The Consonant Amplifier-Limiter

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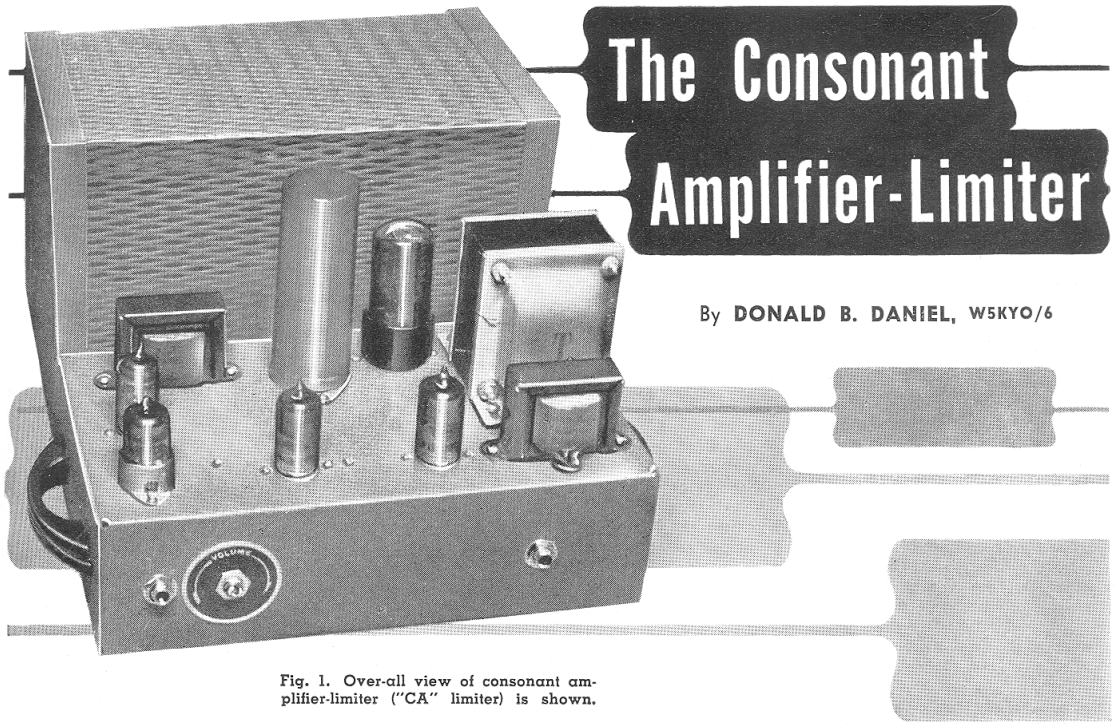


Fig. 1. Over-all view of consonant amplifier-limiter ("CA" limiter) is shown.

New approach to audio limiting features extremely fast attack and release times without the distortion common in clipper circuits. Useful in transmitters and receivers.

SINCE the early days of voice communication by radio, efforts have been made to compress the dynamic range of the human voice to make it more compatible with the electrical characteristics of the communications system. Benefits to be derived from such a procedure are many, and quite often well worth the expense of the compressor equipment that is added.

To prevent confusion as to what type of compression is under consideration, it might be well to define several types of common compressors in terms of their characteristics and merits.

Definitions of Terms

A "compressor" is an automatic variable gain amplifier whose output bears some consistent relation to its input, say one db rise in output for each two db rise in input. Usually this type of equipment will have very low steady state distortion. Most common compressors use some type of a feedback loop that samples the output of the amplifier and regulates the gain of an earlier stage. The time-constants of this type of circuit are necessarily slow to prevent oscillation, motorboating, and distortion. The "attack time" (time necessary to reach steady state condition after a sudden rise in input level) may well be several milliseconds. The "release time" (time necessary to reach a steady state condition after a sudden drop in input level) may be several seconds. Such an amplifier is very useful for high-fidelity recording and broadcast radio where an operator is in constant attendance. Compression of about 10 db is usually considered as an acceptable maximum value.

A "limiter" is an automatic variable gain amplifier whose output level is controlled only after a threshold level has been reached. Here, again, it is quite common to use a feedback content loop to regulate the gain of an early stage. Time-constants are usually slow, like the compressor, and limiting of more than 15 db is usually not recommended.

A "clipper" is a circuit that is designed to prevent the amplitude of a signal from exceeding a preset level. Its time-constants are practically instantaneous and it functions on each cycle of a wave. Distortion is very high, which results in loss of individuality in speakers and a broadening of the spectrum occupied by the speech. Low-pass filters are usually used in conjunction with clippers to limit the spectrum and reduce distortion. Clipping of more than 15 db is considered objectionable by many. Nevertheless, clipping has been very useful because of its simplicity and ability to prevent overmodulation when employed in radio transmitters.

