

**B&K PRECISION'S  
GUIDEBOOK  
TO  
FUNCTION  
GENERATORS**

***BK PRECISION***<sup>®</sup>

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# **BK PRECISION®**

## **GUIDEBOOK TO FUNCTION GENERATORS**

Function Generators are one of the most important and versatile pieces of test equipment that a Technician or Engineer can use. In both design and troubleshooting, the circuit in question often requires a signal to simulate its normal operation. The specific type of signal can vary widely from one circuit to another. Modern function generators are able to provide a very wide variety of signals, which will meet a vast majority of these requirements. Even today's most basic units are capable of sine, square, and triangle outputs over a range of frequencies, from less than 1 Hz to at least 1 MHz, with variable amplitude and adjustable DC offset. Many generators include extra features, such as higher frequency capability, variable symmetry, fre-

quency sweep, AM and FM operation, and gated burst mode.

Although applications for function generators are virtually unlimited, here are just a few of the more common uses:

- Research and development
- Secondary and post secondary educational institutions
- Electronic and electrical equipment repair shops.
- Consumer products repair shops

- Government repair facilities
- Electronic hobbyists

In order to use a function generator to its best advantage, the Technician or Engineer should have a basic understanding of how a function generator works, as well as a good understanding of the unit's controls, features, and operating modes. This guidebook is useful to those with little knowledge of function generators, as well as the experienced Technician or Engineer who wishes to refresh his/her memory or explore new uses for function generators.

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Note: the following terms are defined in the context of function generators. Some may have additional meaning in other areas of electronics.

**AM (Amplitude Modulation)** - The process of varying the amplitude of one signal in accordance with the amplitude of another. Typically, the signal being varied is a continuous sine wave, modulated by a lower frequency signal.

**Amplitude** - Voltage magnitude of a waveform. Most commonly expressed in volts peak-to-peak, it is also often stated in rms (root-mean-square) volts (for sine waves).

**Attenuation** - A decrease in signal amplitude. Usually expressed in decibels (dB). The output level control of a function generator provides variable attenuation. Some generators also provide larger steps of attenuation via push buttons.

**Burst** - See Gated Burst.

**CMOS (Complementary Metal-Oxide-Semiconductor)** - An integrated circuit family which can operate from any supply voltage between 3V and 12V (up to 18V in some varieties), and has low and high supply voltage, respectively.

**DC Offset** - Settable DC voltage superimposed with signal output. Used to match the DC voltage at point of signal injection or for other special applications.

**Distortion (Sine Wave)** - A measurement of waveform irregularities that are introduced to an otherwise pure waveform. Function generators typically have less than 0.5% distortion at frequencies up to 100 kHz.

**Duty Cycle** - Percentage of cycle during which the waveform is working (usually the more positive portion of a square wave or pulse waveform). Pulse width period divided by pulse repetition period. The duty cycle of a perfect square wave is 50%. The duty cycle of a waveform with a pulse width of 10 ms and a pulse repetition period of 100 ms is 10%.

**FM (Frequency Modulation)** - The process of varying the frequency of one signal in accordance with the amplitude of another. Typically, the signal being varied is a continuous sine wave, modulated by a lower frequency signal. The modulated signal generally varies around some mean frequency; the amount of variation is known as the deviation.

**Fall Time** - A measurement of how long it takes a square wave to descend from 90% to 10% of its trailing edge height.

**Function** - A relationship between voltage and time, typically periodic, such that for any specific instant in time, the value of the voltage can be determined. Common functions are sine, triangle and square waves, pulse trains and ramps.

**Gate** - A control voltage, typically TTL level, used to turn the output of a function generator on and off.

**Gated Burst (Tone Burst)** - A signal being gated (turned on and off) by another signal. It is so named because the resulting output is usually a burst of many cycles followed by an "off" period of arbitrary duration. However, a "burst" may consist of as few as one or two cycles. Although the term "tone burst" is sometimes used, the frequency of the gated signal need not be limited to the audio range.

