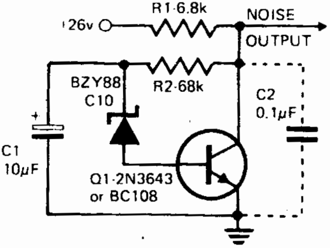
WHITE AND PINK NOISE GENERATOR



A basic noise generator can be built using one transistor and a Zener diode.

The 10 volt Zener acts as the noise source and also stabilizes the transistor operating point. Adding capacitor C2 will change the output from 'white' noise to 'pink' noise.

Output level for components specified will be about 15 V for white noise and about 14.5 V for pink noise.

The transistor should be a BC 108 or 2N3643 – other similar transistors will do.

Maximum-length shift register generates white noise

by Henrique Sarmento Malvar
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Using a circuit based on a maximum length sequence generator,[1] this simple unit inexpensively provides a source of white noise over a range of up to 200 kHz. It is far superior to generators that use a reverse-biased base-to-emitter transistor junction, which provides quasi-white noise over a very limited portion of the spectrum. Using two integrated circuits comprising a 25-stage shift register, it can be built for less than $6.

A_1 and A_2 form the n-stage shift register driven by clock G_1–G_2, with A_1 an 18-stage device and A_2 being eight stages in length. A_1 and A_2 are driven simultaneously but out of phase with respect to each other.

The output from stage 7 of A_1 and the last stage of A_2 is applied to G_3 in the feedback loop G_3–G_4, so that a register sequence length of 2^{n-1} clock periods is obtained. Note that G_4 provides signal inversion, so that on power up (the all-zero output state of A_1 and A_2), the noise generator will be self-starting.

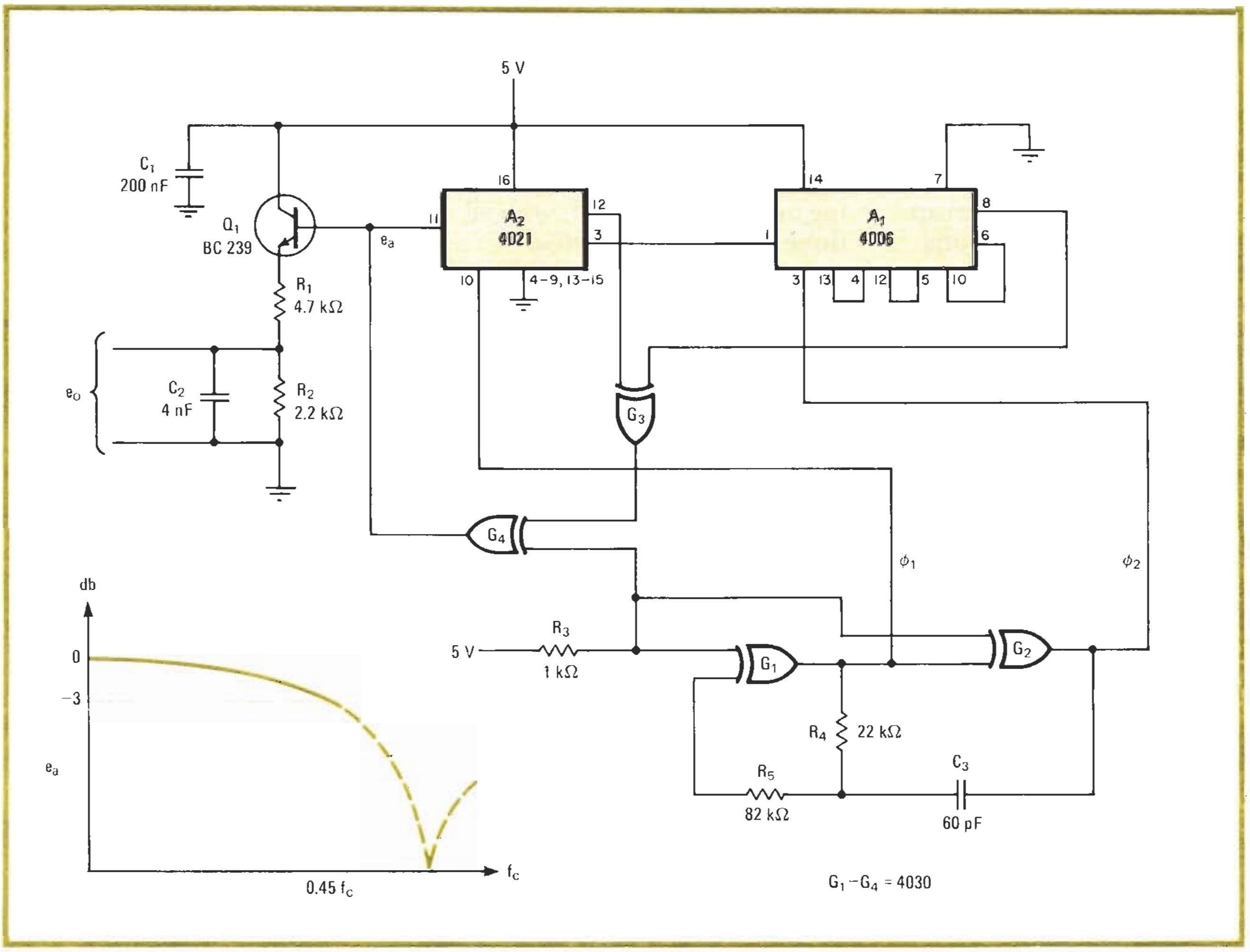
It can be shown that the spectrum of the signal at the output of A_2 will contain several discrete frequencies, separated by $f_c/(2^{n-1})$, where f_c is the clock frequency, in this case 200 kHz. Because n is large, the separations between the discrete frequencies become so close (here, it will be 0.006 Hz with a sequence period of 150 seconds), that the spectrum may be considered continuous. So although the noise is pseudorandom because of the method used to produce it, the difference in the spectral properties of the noise as compared with the ideal is minimal.

As for the amplitude of the output envelope, it will vary with frequency as $(x^{-1} \sin x)^2$, where $x = f/f_c$. Here, the -3-dB point will occur at $f = 0.45\ f_c$, as shown in the curve at the lower left of the figure.

Q_1 serves as a buffer. The network $R_1R_2C_2$ is a low-pass filter that has been added for an application requiring noise to be confined (bandlimited) to the audio frequencies. Its -3 dB point occurs at 25 kHz. □

References
1. I. H. Witten and P. H. C. Madams, "The Chatterbox-2," Wireless World, Jan. 1979, p. 77.

Spectrum spread. 25-stage shift register creates closely spaced signals of discrete frequency for generating pseudorandom white noise over wide range. Spectral response of source (bottom left) is flat from dc to 0.45 f_c, where f_c is the clock frequency.



WHITE NOISE EFFECTS UNIT

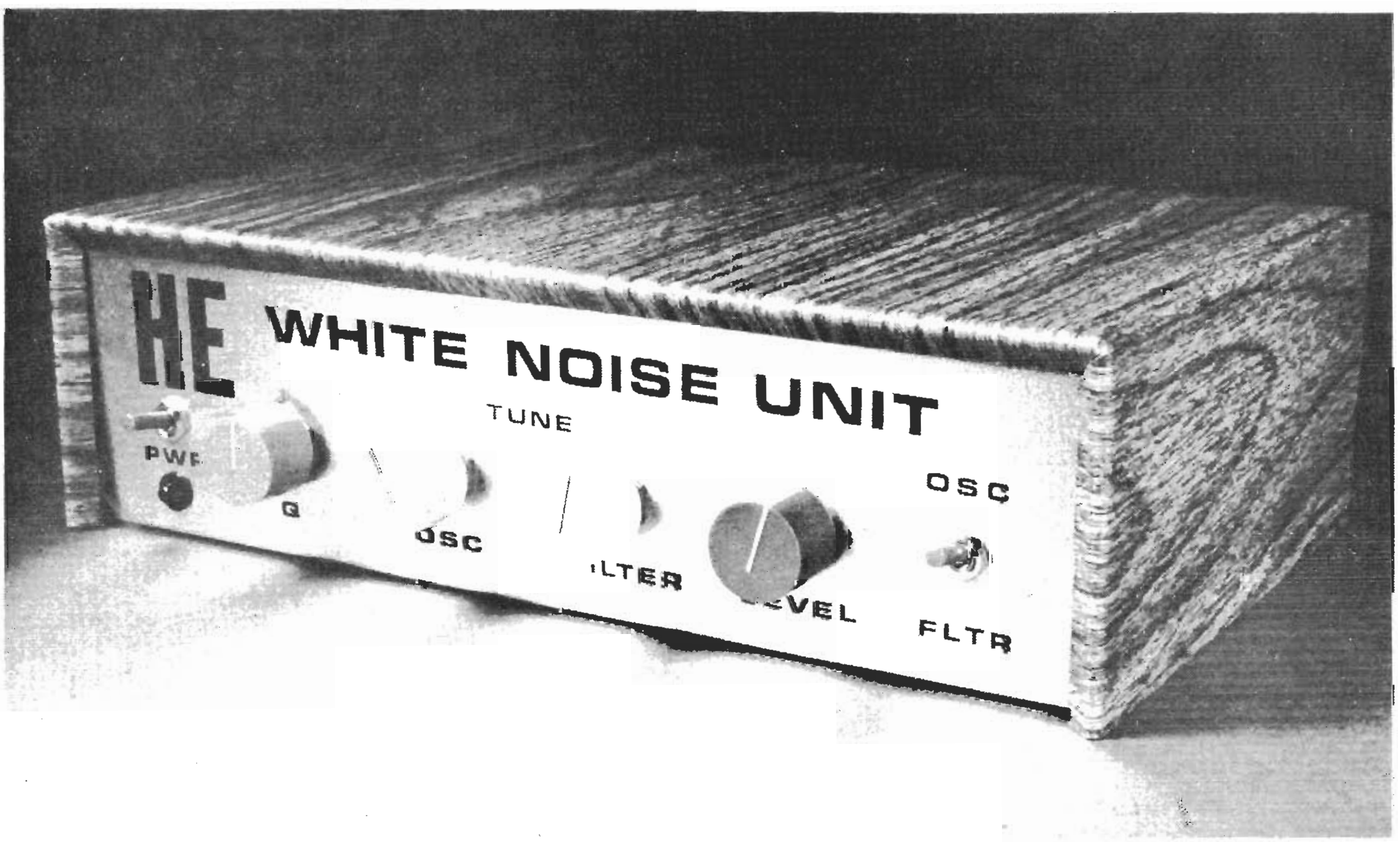
Simulate the soothing sound of wind, waves and surf on the beach, or the roar of jet aircraft and steam trains, with this White Noise Effects Unit.

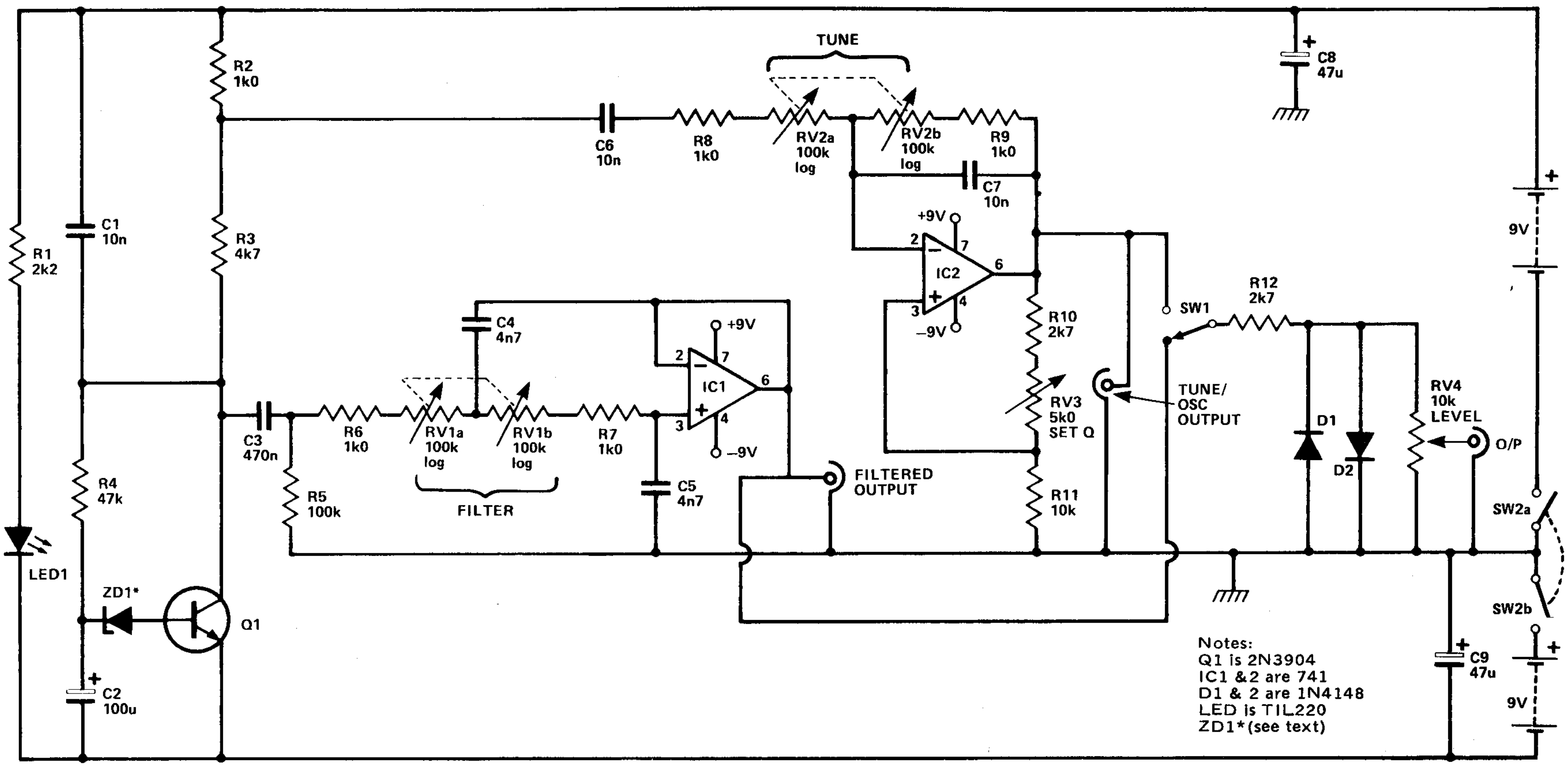
THIS COMPREHENSIVE little unit gives an excellent introduction to special sound effects. It contains a white noise generator, a variable-frequency low-pass filter and a variable-frequency tuned amplifier. This combination enables you to use the HE unit to generate a whole range of interesting sound effects, including those of wind, waves, surf, waterfalls, jumbo jets and 'steam' sounds, etc. As an added bonus, you can also use the unit as a variable-frequency 'tone' generator.

White noise can be simply described as a signal containing a full spectrum of quite randomly generated frequencies or 'tones', all with randomly determined amplitudes, but which have equal mean power when averaged over a reasonable unit of time. The basic sound of white noise resembles that of hissing steam, but this sound can be greatly modified, to give very interesting effects, by passing it through the types of filters that we have used in the HE design.

The HE white noise effects unit is battery powered, and has a panel-mounted LED (light-emitting diode) to indicate the ON state. Variable front-panel controls are provided for the control of the low-pass FILTER frequency, the tuned-amplifier TUNE frequency, the tuned-amplifier SET Q or 'tuning sharpness' adjustment (which also gives the 'tone' generation facility), and for the control of volume or LEVEL.

The unit is provided with three output sockets. The main output is via a mode selector (FILTERED or





TUNE/OSCILLATE) switch and the LEVEL control and a pair of amplitude-limiting diodes. Direct outputs are also provided from the two filters for feeding into auxiliary circuits such as mixers, modulators, or envelope generators, to produce more elaborate special effects.

Construction

Most of the circuit is wired up on a single PCB. Follow the overlay carefully, taking special note of the polarities of all semiconductors and electrolytic capacitors. The most important component in the whole unit is the noise generator diode, ZD1. This can either be a selected 'noisy' 5V6 to 10 V zener diode (ones from 'bargain'

HOW IT WORKS

The heart of the unit is the white noise generator, which is designed around transistor Q1 and zener diode ZD1. This zener diode can either be a specially selected 'noisy' type, with a **zener voltage in the range 5V6 to 10V.** The device is connected in series with the base of Q1 and is biased into its breakdown region at a low current from a low-impedance source via R4 and C2. Q1 is wired as a common emitter amplifier, with high-frequency roll-off provided by C1. When a reasonably noisy component is fitted in the ZD1 position, a noise signal of a few hundred junction of R2 and R3, and is fed on to the variable-frequency tuned amplifier formed by IC2 and its associated components. This amplifier makes use of a Wien tuning network (C6-R8-RV2a and C7-R9-RV2b), and can be tuned over the approximate range 150 Hz to 15 kHz via RV2. The Q or tuning sharpness of the circuit is variable via RV3, and can be varied from 'very low' to 'almost infinite'. When RV3 is set above the 'almost infinite' level IC2 acts as an unregulated tuned oscillator, and generates a rectangular output waveform that is variable from 150 Hz to 15 kHz via RV2: a certain degree packs seem to have a particularly high yeild of noisy types). When a suitably noisy component is used, the noise signal at the collector of Q1 will have a mean amplitude of a few hundred millivolts RMS.

