follower. Delayed pulses, obtained from separated synchronizing signal, operate the clamp circuits during the back-porch interval. Such a circuit can restore the correct picture back level and maintain it regardless of picture content, incorrect or spurious low frequencies, or switching transients. Restoration is also independent of synchronizing-signal height, which means that the red and blue backgrounds remain correct when these channels are switched to the green signal, as when reproducing a black-and-white picture from a low-band station.

The synchronizing signal is separated from the green-channel signal. Fig. 11 is a block diagram of the green video amplifier and the synchronizing-signal circuits.

Safety circuits are provided for protection of the kinescopes in the event of deflection or power failure. Protection against power failure, such as a blown fuse or disconnected cable, is necessary since the deflection would cease before the accelerating voltage, and an undeflected spot would remain long enough to damage the kinescope screen.

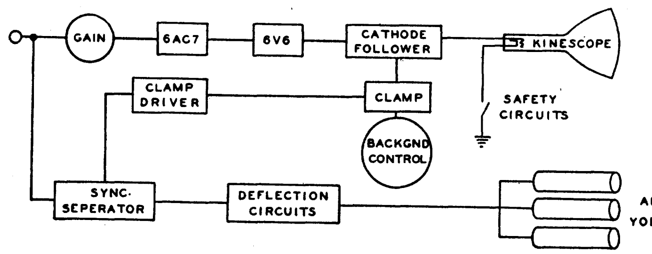

Fig. 11—Video block diagram of green channel.

Electrical Noise Generators*

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***Summary*—A new noise source consisting of a gas tube in a transverse magnetic field has been developed. Characteristics of the noise source are presented, together with some consideration of the problems in the amplification of noise. Typical noise-amplifier circuits are given for frequency bandwidths from 0.1 to 2.5 and 5 megacycles, respectively.**

Introduction

As PART of a noise-application program a study was made of various noise sources capable of providing high-level random-noise signals. In general, it was necessary to have signals consisting of random noise having frequency components extending over wide bandwidths. In addition, it was desirable to have no oscillations present in the signal. Obviously, it was desirable to have a high level of random-noise voltage available to simplify problems of amplification. In the course of this study a gas-tube noise source was developed with random noise output much higher than could be obtained from thermal noise,[1] shot noise,[1] or even photomultiplier[2] tubes. The noise output of the tube was amplified in order to provide sufficient noise power for modulation. The design of noise amplifiers presents special problems not ordinarily encountered in video-amplifier design.

The noise measurements recorded in this paper were made by two spectrum analyzers. One of these[3] measured the noise in a 33-kilocycle bandwidth in the frequency range 100 kilocycles to 10 megacycles. The other[4] permitted measurements from 25 cycles to 1 megacycle. Both spectrum analyzers were designed to present a high impedance to the noise source and to minimize distortion of the spectrum due to clipping.[5] The noise spectra were assumed flat over the bandwidth of the analyzers. Thus the noise was measured in units of root-mean-square volts/$(\Delta f)^{1/2}$, where Δf was an arbitrarily chosen small bandwidth. In studying a wide range of noise sources and generators it was generally found convenient to refer the spectral data in decibels to the arbitrary level of 10 microvolts per $(\text{kilocycle})^{1/2}$. The level of the shot-noise voltage developed by a diode with a plate current of 10 milliamperes and a 3000-ohm plate load is 26 decibels below this reference level. The root-mean-square voltage obtained by integrating an experimentally determined spectrum of irregular shape agreed well with the value obtained with a wide-band thermocouple voltmeter.

Gas-Tube Noise Source

The noise source developed consisted of a 6D4 miniature gas triode placed in a transverse magnetic field pro-

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[1] E. B. Moullin, "Spontaneous fluctuations of voltage," Clarendon Press, 1938.

[2] W. Shockley, and J. R. Pierce, "A theory of noise for electron multipliers," Proc. I.R.E., vol. 26, pp. 321–332; March, 1938.

[3] G. P. McCouch, and P. S. Jastram, "Video spectrum analyzer," Harvard Radio Research Laboratory Report, OEMsr 411; p. 96.

[4] J. D. Cobine and J. R. Curry, "Range extender for General Radio 760 A sound analyzer," R.S.I., vol. 17, pp. 190–194; 1946.