The ability of a clipper to prevent overmodulation results from its extremely fast attack on a wave after it exceeds the threshold. A good clipper has no overshoot. A clipper also has extremely fast release. A weak signal following one cycle after a wave that is heavily clipped will not be limited. This means that a weak consonant that follows a loud vowel in human speech will be given full amplification, although the preceding vowel was severely clipped. This amplifying of weak sounds in relation to soft sounds is often referred to as "consonant amplification," which may be abbreviated for convenience and simplicity as "CA."

Response Speed

"Consonant amplification" is an asset in communications equipment which must overcome channel noise, but it would not please a hi-fi enthusiast. Clipping is an excellent way to produce consonant amplification, but the increase in distortion with increased clipping places a practical limit on the extent to which this process can be carried on in actual equipment.

At this point it may be of interest to consider just how fast an amplifier must operate to be satisfactory as a

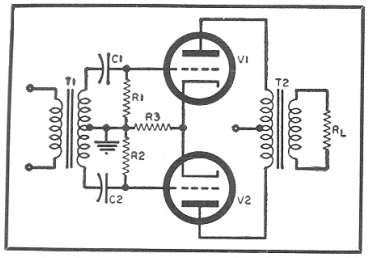


Fig. 2. Simplified schematic diagram of basic push-pull grid bias limiter circuit. Note the use of capacitors to isolate the tube grids from the input transformer. Variable mu triode tubes are employed in actual circuit.

consonant amplifier. Human speech does not usually start abruptly, nevertheless, there are audible sounds that occasionally have steep wavefronts. Therefore, it is probably desirable to have an attack that will function on the first half cycle of any audio tone that is expected to be present. Assuming a maximum audio frequency of 5000 cps, this would require an attack of one ten-thousandth of a second or 100 microseconds. An attack of this speed will insure that there is no overshoot and its resultant overmodulation in ordinary transmitter usage.

To arrive at the slowest release speed at which satisfactory consonant amplification is accomplished is very difficult because of the great variance of speed of speech between speakers. It is probably a good idea to make the release as fast as possible, and in any case faster than 200 milliseconds, which is the nominal speed at which the human ear can detect sudden changes in amplitude.[1]

The "C A" limiter pictured in Fig. 1 accomplishes the dual objectives of an extremely fast attack and a very fast release without the excessive distortion of a clipper circuit through a new approach to audio limiting. Possibly this is best described as push-pull grid bias limiting.

Fig. 2 is a simplified schematic of the basic push-pull grid bias limiter circuit. It can be spotted as a typical push-pull amplifier with transformer input and output. It differs from a typical amplifier in two respects. First, the tube grids are isolated from the input transformer by capacitors C_1 and C_2. Second, V_1 and V_2 are variable *mu* triodes.

Principles of Operation

The push-pull grid bias limiter operates as follows: The input signal e_{in} is coupled by transformer T_1, through capacitors C_1 and C_2, to the grids of V_1 and V_2. Tubes V_1 and V_2 are cathode biased by resistor R_3. If the input signal is less than the bias voltage the circuit performs as a linear amplifier. When the input signal exceeds the cathode bias the grids draw current in quite the same manner as any class B power amplifier. The grid current charges C_1 and C_2, thus creating an additional grid bias. This additional grid bias reduces the *mu* of V_1 and V_2 and thus reduces the gain of the amplifier. The greater the input signal, the lower the amplifier gain. Distortion produced by the non-linear operation characteristics of the variable *mu* tubes is predominantly even-order harmonic and is, therefore, phase cancelled in the audio output transformer T_2.

There is a practical limit to the amount of variable gain that can be accomplished in the simple push-pull grid bias limiter without exceeding a maximum distortion of 10%. With the tubes now available this seems to be about 10 db. Fortunately, it is possible to cascade several stages to obtain any desired amount of limiting. Two stages of resistance-coupled push-pull grid bias limiting were used in the amplifier pictured in Fig. 1 to accomplish 20 db limiting with less than 10% distortion. See Fig. 3.

Referring again to Fig. 2, consideration of the factors that control attack and release time will indicate the possibilities of this circuit. Typical values for C_1 and C_2 are 0.01 μfd. Typical values for R_1 and R_2 are 2.2 megohms. A typical output impedance for transformer T_1 could be 15,000 ohms. The grid conductivity of tubes V_1 and V_2 will be only a few hundred ohms at most and can be disregarded. The time-constant for the charging of C_1 or C_2 is $15{,}000 \times 0.01 \times 10^{-6}$ or 150 microseconds. When the input signal suddenly drops in level, capacitors C_1 and C_2 will start to discharge through their respective resistors R_1 and R_2. The discharge time constant is $2.2 \times 10^{6} \times 0.01 \times 10^{-6}$ second, or 22 milliseconds.