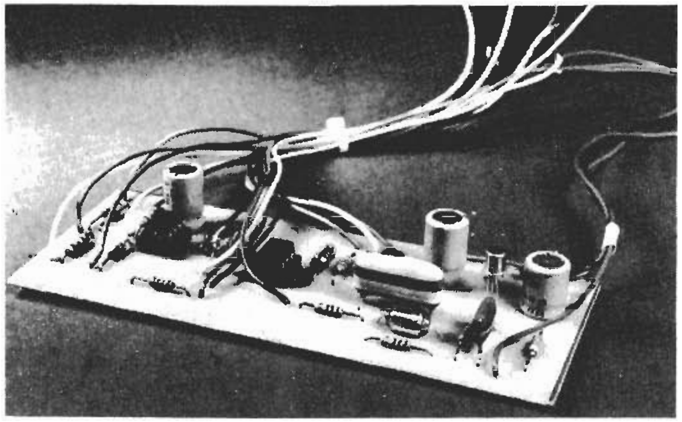
When construction of the PCB is complete, fit it into a suitable box and complete all interwiring. Then connect the main output of the unit to an audio amplifier, switch on, and listen to the fascinating effects that the unit can generate.

millivolts RMS appears at the collector of Q1.

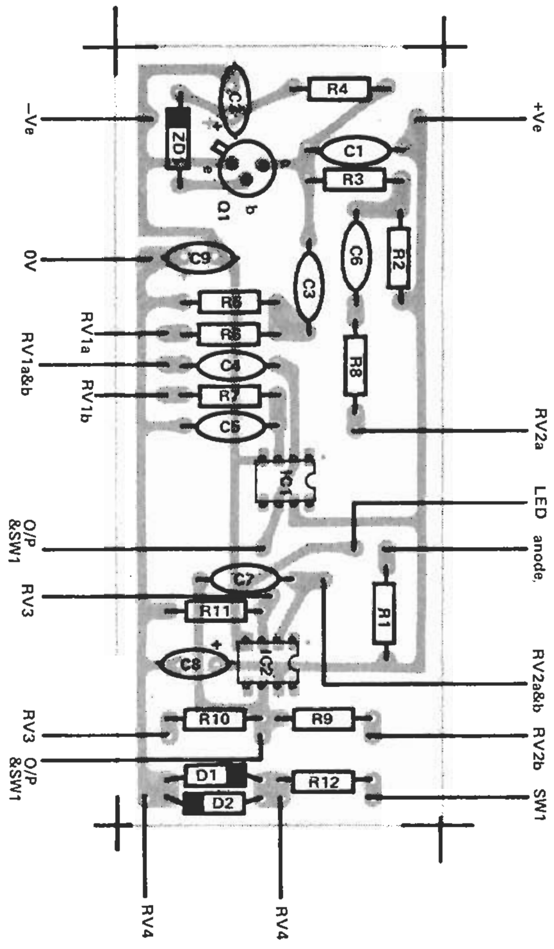
The noise signal from Q1 collector is fed into the variable-frequency low-pass filter formed by IC1 and its associated components. This filter passes all signals below a certain turn-over frequency, but rejects signals above that frequency. The filter is a second-order type, and rejects signals at a rate of 12 dB/octave. The turn-over frequency is variable over the approximate range 220 Hz to 24 kHz via RV1.

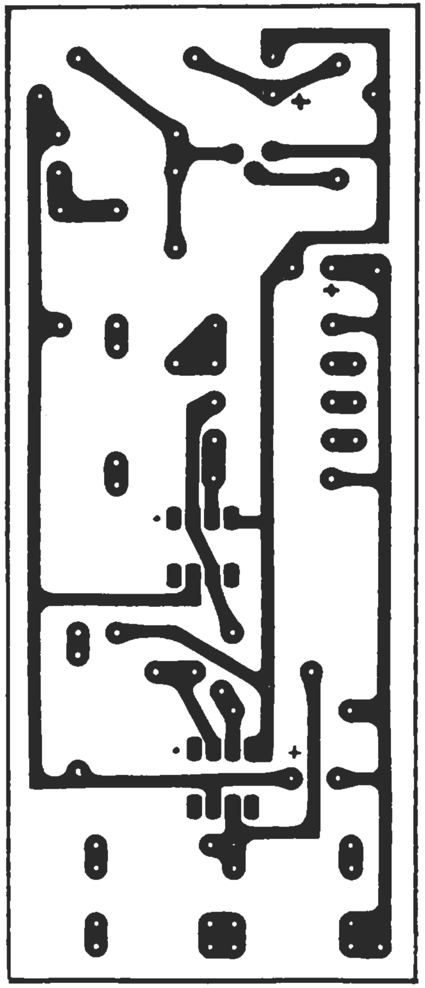
A second noise output is taken from Q1 at the point where an appreciable degree of interaction occurs between RV2 and RV3.

The outputs of the filter and the tuned amplifier/oscillator are taken directly to their own output sockets, and are taken to a master output socket via selector switch SW1 and LEVEL control RV4. Silicon diodes D1 and D2 are wired across RV4 to limit the peak-to-peak output signal level to about 600 mV, and ensure that cones will not suddenly be blown from their speakers if RV3 is inadvertently set to the 'oscillate' mode.



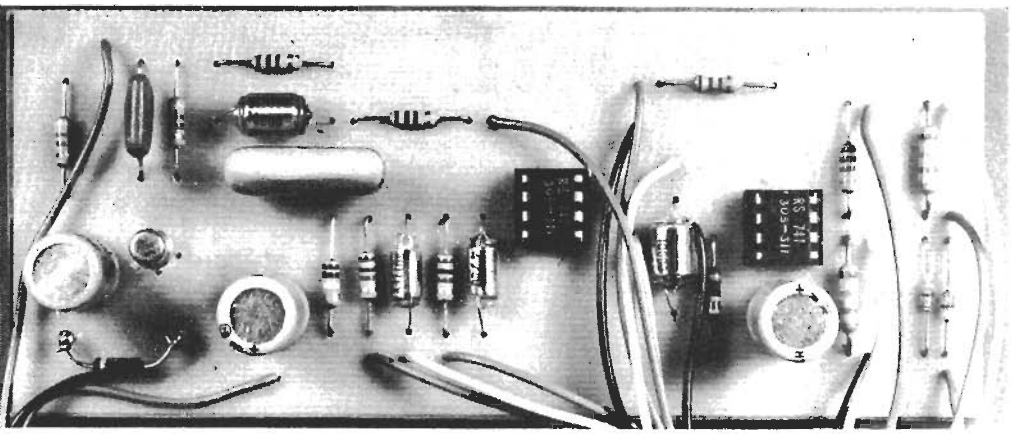
PCB with flying leads, ready for installation.





PARTS LIST

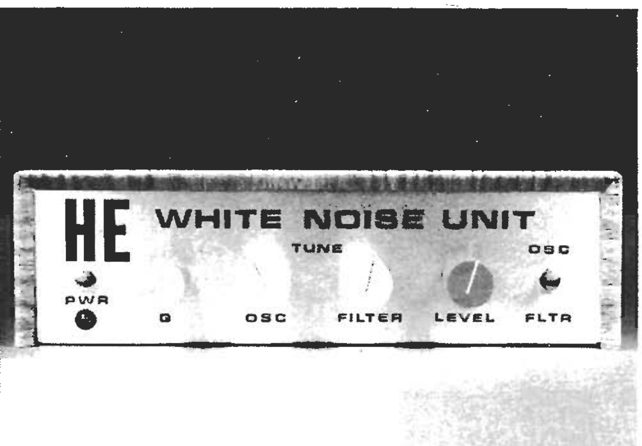
R1	2k2	C3	470n polyester
R2, 6, 7, 8, 9	1k0	C4, 5	4n7 polystyrene
R3	4k7	C6, C7	10n polystyrene
R4	47k	C8, C9	47u electrolytic
R5	100k		
R10, 12	2k7	SEMICONDUCTORS	
R11	10k		
		Q1	2N3904
POTENTIOMETERS		D1, D2	IN4148
RV1, 2	Dual Ganged 100k log Carbon,	ZD1	see text
		IC1, IC2	741
RV3	5k0 Lin Carbon	LED	TIL 220
RV4	10k Log Carbon		
		MISCELLANEOUS	
CAPACITORS		3 phone-sockets	
C1	10n polyester	2 9V batteries and clips	
C2	100u electrolytic	case to suit	

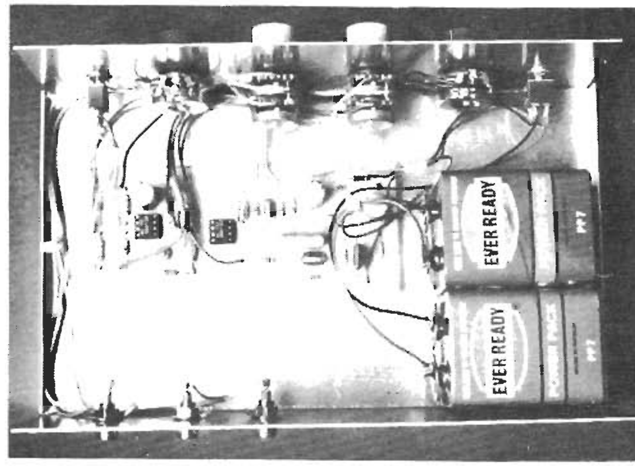


Top view of completed PCB.

Below Right: Internal view of the unit, ready to switch on.

Below Left: The front panel lay-out we use on our unit.
transistor gain tester





A valuable audio analysis tool

BUILD A LOW-COST WHITE/PINK NOISE GENERATOR

BY JOHN E. PFEIFER

AND WILLIAM EPPLER

A NOISE SOURCE that has predictable amplitude and frequency characteristics is a valuable tool for making real-time audio spectral analyses. For flexibility, it should have two different noise signals—white and pink. A commercial noise source with these characteristics would probably be too expensive for the home user, but you can build the instrument described here at only nominal cost.

This Audio Noise Source was designed as a companion to the "Hand-Held LED Spectrum Analyzer" (PE September 1979). However, it can also be used with any other constant-Q analyzer or any other multiple fixed-bandpass filter real-time device that requires a noise source to provide equal power in each of the measurement bands.

White and Pink Noise. White noise, so called because of an analogy to white light, contains all frequencies within a specified bandwidth at equal energy. Since white noise contains equal noise energy per hertz, it is most compatible with constant-bandwidth analyzers, such as the heterodyne, swept-filter, and digital fast-Fourier-transform (FFT) types.

Since the bandwidth of a filter with given Q is proportional to the center frequency of the filter, a 10,000-Hz filter has 10,000 times as many hertz in its bandpass as does a 1000-Hz filter. A complementary noise characteristic can be derived from white noise by using a 1/f *energy* filter in which energy must decrease at a 6-dB/octave rate.

Since the voltage of an electrical signal is proportional to the square root of the power, the noise voltage must decrease at a square-root of 1/f rate or 3 dB/octave. With a similar analogy to white light filtered in this manner, the resulting signal is called "pink" noise.

The frequency characteristics of both white and pink noise are shown in graph form in Fig. 1.

Noise Generation. Among the various methods of generating white noise, the most common employs the avalanche or reverse-breakdown characteristics of a pn junction. The "Surfer" (June 1979) is a good example of this type of circuit. In measurement-quality systems, the noise junction must be selected, operating-current trimmed, and gain adjusted to yield the required noise quality and amplitude uniformity. For highest accuracy, junction temperature should be stabilized or compensated. Even with these restraints, this technique is widely used in r-f and very broadband applications.

A wholly different approach is the use of a random digital number generator as a noise source. If the bandwidth of interest is sufficiently restricted, a digital technique used in many computer programs to generate a pseudorandom sequence can be applied. In this form, a pattern of 1's and 0's statistically uniform in character will be produced. The sequence generated is stable and repeatable in both amplitude and character to within a small fraction of a decibel. General implementation of this approach (Fig. 2) consists of an N-stage shift register with a tap at stage M. Both M and N are inputs to a modulo-2 adder (exclusive-OR gate) that feeds the shift register input clocked by an oscillator. Proper choice of M and N will produce a maximum sequence length of $2^N - 1$ clock pulses.

About the Circuit. The schematic diagram of the Audio Noise Source is shown in Fig. 3. The N-stage shift register is divided into M-stage register *IC2* and (N−M)-stage register *IC3*. Both *IC2* and *IC3* are CMOS shift registers.

The *IC1D* section of the quad XOR gate performs the modulo-2 addition function. The remaining three sections of *IC1* are connected as inverters in a standard CMOS oscillator configuration. Oscillation frequency is determined by *R1* and *C1* and, with the values specified, is about 300 kHz.

Both *IC2* and *IC3* can be wired to be 4, 5, 8, 9, 10, 12, 13, 14, 16, 17, or 18 stages in length. With these available lengths, two ICs can be cascaded for an M of 13 and an N of 31 to produce a length of $2^{31} - 1$ clock periods—almost 2 hours in duration. This is the longest sequence that can be generated with two 4006 shift registers and the elementary two-input feedback mechanism. The noise half-power frequency exceeds 100 kHz, and the output can be from any point along the register.

In *S1*'s WHITE position, the register's output passes through a one-pole low-pass filter consisting of *R8, R9, R10,* and *C8* at about 72 kHz and is buffered by *Q1.* The white-noise spectrum available at *J1* is flat to within ±0.33 dB from 10 to 20,000 Hz.

To obtain pink noise, a 3-dB/octave low-pass filter must be synthesized. Since a simple pole or zero filter has a 6-dB/octave slope, several lag networks can be cascaded so that the zeros of one section partially cancel the poles of the next. The network consisting of *R4* through *R7* and *C3* through *C7* exhibits a −3-dB/octave slope ±0.5 dB from 10 to 40,000 Hz. To maintain the high accuracy inherent in the design, the capacitors and resistors that make up the network should have 5% tolerances. Amplitudes of the white and pink noises are dependent on the supply voltage and measurement bandwidth. The rms potential is roughly 0.01 volt from 20 to 20,000 Hz. With a 9-volt supply, the output potential of either white or pink noise is 90 mV. (Current consumption with a 9-volt battery is less than 8 mA.) As shown in Fig. 1, the white-noise voltage is adjusted to be equal to the pink-noise voltage at 2870 Hz.

The circuit is designed to function properly from a 3-to-15-volt dc power source. Current consumption is very low, owing to the use of CMOS devices.

Construction. This is a relatively easy project to build, thanks to its limited number of components. Since there are no restraints on component layout and wire routing, just about any wiring technique can be employed. However, to make the project as compact as possible, it is best to use a printed circuit board, an etching-and-drilling guide and components-placement diagram for which are shown in Fig. 4.

If you use a pc board, wire it as shown. You can use sockets for the ICs if desired, and do not forget to install the three jumpers. Be sure to properly orient the ICs, *Q1,* and *C9,*

Mount the finished circuit-board assembly and *B1* and its battery holder in a small box. Function switch *S1* and output jack *J1* can be mounted on the front of the box and connected to the circuit board assembly with short lengths of hookup wire. Finally, use a dry-transfer lettering kit to label the positions of *S1* and identify *J1.*

Applications. Since both pink and white noise are statistically random quantities, characterizing them by a single voltage or power specification is difficult at best. Special sampling techniques using a specified time and frequency "window" coupled with a true-rms detector are required.

