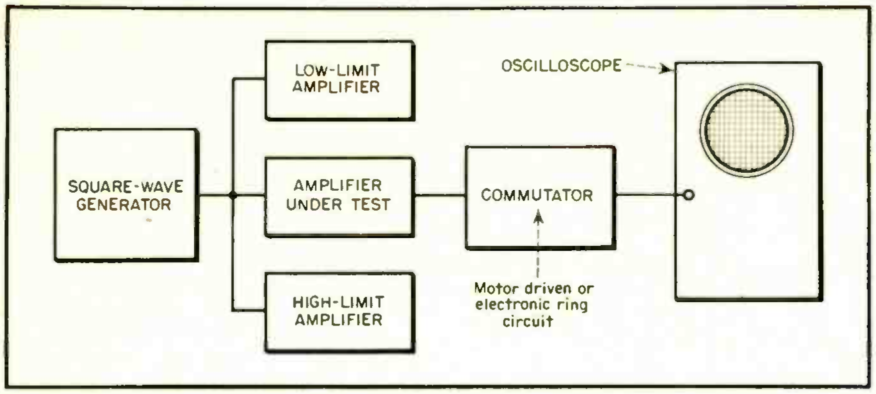

Fig. 2. Method of using square-wave test in amplifier production testing. Response of amplifier under test is compared with those representing upper and lower limits.

1B, relative frequency response information may be readily gained.*

If many amplifiers of the same type are to be tested for frequency response characteristics carrying broad tolerances, the square-wave method becomes even more attractive. Limits may be established on the oscilloscope screen in several ways. One approach is to provide a transparent screen for the cathode-ray tube on which lines are scribed to represent the responses of two amplifiers tested by steady-state methods and known to be within the desired tolerance by the possible error in observation of the display.

An extension of this method is illustrated in *Fig. 2*. Here the square wave is applied simultaneously to the input terminals of three amplifiers. Two of these have characteristics representing the upper and lower acceptance limits and the third is the device being tested. The outputs of these amplifiers are applied in sequence to the oscilloscope "Y" axis. Both this commutation rate and the "X" axis deflection are in synchronism with the square-wave generator output.

Phase Distortion

Phase distortion, or the departure from linearity of the phase-frequency characteristic of an amplifier or coupling network, is fortunately of little importance in audio-frequency work. However, in the design of feedback amplifiers, the frequencies at which the amplifier output voltage has shifted in phase by 180° from that at the point at which it is fed back are very important. From a knowledge of these frequencies and of the amplifier gain (without feedback) at these frequencies, the maximum amount of negative feedback that can be used with reasonable stability can be determined.* However, this phase information is much more readily obtained by using a sine wave audio frequency generator and an oscilloscope. Admittedly, the square wave output of an amplifier is a very sensitive indication of departure from linearity of the phase vs. frequency characteristic. For example,** a phase error of 2° at the fundamental frequency of the square wave produces a 10 per cent slope in the waveform (*see Fig. 3*). This type of information is of incalculable value in the testing of a video-frequency amplifier, but is of doubtful worth in connection with audio-frequency amplifiers.

However, this phase vs. frequency characteristic is important in an indirect way. It is well known that the transient response of an amplifier may be completely specified by the gain vs. frequency and the phase vs. frequency characteristics. The calculation of this transient response is laborious if performed analytically, and inaccurate if performed graphically. In general, sharp discontinuities in the frequency response curve of an amplifier foster the production of transient oscillations which blur or mask what should have been discrete, staccato sounds.

In *Fig. 4* are shown the steady-state frequency and phase response curves of a typical amplifier. The response of this amplifier to a 5 kc square wave is shown in *Fig. 5*. Note the tendency for a slight transient oscillation to occur at the leading edge of the pulse. In *Fig. 4*, are shown the response curves of the same amplifier with approximately 17% of inverse voltage feedback. The steady state characteristics are seen to be somewhat improved by the addition of the inverse feedback. However, the response of the amplifier to a 5 kc square wave (*Fig. 5*) shows that the transient oscillation noted before now has a longer decay time. The frequency of the damped wave train is approximately 40 kc which indicates that at that frequency the product of the no-feedback gain and the fraction of the output voltage fed back is less than unity, since the oscillation is damped. Also, the fact that the addition of feedback lessens the damping indicates that at the frequency of the oscillation, the overall phase shift has exceeded 180°. Thus it is seen that the square wave approach to audio amplifier testing is of great value whenever direct information of the transient response is desired.

