be converted into a rectangular wave that preserves the spectral content of the program. A sophisticated modulator is therefore a necessary element of the second IC. Integration of the entire output drive circuit was made possible by the selection of NMOS power transistors. Housekeeping functions were distributed among the two devices as required, with some functions being included in both parts to allow each IC to be used alone in other applications.

5. LOW NOISE LINEAR SECTION

Fig.3 represents the block diagram for the low noise signal processing circuitry. The linear IC contains all active components necessary to implement these functions. External passive components

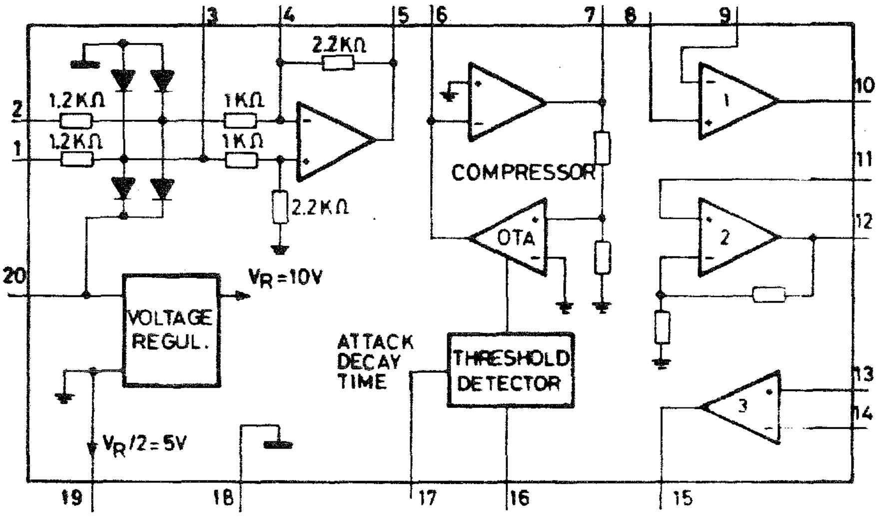

Fig.3. Block diagram of the low noise chip.

are required only for setting gain, determining equalizer frequency response, enabling the compressor and bypassing the power supply.

A well known problem of car radio design is the electrical noise voltages typical of the automotive power supply. Audio frequency ripple (typically 1Vpp) induced by operation of the alternator, and periodic and episodic voltage spikes from engine and electrical accessory functions require excellent power supply rejection to avoid audible noise, especially in a high gain system. The supply section includes an on-chip voltage regulator to supply a clean positive rail to all signal processing circuitry on the chip. A bandgap based design (Fig.4) implements a 10V regulated supply for the diff amp, compressor, and op amps, contributing to a power supply rejection of 80dB. The regulator also generates an AC ground potential of 5VDC, to which the entire audio signal chain (including the power amp IC) is referenced. The 5V supply is capable of sourcing and sinking up to 10mA and it can survive a short circuit to chassis ground for an indefinite duration. This is a necessary feature for a source whose output is distributed to remote points on the PC card, as shorts are a fact of life in both the production and service environments. The AC ground is brought to pin 19 for external connections.

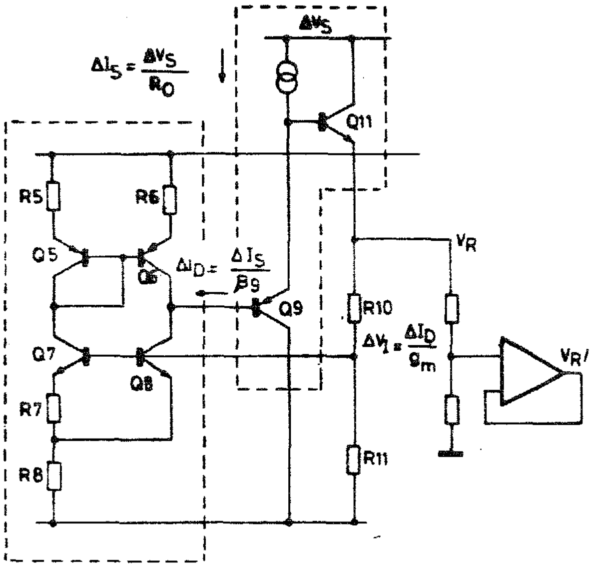

Fig.4. Voltage regulator configuration.

The input stage (Fig.5) is an inverting differential-to-single-ended converter, with an input clamping diode network to protect the device from transient voltages. This low noise stage is fully monolithic, with a precision integrated resistor bridge providing a minimum of 40dB of common mode rejection. Output self-noise voltage is limied to a maximum of $2.8\mu V$ (BW=20kHz). These characteristics reject noise picked up in the car's wiring harness and maintain the 100+ dB signal to noise ratio of the program source.

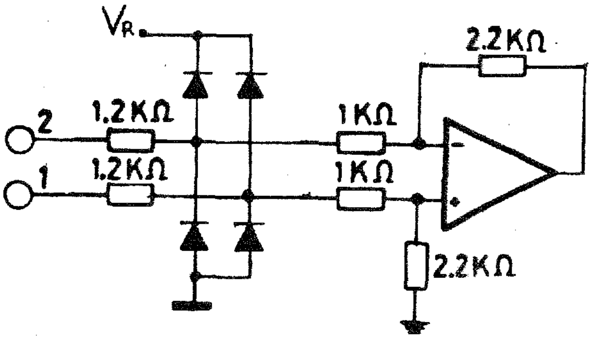

Fig.5. Differential input stage.