[5] D. Middleton, "The response of biased saturated linear and quadratic rectifiers to random noise," *Jour. Appl. Phys.*, vol. 17, pp. 778–801; October, 1946.

duced by a small permanent magnet (Fig. 1).[6] The magnetic field has the property of eliminating undesirable oscillations characteristic of gas tubes, and at the same time increasing the level of the high-frequency noise.[7,8]

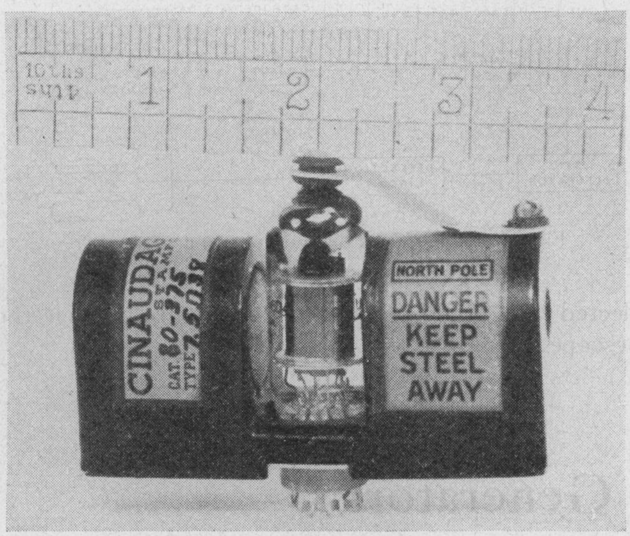

Fig. 1—6D4 permanent-magnet noise source.

The 6D4 tube was chosen because it combined the desirable features of small size, low power drain, and great uniformity from tube to tube.

The values of the magnetic field, load resistance, and operating current were chosen after a systematic study of the effects of these variables on the noise spectrum. The effect of the magnetic field on the spectrum is shown in Fig. 2. A flux density of 375 gauss was chosen to give

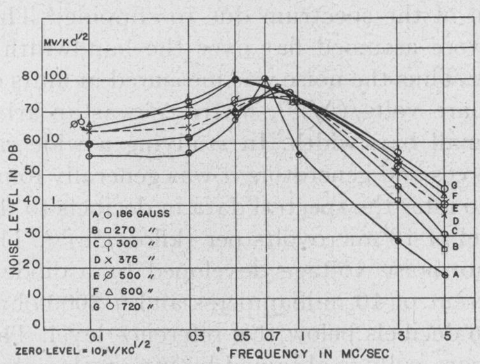

Fig. 2—Effect of magnetic field strength on the 6D4 noise spectrum. Electromagnet used. Load resistance = 20,000 ohms. Anode current = 5 milliamperes.

the maximum high-frequency noise consistent with the requirements of a readily equalized spectrum and compact construction of the permanent magnet. The magnet itself consisted of two short alnico bar magnets supported in an aluminum casting. No magnetic return path was necessary. The field was directed transverse to the normal flow of current and polarized to deflect the arc to the top of the tube.

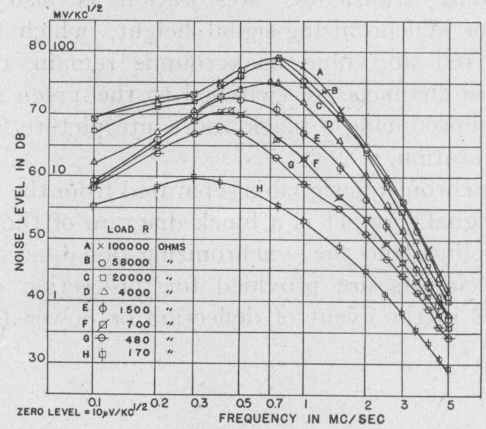

Fig. 3—Effect of load resistance on the 6D4 noise spectrum. Standard permanent magnet used; $B = 375$ gauss. Anode current = 5 milliamperes.