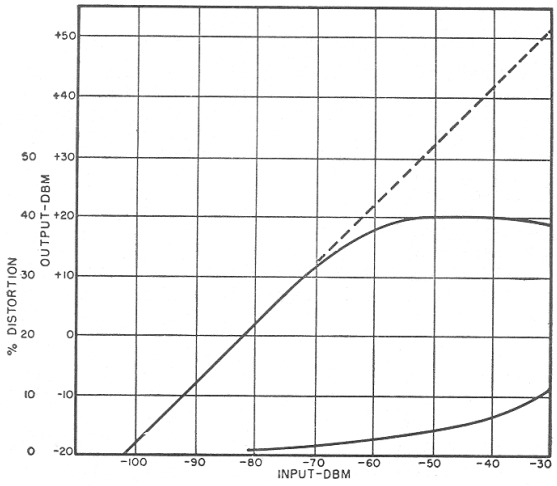


Fig. 3. Upper curve shows consonant amplifier-limiter output versus input. Lower curve is the total harmonic distortion of the special limiter.

Complete Circuit

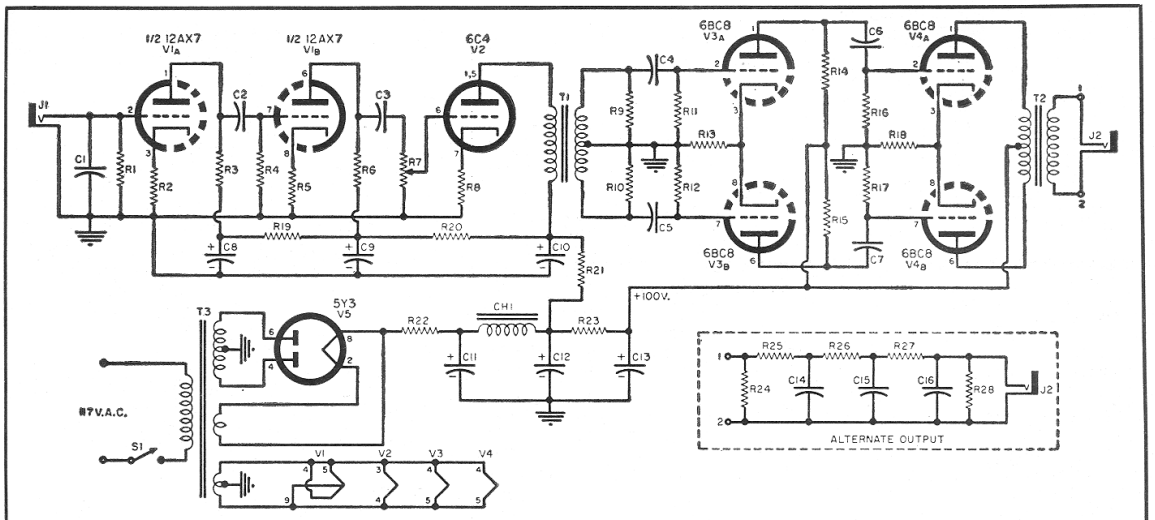
Fig. 4 is the complete schematic of the "C A" limiter. A 12AX7 is utilized as a two-stage preamplifier for the 6C4 driver stage. There is sufficient gain and drive power to drive the two-stage push-pull grid bias limiter from a crystal or high impedance dynamic microphone. Noise level is an important factor in the preamplifier. If it is planned to utilize 20 db of limiting at maximum output, the preamplifier must have 20 db lower noise level than normal. For communications or recording purposes, a noise level of —40 db is usually acceptable. This necessitates a —60 db noise level in the preamplifier. This is accomplished by a well filtered d.c. supply and by placing the input tube and mike jack diagonally across the chassis from the power transformer. Lead lengths are kept as short as possible. It is also advisable to select a good low noise 12AX7 if you have the opportunity. In cases where a still lower noise level is desired, it is possible to remove the filament center-tap from ground and return the filaments to ground through a 50-ohm potentiometer that can be balanced for minimum hum and noise level.

Output of the "C A" limiter is +20 dbm to a 600-ohm load. This is sufficient power to drive a speaker or a high power modulator. For those who wish to use the "C A" limiter to drive a commercially built transmitter, such as a *Collins* 32V3, or a tape recorder, it is advisable to use the optional output circuit. This provides a —25 dbm output, plus attenuation, of all frequencies above 3000 cycles. The low distortion of the "C A" limiter does not make it necessary to have a low-pass filter at the output, but it is quite often desirable for communications and voice recordings.