The compressor block diagram is shown in Fig.6. Theory of operation, as described in reference [1], is to utilize an operational transconductance amp (OTA) to vary the effective feedback resistance (R_L) of an inverting op amp stage. The overall gain of the stage is then controlled by the OTA bias current, which is generated by an internal voltage controlled current source (VCCS). Two independent drive schemes are implemented, one contained on the linear IC, the other utilizing overload detection circuitry in the power amplifier discussed below. The latter approach allows the system to deliver absolute maximum power before limiting.

The first drive scheme has been described previously [1] and consists of a window comparator whose input (pin 16) is usually taken from the output of the equalizer (pin 15 of the linear IC or pin 4

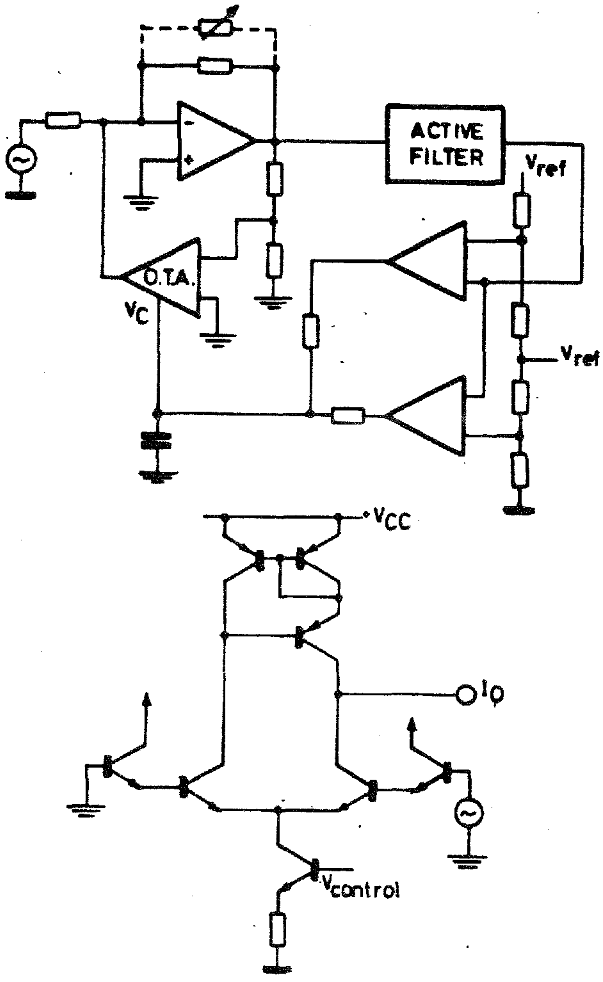

Fig.6. Compressor structure.

of the power amp IC). This comparator detects signal excursions that exceed externally programmed thresholds (set by a resistor). Voltage drive to the VCCS (this voltage appears at pin 17) is stimulated by detection of excess signal levels at pin 16, reducing the compressor gain and limiting system distortion to less than 3% with up to 30dB overload. The other compressor control scheme is implemented by driving point A from an external network or source.

With a compressor amp maximum output voltage defined by the overall system gain budget, the maximum output current capability of the OTA and the desired compression range (30dB here) determine the value of the fixed feedback resistor in the circuit.

$$R_{F(min)} = (V_{O(pk)}/I_{OTA(max)})\cdot(CR-1) \qquad (1)$$

where: R_F is the compressor fixed feedback resistor

$V_{O(pk)}$ is the maximum compressor amp output voltage

$I_{OTA(MAX)}$ is the max OTA output curr.

CR is the desired compression range expressed as the ratio of normal-to-minimum gain.

In our system Vo(pk) is 2.4V and CR is 31.6 (30dB). Substituting these values in (1) we have:

$$R_{F(min)} = 76/I_{OTA(max)}$$

Standard "off the shelf" OTA designs were used in previous implementations. These circuits have limited input voltage range, limiting Vo(pk) and providing maximum output currents of slightly over 1mA. This calculates to a minimum fixed feedback resistor of 75 kohms in the compressor stage. The small signal gain of this stage is determined by the particular application, and is often as low as -2dB. This in turn called for a large (100k) input resistor, which becomes the dominant source of noise in the system. The OTA in the custom design is based on the classical OTA structure but includes a high current output stage that delivers over seven times the current as the off the shelf circuit. This allows the resistances associated with this stage to be limited to a maximum of 15kohms.

Another critical parameter of the OTA is DC input offset voltage. A DC term will appear in the compressor output:

$$V_{O(DC)}=g_m R_F V_{OS}$$

where Vo(DC) is the DC offset of the compressor amp output and

Vos is the OTA input DC offset voltage.

With RF = 10kohms and gm = 0.1A/V (min) the DC voltage at the compressor amp output will be some 100 times the OTA input offset voltage. The injection of this DC term at onset of compression can result in audible artifacts even if the equalizer is not DC coupled, therefore the OTA was carefully designed for minimum input offset voltage.

As with all systems that dynamically vary the gain of an audio signal, the compressor attack and decay times must be carefully selected to minimize listener perception of circuit function. In use we have found that different applications may require various time constants; Pin 17 provides a point to connect a network for control of compressor ballistics. We have also encountered applications that called for filtering of the compressor drive to effect frequency selectivity or weighting to the compressor function; this can be done by connection of the appropriate network at pin 16.