The gas tube requires a high nonreactive load resistance in order to develop the highest-level high-frequency noise. The effect of load resistance is shown by Fig. 3. It was found desirable to use a load resistance of about 20,000 ohms, since the higher values have little effect on the noise spectrum and lower values reduce the level and shift the maximum in the spectrum to lower frequencies. Fig. 4 shows the noise spectra for various anode currents within the range practical for the 6D4. The effect of anode current is greatest at the high fre-

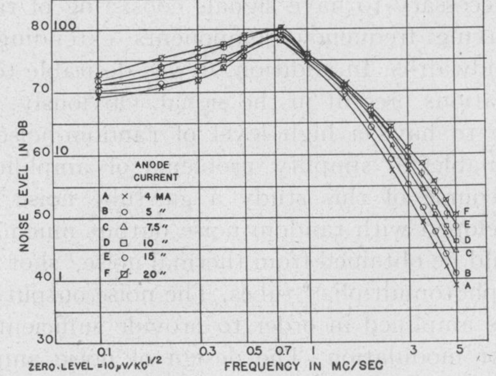

Fig. 4—Effect of anode current on the 6D4 noise spectrum. Standard permanent magnet used; $B = 375$ gauss. Load resistance = 20,000 ohms.

quencies, and negligible at the peak. The low-frequency spectrum (not shown in the figure) is substantially flat down to 25 cycles at the level indicated for 100 kilocycles in Fig. 4. The root-mean-square voltage for the band 25 cycles to 5 megacycles is 2.5 volts with a peak-to-peak voltage of 18 volts. The 6D4 tube was found to operate stably in the magnetic field for at least 600 hours with no appreciable change in noise output. The

[6] Special design, made by Cinadagraph Corporation, as Catalog No. 80–375.

[7] J. D. Cobine, and C. J. Gallagher, "Noise and oscillations in hot cathode arcs," *Phys. Rev.*, vol. 80, p. 113, 1946. Also, *Jour. Frank. Inst.*, vol. 243, pp. 41–54; 1947.

[8] C. J. Gallagher, and J. D. Cobine, "Effect of magnetic field on noise and oscillations in hot cathode arcs," *Phys. Rev.*, vol. 70, p. 113, 1946. Also, *Jour. Appl. Phys.*, vol. 18, pp. 110–116; January, 1947.

standard deviation of the noise level for a large number of these units was 1.3 decibels. Thus, the 6D4 noise unit is a suitable primary noise source capable of generating a continuous spectrum of any bandwidth in the range 25 cycles to 5 megacycles.

Design and Equalization of Wide-Band Noise Generators

Although the noise spectrum of the Sylvania 6D4 tube falls off rapidly at frequencies higher than 700 kilocycles, it is possible to build a high-level noise generator that gives as an output a noise spectrum that is flat up to 5 megacycles if suitable equalizing circuits are used in the various amplifying stages.

The following discussion summarizes the principles involved in designing and building wide-band noise amplifiers. Ordinarily, all or some of the following characteristics of the output of a noise amplifier should be specified: (1) cutoff frequencies, (2) shape of spectrum, (3) peak-to-peak voltage, (4) type and degree of clipping, and (5) power output.

It is important to keep in mind that the spectrum is an integrated measurement. The grid of a tube "sees" the instantaneous noise voltage which cannot be determined from the root-mean-square voltage as given by the spectrum. The peak-to-peak voltage, which determines the degree of clipping, must be obtained by other measurements. The method of measuring the spectrum has been discussed in the first part of this paper. The most convenient way to measure the peak-to-peak voltage is to put the noise on the horizontal plates of a calibrated wide-band oscilloscope and make the horizontal deflection zero. Observation of the noise voltage on an oscilloscope will also show to what extent the positive and negative peaks are clipped. Often the clipping is unsymmetrical, so in the general case the peak-to-peak voltage cannot be determined by means of a positive-peak-reading voltmeter. Power output may be determined from the root-mean-square current flowing through a known noninductive resistor. It should be pointed out that a statement of power output alone is deceptive unless the output spectrum is also defined.