When the noise source is applied to a spectrum analyzer, the slowest sweep speed or longest averaging time consistent with a reasonable measurement should be selected. If you use the companion LED Spectrum Analyzer in our September issue, set the DECAY switch to SLOW when performing noise analyses. Even in this condition, the

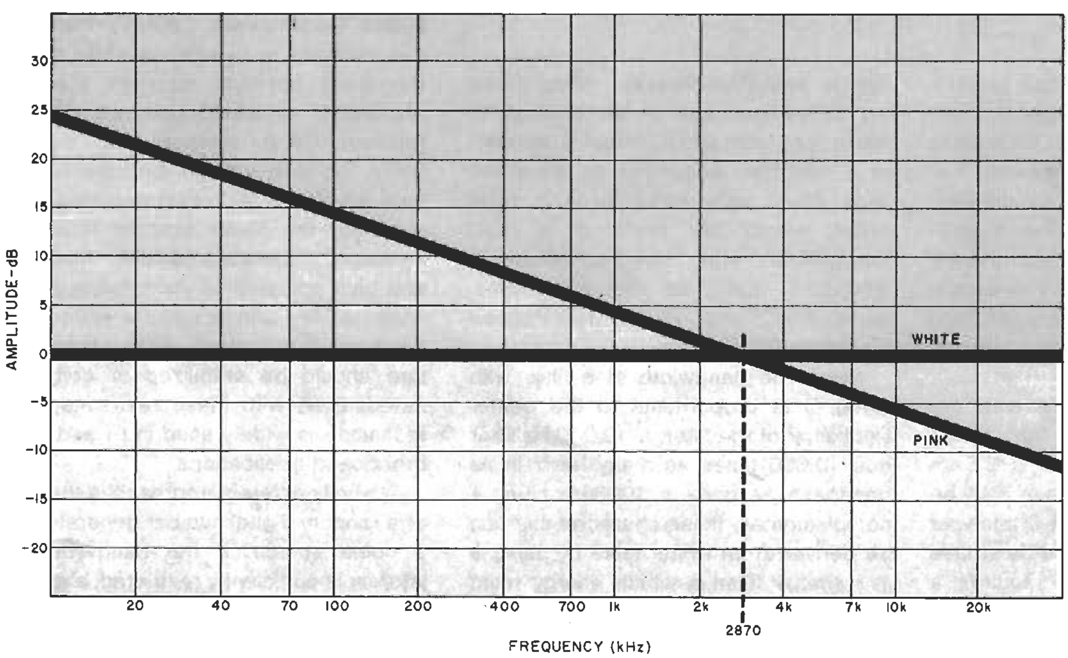


Fig. 1. Noise spectra of white and pink noise. In the generator described here, the two amplitudes are similar at 2870 kHz.

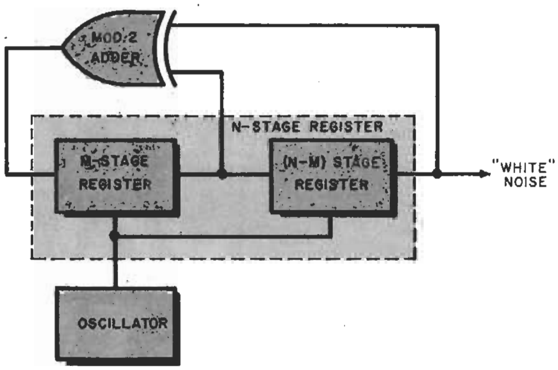


Fig. 2. Block diagram of a pseudo-random noise generator used to create white noise.

lower-frequency channels might exhibit some amplitude flicker. However, high-accuracy measurements are still possible if you mentally average the display reading. Simply note which particular channel LED is on most of the time.

The microphone in the LED Spectrum Analyzer is a free-field type, which should be pointed directly at the sound source. To avoid substantial errors in the middle-frequency region, caused by reflections and absorptions of your body, stay as far from the pickup as practical when making measurements.

Positioning the analyzer a proper distance from the source is also of critical importance for accurate measurements. Data taken too near the source will display wide variations with small changes in analyzer position due to diffraction and dispersion irregularities. Readings taken too far from the source are prone to environmental reflections and noise.

In the optimum free-field area, the inverse square, law relating sound intensity to changes in distance from the source, applies. Thus, if the distance from the source to the analyzer is increased by a factor of 1.33, the sound level should decrease by 2.5 dB. This distance is usually greater than one wavelength of the lowest frequency to be measured. At 63 Hz, about 18' (5.5 m) may be adequate. The microphone should be no closer than twice the largest dimension of the source.

Loudspeaker Evaluation. Figure 5 illustrates a typical system interconnection for loudspeaker testing and evalua-

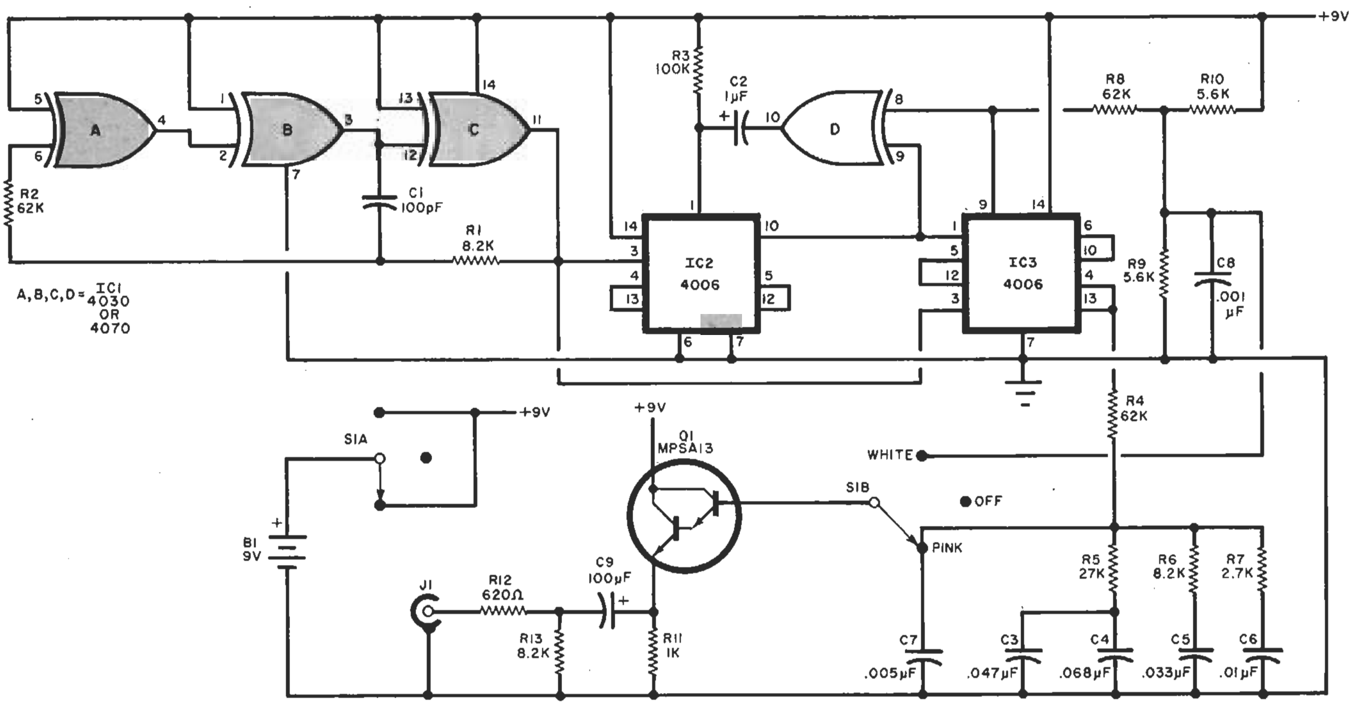


Fig. 3. Noise generator consists of two 18-stage shift registers with an adder.

PARTS LIST

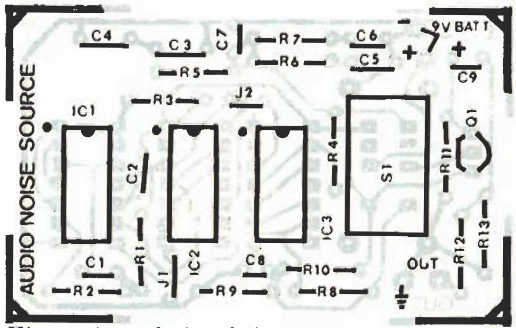
B1—9-volt battery
C1—100-pF, low-temperature-coefficient
C2—1-μF, 16-volt electrolytic
C3—0.047-μF, 100-volt 5% Mylar
C4—0.068-μF, 100-volt 5% Mylar
C5—0.033-μF, 100-volt 5% Mylar
C6—0.01-μF, 100-volt 5% Mylar
C7—0.005-μF, 100-volt 5% Mylar
C8—0.001-μF, 100-volt 10% Mylar
C9—100-μF, 10-volt electrolytic
IC1—CD4030AE quad XOR gate (or similar)
IC2,IC3—CD4006AE 18-stage shift register (or similar)
J1—Phono jack
Q1—MPSA13 Darlington transistor
The following are 1/4-watt, 5% resistors:
R1,R6,R13—8200 ohms
R2,R4,R8—62,000 ohms
R3—100,000 ohms
R5—27,000 ohms
R7—2700 ohms
R9,R10—5600 ohms
R11—1000 ohms
R12—620 ohms
S1—Dp3t switch
Misc.—Suitable enclosure; battery holder; hookup wire; etc.

Note—The following are available from Gold Line Inc., P.O. Box 20, Redding, CT 06875 (Tel: 203-938-2588): Complete kit including case for $39.95. + $1.50 for shipping and handling. Also available separately: etched, drilled, and screened pc board for $7.95. The companion ASA-10 hand-held LED audio analyzer kit (Popular Electronics, September 1979) is available for $139.00 ($199.95, wired and tested). Connecticut residents, please add 7% sales tax.

tion. The pink-noise source can be either the noise generator described above or a pink-noise record or tape. All tone controls and equalizer settings should be defeated or set flat.

Adjust amplifier level for moderate volume and adjust analyzer gain for the flattest display near the 0-dB level with the DECAY switch on the LED Spectrum Analyzer set to SLOW. The spectrum analyzer will then display the combined response of the speaker, room and electrical signal path.

By connecting the amplifier's speaker terminals to the analyzer's external input, the electrical signal conditions can be determined and subtracted from the combined response. Moving the analyzer with its built-in microphone around the test area will provide an indication of the speaker's directional characteristics. On the other hand, leaving the analyzer stationary and moving the speaker around will demonstrate the importance of proper speaker placement in optimizing frequency response.



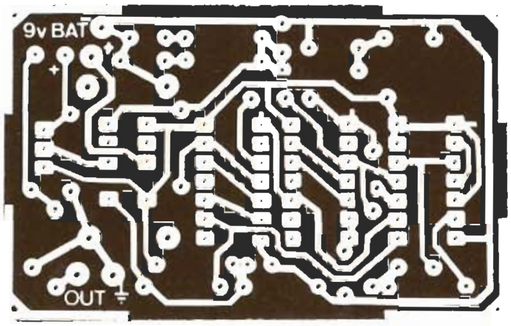


Fig. 4. Actual-size foil pattern (above) and component installation for noise generator.

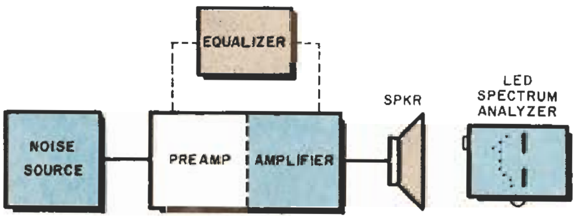


Fig. 5. To test a speaker, use noise generator to drive audio system and hold LED spectrum analyzer at various points in sonic field.

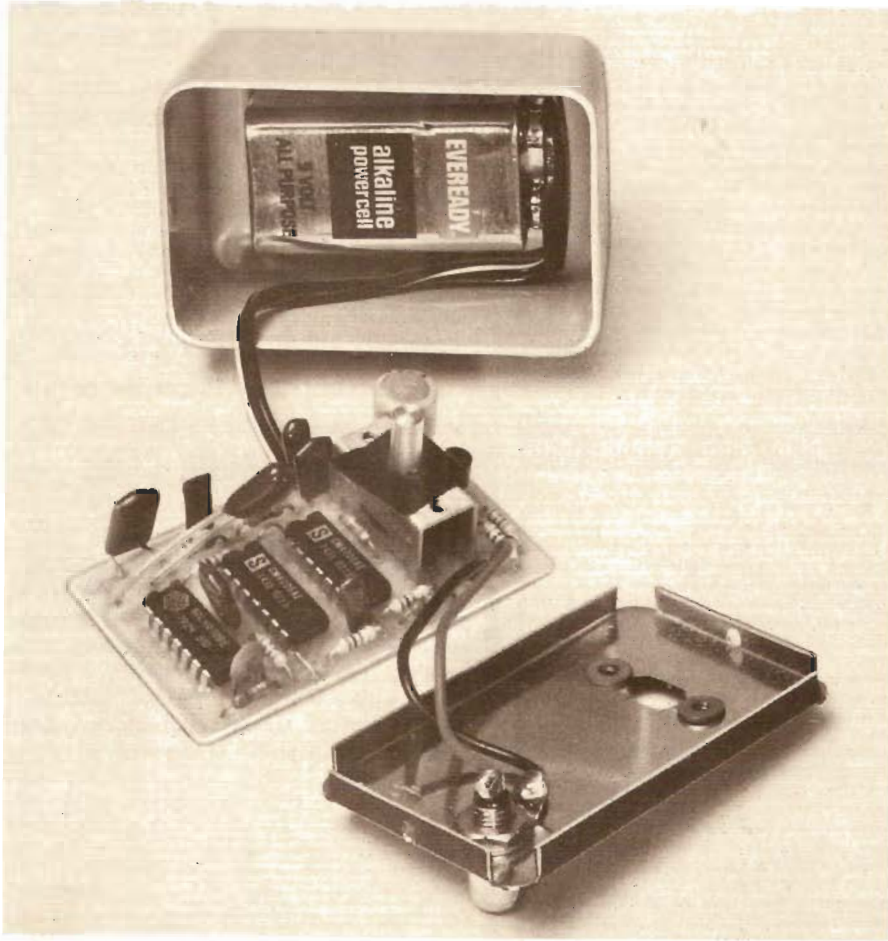


Photo shows construction of author's prototype generator. Use of printed circuit board makes the unit as compact as possible.

Environment Equalization. If a sound system has suitable tone-control flexibility or a graphic or parametric equalizer, a typical listening environment can be considerably improved, using the setup shown in Fig. 5. Real-time analysis (RTA) has been successfully applied to living rooms, concert halls, discos, and even to vehicles. In the last case, the advent of autosound systems with equalizers and high-quality amplifiers and speakers makes RTA an exciting prospect in achieving realistic mobile sound.

With the analyzer placed in the anticipated normal listening position and all frequency balance controls set flat (or switched out), apply pink noise at a moderate level. In stereo or quad systems, apply the signal to only one channel at a time. Make small changes in speaker system position and orientation, if possible, to optimize the frequency response displayed on the analyzer. Any crossover controls can now be adjusted. Finally, tone and equalizer settings can be optimized to flatten overall frequency response to within a couple of decibels.

Do not assume that the settings developed for one channel can be applied to other channels. Each speaker system should be equalized separately.

Tape-Recorder Alignment. Play a high-accuracy prerecorded pink-noise tape with the analyzer connected to the tape recorder's output. (The internal microphone is not used.) Adjust playback-head azimuth for maximum output in the 16-kHz channel. The oscilloscope output of the Hand-Held LED Spectrum Analyzer can be useful for highest resolution. Complete the play alignment by adjusting the reproduce equalization controls for a flat spectral display.

Begin record alignment with the tape you normally use and pink noise fed to the recorder's input. Assuming you have a three-head recorder capable of simultaneous recording and *tape* monitoring, connect the analyzer to the deck's output. Adjust record-head azimuth for a maximum 16-kHz output. Then adjust record bias (if accessible) for maximum at 1 kHz. Increase bias current until a 2-dB drop in the 16-kHz response is obtained. Finally, trim the record equalization controls for flattest displayed frequency response.

Aligning two-head tape decks is more time consuming. Each time an adjustment is made during record, the tape must be rewound and played to determine the effects of the adjustment.

In either case, tape-recorder alignment using RTA is much easier and faster than conventional methods.

Noise Abatement. The Walsh-Healy Public Contracts Act and OSHA have set standards for permissible noise-exposure levels to avoid hearing damage. Noise-abatement procedures are often required to comply with these standards. The techniques are well documented and can be extremely effective, provided the noise-frequency spectrum is known.

Enter RTA! When the noise frequencies to be attenuated are known, the characteristics of damping materials and their placement can be determined and dimensions of required resonant cavities can be calculated. Time-consuming "cut-and-try" procedures can be kept at a minimum, and the results of abatement engineering can be easily documented. ◇

Experimenter's Corner

By Forrest M. Mims

EXPERIMENTING WITH NOISE

THOSE of us who appreciate good-quality sound reproduction might disagree about the definition of good music, but it is safe to say that all audio enthusiasts share a common opinion of noise—the less the better! Noise is equally unpopular among radio astronomers, biomedical engineers, radio communications users, and others who work with low-level electrical and electromagnetic signals.