**Haversine** - A sine wave offset such that its negative peak rides on the zero-volt base line.

**Linear** - Term used to describe one type of sweep generator operation, in which the rate of frequency change is constant throughout the sweep.

**Linearity (Triangle Wave)** - A measurement of the slope "straightness" of a triangle waveform. Measured as a percentage where 100% is perfect.

**Logarithmic** - Term used to describe one type of sweep generator operation, in which the time period for each "decade" of frequency change (i.e. 20 Hz to 200 Hz, 200 Hz to 2 kHz, etc.) is equal. This produces a slow rate of frequency change at the low end of the sweep, changing to a much faster rate at the high end.

**Offset** - See DC Offset

**Peak-to-Peak** - A method of expressing the amplitude of a sine, triangle or square wave. The peak-to-peak voltage represents the voltage difference between the maximum and minimum value of the waveform.

**Periodic** - Occurring in repeated cycles or periods.

**Pulse Repetition Period** - Time between two successive leading (or trailing) edges of a pulse train, usually expressed in microseconds or milliseconds.

**Pulse Repetition Rate** - Frequency of a pulse train, usually expressed in pulses per second or in hertz.

**Pulse Width** - Period of time (usually measured in  $\mu$ s) that pulse is active.

**Ramp Waveform** - A triangle wave whose excursions between minimum and maximum have been altered so as to be unequal in length. For example, the positive-to-negative portion may constitute 70% of the period, while the negative-to-positive cycle uses 30%. Such variation corresponds to adjustment of symmetry in a square wave. A ramp with one transition almost vertical is commonly called a sawtooth.

**Rise Time** - A measurement of how long it takes a square wave to ascend from 10% to 90% of its rising edge height.

**RMS (root-mean-square)** - A method of expressing the amplitude of a periodic waveform, most commonly used with sine waves. The rms voltage of a periodic waveform is the value of a DC voltage which would deliver the same effective power to a load as does the periodic waveform.

**Sawtooth** - A ramp waveform in which one of the transitions between minimum and maximum, either positive- or negative-going, is nearly vertical.

**Sine Wave** - A waveform, available on most function generators, which fulfills the equation  $y = \sin t$ , where  $y$  is output voltage and  $t$  is time. The waveshape varies gradually and periodically between a minimum and maximum value, with steep slope at the zero-crossings and zero slope at the peaks.

**Slewed Sine** - A sine wave whose excursions between minimum and maximum have been altered so as to be unequal in length. For example, the positive-to-negative portion may constitute 70% of the period, while the negative-to-positive cycle uses 30%. Such variation corresponds to adjustment of symmetry in a square wave.

**Square Wave** - A periodic waveform that alternately assumes one of two fixed values, usually for equal lengths of time. When these times are not equal, the waveform becomes a pulse (train). The transition times (rise/fall times) are negligible by comparison.

**Stability** - Amount of amplitude change (amplitude stability) or frequency change (frequency stability) over a specified period of time after unit is thoroughly warmed up.

**Sweep** - A repetitive variation of the output frequency of a function generator between two end values usually known as the start and stop frequencies. Frequency control is commonly accomplished by a linear ramp or sawtooth waveform, although logarithmic or other functions may be used.

**Sweep Rate** - Reciprocal of sweep time; number of sweeps in a given period of time.

**Sweep Time** - The period of time required to complete one full cycle of sweep. Variable on most generators.

**Sweep Width** - The frequency band that a sweep generator covers.

**Symmetry** - A measurement of the equity of time period of both halves of a square wave cycle.

**Tone Burst** - See GATED BURST.

**Triangle Wave** - A waveform that varies periodically between a minimum and maximum value, in similar fashion to a sine wave. However, its positive- and negative-going excursions have constant slope; that is, they are straight lines. For a triangle wave, these excursions are of equal length; if not, the waveform becomes a ramp.

**Triggered Mode** - An operating mode in which a function generator provides one cycle of output each time it is externally triggered. The output can thus be synchronized to an external source.