Fig.7 shows the frequency responses of 32 production equalizers for the system described herein. These responses vary over 40dB in gain, and can require features with "Q's" of up to 4 at any frequency in the audio band. Three uncommitted wideband, low noise operational amplifiers are included in the linear IC for implementation of the required filter characteristic. Due to pin count limitations, the second of these (pins 11 and 12) is assigned a fixed gain of +4V/V (12dB) with internal resistors, eliminating the need to bring its inverting input terminal to an external pin. An additional stage in the power amp IC can be used for additional frequency shaping, or to free up one of the op amps in the linear chip for other control or signal processing tasks. These might include compressor drive frequency or phase-reponse modifiers to realize some of the compressor variations noted above.

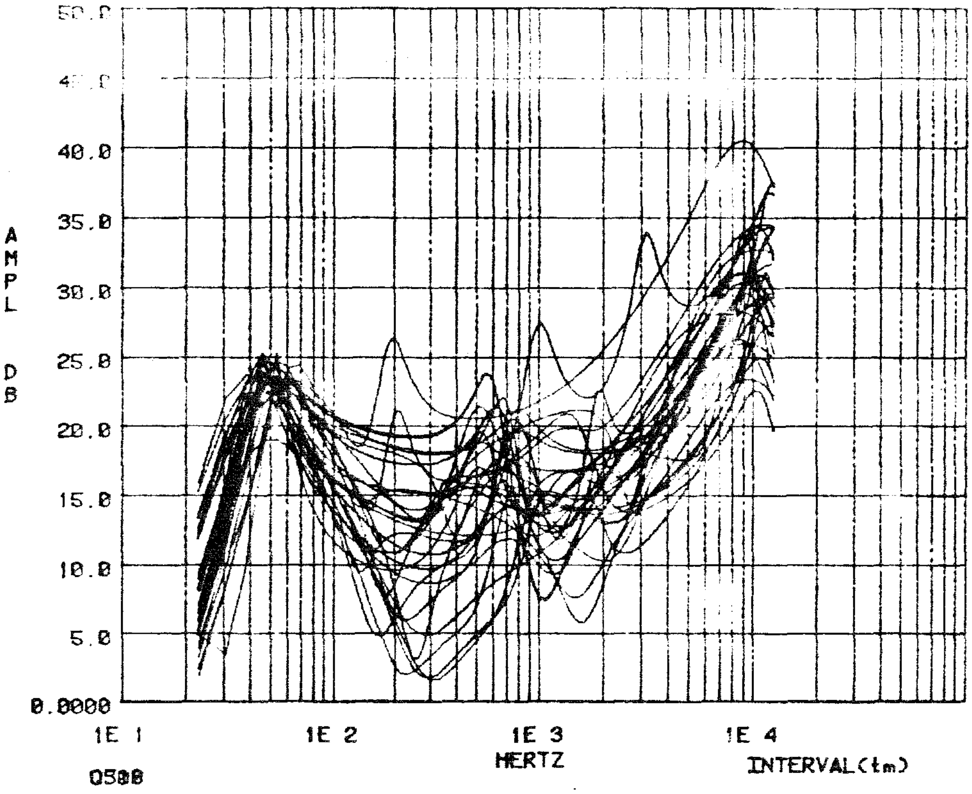

Fig.7. Equalizer frequency response.

Note that the in band gain of all the equalizer frequency responses is always greater than 0dB. This is necessary for proper function of the compressor loop, as the system must clip first at its output ifoverload is to be detected there. The multiple drive points of the custom compressor circuit may provide opportunities for greater flexibility in this area.

Because this low level circuitry is after the system volume control, the circuitry must be designed for low noise. The need to realize arbitrary equalizer frequency responses with minimum component count has led to filter topologies that can have noise gains that are as much as 40dB above the signal gain of the stage. The need to preserve the 100dB S/N at the output of the qualizer adds to the burden on the IC designer.

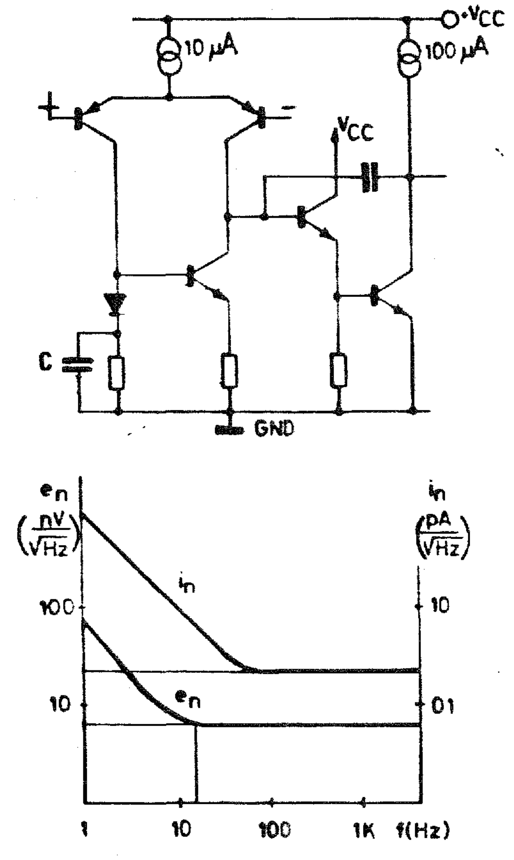

Fig.8. Input stage of low noise amplifier.