So much engineering effort is devoted to the suppression of noise (it can *never* be entirely eliminated) that it might come as something of a surprise that there are many useful applications for noise. These include acoustics measurements, instrument calibration, antenna tuning, signal jamming, data encryption, electronic music and even applied psychology! This month, we'll examine several methods of generating noise and explore a few of its uses. First, let's define a few basic terms.

Noise can loosely be called an electronic or electromagnetic weed. More precisely, noise is an undesired electronic or electromagnetic signal having frequency components within the frequency range of interest which tends to interfere with the reception or detection of desired signals. By definition it excludes crosstalk and interference from other information-carrying signals within the frequency range of interest.

There are many kinds of noise. We are primarily interested in *white noise* and *pink noise*. White noise is a complex waveform with a Gaussian amplitude probability characteristic. It is formed by contributions from all frequencies over a theoretically infinite but, in practice, broad and specified bandwidth. White noise has a flat (constant) spectral power density. Thus, it contains equal energy per unit of frequency (Hertz). Transduced, audible white noise contains equal contributions from all audio frequencies perceptible to the human ear. It is thus analogous to white light, which comprises all wavelengths (colors) perceptible to the human eye.

Pink noise is also a complex waveform with a Gaussian amplitude probability characteristic and is also formed by contributions from all frequencies over a theoretically infinite but, in practice, broad and specified bandwidth. Pink noise contains equal energy levels in each octave of its spectrum. Because each next-higher octave possesses twice the number of discrete frequencies (in hertz) as compared to the octave immediately below it, the low-frequency components of pink noise have higher amplitudes than the high-frequency components. This is necessary if pink noise is to contain equal amounts of energy in each octave of its spectrum. Audible pink noise, therefore, has more bass content than white noise and sounds "warmer."

Plots of amplitude versus frequency for white noise (dashed line) and pink noise (solid line) appear in Fig. 1. Note that pink noise displays a −3/dB octave slope. If white noise is routed through a low-pass filter having a −3-dB/octave response, the filtered signal will be pink noise. Pink noise is commonly used as a test signal in audio work because many audio spectrum analyzers are "constant percentage bandwidth" instruments. That is, the passband of each bandpass filter in these analyzers is an unchanging percentage of its center frequency. Therefore, the higher the center frequency of the filter, the broader its bandpass. If white noise is applied to such an analyzer, a rising 3-dB/octave characteristic will be displayed. If pink noise is applied to the analyzer input, a flat amplitude-versus-frequency characteristic will be indicated. The most common audio applications for a pink noise source and such a spectrum analyzer is in frequency-response testing of audio preamplifiers and amplifiers and in the equalization of an audio system in a listening room.

Now that we have examined some basic ideas about noise, let's see some circuits that generate and employ it.

Diode Noise Generators. The simplest noise generator is a forward-biased diode. Figure 2 shows a basic diode noise generator that you can quickly assemble. Connect the circuit to an audio amplifier (capacitive coupling might be necessary) and the speaker will produce a continuous rushing or hissing sound.

A circuit like this can be used to adjust a radio receiver for optimum noise figure. With a suitable diode such as the 1N21 or 1N23 and short, point-to-point wiring, the generator will produce wideband noise with components extending as high as 148 MHz. The ARRL *Radio Amateur's Handbook*, which describes how to make receiver noise adjustments, suggests adding a 500-pF capacitor between the anode of *D1* and ground. It also suggests inserting a 50,000-ohm potentiometer, preferrably one with a logarithmic taper, in series with the anode of *D1* and the positive power supply terminal to permit adjustment of the noise amplitude.

If you like to experiment, try various kinds of diodes for *D1*. A red LED, for example, produces both light *and* noise. Of course, you must increase the value of *R1* to protect the LED from excessive current levels. Use 470 ohms when the voltage of *B1* is +6 volts and 820 ohms when *B1* is a 9-volt battery.

Transistor Noise Generators. When reverse-biased beyond the avalanche point, the emitter-base junction of a bipolar junction tran-

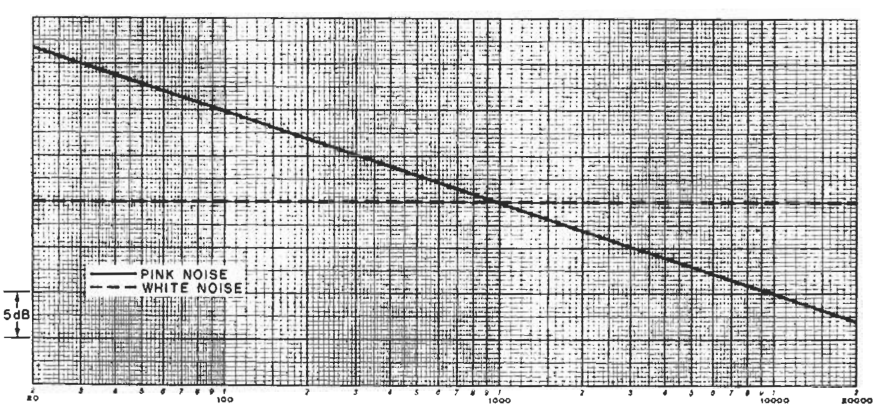


Fig. 1. Plots of amplitude versus frequency for white noise and pink noise.

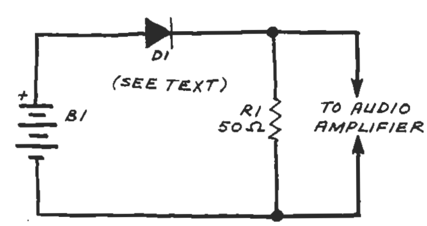


Fig. 2. Simple schematic of basic diode noise generator.

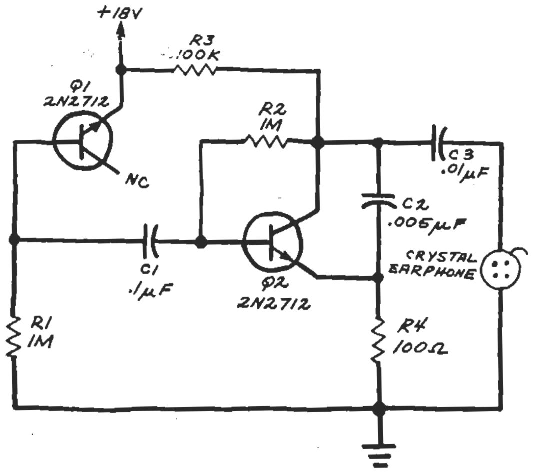


Fig. 3. Noise generator designed by John Simonton.

sistor generates noise. In the winter edition of the 1975 *Electronic Experimenter's Handbook*, John S. Simonton, Jr. described how to assemble a pocket-size sonic noise generator based upon this effect. John noted in his article that pink noise is an excellent mechanism for masking and thereby concealing low-level sound such as a confidential conversation. John also noted that audible pink noise can help produce a feeling of relaxation and can in some cases block pain stimuli.

Figure 3 is the schematic diagram of John's circuit. In operation, *R1* limits the current through the reverse-biased emitter-base junction of *Q1* to a safe value. The noise signal is coupled to amplifier *Q2* via *D1*. After the noise has been amplified, *C2* shunts some of the high-frequency components to ground. The resulting output signal, which is transduced by a high-impedance earphone, is a reasonable approximation of pink noise.

John points out that most 2N2712s will produce noise, but some will not. Should you want to try other transistor types, make sure they have an emitter-base breakdown voltages of less than 18 volts.

Shift Register Digital Noise Generators. Figure 4 shows a simple 7-stage shift-register pseudorandom bit generator which produces a sequence of 127 bits before recycling. Other shift-register/exclusive-OR gate arrangements can be used to produce shorter or longer sequences.

White noise is synthesized when a pseudorandom bit generator such as the one in Fig. 4 is clocked at a sufficiently fast rate. Shift-register generated noise is not necessarily as random as that produced by a diode, especially if a relatively small number of stages is involved. But the noise level is more uniform and of a much higher amplitude than that from a diode.

If you would like to experiment with digital noise generators of this type, see pages 277 to 283 of *TTL Cookbook*, by Don Lancaster (published by Howard W. Sams). Don describes several interesting applications, including a scrambler for encoding computer data, and he also gives schematics of several shift-register pseudorandom sequencers.

S2688/MM5837 Digital Noise Generator. The S2688/MM5837 (National Semiconductor) is a complete PMOS digital noise generator in an 8-pin mini-DIP. The internal circuit, shown in Figure 5, consists of a 17-stage shift register, some gates and a clock. Pseudorandom bit patterns are produced by connecting the outputs of the 14th and 17th stages of the shift register to an exclusive-OR gate whose output is applied to the input of the first stage in the shift register.

A 17-input NOR gate monitors the output of each stage of the shift register. Should the outputs of all 17 stages simultaneously go low, the NOR gate prevents a lockup condition (a continuous output of all 0's) by automatically applying a logic 1 to the third input of the exclusive-OR gate. This, in turn, applies a logic 1 to the first stage of the shift register.

The S2688/MM5837 is exceptionally easy to use. If the output is connected to an op amp or other high-impedance circuit, the chip can be powered by a single supply ($V_{SS} = 0$ V and $V_{DD} = -14$ V ± 1 V). If the chip must drive a low impedance, V_{GG} should be connected to -27 V $\pm$ 2 V.

Though it is recommended that V_{DD} be within a volt of -14 V, I've found that the internal clock speed can be altered by varying V_{DD}. Here's what I measured:

V_{DD}	Approximate Clock Frequency (Hz)
−5	0
−6	0.7
−7	2267
−8	8731
−9	16,382
−10	23,531
−11	32,564
−12	38,347
−13	40,010
−14	37,800
−15	33,173

Because broadband noise is best suited for most audio applications, it's evident that a supply voltage of −12 to −14 volts gives the best noise quality. However, the lower frequency noise generated when lower supply voltages are used has several possible applications. For example, when V_{DD} is between −6 and −7 volts and the noise generator is coupled to an audio amplifier, the random clicks of a radiation counter can be simulated.

(Continued on page 82)

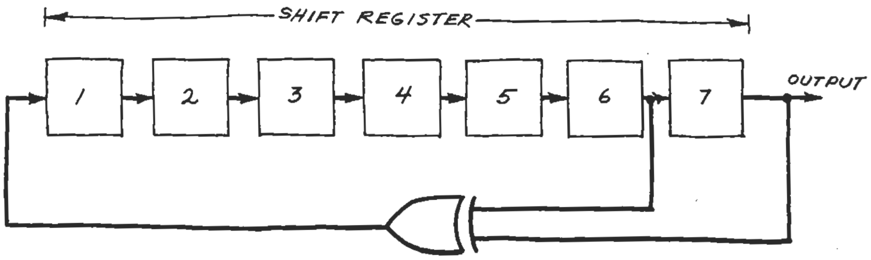


Fig. 4. Basic pseudorandom bit generator.

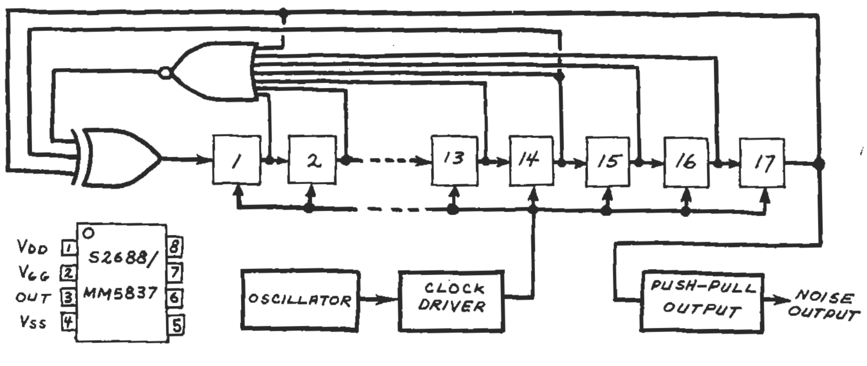


Fig. 5. Block diagram of S2688/MM5837 digital noise generator.

S2688/MM5837 Pink Noise Generator. Pink noise, which is required for room equalizing and other acoustical applications, can be produced by following an S2688/MM5837 with a −3 dB/octave low-pass filter. One such filter appears in National Semiconductor's *Audio Handbook* (Fig. 2.17.6, p. 2-56) and is shown connected to an S2688/MM5837 in Fig. 6. The pink noise produced by this generator contains equal amounts of energy in each octave of the audio spectrum from 20 Hz to 20 kHz. The output is about 1 volt of pink noise superimposed on an 8.5-volt dc level.

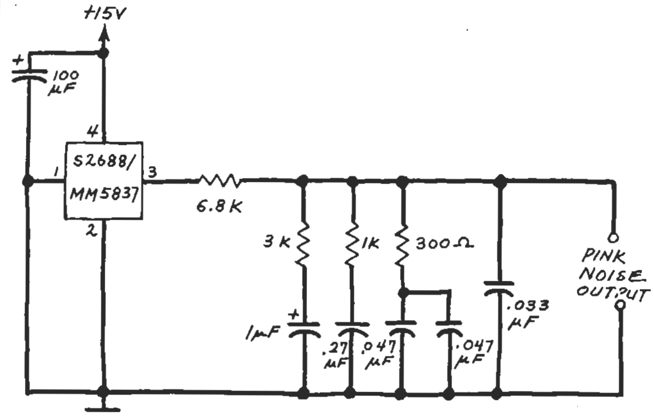


Fig. 6. Pink noise generator using S2688/MM5837.

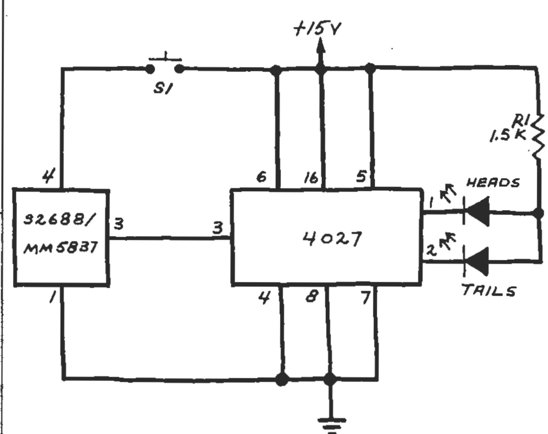


Fig. 7. Noise generator coin tosser.

Coin Tosser. Circuits that produce a completely random binary output are much in demand. Figure 7 shows a simple random-output circuit made from a noise generator and a 4027 flip-flop operated in its toggle mode.

Pressing *S1* applies power to the noise-generator chip and causes noise pulses to be applied to the flip-flop. The output LEDs appear to glow continuously even though they are rapidly being switched on and off by the noise pulses. Releasing *S1* turns off the noise chip. The logic states at the outputs of the 4027 then reflect the input status at the time that the noise is cutoff. Therefore, only one of the two LEDs glows.

Ideally, the output of the tosser should be completely random. With my circuit, however, in 100 tosses, green came up 56 times and red 44 times. I tried another 100 tosses and this time green came up only 43 times while red came up 57 times. These results seemed contradictory and not very random until I added them together. The result: In 200 tosses green glowed 99 times and red glowed 101 times.

SN76477N/SN76488N Complex Sound Generator. This versatile chip is literally a complete sound-effects machine in a 28-pin DIP. It includes a noise generator which can be modulated by a low-frequency oscillator to produce propeller-aircraft, steam-engine, snare, and other sounds.

There are so many uses for the SN76477N/SN76488N that we can't do this chip justice here. If you want to find out more about its operation, see the Texas Instruments data sheet and pages 42 and 43 of the *Engineer's Notebook* (Radio Shack). ◇

Shift register with feedback generates white noise

by Marc Damashek
Clarke School for the Deaf, Northampton, Mass.

A shift register with linear feedback generates a pseudorandom sequence of pulses that can be used without digital-to-analog conversion or audio processing as extremely high-quality audio white noise. The output from the register, fed directly to an audio amplifier, produces a power spectrum that is flat to within ±1 decibel over the entire audio range.

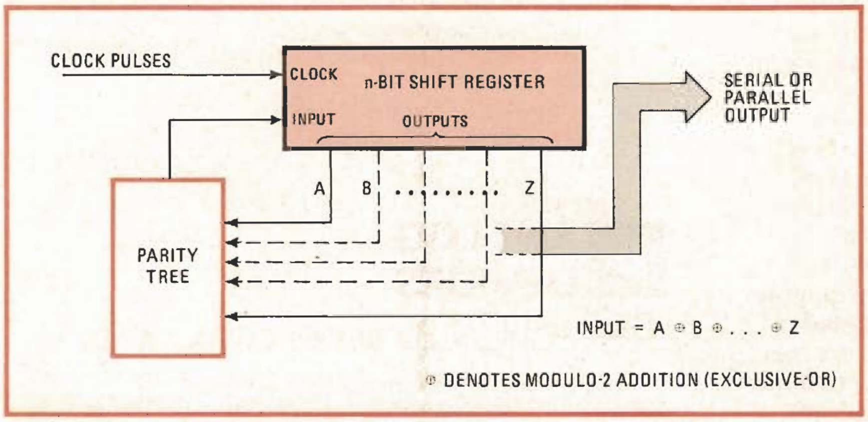
The operating principles of a linear-feedback shift register (LFSR) are illustrated in Fig. 1. The input to the first stage of an n-bit register is determined at each clock pulse by the exclusive-OR (parity) function of some output taps of the register. Choosing these taps is the crucial step in constructing a LFSR that performs as required.

