Audio Amplification

—Paul Weathers*

Amplification has come a long way since carbon amplifiers. And each era considered its state of the art as perfect. How close to an ideal product are we now?

Before Thermionic Vacuum Tubes

Most of us in the audio profession take for granted that audio amplification is a practically perfected art in the chain of recorded, transmitted and reproduced sound. Compared to the early efforts of engineers before vacuum tubes were developed, the audio amplifier of even 30 years ago seemed perfect. The first successful sound amplification was accomplished by the use of highly resonant carbon amplifiers. These were the first "solid-state" amplifiers and were current amplifiers of low impedance. They operated in the same way that carbon microphones operate by varying the pressure on carbon granules. The carbon granules provided a variable resistance inversely proportional to the applied pressure used to modulate a current flowing through the carbon granules. In the case of a carbon microphone the pressure is applied directly by the diaphram. In the amplifier application the pressure is applied by an electromagnetic transducer to produce current amplification.

Vacuum-Tube Amplification

The vacuum tube was the first development which made possible the amplification of tiny voltages at high impedance with relatively little noise and distortion. In fact a good class "A" vacuum-tube amplifier in the 1920's could boast of distortion figures of under 2% and most engineers felt that very little needed to be done since these amplifiers were so far advanced over any transducers available.

Inverse Feedback

Fortunately there are many engineers who are never satisfied with what others consider perfection. Out of the laboratories of engineers dedicated to progress came *inverse feedback*, a fundamental development which completely revolutionized the audio industry in the early 1930's and made possible a really tremendous advancement in the audio art. This development was, in fact, so fundamental that it is the basis for all present day "nearly perfect" amplification systems, whether they be vacuum tube or solid state.

How Can Amplifiers Be Further Improved?

The weakest link in the chain of an audio amplification system is the coupling the input and output of amplifiers to the transducers or modulating systems. Although transformers have been greatly improved by advanced winding techniques and magnetic materials, they have not completely solved the problem of matching transducers to the input or output of otherwise nearly perfect amplifiers. One might wonder, why bother with the most perfect link in the audio chain? Concentrate on the transducers so that their impedances do not change with frequency, or combine the amplifier with the transducer to improve the control of the transducer by intergrated feedback. In fact, much *is* being done to perfect transducers by closer integration with amplifiers, but when electrical isolation is required, coupling by transformers, (even with their limitations) is the accepted practice.

The Development Of Solid-State Devices

The development of solid-state devices is undoubtedly as great an advancement in the audio art as was inverse feedback as a perfecting technique. Solid-state amplification makes possible the matching of power amplifiers to low-impedance loads without using bulky power output transformers with their characteristic hysterisis loop and limited frequency range. The elimination of the output transformer makes possible an all-encompassing inverse feedback loop from transducer to input stage to provide less critical

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matching to output transducers and the virtual elimination of distortion within the loop. Concentrated feedback around one or two stages is often combined with over-all output to input feedback to keep phase shift within bounds.

Input matching in solid-state amplifiers is now more versatile than with vacuum tubes and, in cases where electrical isolation is not needed, without using transformers. A solid-state device can be selected which will match low-impedance transducers for minimum noise and maximum energy transfer or, when high-impedance inputs are required, to match high-impedance devices even up to many megohms, there is a solid-state circuit to effect a perfect match.

Are the arguments which we sometimes hear that vacuum-tube sound is superior to transistor·sound valid? There are also those who are just as certain that there are some subtle phenomena associated with transistor sound which makes it superior to vacuum-tube sound. These are arguments reminiscent of *triode sound* versus *pentode* sound in the 1930's. The differences are based upon easily measurable parameters and has nothing to do with whether the amplification is solid state or vacuum tube, triode or pentode. Most of the effects noticed are traceable to:

1. *Difference in damping factor on the output transducer.*
2. *Slow recovery of circuits when overloaded by short duration transients.*
3. *Regeneration or positive feedback at some part of the amplified spectrum.*
4. *Development of parasitics when excited by certain signals.*
5. *Instability of the power supply in its relationship to linearity of the amplification system as polarizing voltages vary with signal.*

Although variation in damping factor represents one of the most obvious differences between triodes and pentodes as output devices, engineers found that strategically applied inverse feedback could easily eliminate this difference. However, unless careful attention was given to phase shift, very often the amount of inverse feedback had to be increased to the point where parasitics might develop at super-audible frequencies or regeneration might occur at subaudible frequencies thus producing conditions described above in 2, 4, and sometimes 5.

It became a well-known fact that reasonably good results could be obtained by almost any engineer when triodes as output devices are used but it takes a highly experienced and talented engineer to design a superb sounding pentode or beam-power output tube power amplifier employing optimum feedback capable of feeding a resistive or reactive load with complete stability.

It has been demonstrated that solid-state power amplifiers using no output transformers can exceed the damping characteristics of the best triode power amplifiers, even when using feedback. The difference is in the elimination of the transformer. With solid-state amplifiers the damping factor can be so great that the power amplifier controls the movements of loudspeakers with extreme accuracy at low frequencies resulting in sound with less coloration; a noticeable improvement to the discriminating listener.