Fig.8 shows the basic structure for the low noise amplifier that is used for the equalizers, compressor and input stages. Input referred noise ressults only from the voltage and current noise of the two input PNP transistors. The spectral density of this noise is stated in the same figure and is less than 10nV/√Hz for any practical impedance level. The amplifiers have enough output current source and sink capability to allow loads as low as 1kohm, again for optimum noise performance.

But low noise in IC technology comes not only from circuit design. Careful IC processing and low temperature oxidation are necessary to avoid stacking faults and any crystal defects, which are known to generate popcorn noise bursts. These steps have been implemented in the low noise process used to manufacture this linear integrated circuit. An indication of the power of this process is the excellent flicker noise performance, as compared with state-of-the-art CMOS amplifiers.

7. SWITCH-MODE POWER AMPLIFIER IC

The block diagram of the power amp is shown in Fig.9 The main components of the power amp are:

- Power supply filter consisting of a 150µH inductor, two subminiature 470µF electrolytic capacitors and three 1µF surface mounted ceramic capacitors.

- Custom integrated circuit with switching modulator, output drive, muting, fault protection and housekeeping functions including on-chip voltage regulators for power supply ripple rejection as in the linear part.
- Four NMOS TO-220 60V, 12A, 0.07ohm (typ.) power transistors in a H-bridge configuration.
- Output filter consisting of two 15µH low loss inductors and a 0.47µF film capacitor to reduce RF emissions.

- Sheet metal shield that can serve as a heatsink for the output transistors in applications requiring more than 30W continuous power.

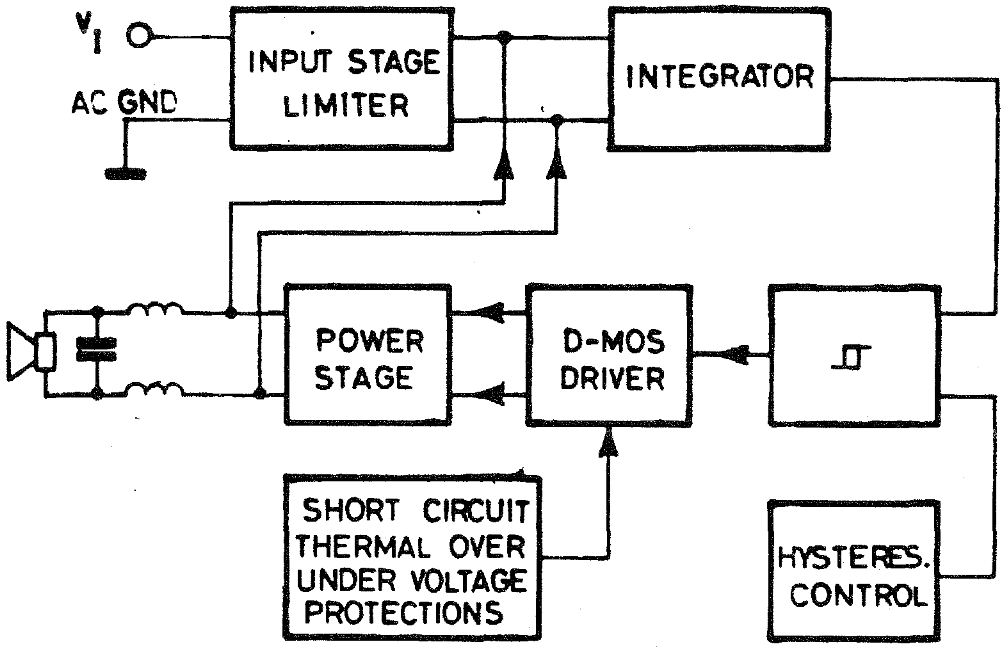

Fig.9. Power driver block diagram.

Several problems have prevented the large scale use of switch-mode power processing in audio applications. Constraints on an amplifier of this type for car stereo include:

- Large bandwidth (20Hz to 20kHz)
- Severe distortion specification (0.3%, full power)
- Very high duty cycle range (5% to 95%) to achieve maximum utilization of the low voltage automotive supply.

Modulation schemes for switching amplifiers fall into two categories: clocked systems based on fixed frequency oscillators and free running or 'self-oscillating' types. The classic PWM (Pulse Width Modulation) system is the typical realization of the clocked system. It lacks the bandwidth, the low distortion and the dynamic range necessary for the present application. Efforts to add these features to PWM systems have traditionally resulted in very expensive, complicated amplifiers not suited for mass production.

The self-oscillating approach [2] solves the bandwidth, distortion and dynamic range problems but has an inherent aliasing problem, as the operating frequency varies inversely with signal level. To make matters worse, the switching frequency falls off very sharply at the highest signal levels. This requires the designer to be quite conservative in setting gains for maximum output power, as typical component tolerances preclude operating at the nominal 'knee' of the switching frequency curve. The result of this conservatism is to sacrifice some 30% of available output power. Consequently designers of these systems have devised menas of limiting th minimum switching frequency, or they have attempted to operate at very high frequencies (~500kHz). The drawbacks have been an inability to regain all available power without audible artifact in the former case, and RF radiation and poor efficiency in the latter.

The approach chosen for the present application solves all of these problems by implementing a free running "Two-State Modulation" scheme [3] augmented by a newly devised frequency control function with circuitry that scales critical modulator parameters for changes in supply voltage and signal level.