For an n-bit shift register, taps can be chosen so that the register cycles through $2^n - 1$ different states before repeating any previous state. All possible n-bit words are generated except the word containing only 0s [*Electronics*, Nov. 27, 1975, p. 104]. In addition, with the use of only two taps, some shift-register lengths can produce these maximal-length sequences. A partial list of such registers is given in the table, which is excerpted from "Shift Register Sequences," by S. Golomb (Holden-Day Inc., San Francisco, 1967). As the table shows, even shift registers that are only moderately long can produce astronomically long sequences.

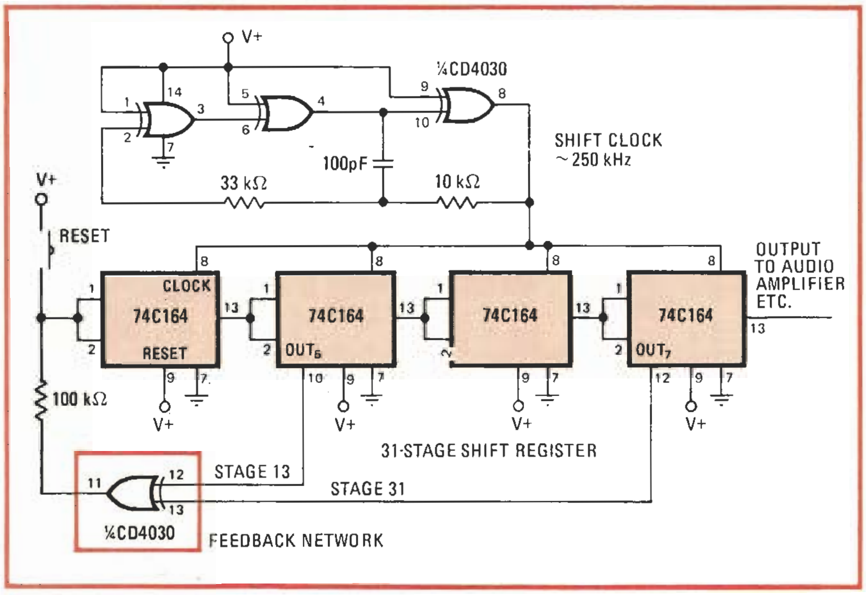
An appropriate clock and a sufficiently long register generate a flat power spectrum of audio white noise, using the digital bit stream itself as the noise source. Fig-

MAXIMUM-LENGTH LINEAR-FEEDBACK SHIFT REGISTERS THAT REQUIRE ONLY TWO FEEDBACK TAPS

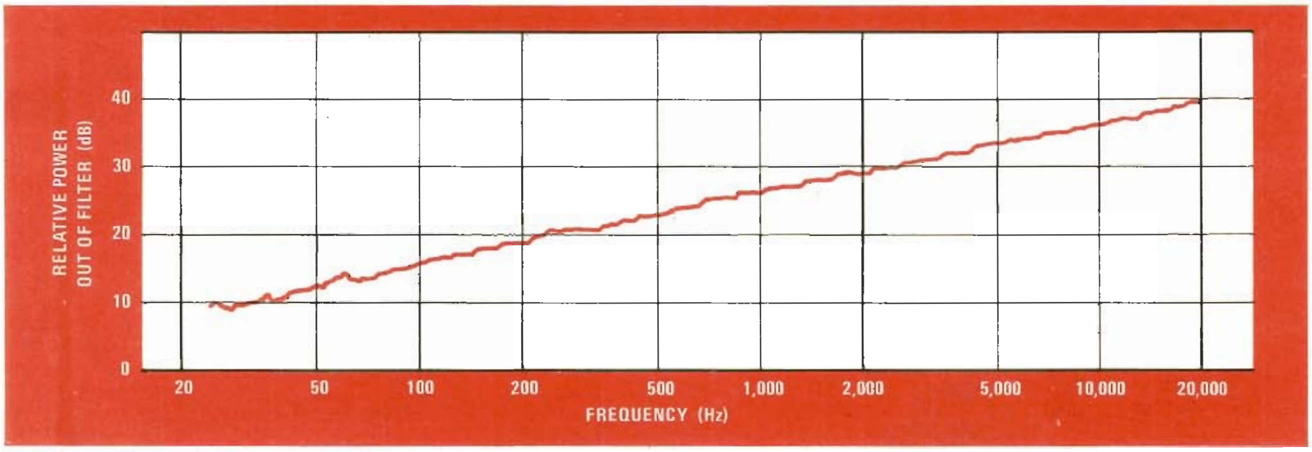
No. of stages	Stages at which taps are placed	Sequence length	Duration of sequence using 250-kHz clock
7	1, 7 or 3, 7	127	0.51 ms
9	4, 9	511	2.0 ms
10	3, 10	1,023	4.1 ms
11	2, 11	2,047	8.2 ms
15	1, 15 or 4, 15 or 7, 15	32,767	131 ms
17	3, 17 or 5, 17 or 6, 17	131,071	0.52 s
18	7, 18	262,143	1.0 s
20	3, 20	1,048,575	4.2 s
21	2, 21	2,097,151	8.4 s
22	1, 22	4,194,303	17 s
23	5, 23 or 9, 23	8,388,607	34 s
25	3, 25 or 7, 25	33,554,431	2.2 m
28	3, 28 or 9, 28 or 13, 28	268,435,455	18 m
29	2, 29	536,870,911	36 m
31	3, 31 or 6, 31 or 7, 31 or 13, 31	2,147,483,647	2.4 h
33	13, 33	8,589,934,591	9.5 h
35	2, 35	34,359,738,367	1.6 d
36	11, 36	68,719,476,735	3.2 d
39	4, 39 or 8, 39 or 14, 39	5.5×10^{11}	25 d
41	3, 41 or 20, 41	2.2×10^{12}	102 d



1. Pseudorandom pulses . . . In this linear-feedback shift register, some of the output ports are connected back to the input through an exclusive-OR circuit. Depending upon which output taps are fed back, a nonrepeating sequence of any length up to $2^n - 1$ binary words can be generated.



2. . . . generate noise . . . This 31-stage linear-feedback shift register is arranged to produce a maximum-length pseudorandom bit sequence by connection of stages 13 and 31 back to input. Output bit stream, which can be taken from any port, constitutes a white-noise source.



3. . . . like this. The output power spectrum of the circuit in Fig. 2, measured directly at the output of stage 31, slopes upward because filter bandwidth is proportional to frequency. The slope of 3 dB/octave indicates white noise. Reference level (0 dB) was chosen arbitrarily.

ure 2 shows a 31-stage LFSR, with taps at stages 13 and 31 and a shift clock running at 250 kilohertz.

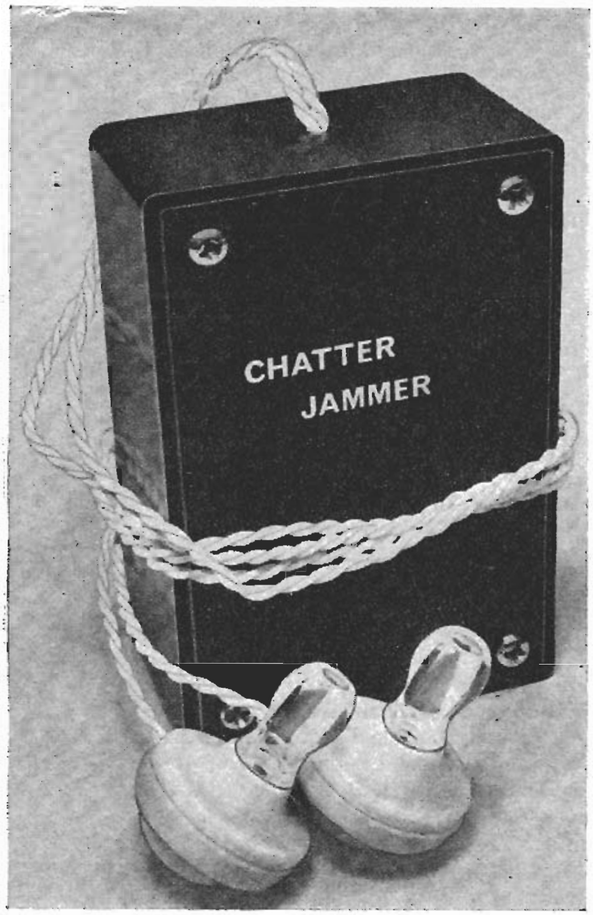
Any shift register that provides access to the required feedback bits will serve. For instance, two CD4006s might have been used instead of the 74C164s. With only three ICs, these shift registers can give access to bits 13 and 31. For a white-noise generator in audio applications, the component values are noncritical. The reset button ensures that at least a single 1 is initially in the shift register, but the manual button can be replaced by a more elaborate initialization circuit if desirable.

The audio-power spectrum from the circuit in Fig. 2, measured directly at the output of stage 31, is shown in Fig. 3. A series of ⅓-octave filters measures the spectrum. The curve is inclined upward at a rate of 3 decibels per octave, matching the increasing bandwidth of the filters. The deviation from a straight line inclined 3 dB/octave is less than 1 dB over the frequency interval from 25 Hz to 20 kHz. The largest deviation occurs at the power-line frequency of 60 Hz. The table shows that the string produced by this register is longer than 2 billion bits and, at a 250-kHz clock rate, will take more than two hours to repeat.

The LFSR pulse sequences are also used for error-correcting codes, spread-spectrum techniques [*Electronics*, May 29, 1975, p. 127], and other random-selection processes. In a maximum-length LFSR n bits long, the bit string produced is statistically identical to $2^n - 1$ flips of an ideal coin (one with precisely equal probabilities of landing heads or tails). Thus, for example, a 17-stage LFSR can generate the equivalent of 131,071 coin-flips. Any stage of the register may provide the output, since every bit is eventually shifted the entire length of the register.

Such a device could be useful for producing uncorrelated stimuli in a psychophysical experiment, because it could easily determine which of two possible stimuli to present to a test subject. It can do so with an undiscernible, yet repeatable, pattern so that a second test subject could be given the same sequence of stimuli. If the bit string from the 31-stage register in Fig. 2 were used for test stimuli with an average interval between stimuli of 5 seconds, it would not repeat for 340 years. □

Designer's casebook is a regular feature in Electronics. We invite readers to submit original and unpublished circuit ideas and solutions to design problems. Explain briefly but thoroughly the circuit's operating principle and purpose. We'll pay $50 for each item published.



BUILD A PINK NOISE GENERATOR

CUT OUT NOISE POLLUTION AND KEEP YOUR COOL

This article is about a unique device that masks disturbing noises by substituting the gentle "rushing" sound of pink noise. Self-contained, the pink noise generator can be assembled in less than an hour. Its masking effect should not be underestimated.

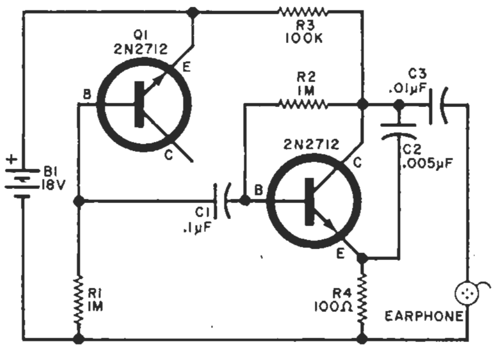
EVERY FAN of spy movies knows that the best way to keep hidden mikes from picking up top-secret information is to repeat the information only while you've got a shower running. Why? Because the sound of the shower covers up the conversation. Probably any sound, such as jack hammers or rock and roll music would do, but a real pro spy will settle only for a shower because it simulates a thing called pink noise.

Pink noise is a special case of a large general class of signal called white noise. Whereas white noise is a Gaussian (equal probability) distribution of all possible frequencies, pink noise is a distribution which is weighted toward the audio spectrum.

Besides being able to mask outside sounds, white noise has some other interesting properties. For instance, many people find a rain storm relaxing; and, while other effects such as the high concentration of ionized air may have some effect, at least part of the general feeling of well-being can be traced to the sound of the falling raindrops—a type of pink noise. The same is true of the sound of the ocean.

Some years ago a group of dentists experimented with the use of pink noise in the place

BY JOHN S. SIMONTON, JR.



PARTS LIST

B1—Two 9-volt transistor batteries connected in series
C1—0.1-µF disc capacitor
C2—0.005-µF disc capacitor
C3—0.01-µF disc capacitor
Q1,Q2—2N2712 transistor (see text)
R1,R2—1-megohm, ½-watt, 10% tolerance resistor
R3—100,000-ohm, ½-watt, 10% tolerance resistor
R4—100-ohm, ½-watt, 10% tolerance resistor
Misc.—Crystal earphones (2); printed circuit board (optional); plastic or Bakelite case; hookup wire; solder; etc.
Note—The following items are available from PAIA Electronics, Inc., P.O. Box 14359, Oklahoma City, OK 73114: etched and drilled printed circuit board for $1.00; complete kit of parts, including PC board but not including batteries for $4.75.

Fig. 1. Operated in avalanche, Q1 serves as pink noise source. To preserve constant-level signal characteristic of pink noise, C2 shunts appropriate levels of high frequencies away from earphone.

of local anesthetics. The results were questionable but in some patients the noise seemed to create a definite reaction on the nervous system so that pain sensations were blocked. Finally, several rock and roll groups mix a little pink noise in with their recordings to add body to the sound—which may be why so many of them are unintelligable.

The point of all this is that, if you must work in a noisy environment and sometimes have trouble concentrating or if you're just "up tight," you might want to try the "Chatter Jammer," a cheap, shirt-pocket-size generator of pink noise that not only keeps the noise out but will probably soothe your nerves as well.

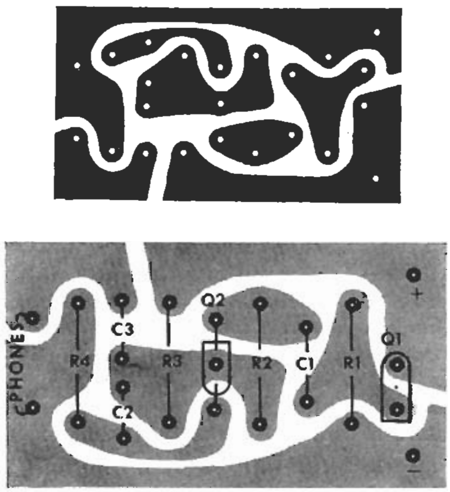


Fig. 2. PC board etching and drilling guide at top is shown full size. Directly above is components placement and orientation diagram.

Theory of Circuit Design. As can be seen from the schematic diagram in Fig. 1, the circuit of the Chatter Jammer is very simple. Transistor *Q1* is a silicon type that has a low emitter-to-base breakdown voltage rating. The base-emitter junction is reverse biased by the two series-connected 9-volt batteries that make up *B1*. In this setup, the base-emitter junction is operated in an avalanche condition.

Resistor *R1* in the base circuit of *Q1* limits the current flow through the junction and also serves as the load resistor for the shot noise which results from the avalanche process. The random ac voltage fluctuations produced by the avalanche effect are coupled into a single common-emitter amplifier stage, *Q2*, through capacitor *C1*. Once the signal is amplified, it is coupled through *C3* to the crystal earphones where it can be heard as a "rushing" sound similar to the sound you would hear if you held a seashell to your ear.

Capacitor *C2* shunts some of the high-frequency signal amplitude away from the earphone. As a result, all sound frequencies reaching the earphone are at one signal voltage level, giving the sound its "pink" characteristic.

Construction. There are only a dozen parts that make up the circuit of the Chatter

Jammer, including the earphones and battery pack. Add to this the fact that there are no high frequencies involved that could cause assembly problems, and you can readily see that just about any method of construction can be used. A printed circuit board, however, makes the project more compact and rugged. So, if you make your own circuit board, use the etching and drilling guide and components placement diagram in Fig. 2.

During construction, there is one point that you should be aware of. There is the remote possibility that the first transistor you try for *Q1* might not be a good noise source. Some transistors may not avalanche at all, while others may produce a very "grainy" sound. About 95 percent of all 2N2712 transistors will give the proper results; so, if you buy two for the project, at least one and probably both will work fine.