Applications

Applications of the "C A" limiter are probably more varied than is expected of usual special-purpose amplifiers. Its use to produce a very high average percentage modulation without overmodulation is, of course, a natural. As an amplifier for your phone patch, it can't be beat. It functions extra well as an automatic gain control for conference recordings,

[1] "Principles of Underwater Sound," National Defense Research Committee Report, Volume 7, 1946.



R_1, R_4—470,000 ohm, ½ w. res.
R_2, R_{14}, R_{15}—3300 ohm, ½ w. res.
R_3—100,000 ohm, ½ w. res.
R_5—2700 ohm, ½ w. res.
R_6, R_{19}, R_{25}, R_{26}—47,000 ohm, ½ w. res.
R_7—.5 megohm audio taper pot
R_8—330 ohm, ½ w. res.
R_9, R_{10}, R_{27}—4700 ohm, ½ w. res.
R_{11}, R_{12}, R_{16}, R_{17}—2.2 megohm, ½ w. res.
R_{13}, R_{18}—150 ohm, ½ w. res.
R_{20}—27,000 ohm, ½ w. res.
R_{21}—15,000 ohm, ½ w. res.
R_{22}—100 ohm, 2 w. res.
R_{23}—2200 ohm, 2 w. res.
R_{24}, R_{28}—470 ohm, ½ w. res.
C_1—3300 μμfd. mica capacitor
C_2, C_3, C_4, C_5, C_6, C_7, C_{13}—.01 μfd., 400 v. capacitor
C_8, C_9, C_{10}—20 μfd., 250 v. elec. capacitor
C_{11}-C_{12}-C_{13}—40/80/60 μfd., 350 v. elec. capacitor (Sprague TVL 3640)
C_{14}—.001 μfd., 200 v. capacitor
C_{16}—.1 μfd., 200 v. capacitor
J_1, J_2—Open circuit jack
S_1—S.p.s.t. switch (on R_7)
CH_1—10 hy., 50 ma. choke
T_1—Driver trans., single plate to push-pull grids. 1.33: 1 ratio (Triad A-83X)
T_2—Output trans, single plate or push-pull tubes to line. 18,000 ohms c.t. to 600/250/50 ohms (Triad A-53X)
T_3—Power trans. 250-0-250 v. @ 75 ma.; 5 v. @ 2 amps; 6.3 v. c.t. @ 2.5 amp. (Triad R-8A)
V_1—12AX7 tube
V_2—6C4 tube
V_3, V_4—6BC8 tube
V_5—5Y3 tube

Fig. 4. Complete schematic diagram of the consonant amplifier-limiter circuit. A 12AX7 is utilized as a two-stage preamplifier for the 6C4 driver stage. This, in turn, feeds the pair of 6BC8's operating as a two-stage push-pull grid bias limiter.

group pickups, and other such uses.

A not-so-usual application for the "C A" limiter is the output of your receiver. Feed the input through an appropriate pad so that the input stages won't be overdriven and connect a 600-ohm speaker to the output. You may be surprised at how loudly +20 dbm will drive your speaker. If it is too loud you will probably want to insert a 600-ohm variable "L" pad between the "C A" limiter and your speaker.

It will take a few minutes to get used to operating your receiver with a limited output. It is a good idea to tune across the broadcast band at first. Notice the constant loudness of all stations. If the announcers sound like they are sucking their breath through a pipe, you have the input gain too high.

After you have gained the knack of operating your receiver with this new automatic gain control output, tune to your favorite ham band. Tune in the SSB boys and notice how you can now listen without constantly adjusting the gain control. The same thing is true with your favorite net. You won't miss the weak ones because the audio was turned too low and the loud ones won't rattle your speaker.

The "C A" limiter is a simple straightforward piece of audio equipment. There is no feedback circuit to oscillate or motorboat. It will eliminate overmodulation worries forever, but it will give you some new things to think about. If you have a typical modulator, it is probably designed to give you 25% as much audio power as you have r.f. power. This is fine for unlimited speech. It is also plenty good for limited speech.

If your modulator produces 25% of your r.f. power when driven with a "C A" limiter this will produce a consistent 70% modulation. Before you decide you want 100% modulation, think a little further. What will it cost you and what will you get for your money? You will have to double your modulator's power output capabilities, which means bigger tubes and a bigger power supply. For this effort and expense you get 3 db more audio at the receiver output at the other end. Can you hear 3 db rise in audio? Sure, if you listen carefully over a high-fidelity system. You will probably notice it more over a typical communications receiver, because that last 3 db produces distortion in receivers that utilize diode-type second detectors. It is doubtful that increased receiver distortion is either useful or desirable. You will get better reports if you keep your modulation at 70 or 80 per-cent with a good high-speed speech limiter. -30-

Fig. 5. Underside of the "C A" limiter showing the simple straightforward construction. Power supply components may be seen near the bottom of the photograph.