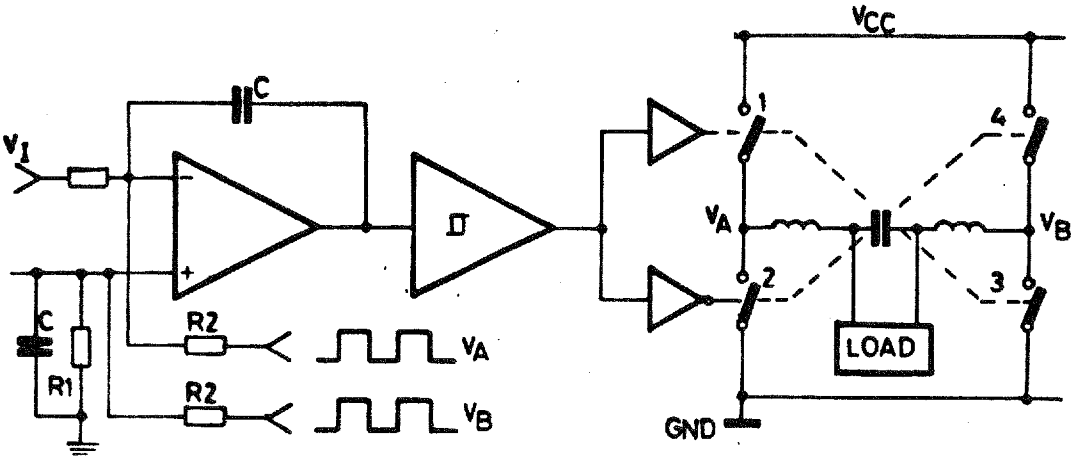

Fig.10. Free running oscillator principle.

As shown in Fig.10, the circuit is basically a relaxation oscillator that integrates the balanced output signals and presents the result to a hysteretic switch, whose commutation drives the power stage. This system is analyzed in detail in [1] and [2]. The commutation frequency is given by:

$$f_{SWITCH} = \frac{V_{CC}^2 - (GV_{in})^2}{2V_{CC}} \cdot \frac{1}{2R_2 C V_H} \tag{2}$$

Where: G is the power amp voltage gain (= R2/R1), and

V_H is the voltage comparator threshold

Clearly, as the drive approaches its maximum, the switching frequency tends to zero, generating aliasing. However, we do have a degree of freedom: V_H. By modulating the hysteresis thresholds with the input signal itself, we can stabilize the switching frequency, provided we can guarantee that:

$$V_H = V_{CC} - \frac{(GV_{in})^2}{V_{CC}}$$

Of course this is a first order analysis. Second order effects, such as power transistor voltage drop (Vds) and finite commutator delays influence performance. Various compensation schemes having different levels of sophistication can be employed according to the level of stabilization and distortion that can be tolerated. But second order effects notwithstanding, the implementation of frequency stabilization as described above represents a significant advance in the performance of switch-mode amplifiers. Following is a brief analysis of the three basic building blocks of the amplifier.

a) Comparator

The comparator, shown in Fig.11, is a classical, fully-balanced two-stage structure with level shifter. To the

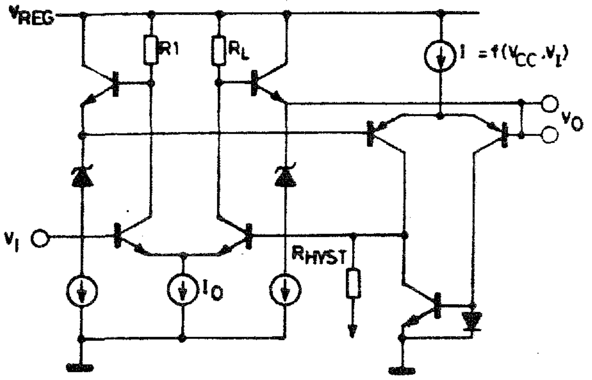

Fig.11. Comparator design.

positive input is fed a current:

$$I_H = f(V_{CC}.V_{in})$$

that, phase-shifted according to the output state, develops a voltage across Rhyst that results in the correct hysteresis in the comparator. Both the input signal and hysteresis are symmetrical with respect to an internal AC ground (discussed below). Commutation delay is about 50ns. I_H is obtained with a piecewise approximation technique, based on algebraic sums of currents that are functions of Vcc and Vin. The input stage, discussed next, implements a full-wave rectification that simplifies post-processing.

b) Input Limiter (Fig.12)

The use of frequency stabilization does not relieve the necessity of maintaining the input signal voltage range within acceptable bounds as it is still possible to overdrive the modulator and so produce a condition of continuous conduction of the power bridge. The circuit shown in Fig.12 implements this function by multiplexing the input stage of an op amp. This op amp is used as the series element in the signal path immediately preceding the integrator (pins 1,2 & 3). When the op amp output voltage exceeds a fixed fraction of Vcc, control of the amplifier output voltage is taken by two limiting stages (S1 and S2), which are able to dominate the current signal from the input at the control node N1. This input signal clamping is absolute protection from destructive overdrive and aliasing. Another feature of this input amplifier is its "impending overload" indicator circuit. As the limiting stages are activated, a current sink is turned on. This sink is connected to pin 7 of the IC, allowing a direct connection between that pin and pin 17 of the linear IC for compression only under conditions of actual impending power amp clipping.

These input limiter amp features and the frequency stabilization discussed above result in a switch-mode power amp that can operate at 95% duty cycle with low distortion and no possibility of latch up or aliasing. Fig.13 demonstrates the advantage of this system. Switching frequency at the intended maximum output voltage of 10V (2 ohms) remains above 90kHz.