A power switch is not used on the Chatter Jammer for a very good reason. The current drain of the project's circuit is in the low-microampere region which means you will obtain essentially shelf life from the batteries even if the project is left on at all times.

Since the life of most 9-volt transistor batteries is so long, there is no reason why you should not simply solder leads from the batteries into the circuit instead of using battery clips that add to the project's cost. If you use stiff wire for the power leads, the leads can also support the circuit board.

The whole circuit, including board and batteries, fit neatly into a 3¼" × 2⅛" × 1⅛" plastic or Bakelite box (see photos). First drill a small exit hole for the earphone leads in one end of the box. Pass the leads of two crystal earphones through the hole and tie a knot about 2" from the free ends of the leads. Solder the leads to the appropriate points on the circuit board. (Note: Two earphones are used with the Chatter Jammer to increase the project's effectiveness. The addition of the second earphone will not affect the life of the battery supply.) A thin piece of Styrofoam can be cut to fit inside the case to keep the battery pack from working loose.

How To Use. Once the Chatter Jammer is operating properly, the only operation involved is to plug the earphones into your ears. You should immediately hear a rushing sound. Don't be surprised if it takes a minute or so to get used to the sound and feel of the earphones. After a short time, you will not be conscious of the rushing sound, nor will you be disturbed by extraneous sounds.

Musicians can try using the Chatter Jammer as a noise source by leaving the earphones off and connecting the output of the project to an unused high-impedance input of their instrument amplifiers. For a really strange effect, try passing the pink noise through a variable passband amplifier such as the "Waa-Waa" (POPULAR ELECTRONICS, Jan. 1970).

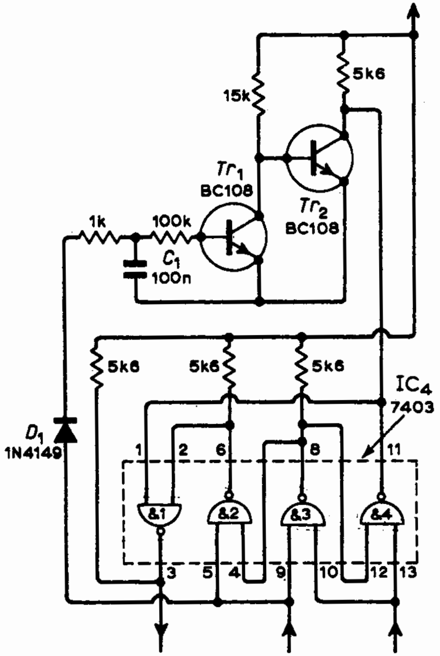
After you have used the Chatter Jammer for a while, you will be resorting to it whenever conditions prevent concentration or relaxation. It's sort of like having your own soothing rain sounds wherever and whenever you seem on edge. —30—

To keep batteries in place and prevent circuit board from rattling, place piece of rigid foamed plastic, cut to size, under circuit board as shown.

White noise generator

While the method of noise generation described by Mr. Beastall is very effective, his circuit can suffer from one very serious defect. If it happens that all the stages of the shift register are at 0 at switch on, the exclusive OR will give an output of 0 and thus the noise generator will not start.

This difficulty can be easily overcome by the addition of the circuit shown. So long as the output from the register (input to pin 9 of IC_4) switches between 0 and 1, D_1 will switch on, periodically charging C_1 and keeping Tr_1 bottomed. This switches Tr_2 off so that the circuit does not interfere with the normal running of the noise generator. However, should the output be 0 continuously, Tr_1 will turn off, turning Tr_2 on and earthing the input to gate 1. This injects a 1 into the input of the shift register thus causing the noise generator to start. Note! This modification will



Mr Waddington's modifications to Mr Beastall's white noise generator.

not work if a 7400 gate package is used as the 'wired OR' used at the input of gate 1 would cause gate 4 to burn out!

D. E. O'N. Waddington,
St. Albans,

AUDIO NOISE GENERATOR

eti project 441

Simple circuit generates both white and pink noise.

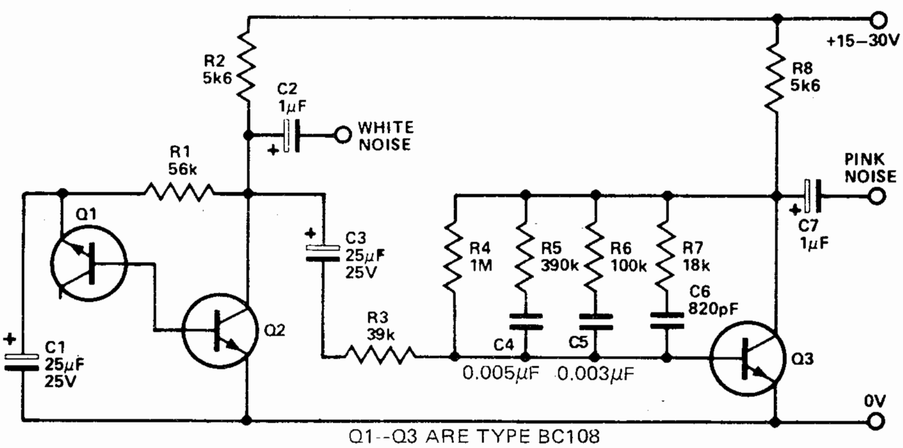
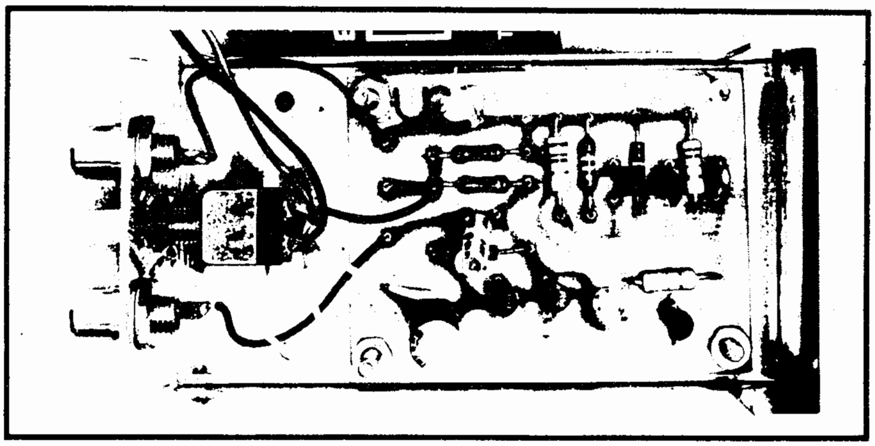


Fig. 1. Circuit diagram of the noise generator.

PARTS LIST — ETI 441				
R1	Resistor	56k	½W	5%
R2	"	5k6	½W	5%
R3	"	39k	½W	5%
R4	"	1M	½W	5%
R5	"	390k	½W	5%
R6	"	100k	½W	5%
R7	"	18k	½W	5%
R8	"	5k6	½W	5%
C1	Capacitor	25μF	25V	electrolytic
C2	"	1μF	25V	electrolytic
C3	"	25μF	25V	electrolytic
C4	"	0.005μF		polyester
C5	"	0.003μF		polyester
C6	"	820pF		ceramic
C7	"	1μF	25V	electrolytic

Q1-Q3 Transistor BC548, BC108 or similar
PC board ETI 441
CASE
BATTERIES
OUTPUT SOCKETS
North America: Use any NPN transistor with a gain of 100 or more (such as the Radio Shack RS2013s)



NOISE is generally an undesirable phenomena that degrades the performance of many measurement and instrumentation systems. It therefore seems strange that anyone should want to generate noise, but this is often the case.

Noise generators are often used to inject noise into radio-frequency amplifiers in order to evaluate their small signal performance. They are also used to test audio systems, and as random signal sources for wind-like effects in electronic music.

There are two commonly used noise source characteristics, 'pink' and 'white'. White noise is so called because it has equal noise energy in equal bandwidths over the total frequency range of interest. Thus, for example, a white noise source would have equal energy in the band 100 to 200 Hz to that in the band 5000 to 5100 Hz.

If white noise is filtered or modified in any way it is referred to as coloured noise or, often more specifically, as 'pink' or 'grey' noise. The term pink noise should be restricted to the noise characteristic that has equal energy per percentage change in bandwidth. For example with true pink noise the energy between 100 Hz and 200 Hz should equal that between 5000 Hz and 10 000 Hz (100% change in both cases).

Pink noise therefore appears to have more bass content than does white noise, and it appears to the ear to have a more uniform output level in audio testing. To change white noise to pink noise a filter is required that reduces the output level by 3 dB per octave (10 dB per decade) as the frequency is increased. The ETI 441 Noise Generator is designed to provide both white and pink noise as required.

HOW IT WORKS – ETI 441

In the days when vacuum tubes were in common use the most commonly used form of noise generator was a vacuum-tube diode operated in the current saturation mode. Nowadays noise generators may be very complex indeed. Highly complex digital generators which produce psuedo-random digital noise may cost many thousands of pounds An example of a simpler type of digital noise source may be found in our synthesizer design (see International Music Synthesizer 4600 ETI March 1974). However for audio work of a general nature the most commonly used, and the simplest, method is to use a zener diode as a noise generator.

Transistor Q1 is in fact used as a zener diode. The normal base-emitter junction is reverse-biased and goes into zener break-down at about 7 to 8 volts. The zener noise current from Q1 flows into the base of Q2 such that an output of about 150 millivolts of white noise is available.

The 'zener', besides being the noise source, also biases Q2 correctly, and the noise output of Q2 is fed directly to the White Noise output.

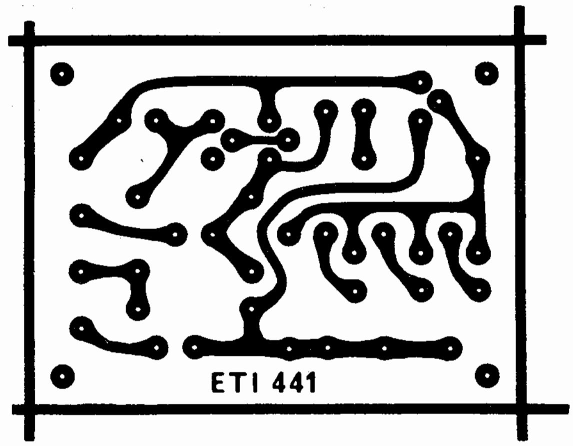
To convert the white noise to pink a filter is required which provides a 3 dB cut per octave as the frequency increases. A conventional RC network is not suitable as a single RC stage gives a cut of 6 dB per octave. Hence a special network of Rs and Cs is required in order to approximate the 3 dB-per-octave slope required. Since such a filter attenuates the noise considerably an amplifier is used to restore the output level. Transistor Q3 is this amplifier and the pink noise filter is connected as a feedback network between collector and base in order to obtain the required characteristic by controlling the gain-versus-frequency of the transistor. The output of transistor Q3 is thus the pink-noise required and is fed to the relevant output socket.

CONSTRUCTION

Construction is relatively simple and almost any of the common methods, such as Veroboard or Matrix board, may be used if desired. For neatness and ease of assembly it is hard to beat a proper printed-circuit board and for this reason we have provided details of a suitable board.

Almost any type of NPN transistor will do for the generator provided that the one used for Q3 has a gain of 100 or more.

For use as a separate instrument in general experimentation the unit will need to be powered by a pair of nine-volt batteries. However if the unit is to be built into some other piece of equipment, as is often the case, any supply within the equipment which has an output of between 15 and 30 volts dc will be suitable. ●



Printed circuit layout. Full size 67 x 49 mm.

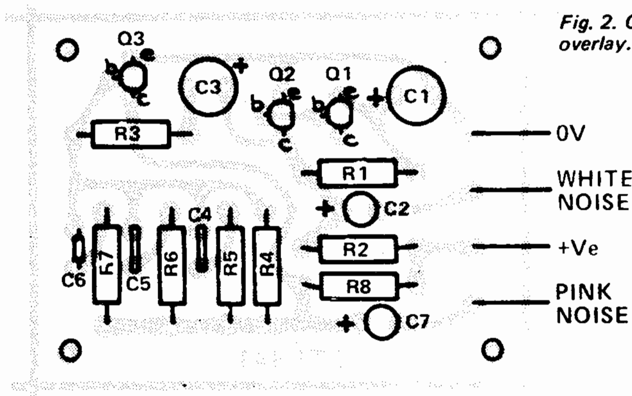
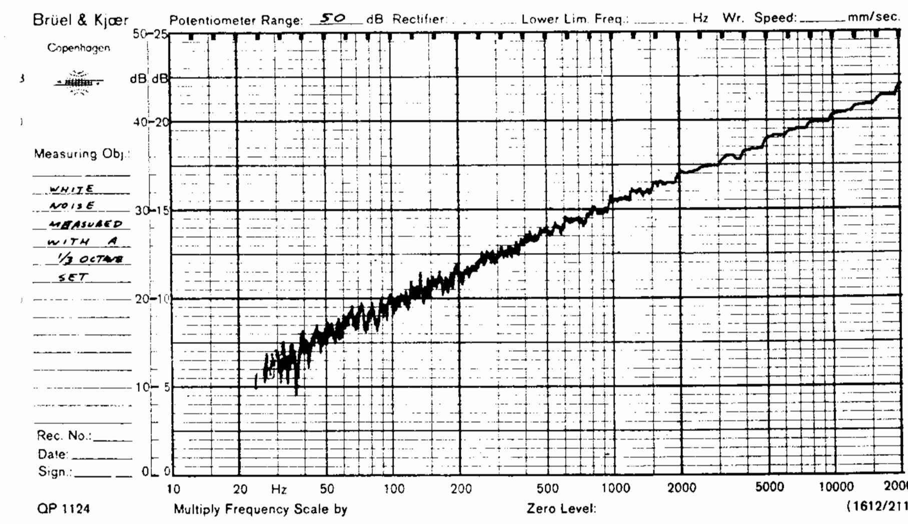
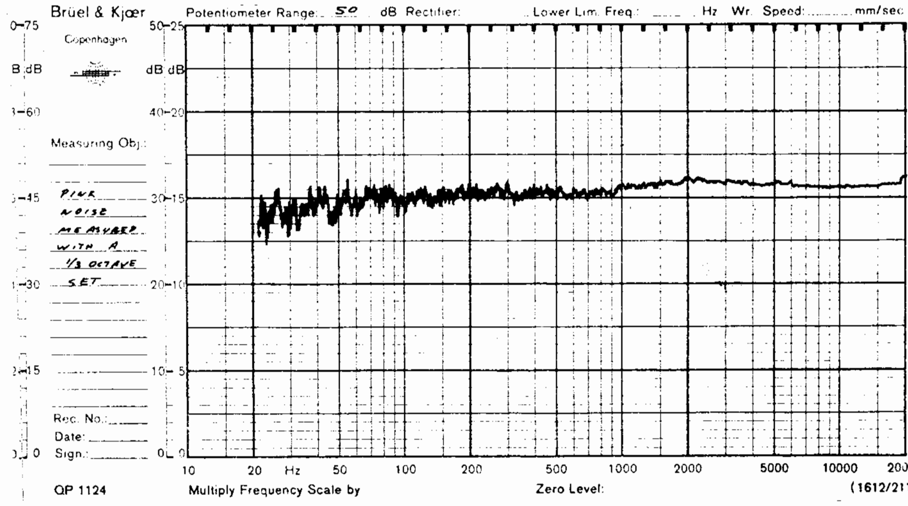


Fig. 2. Component overlay.



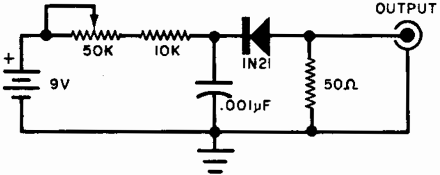


WIDEBAND NOISE GENERATOR

Q. ***I've heard that a "white" noise generator is very useful in checking out shortwave receivers. I'd like to experiment with one, but don't have a circuit. Do you?***

—Stu Goldberg, Cambridge, MA

A. The circuit shown will produce wideband r-f noise. It uses a reverse-biased diode and has a low-impedance output. You can use it to align the receiver for optimum performance.



NOISE GENERATOR

Usually, noise is something we want to get rid of.
However, there are applications in which noise is turned to practical use, such as for measuring and testing audio systems.
A digital method of generating so-called pseudo-random 'white' and 'pink' noise is described in this article and applied in a practical circuit.

Noise is one of the oldest known and still the most fascinating signals in modern electronics. It is a signal which apparently varies at *random* with time. 'Apparently', because certain laws of probability and statistics are obeyed. These mathematical backgrounds provide us with quantities which can accurately define such a signal. They say something about the probability of a certain value being assumed, and become relevant only after the noise signal has been observed during a long period.
An example of such a mathematical quantity is the mean square value of the noise voltage, $\overline{v^2}$. The root is the root mean square (RMS) value of the noise voltage.