In broad outline, wide-band noise amplifiers bear a considerable resemblance to ordinary video amplifiers but in detail they differ in many respects, particularly if a high level or a clipped output is desired. In ordinary video amplifiers the tubes use class-A_1 linear operation (i.e., there is no nonlinear distortion) and frequency and phase distortion are eliminated by properly designed coupling circuits. Where high power output is required, noise amplifiers are overdriven because of the high peak-to-root-mean-square ratio of the noise from the noise source. This ratio may be as high as 5 to 1, compared to 1.4 to 1 for sine wave. High power output requires high root-mean-square voltage, not high peak voltage. Overdriving the amplifier results in a clipped noise signal, which is usually permissible and increases the power output. Thus, the dynamic operation of a noise amplifier is different from that of an ordinary video amplifier. In a noise amplifier, nonlinear distortion will be present. On the negative swing the grid voltage goes beyond cutoff, and on the positive swing grid current is drawn. The positive grid swings may even cause the tube to operate in the saturated region. Thus r_p and g_m of the tube change constantly, as does the load impedance which the tube sees because of grid current drawn by the following stage. The clipping that occurs when an amplifier is overdriven causes a change in the spectrum. The general effect is to increase both high-frequency and low-frequency components, with the greater increase in the low frequencies.[5] Thus, the equivalent-plate-circuit theorem cannot be used in designing equalizers. Also, it is not possible to determine the nature of the output noise spectrum by measuring the frequency response of the amplifier with a sine wave. The only completely satisfactory way to adjust the output spectrum is to excite the amplifier with the operating noise signal and adjust the circuit constants while observing the noise output with a spectrum analyzer.

The drop-off in the spectrum of the 6D4 at high frequencies is caused by phenomena taking place inside of the tube. It is not a result of the ordinary shunting effect of interelectrode capacitances. Thus the spectrum cannot be made flatter by reducing the load into which the 6D4 works.

It has been found that it is impractical to put an equalizing circuit, particularly one for the high frequencies, between the 6D4 tube and the first amplifying tube. The reason for this is twofold. First, such a circuit has relatively little effect because the 6D4 has such a high internal impedance that high-Q circuits cannot be obtained. The other reason is that such circuits may cause the 6D4 to oscillate as a relaxation oscillator. It was found best to insert equalizing circuits in the plate circuits of the amplifying tubes.

First, consider the problem of obtaining a flat noise spectrum. For convenience, assume in the following discussion that the spectrum is to be flat to 5 megacycles. It will be noted that at 5 megacycles the spectrum of the 6D4 unit is about 30 decibels below the maximum, which is at 700 kilocycles. In order to bring up this high-frequency portion, a shunt-peaking circuit is the most satisfactory. The peaking circuit acts as a parallel-resonant circuit, the capacitance between tubes forming one arm. The circuit should resonate at 5 megacycles and the Q of the circuit is determined primarily by the load resistance. If the following tube draws grid current, as it usually does, the Q of the circuit is lowered and it may be impossible to obtain the desired elevation of the high-frequency end of the spectrum in one stage.

A sine-wave signal and a vacuum-tube voltmeter can be used to adjust the inductance of the peaking coil so that the resonant frequency of the circuit is at the proper point, e.g., 5 megacycles in this case. (For experimental use it is convenient to use coil forms provided with adjustable powdered iron slugs.) It is not very practical to calculate in advance the most advantageous size of the load resistor. It must be adjusted more or less by trial and error, using the analyzer to determine the noise spectrum.

It should be remembered that the chief purpose of the first amplifying tube is to amplify differentially, i.e., it should bring up the 5-megacycle region by a factor of 30 over that of the 700-kilocycle region. This means that a very small value (50 to 200 ohms) of load resistor R_b will be used in the shunt-peaking circuit. Little success has been experienced in using a series-peaking circuit to raise the higher-frequency portion of the 6D4 spectrum to such an extent. A minor advantage of the shunt-peaking circuit is that it is far easier to adjust.

Usually it is impossible to raise the high-frequency portion of the spectrum sufficiently in one stage. Even when this is possible, intertube capacitance must be compensated for in the later stages. The slight additional peaking that is required, and the compensation that is necessary on account of capacitance, can be achieved very well by using series-peaking circuits. They have the advantage of having a greater over-all amplification compared to the shunt types of peaking circuit.