Now to apply the second major design consideration, that of output level and impedance, to audio-frequency amplifiers which ultimately supply sound power to human ears. Here also, the output power must be measured in terms of sinusoidal power to be readily compared with the findings of other workers. A rough idea of output power may be obtained by discarding the output due to all but one of the frequency components in the square wave. This is hardly a practical approach, and is mentioned for any possible academic value. If it desired to measure the peak power output capabilities of an amplifier, a short duration, rectangular pulse may be used to drive the amplifier. The repetition frequency of this pulse is chosen low enough so that the average power capabilities of the system are not exceeded. The amplitude of the output pulse may be measured with a calibrated oscilloscope or an adequate peak reading voltmeter.

The third major design consideration, that of input impedance and level, may be disposed of insofar as the square wave approach is concerned by mentioning that a rough idea of the input-level-handling capabilities of the unit may be obtained by observing the changes in output waveform as the input level is increased from zero. Any useful information, in a quantitative sense, concerning input level maxima for given distortion percentages must be acquired with steady state techniques.

The fourth and last design consideration, that of signal-to-noise power ratios, is important since the ear recognizes and objects to these disturbances long before it notices the effects of non-linear and frequency distortion. Again, the square wave analysis produces no useful information on this subject.

The foregoing discussion has been confined to amplifiers in the audio spectrum which will drive an electro-acoustic transducer and thence drive

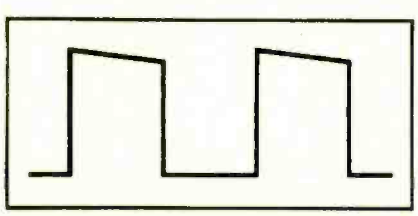

Fig. 3. A phase error of 2° at the fundamental frequency produces a 10 per cent slope in the square wave form.

*Swift, "Amplifier Testing by Means of Square Waves" *Communications*, Vol. 19, Feb. 1939.

**Radio Engineer's Handbook, F. E. Terman.

the human ears. We have pointed out that non-linear distortion is the most severe problem in this case and that the square wave is not a suitable test waveform for obtaining information on the behavior of the amplifier in this regard. In checking the frequency response within broad limits, the square wave provides quick results. As for determining the behavior under shock from a steep wave front signal, the square wave method gives a direct and quantitative answer.

It is also possible to estimate the overall bandwidth of an amplifier from the transition time. The transition time is defined as the time required for the output pulse to increase from 0.1 to 0.9 of full amplitude. This measurement must be made with a square wave generator and oscilloscope which together have a transition time small compared to that of the amplifier under test. The following equation relates bandwidth from the 65 per cent point to zero frequency, to transition time.

$$\tau = \frac{1}{2f_o}$$

transition time in seconds $= \tau$
frequency for 65% response $= f_o$

However, it is to be noted that the above definitions do not hold if the transition is oscillatory.*

Testing Requirements

The testing requirements for amplifiers used in measuring instruments are more stringent than those to be used for listening purposes. Oscilloscope amplifiers must possess amplitude vs. frequency and phase vs. frequency characteristics which depart from linearity by a very small amount. It is desirable to check these amplifiers for frequency response with the usual steady state techniques. The square wave can then be applied and the output waveforms considered in the light of the known frequency characteristic, thus yielding information on the linearity of the phase vs. frequency characteristic. Thus, before the steady state phase data are taken, adjustments are made for a transient output with the fastest transition time consistent with negligible overshoot. This is done at a repetition rate of approximately 0.1 of the maximum frequency that it is desired to transmit with negligible distortion. Then, adjustments are made with a slow repetition rate of square wave for maximum parallelism of the wave tops. Following these adjustments, a steady state phase vs. frequency characteristic may be taken and should show little departure from linearity within the passband.

Again, examination of the amplifier for poorly damped transient oscillations, regeneration, and parasitic oscillations may be undertaken simultaneously with the suggested phase data.