White noise

For one class of noise signals the mean square value of the noise voltage is defined by:

$$\overline{v^2} = c\,\Delta f$$

where $\Delta f = f_2 - f_1$, the difference between the highest and the lowest frequency of the frequency band under consideration (see figure 1). The factor c says something, or rather everything, about the power density spectrum.
If c is frequency-independent, the power density spectrum is constant. This means that all frequencies are then represented equally in the noise. The quantity $\overline{v^2}$ increases with the bandwidth Δf. This type of noise signal, where c is constant, is called 'white noise'.
The term 'coloured noise' is used for signals where c is frequency-dependent within the frequency range under consideration.
Note that in practice, due to physical limitations, noise can only be 'white' in a band-limited frequency range. If Δf were to become infinitely large while c remained constant, $\overline{v^2}$ and the signal power would also become infinitely large.

Pink noise

One form of coloured noise is 'pink' noise. Both pink and white noise are useful in audio and acoustic measurements. To determine the frequency response of a system, a suitable noise signal is fed to the input. When the output is passed through a band-pass filter with a given central frequency and bandwidth, the r.m.s. value of the noise voltage corresponding to that particular frequency band will be measured. By using several band-pass filters with suitable quality factors and central frequencies, the entire relevant frequency response of the system can be measured.

1. For *filters with a constant bandwidth* the quality factor Q increases proportionally with the central frequency f_c.
   If a noise signal is measured with bandfilters of this type, the r.m.s. value of the output voltage measured for *white* noise is constant for each bandfilter.
2. For *filters with a constant quality factor* Q the bandwidth B increases with the central frequency f_c. A well-known example of this type are the so-called 'octave filters', where the ratio between the highest and the lowest bandpass frequency is 2. 'Third octave filters' are also in common use.
   If white noise is applied to a system with a 'flat' frequency response, selective measurement at the output with this type of filter will show that the r.m.s. value of the measured voltage increases in proportion to the square root of the central frequency. This is equivalent to saying the frequency characteristic rises at + 3 dB per octave.
   To correct for this, it is necessary to include a low-pass filter with a slope of - 3dB per octave.
   This filter is connected between the white noise generator and the

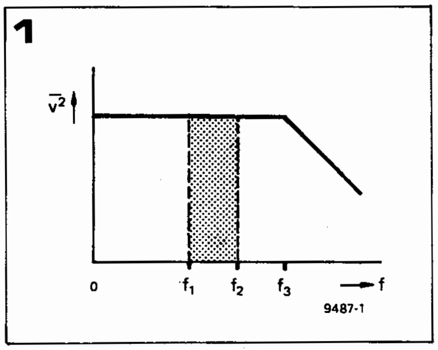


Figure 1. The frequency spectrum of a band-limited 'white' noise signal. The r.m.s. value of the noise voltage in a range Δf between f_1 and f_2 is proportional to the square root of Δf.

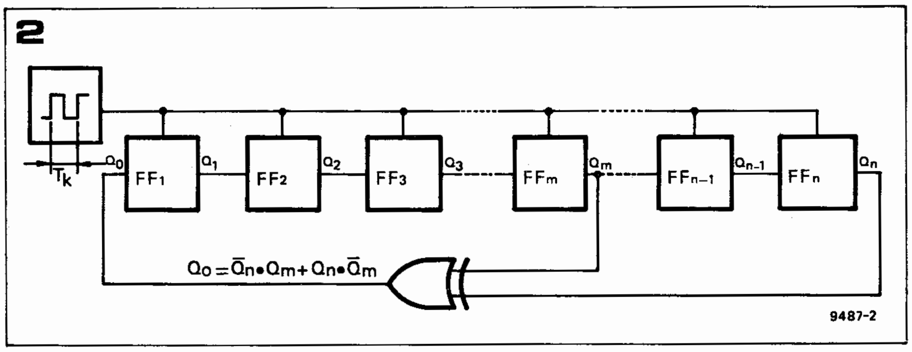


Figure 2. An n-bit shift register in combination with suitable EXOR-feedback will produce pseudo random binary noise.

Table 1

$\frac{t}{T_k}$	Q0	Q1	Q2	Q3	Q4	Q5	Q6	decimal
0	0	1	1	1	1	1	1	63
1	0	0	1	1	1	1	1	62
2	0	0	0	1	1	1	1	60
3	0	0	0	0	1	1	1	56
4	0	0	0	0	0	1	1	48
5	1	0	0	0	0	0	1	32
6	0	1	0	0	0	0	0	1
7	0	0	1	0	0	0	0	2
8	0	0	0	1	0	0	0	4
9	0	0	0	0	1	0	0	8
10	1	0	0	0	0	1	0	16
11	1	1	0	0	0	0	1	33
12	0	1	1	0	0	0	0	3
13	0	0	1	1	0	0	0	6
14	0	0	0	1	1	0	0	12
15	1	0	0	0	1	1	0	24
16	0	1	0	0	0	1	1	49
17	1	0	1	0	0	0	1	34
18	0	1	0	1	0	0	0	5
19	0	0	1	0	1	0	0	10
20	1	0	0	1	0	1	0	20
21	1	1	0	0	1	0	1	41
22	1	1	1	0	0	1	0	19
23	1	1	1	1	0	0	1	39
24	0	1	1	1	1	0	0	15
25	1	0	1	1	1	1	0	30
26	0	1	0	1	1	1	1	61
27	0	0	1	0	1	1	1	58
28	0	0	0	1	0	1	1	52
29	1	0	0	0	1	0	1	40
30	1	1	0	0	0	1	0	17
31	1	1	1	0	0	0	1	35
32	0	1	1	1	0	0	0	7
33	0	0	1	1	1	0	0	14
34	1	0	0	1	1	1	0	28
35	0	1	0	0	1	1	1	57
36	0	0	1	0	0	1	1	50
37	1	0	0	1	0	0	1	36
38	0	1	0	0	1	0	0	9
39	1	0	1	0	0	1	0	18
40	1	1	0	1	0	0	1	37
41	0	1	1	0	1	0	0	11
42	1	0	1	1	0	1	0	22
43	1	1	0	1	1	0	1	45
44	1	1	1	0	1	1	0	27
45	0	1	1	1	0	1	1	55
46	1	0	1	1	1	0	1	46
47	1	1	0	1	1	1	0	29
48	0	1	1	0	1	1	1	59
49	0	0	1	1	0	1	1	54
50	1	0	0	1	1	0	1	44
51	1	1	0	0	1	1	0	25
52	0	1	1	0	0	1	1	51
53	1	0	1	1	0	0	1	38
54	0	1	0	1	1	0	0	13
55	1	0	1	0	1	1	0	26
56	0	1	0	1	0	1	1	53
57	1	0	1	0	1	0	1	42
58	1	1	0	1	0	1	0	21
59	1	1	1	0	1	0	1	43
60	1	1	1	1	0	1	0	23
61	1	1	1	1	1	0	1	47
62	1	1	1	1	1	1	0	31
63	0	1	1	1	1	1	1	63

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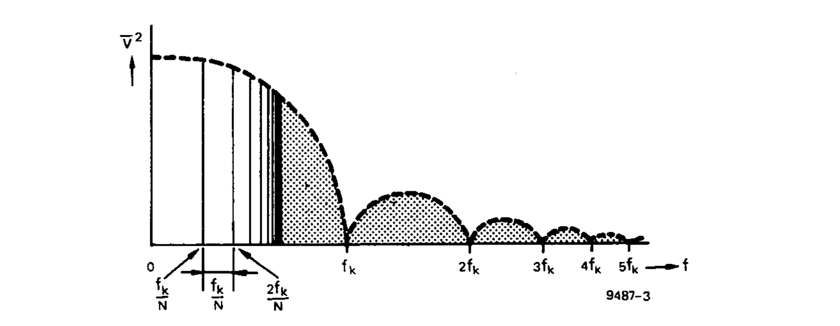

system. The noise signal at the output of this filter is called *pink noise*.

How do we make noise?

This may sound like a ridiculous question considering the fact that the major problem in audio is usually how to get rid of it. However, what is meant is: how can we make noise with the greatest possible spectral purity? And that is something quite different.
White noise can be derived from the noise produced by the BE junction of a transistor that is reverse-biassed into the break-down region. This produces a very low-level signal which must be amplified, and the $\frac{1}{f}$ - noise of the amplifier may be a problem. The signal-to-noise ratio of the amplifier must be very high. An even greater problem is that this type of noise is of thermal origin. The noise (r.m.s. value) is sensitive to temperature variations.

Pseudo random noise

Pseudo random noise, unlike random noise, consists of a periodical repetition of a specific random noise pattern. As an example, imagine that a true random noise signal is recorded on a closed loop of tape. When this tape is played back, the output will be pseudo random nois. An advantage of using pseudo random noise as a test signal is that the measuring time need not be infinitely long. (Theoretically, this is a requirement when measuring with true random noise . . .).

Pseudo random binary noise

It is not too difficult to generate pseudo random noise using digital techniques. A pseudo random binary noise signal is passed through a suitable low pass filter to give the analog noise required. It will be shown that both the binary and the analog noise signal are sufficiently 'noisy'.
The cycle character of pseudo random noise results in a repetition rate T_0 of the analog noise (T_0 is the period of one noise pattern), and as a cycle time T_0 for the binary noise.
Figure 2 gives the block diagram of a binary pseudo random noise generator. The n flipflops FF_1 . . . FF_n are cascaded thus forming an n-bit shift register.
The register is shifted by a clock pulse with period time T_k and frequency f_k.
Since the continuous clocking of only 'zeros' or 'ones' into the shift register will certainly not lead to the required

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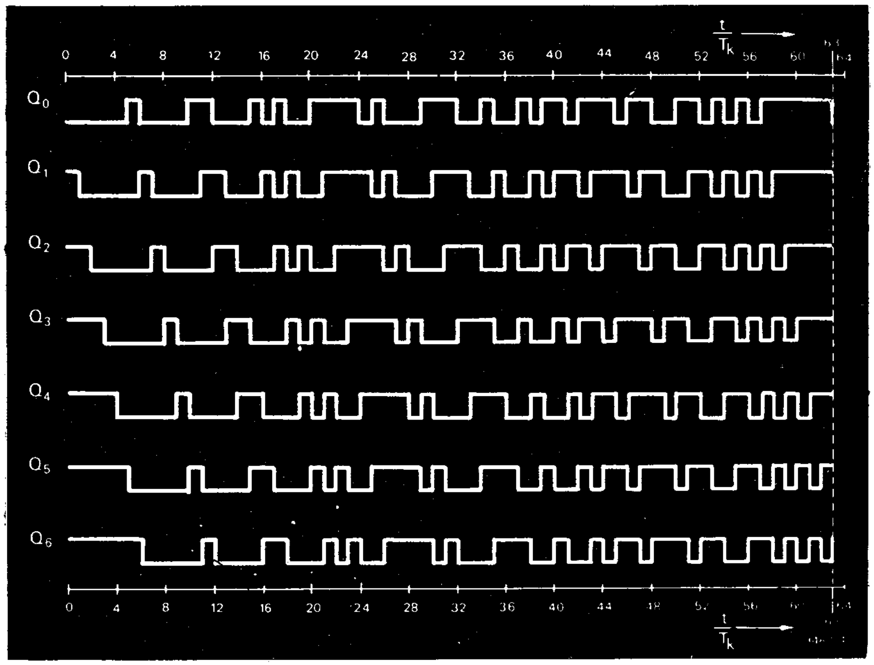


Table 1. The truth table for one complete cycle of a 6-bit shift register with EXOR-feedback from the outputs Q5 and Q6.

Figure 3. The frequency spectrum of pseudo random binary noise.

Figure 4. The pulse diagram corresponding to table 1.

Figure 5. The circuit diagram of the white noise generator. N9 . . . N29, N3 and N4 are needed to terminate the 'all-zero' output condition.

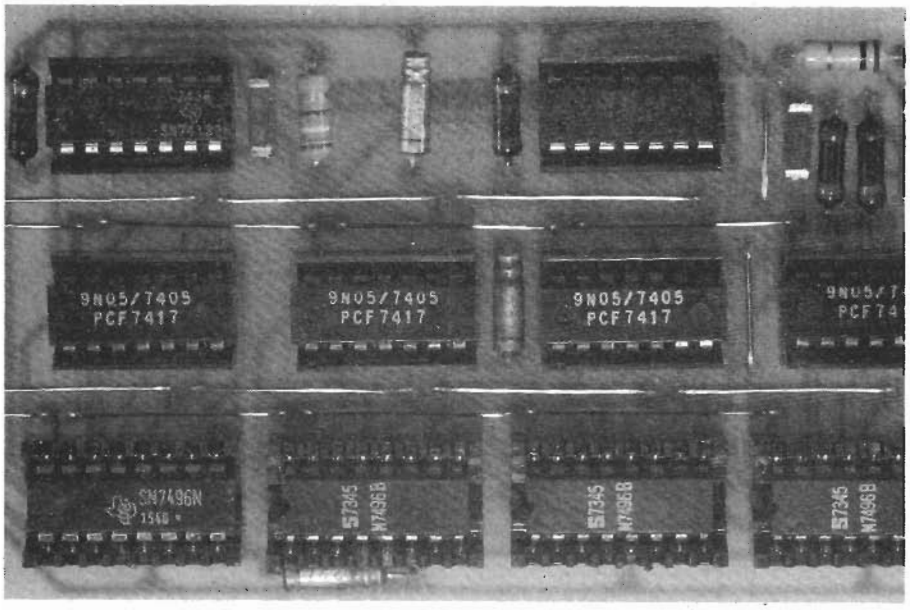
binary noise signal, the first flipflop FF_1 should receive a digital signal which is in some way related to the logic state of the register. The input of FF_1 receives a signal Q_0 which is related to the signals Q_n and Q_m, according to the following truth table:

Q_n	Q_m	Q_o
1	0	1
0	1	1
0	0	0
1	1	0

objective now is to choose values n and m such that the maximum nber of different output states of the pflops $FF_1 \ldots FF_n$ is achieved. This corresponds to the maximum cycle time of the shift register.

This requires some further explanation. The shift register consists of n flipflops, and each of the n Q-outputs can be considered as one bit of an n-bit binary number represented by the contents of the shift register.

If the n flipflops are read out in parallel in the sequence $Q_n, Q_{n-1} \ldots Q_1$, we get an n-bit number corresponding to a given decimal number. The state of Q_1 corresponds to the value of the least significant bit (LSB) *), the state of Q_n corresponds to the most significant bit (MSB) *).



The whole can be regarded as a counter that counts in a seemingly random sequence. The choice of m should be such, that all possible binary 'numbers' occur within a corresponding number of clock pulses. All possible numbers occur only once within the cycle period T_0. This maximum number of logic states is

$$N = 2^n-1.$$

This is one less than the absolute maximum because an 'all-zero' output has to be avoided, since this would otherwise continue infinitely.

The (maximum) cycle time T_0, corresponding to this maximum number of states N is:

$$T_0 = NT_k.$$

If, for a given number of flipflops n, feedback takes place from Q_n and a randomly selected Q_m, there is a good chance that the cycle will be shorter than the maximum cycle time NT_k. It is very difficult to find values of m, corresponding to the selected n, in such a manner that the cycle time is maximum.

Fortunately this work has already been done for us.

Table 2 shows which outputs of the register should be used for the EXOR-feedback, for registers up to a maximum length n = 33. The last column also gives the corresponding cycle time expressed in clock periods T_k.

From table 2 it can be seen that there are always at least two possibilities: either Q_{n-m} or Q_m can be used. In table 2 Q_{n-m} is shown in brackets.

In a number of cases it is necessary to have EXOR-feedback from four Q-outputs. For n = 8, for example, the feedback condition is:

$$Q_0 = Q_2 \oplus Q_3 \oplus Q_4 \oplus Q_8$$

The $\oplus$ sign indicates the exclusive OR-function.

Table 1 shows the truth table for a 6-bit shift register with a cycle time of 63 clock periods. The number in the first column gives the order in which the 'random' numbers appear at the output.

*) The concepts LSB and MSB indicate the place of the bit in the number. They are a measure of the weighting factor allocated to the value of the bit concerned. The MSB is to the extreme left and in the case of an n-bit binary number it indicates (0 or 1) x 2^{n-1}. The LSB indicating the units (0 = even, 1 = odd), is to the extreme right, and has the lowest weighting factor for whole numbers. In the decimal number 1976, digit 1 is the MSB (thousands), and 6 the LSB (units).