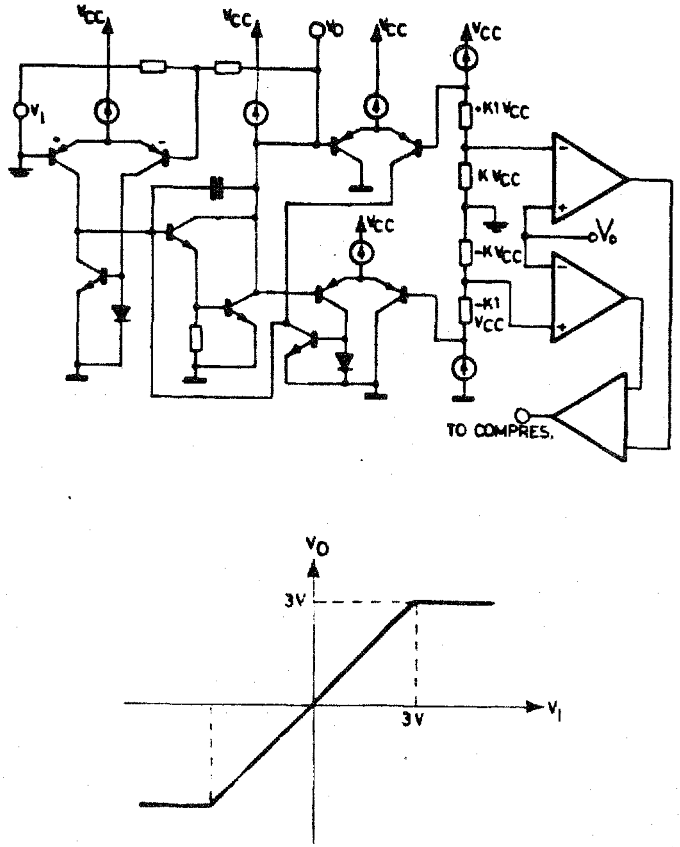

Fig.12. Duty cycle input dynamic limitation.

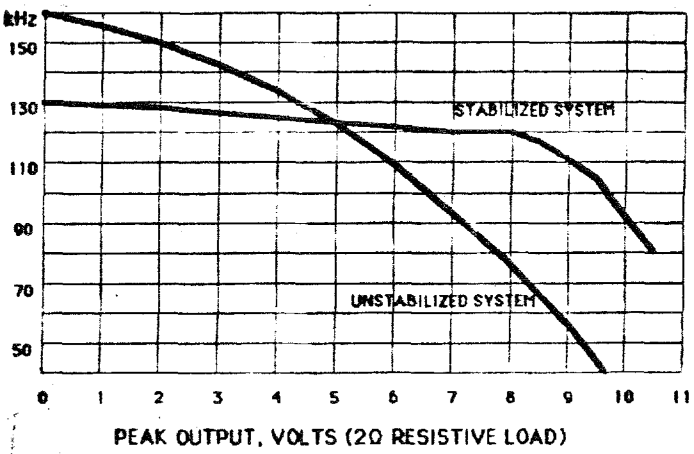

Fig.13. The effect of frequency stabilization on input frequency.

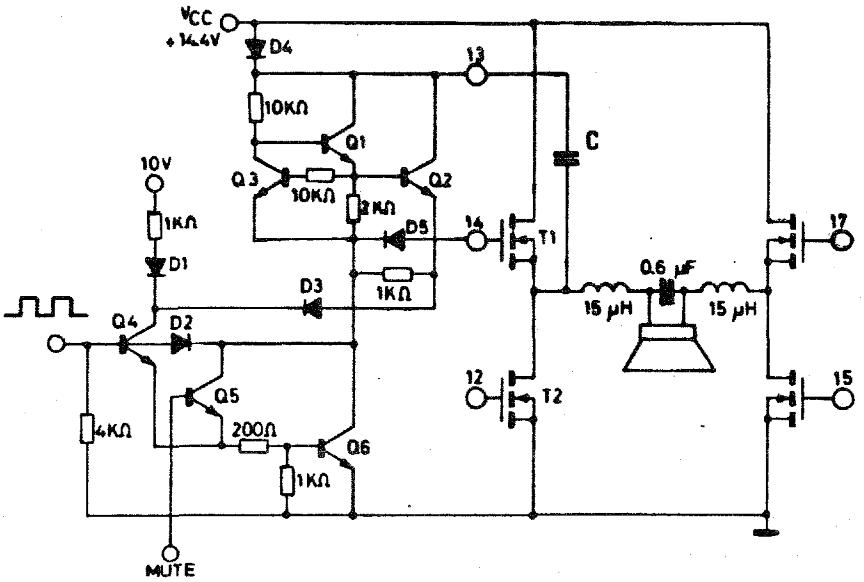

Fig.14. MOSFET driver.

c) Power Transistor Drivers

To date, push-pull power stages using complementary MOS transistors have not been practical due to the intrinsically poor current density of PMOS. Therefore, a H-bridge of N-channel devices was selected as the power stage for this amplifier. The cost of large PMOS devices was traded for the integrable (except for two capacitors) circuit complexity of two bootstrap circuits which are necessary to drive the gates of the uppermost devices in the bridge to 9 volts above the supply. Two 100nF surface mounted capacitors are used as feedback (or flyback) elements from the output of the bridge. The output drive circuits must be carefully designed for rapid transitions, and the timing of these transitions must preclude the possibility of common mode conduction of the upper and lower output devices on each side of the bridge. The drive circuit implemented in the power amp IC is shown in Fig.14.