For low-frequency compensation it usually suffices to put a parallel RC circuit in series with the load resistor. It may be put in the same stage as the shunt-peaking coil. In this case the capacitance of the RC circuit and the high-frequency peaking coil will show series resonance and a dip in the spectrum may occur at medium frequencies. Sometimes advantage may be taken of this by adjusting these circuits so that the dip occurs at 700 kilocycles and is of the proper magnitude. Thus the two compensating circuits achieve a flat spectrum by raising the ends and lowering the hump.

Sometimes it is necessary to pull down either the hump in the 6D4 spectrum or a new peak that may appear in the spectrum at some later stage. A convenient way to do this is to put, at the appropriate point, a series-resonant circuit to ground. L and C are made to

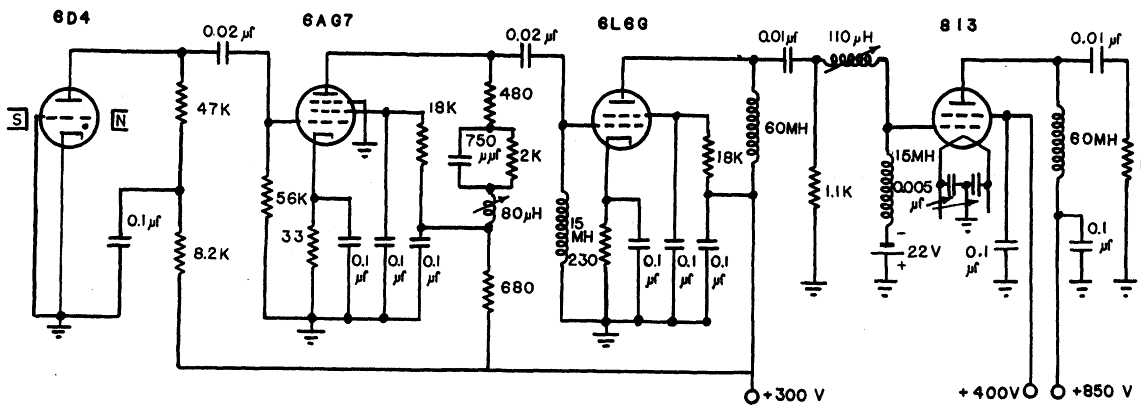

Fig. 5—High-level wide-band (0.1 to 2.5 megacycles) noise generator. R_L either 2000 or 4000 ohms.

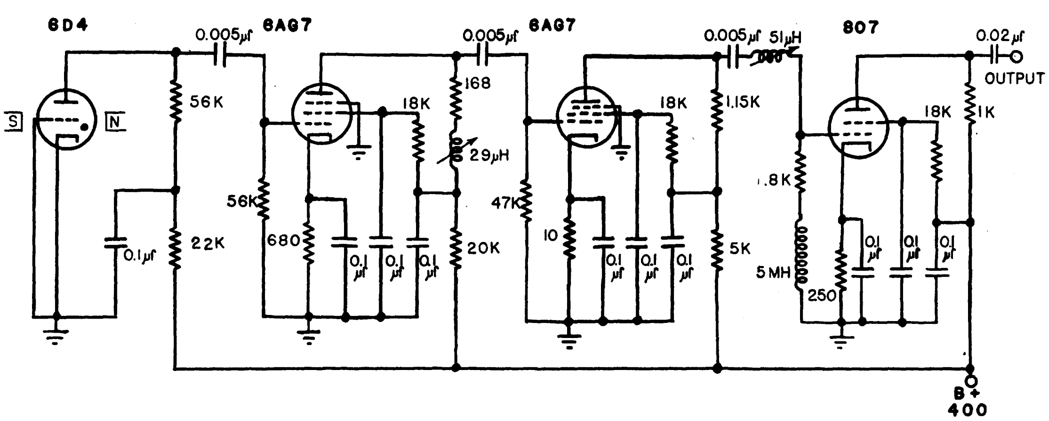

Fig. 6—Wide-band (0.1 to 5 megacycles) noise generator.

resonate at the frequency at which the dip is desired, and the amount of the dip is adjusted by means of a resistance in series with L.