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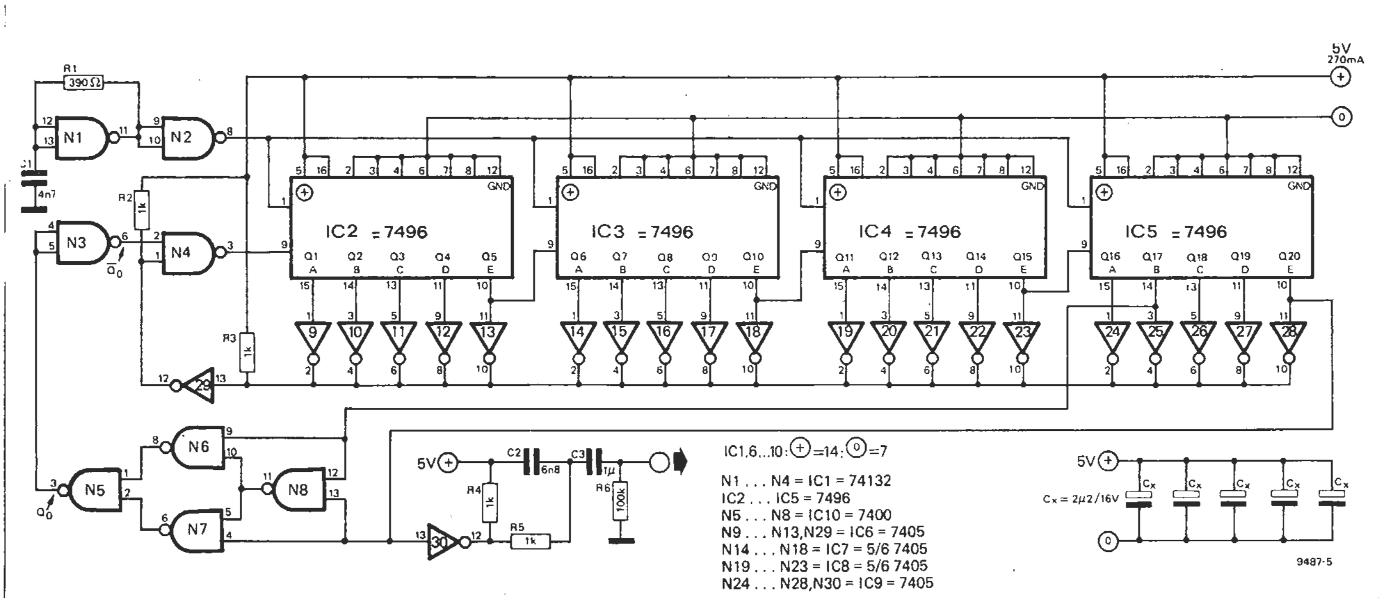

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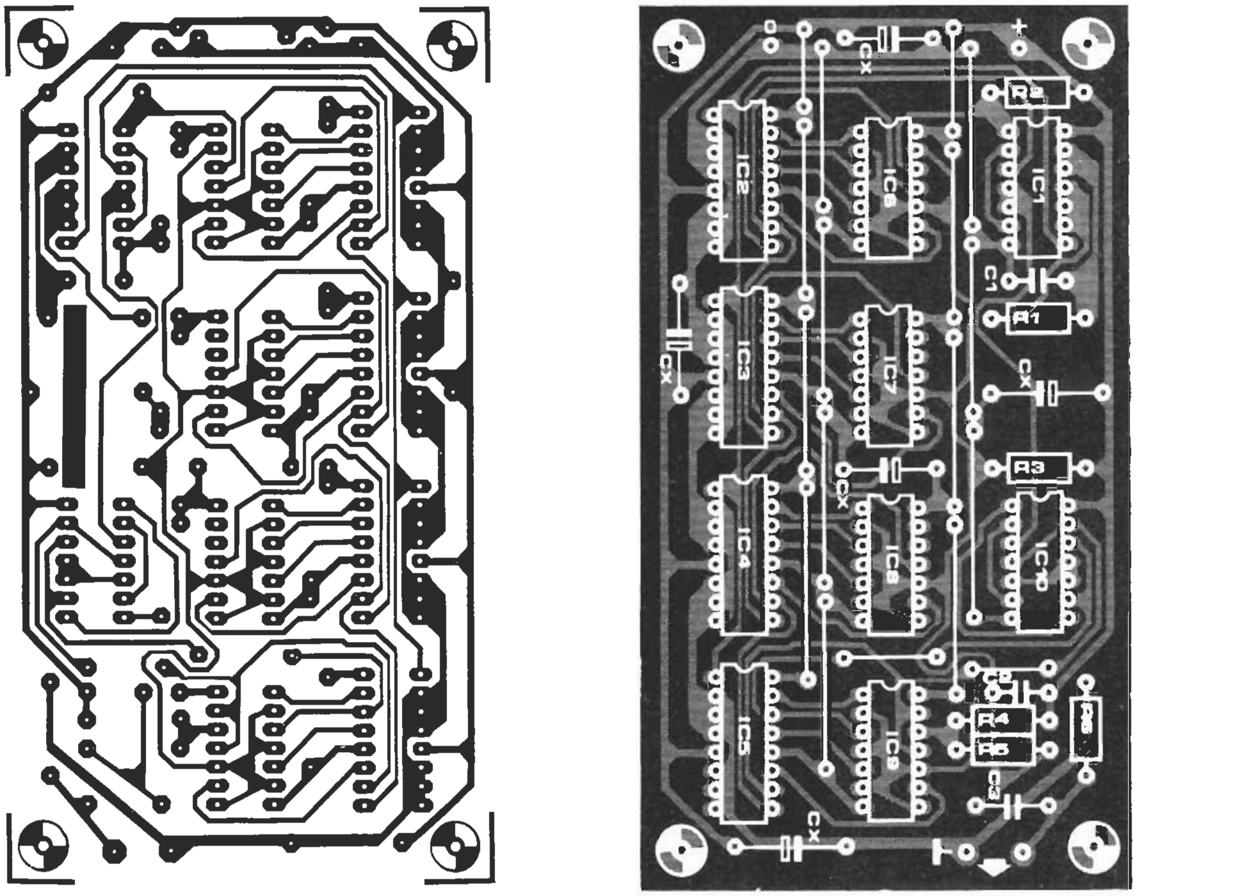

The second column lists the EXOR information Q_0 which is fed to the first flipflop. The next six columns indicate the output from the 6 flipflops and the last column gives the decimal value of the 6-bit binary number, where Q_1 represents the LSB and Q_6 the MSB.
Table 1 and the pulse diagram of figure 4 both clearly illustrate that the circuit is basically a shift register: the bits move one step to the right at each clock pulse. After 63 clock pulses the register is back at its initial state.

The pseudo random character of the output states is expressed as follows:

1. Of the total of N clock periods in one cycle, any particular Q output is 'high' during (N+1) :2 periods, and low during (N−1) :2 clock periods. This is because the zero state of the register is excluded. As n, and with it N, increases, the chance of a logic '0' approaches the chance of a logic '1' (50%).
2. If by traject we mean the number of clock periods within which the logic state of a particular Q output does not change, there are (N+1) : 2 trajects in each complete cycle. Half of these trajects are equal to one clock period; one quarter are equal to two clock periods, one eighth are equal to three clock periods, and so on. There is also one traject that is equal to n clock periods.
3. The number of trajects of each length is equally divided over trajects with logic '0' and ditto with logic '1'; the traject of n-1 clock periods occurs in '0' only and the traject of n clock periods occurs in '1' only. These rules can be verified by means of table 1 and figure 4.

Parts list

Resistors
R1 = 390 Ω
R2, R3, R4, R5 = 1 k
R6 = 100 k

capacitors
C1 = 4n7
C2 = 6n8
C3 = 1 μ
Cx = 2μ2/16 V

semiconductors
IC1 = 74132
IC2, IC3, IC4, IC5 = 7496
IC6, IC7, IC8, IC9 = 7405
IC10 = 7400

Table 2. A survey of possibilities and connections for feedback shift registers with bit lengths ranging from 3 to 33.

Figure 6. The printed circuit board and component layout for the circuit of figure 5.

Figure 7. The circuit of a passive low-pass filter with a slope of 3 dB per octave. If white noise is applied to this filter, pink noise is produced at the output.

Figure 8. Frequency response of the filter of figure 7.

The design described here (figure 5) uses a 20-bit shift register with EXOR feedback from the outputs Q_{17} and Q_{20}. The cycle duration is 1,048,575 (see table 2). It would be possible to set up the truth table, as was done for the 6-bit register in table 1. However, such a truth table would comprise 23 columns instead of the 9 in table 1, meaning that it would be nearly three times as wide The number of lines becomes 1,048,57 instead of the 64 of table 1, whic means that the truth table become more than 16,000 times as long. Sin table 1 occupies a full column of an Elektor page, this truth table would cover over 16,000 pages. So as not to make this article unnecessarily long, we have refrained from publishing the table in question. . . .

The cycle time T_0 of the above-described shift register counter with maximum cycle time can be extended considerably. At n = 33 (see table 2) and a clock pulse frequency of 10 MHz (T_k = 0.1 μs) it takes about 859 seconds (almost 15 minutes) before the cycle is completed. If, instead, a clock period of 1 second is used (f_k = 1Hz), the cycle time would be equal to about 8.6 x 10^9 seconds, considering that one year takes on average 60 x 60 x 24 x 365.25 = 31,558 x 10^6 seconds, it would take over 270 years to complete the cycle! Chances are that this exceeds the life of :he hardware constituting the equipment.

The frequency spectrum

'ure 3 is an attempt to illustrate the :er density spectrum of the pseudo 'om binary noise on the Q-outputs. spectrum is not continuous, but sists of an infinite number of lines. ' spacing between the lines (fre-ncy difference) equals

$$f_0 = \frac{1}{T_0} = \frac{f_k}{N},$$

so that the spectrum consists of the frequencies

$$0, \frac{f_k}{N}, \frac{2f_k}{N}, \frac{3f_k}{N}, \text{etc.}$$

The envelope of the frequency spectrum varies according to the function $(\frac{\sin x}{x})^2$,

x being related to the ratio between f and f_k. The spectrum contains no component for f_k and multiples thereof. It can be calculated that the power spectrum has dropped 3 dB at a frequency equal to 0.45 x the clock frequency f_k.
The spectrum is equivalent to a band-limited white noise signal (within).1 dB) for frequencies between 0 and $f_k/4\pi$ Hz. To be on the safe side, the band can be limited to

$$f_g = \frac{f_k}{20}.$$

For the final design f_g was set at about 25 kHz, so that a clock frequency f_k of about 500 kHz is needed. Since N equals 1,048,575, the distance between the lines of the frequency spectrum is slightly less than 0.5 Hz. The cycle time T_0 is about 2 seconds.

The circuit

The final circuit is shown in figure 5. 'chmitt trigger gates N1 and N2 are ;ed as a clock pulse generator which ıns at 500 kHz. This drives the clock puts (pin 1) of four 5-bit shift regis-rs IC2 . . . IC5; these are cascaded to form the 20-bit shift register.
The EXOR function is achieved by neans of the gates N5 . . . N8. Feedback s taken from Q17 and Q20, in accordance with table 2. The EXOR feedback signal (the output of N5, Q_0) is fed to the input of the shift register via inverter N3 and gate N4.
Point 1 of N4 is normally 'high' so that the feedback signal arrives at point 9 of IC2. However, if all 20 Q-outputs of IC2 . . . IC5 are 'low', the input of inverter N29 goes high. As a result point 1 of N4 goes low. A '1' is now fed into the register so that the condition of twenty zeros, which might occur due to faults, is terminated.
The output is fed through a low-pass filter (R4, R5, C2) with a cut-off frequency f_g of about 25 kHz and a slope of 6 dB per octave. The output impedance is about 1k; the peak value of the white noise voltage at the output is about 4 V. It can be calculated that this peak value is about 3.16 times the r.m.s. value.
Consequently, this noise signal is eminently suitable for testing loudspeakers and amplifiers. If the drive level is set so that no 'clipping' occurs (this is audible as a change in the timbre of the noise), the amplifier will deliver only 10% of its maximum output power. This will usually mean that the loudspeaker is in no danger of falling victim to the measurements.
To conclude with, figure 7 gives a circuit for a 3 dB per octave low-pass filter. This can be connected to the output to convert the 'white' noise into 'pink'. It is strongly recommended to use 5% capacitors and resistors. Figure 8 shows the frequency response of this filter.

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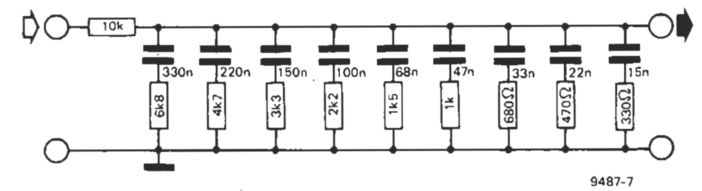

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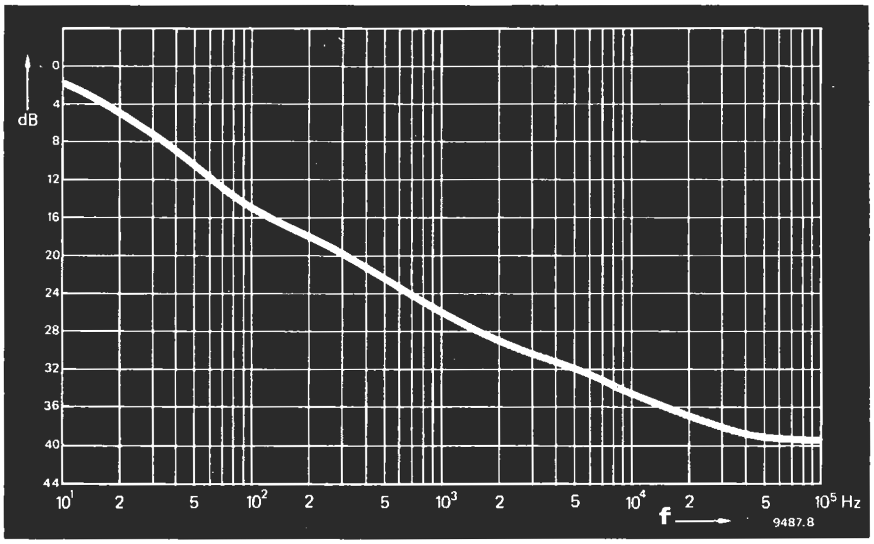

Table 2

length of shift register (n):	Exor feedback taken from outputs:	cycle time in clock periods T_k:
3	Q3 and Q2 (Q1)	7
4	Q4 and Q3 (Q1)	15
5	Q5 and Q3 (Q2)	31
6	Q6 and Q5 (Q1)	63
7	Q7 and Q6 (Q1) or Q4 (Q3)	127
8	x)	255
9	Q9 and Q5 (Q4)	511
10	Q10 and Q7 (Q3)	1023
11	Q11 and Q9 (Q2)	2047
12	x)	4095
13	x)	8191
14	x)	16,383
15	Q15 and Q14 (Q1) or Q 4 (Q11) or Q 7 (Q8)	32,767
16	x)	65,535
17	Q17 and Q14 (Q3)	131,071
18	Q18 and Q11 (Q7)	262,143
19	x)	524,287
20	Q20 and Q17 (Q3)	1,048,575
21	Q21 and Q 2 (Q19)	2,097,151
22	Q22 and Q21 (Q1)	4,194,303
23	Q23 and Q 5 (Q18) or Q 9 (Q14)	8,388,607
25	Q25 and Q 3 (Q22) or Q 7 (Q18)	33,554,431
28	Q28 and Q 3 (Q25) or Q 9 (Q19) or Q13 (Q15)	268,435,455
31	Q31 and Q 3 (Q28) or Q 6 (Q25) or Q 7 (Q24) or Q13 (Q18)	2,147,483,647
33	Q33 and Q13 (Q20)	8,589,934,591

x) This shift register length requires EXOR feedback from four outputs.

Engineer's newsletter

Another odd job for solar cells

If you need a simple noise generator for test purposes and you have a selenium solar cell handy, try biasing it with a voltage source and then applying the cell's output to an audio- or radio-frequency amplifier, suggests Calvin R. Graf of San Antonio, Texas. (In an Oct. 30, 1975 newsletter item, Graf—a heavy hitter on this page—showed us how to make a solar cell into a moisture detector.) Whether it is forward- or reverse-biased, **the solar cell will produce hiss-like white noise with an amplitude that increases directly with the bias voltage** applied over the range of a few volts to about 15 v. And although it can work in the light, it's better kept in darkness, says Graf, because an artificial light source, like an incandescent or fluorescent lamp, causes 60-hertz power-line hum that overrides the cell's white-noise output, especially when the cell is forward-biased. Fluorescent lamps, he notes darkly, are worse than incandescent.

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