The sinking (turn-off) stage is based on a non-saturating darlington configuration. D3 and D5 enhance current capability during negative-going transitions and Q3 reduces power consumption in the low state. The positive going transition is governed by Q1 and Q2, overvoltage on the gate of T1 is generated by bootstrap capacitor C, which is able to double Vcc. Current shunt from Vcc to ground (current mode conduction or "shoot through") is avoided by delaying positive-going transitions with respect to negative-going transitions at the transistor gates. The stage used to drive the lower two devices in the H-bridge is the same as the circuit described above except for the absence of the bootstrap capacitors and diodes. The overall input-to-output propagation delay of these circuits is less than 100ns. Each output circuit can drive an 1800pF capacitive load, allowing use of very large MOS power transistors for higher power systems.

The comparator with dynamically varying hysteresis, the input limiter amp and the monolithic output drive circuits form the heart of the power amp functions and circuitry. In addition to these newly conceived circuit functions, the IC impements a host of traditional power amp and automotive circuit features to enhance system applicability and to avoid damage during malfunctions or fault conditions.

A sub-audio triangle wave ("dither" [1]) oscillator is provided and is internally connected to the hysteresis control circuitry. The function of this circuitry is to spread the RF spectrum of the rectangular wave output of the power amp, reducing interference with the radio receiver. Injection of the sawtooth waveform modulates the switching frequency without affecting the output duty cycle, therefore the waveform does not appear across the load.

An AC ground reference is generated by the voltage regulator in the power amp IC just as it is in the linear part. However, the generator in the power amp IC is a voltage follower, and its nominal output voltage is 4.5V compared to the 5V level produced by the generator in the linear IC which is bidirectional (sources and sinks current). This allows the two (pin 8 of the power amp IC and pin 19 of the linear IC) to be wired in common when both ICs are used as a system. The power amp reference then "slaves" to the linear 5V level, simplifying grounding considerations for the system and allowing the power amp input stage to be used as a single-ended active filter for equalization.

A muting function is implemented by sensing the supply voltage. The power amp turns on when the supply voltage to the IC reaches 10V; the user may program a delay into this feature via an external RC network at pin 20. The amp mutes quickly when the supply rises over 18V or falls below 9V. Particular care has been taken to eliminate spurious noises from the operation of the muting circuitry. The voltage spikes seen on the speaker are less than 5V for less than 50μs at mute transitions. This performance is achieved by circuitry that initializes the integrator and pulls both switching amp speaker outputs to the low state during mute conditions.

The power amp IC dissipates a good deal of power (900mW) and requires thermal protection for survival in ambient temperatures above 100°C. On-chip temperature sensing turns off the power amp when unsafe temperatures are encountered, normal function returns when the temperature falls to safe levels. Another protection circuit senses current in the power transistor bridge via an optional 25milliohm resistor in series with the power supply. This circuit mutes the system upon detection of unsafe current levels, restoring operation upon removal of the fault. Finally, the ICs are designed to withstand the 60V automotive "load dump" condition. Muting at high voltages limits power dissipation to less than 1W with 60VDC on the supply pin, and the part can withstand this condition indefinitely without damage. Technology used is a high current, 30V BVceo bipolar process.

The power amp IC, the four NMOS transistors and the associated external components form an efficient high fidelity audio power amplifier. The performance of the power amplifier application circuit is shown in Figs.15 16 & 17. The first shows distortion at maximum power vs. frequency for two loads typical of the ultimate application. The second shows distortion as a function of power output with a resistive load. Fig.17 is a plot of power

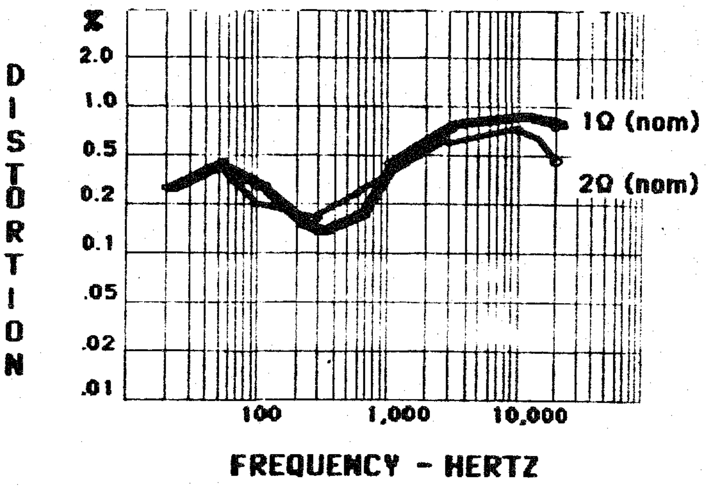

Fig.15. Power amp distortion (speaker load, 7Vrms).

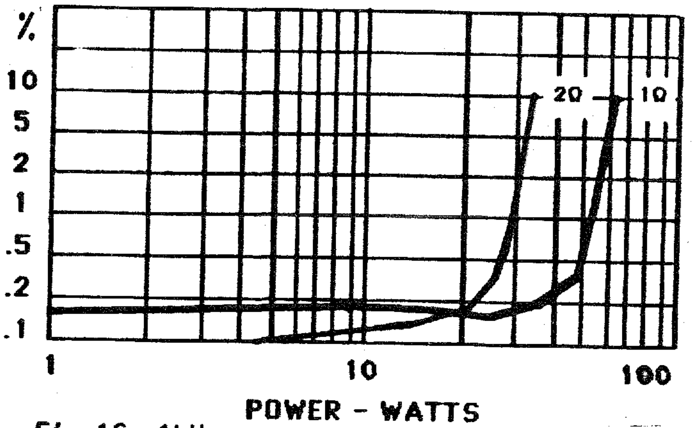

Fig.16. 1kHz power amp distortion (resistive load).