It must be remembered that in any one stage the equalizing circuits for the various portions of the spectrum are usually not independent of one another. Thus it is not possible to make the final adjustment on each one separately. For example, if a shunt-peaking circuit is adjusted to raise the high-frequency portion of the spectrum, and then a series-resonant circuit is put into the same stage to pull down a low-frequency hump that is present, the latter circuit will have an effect on the high-frequency portion of the spectrum.

A few attempts have been made to equalize by means of cathode degeneration. These have not been very successful. The general effect of cathode degeneration is to lower the level of the entire spectrum.

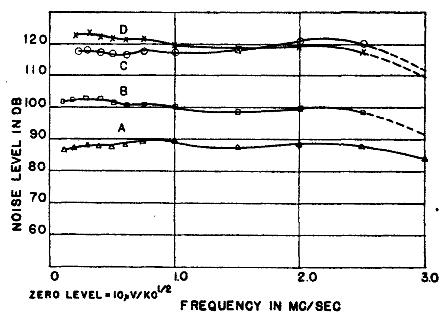

Fig. 7—Noise spectrum for circuit of Fig. 5.

Curve	Voltage Peak-to-peak	Voltage R.M.S.	Power output, watts
D—Plate, 813, R_L=4000 ohms,	1800	590	87
C—Plate, 813, R_L=2000 ohms,	1400	400	80
B—Grid, 813	300	55	—
A—Grid, 6L6G	92	—	—

The amount of clipping can often be adjusted by changing the grid bias. In special cases a resistor can be put in series with the grid so that clipping occurs when grid current is drawn, or diode clippers may be used. An important phenomenon connected with clipping is that, if the noise is clipped severely in one of the intermediate stages of a multistage amplifier, it will not as a rule appear clipped to the same extent in later stages. Sometimes it even becomes practically unclipped. This action has been observed many times and its practical importance is that if one desires a clipped output from the final stage, one cannot simply arrange things so that the clipping occurs at an earlier stage and then expect the clipped signal to be transmitted through the later stages with the usual voltage inversions. This phenomenon is probably caused by phase distortion. In clipped noise a completely random distribution of the phases of the noise components does not exist. Phase distortion restores the randomness in the phase relations.

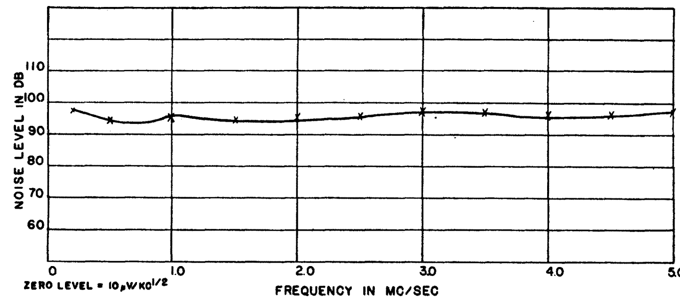

Fig. 8—Noise spectrum at plate of 807 for circuit of Fig. 6. Peak-to-peak voltage = 285 volts.

Both low-pass and high-pass filters have been used when it has been desired to obtain spectra with special characteristics. As a rule they are not very successful when they are used in intermediate stages. The effect, of the filter is partially counteracted by later clipping, which tends to raise the level of the low- and high-frequency components. However, filters work very well on the output of the amplifier. They can be calculated from ordinary circuit theory. In this connection, Rice has shown that, if clipped noise is fed into a narrow-pass filter, the noise coming out of the filter will be unclipped.[9]

Typical amplifiers designed according to the foregoing principles are shown in Figs. 5 and 6. These amplifiers were designed to give substantially uniform noise spectra extending from 100 kilocycles to 2.5 and 5 megacycles, respectively. The output spectra are shown in Figs. 7 and 8. In additions the spectra obtained at the intermediate stages of the 2.5 megacycles amplifier are shown in Fig. 7. Although these amplifiers were designed to modulate high-frequency oscillators, it was not possible to determine the equivalent "impedance" presented to the modulator by the oscillator. The spectra were obtained with the last amplifier working into a pure resistance load.

Acknowledgment

The authors wish to acknowledge the generous assistance of C. J. Gallagher.

[9] S. O. Rice, "Mathematical analysis of random noise," *Bell Sys. Tech. Jour.*, vol. 24, pp. 46–156; January, 1945.