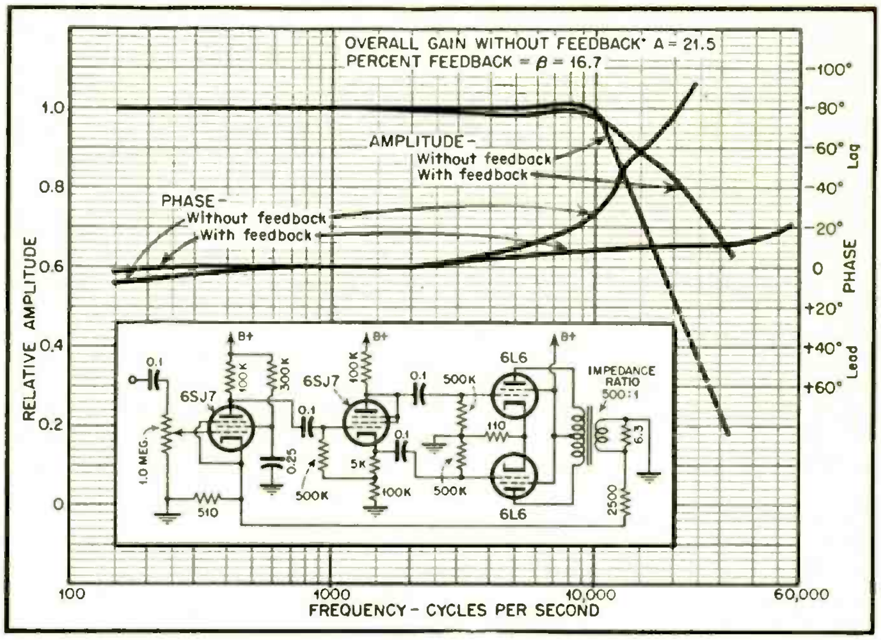

Fig. 4. Steady state frequency and phase response curves of a typical amplifier, with and without feedback.

The third general type of amplifier mentioned was that variety used in control service. Often, the non-linear distortion requirements are very lax. Mere capability of handling the range of input voltages to be encountered with 10 to 20 per cent departure from linearity is often adequate. The frequency-response characteristic may have great importance, and inflections and maxima or minima must be located accurately in frequency. The square wave may be employed to check the approximate location of these critical points before final adjustments are made. *See Fig. 5.*

Fourier Analysis

Through application of the Fourier series method of analysis, it is possible to deduce the steady state amplitude and phase characteristics which were responsible for the shape of the observed output of the square-wave-driven amplifier. This method requires a method of accurately measuring distances along the oscilloscope time axis and also the corresponding ordinates. Then follows a lengthy graphical integration which becomes more laborious the more varied the outline of the output pulse. This all seems a very laborious method of obtaining steady-state data which can be obtained by direct measurement.

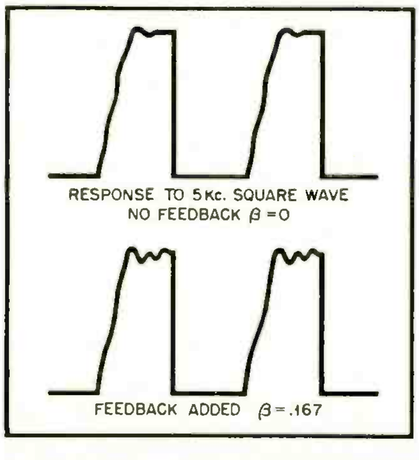

Fig. 5. Square wave response of amplifier shown in Fig. 4, with and without feedback.

The trend in present-day engineering is to confine the use of transient techniques to devices such as video amplifiers and pulse amplifiers, the ultimate aim of which is to amplify or shape a transient phenomenon properly. In the case of the audio-frequency amplifier, steady-state amplification is of foremost interest and hence steady state techniques give, in general, the most informative results with a given effort. Mention has been made of several well-known examples of correlation between steady-state and transient response data because much attention has been drawn to them recently by the television problem. In every case, confining the frequency range under discussion to the audio region so simplifies the taking of direct steady-state or transient response data that it seems foolish to resort to laborious calculations to deduce one set of information from the other.

The greatest simplification provided by limiting the response requirements of an amplifier to the usual audio-frequency signals is that perfectly satisfactory transmission is obtained if the frequency components that go to make up a complex waveform are not shifted in phase

[*Continued on page* 57]

*Eaglesfield, "Transition Time and Pass Band" *Proc. I.R.E.* Feb. 1947.