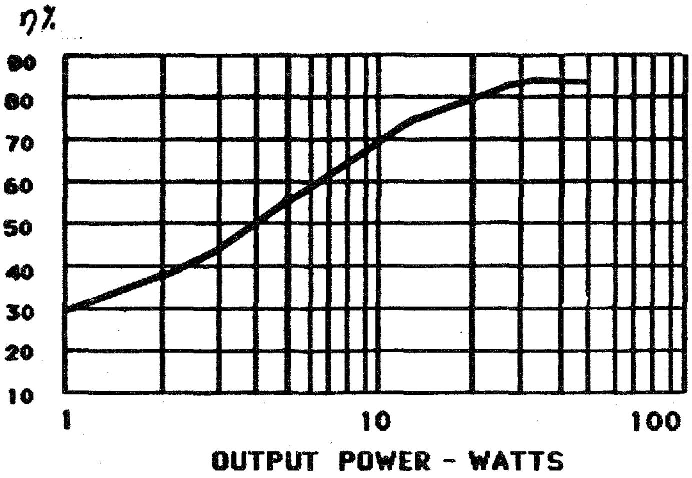

Fig.17. Power amplifier efficiency.

conversion efficiency for the whole printed circuit card. Note that this includes about 1W that is dissipated by the IC, leaving less than 1W each for the power transistors to dissipate for 30 watts delivered to the load. Clearly there is no need for heat sinks at this power level. A photograph of the power amp chip is shown in Fig.18.

Fig.18a. Photograph of the low noise chip.

Fig.18b. Photograph of the power driver chip.

SUMMARY

Table one summarizes the overall module performance and demonstrates a level of performance that clearly meets the definition of High Fidelity. The custom bipolar integrated circuits that are employed meet all parametric specifications through circuit complexity and process control rather than expensive option of post-diffusion trimming.

The linear IC realizes a level of performance that allows its use in any high fidelity application and provides unusual flexibility for a part designed for such a rigidly specified role. The uncommitted operational amplifiers contained in the device give the system designer opportunities for incorporating his or her own hard wired or user adjustable signal processing and/or control functions into new products.

Achieving excellent power conversion efficiency, the power amp IC overcomes the limitations that have traditionally plagued audio switch mode power amp designs. Worst-case power dissipation is less than 1W per power transistor at an output power of 30W continuous, and does not require any heatsinking for operation at this power level.

Although these devices were conceived as components of a given system, they can be used together or independently in other systems, furnishing the industry with powerful new building blocks for high quality audio applications.

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3. Veranth, J.L.: Switching Amplifier for Vehicular Audio; SAE International Congress & Exposition, Feb-Mar '84.

Output noise voltage			100µV
Output offset voltage			15mV
Common mode rejection ratio			60dB
Supply voltage rejection			60dB
THD	f=50Hz	Vo=70mV	0.01%
		Vo=7V	0.1%
	f=1kHz	Vo=70mV	0.01%
		Vo=7V	0.1%
	f=10kHz	Vo=70mV	0.07%
		Vo=5V	0.4%
Switching frequency			
	Vin=0V		125kHz
	Vin=Vin (limiting)		63kHz
Efficiency		Po=25W	85%

Table I: SYSTEM PERFORMANCE (Vs = 14.4V; RL = 2ohms)

BIOGRAPHIES

Michael D. Rosen

Michael Rosen studied electrical engineering with concentrations in audio, acoustics, electroacoustics and computer engineering at the Georgia Institute of Technology. Upon graduating with a bachelor's degree (EE) in 1980, he joined the Bose Corporation as a product development engineer in the newly formed OEM automotive products group, where his responsabilities have included the specification and design of transducers, linear and switch-mode electronics, microelectronics and systems. Mr Rosen is an avid amateur trombonist and performs regularly with several Boston area orchestras and wind ensembles.

Pietro G. Erratico

Pietro Erratico was born in Milan in 1947 and earned an honours degree in nuclear engineering at the Politecnico di Milano. Previously involved in research on semiconductor materials, he joined SGS in 1973 to work on various aspects of IC design. At present he is the head of IC development at the SGS Bipolar IC Division's R & D Center near Milan. Mr Erratico is the author of numerous papers and holds several patents in the IC design field.

Enzo Casini

Enzo Casini was born in Montepulciano, Italy, and graduated in electrotechnics at the 'G. Feltrinelli' Technical Institute, Milan, in 1973. He joined SGS in 1973, working initially on the applications of semiconductor devices. Since 1976 he has designed linear integrated circuits, specializing in ICs for audio frequency applications.

Claudio Diazzi

Claudio Diazzi was born in Milan, Italy, and graduated with honours in Nuclear Engineering at the Politecnico di Milano in 1979. He joined SGS in 1980, initially as an application engineer studying the applications of discrete power devices in switch-mode power supplies and DC motor control. Since 1981 he has designed linear integrated circuits, working mainly on switchmode devices for the industrial and audio fields. Mr Diazzi holds two patents relating to integrated circuit design.