There are those who will argue that a certain amount of coloration is desirable in a sound system. Coloration by choice is the important objective, since the lack of coloration is the more desirable achievement. Coloration can be added in a variety of ways to any sound system if it is desired but coloration should not be the criterion in choosing between "triodes *versus* pentodes" or "vacuum tubes *versus* transistors". All of the differences between triode, pentode and transistor amplifiers can be measured or visually observed on oscilloscopes. These differences can be so minimized by careful design that listening tests comparing triodes, pentodes, beam power and transistors sound so neatly alike that a blindfold test completely confuses the most critical observers. One reason for this is that the most perfect program material and the most perfect transducers have far more distortion and coloration than that contributed by the differences in the various but highly perfected amplifiers under comparison.

Solid state provides the designer with so many new approaches to the perfect amplifier that there is little doubt in the minds of progressive engineers that solid state has taken over in audio leaving vacuum tubes as one of the great stepping stones in the search for perfect electronic amplification.

An examination of some of the advantages of solid state and the myriad of new circuits made possible to improve audio, leaves the imaginative engineer almost spellbound with the possibilities of miniaturization, elimination of heat, pinpoint control of polarizing potentials, elimination of noises due to long lengths of connecting wire, plug in modules for easy servicing, intregration of amplifiers with transducers and general reduction in costs.

Miniaturization is not just an advantage in portable equipment. The new IC's eliminate many components and reduce the stray noise pickup area making possible a simplification of shielding to attain a new perfection in noise rejection. The elimination of heat makes possible closer spacing of components along with vastly longer life. Housings can be smaller, requiring little or no ventilation, at less cost.

Zener diodes make possible pinpoint control of polarizing voltages and when combined with transistors, can provide filtering and isolation of voltage sensitive circuits literally not possible by other means.

FET's

FET's take away one of the principal advantages which tubes had over solid-state devices i.e. high-input impedance and low noise. Some vacuum tubes still have a slight edge over FET's in high gain applications for consistently low noise, but the fact that laboratory samples of FET's have approached and exceeded the quietest vacuum tubes is an indication that it is only a matter of time, by perfecting production techniques, that FET's will replace vacuum tubes for all high-impedance input applications. FET's have other characteristics of great interest to audio designers. It is possible to incorporate them in automatic compression or expansion circuits without utilizing balancing devices to eliminate control transients and the degree of compression and expansion can go much farther than was possible with more complicated circuitry using the old familiar techniques of balancing out control transients.

It is conceivable that a low-level pilot tone pitched above audibility and modulated by the compressor can be utilized in reproduction to recreate the original dynamic range with minimal time lags in the control circuits and without undesirable transients. This is an area which should be explored more thoroughly.

The characteristics of FET's and other solid-state devices lend themselves to automatic control of dynamic range, frequency range, and activation of additional transducers to produce dynamic effects never before attained.

State-of-the-art amplifiers can be manufactured so that little servicing will ever be required but the service technician will be under a tremendous handicap to correct a non functioning amplifier whose parts he cannot see and whose wiring junctions are smaller and closer together than the end of his finest probe. That is unless a plug-in modular substitution system is used.

This brings us to the final Utopian concept. Let us make all amplifiers in modular form and have the modules plug in using techniques which have been highly perfected in the computor field. Modern connectors have become so perfect that they are consistently as good as connections soldered by hand.

There are those who will dispute this statement but these connectors are used in critical application where failure could be disastrous and have proven their dependability. Besides, vacuum tubes have been plugged in, even in the most critical applications. Why not modules containing circuits?

The Ideal Amplifier

To sum up, the state of the art amplifier of today can have:

1. *A fully regulated power supply with no measurable ripple and practically zero source impedance, making class "B" amplifiers attain even greater perfection.*
2. *Capability of matching to selected output load impedances without output transformers (except for line feeding amplifiers requiring balanced lines and exact line matching).*
3. *Capability of matching input impedances with maximum transfer efficiency and low noise from a few hundred to many megohms.*
4. *Modular construction for substitution servicing.*
5. *Compact, to take up a minimum of room, with a minimum of required ventilation.*
6. *Output damping characteristics so great that the output load looks back into a virtual short circuit, so that the lack of coloration of output transducers is limited only by the transducer's series resistance.*

The resistance of the audio industry to changing technology is no longer as persistant as it was a decade ago. In fact, the avalanche of advanced technology has been applied so rapidly during the past three years that obsolescense of equipment has progressed at an unprecedented rate. Also, service technicians have been unable to keep pace with rapidly advancing technology and they are looking for some sound answers to their pyramiding maintenance problems.

It is very important that these highly advanced products be more easily assimilated and maintained at their peak of perfection without requiring an engineer in constant attendance. It is highly important that state-of-the-art products include simplification of application and maintenance to assure a continued peak of performance. The hardware and information is available in quantity and quality. It is up to the design engineer to break away from traditional concepts which have outlived their usefulness thus making maximum use of the new tools at their command.