**TTL (Transistor-Transistor Logic)** - An integrated circuit family which normally operates from a +5 V supply and has low and high logic thresholds of +0.8 V and +2.4 V, respectively.

**Variable Duty Cycle** - Same VARIABLE SYMMETRY.

**Variable Symmetry (Variable Duty Cycle)** - A feature offered on many generators which

allows adjustment of output symmetry from very high to very low duty cycle. This converts square waves into pulses and triangle waves into ramp waveforms. The feature can usually be switched off to provide equal symmetry (50% duty cycle).

**V:f (orV/f)** - DC output voltage proportional to frequency.

**Voltage Controlled Frequency** - Same as VCG.

**Voltage Controlled Generator (VCG)** - A generator that changes output frequency with a change in the applied voltage.

**VCG Input** - An input offered on most function generators which allows the internal VCG to be controlled by an externally applied signal.

**Waveform** - The output of a function generator; term usually applies to a graphical representation of that output on an oscilloscope screen.

## BASIC FUNCTION GENERATOR CONTROLS

Fig. 1 depicts a hypothetical function generator whose front panel includes most of the typical jacks and controls found on modern function generators, although names of the individual controls may vary from unit to unit. Whereas this figure assigns one function to each control, actual units often combine multiple functions in single controls for simplicity of panel layout.

1. **POWER Switch.** Turns power on and off.
2. **DUTY CYCLE Switch.** When engaged, enables operation of DUTYCYCLE control (7).
3. **CMOS LEVELSwitch.** When engaged, changes the TTLsignal to CMOS signal at the TTL/CMOS jack and enables operation of CMOS LEVELControl (8).
4. **DC OFFSET Switch.** When engaged, enables operation of the DC OFFSET control (11).
5. **-20dB Switch.** When engaged, the signal at the OUTPUT jack is attenuated by 20 dB.
6. **RANGE Switch.** Selects output frequency range. Eight ranges from 2 Hz to 20 MHz. Switch indicates maximum frequency of range and is adjusted with COARSE FREQUENCY control to 0.1 times the maximum. For example, if the 200 kHz range is selected, the output frequency can be adjusted from 20 kHz to 200 kHz.
7. **DUTY CYCLE Control.** Activated by the DUTY CYCLE Switch (2). Rotation from center position adjusts the duty cycle of the main OUTPUT signal and TTL/CMOS signal.
8. **CMOS LEVEL Control.** Rotating this control clockwise increases the amplitude of the CMOS signal at the TTL/CMOS jack.
9. **FUNCTION Switch.** Selects sine, square or triangle waveform at OUTPUT jack.
10. **OUTPUTLEVELControl.** Controls the amplitude of the signal at the OUTPUT jack. Output level can be decreased by approximately 20 dB with this control.
11. **DC OFFSET Control.** Activated by the DC OFFSET Switch (4). Clockwise rotation from center changes the DC offset in a positive direction while counterclockwise rotation from center changes the DC offset in a negative direction.
12. **VCG/MOD INPUTJack.** Controlled by MODULATION OFF/ON Switch (33). When MODULATION OFF is selected, jack is the Voltage Controlled Generator input and permits external control of generator output frequency by a DC voltage input at this jack. A positive voltage will decrease frequency. When MODULATION ON is selected, jack becomes modulation input source.
13. **OUTPUT Jack.** Waveform selected by FUNCTION Switch as well as the superimposed DC OFFSET voltage is available at this jack.
14. **BURST INPUT Jack.** Input for external gating signal for Burst operation.
15. **TTL/CMOS Jack.** TTL or CMOS square wave, depending on the position of the CMOS LEVELswitch (3) is output at this jack. This output is independent of the OUTPUT LEVEL and DC OFFSET controls.
16. **EXT. COUNTER INPUT Jack.** Input for external frequency measurements.
17. **BURST WIDTH Control.** Adjusts the duty cycle of the internal burst gate.
18. **% MODULATION Control.** Adjusts the percentage of AM or FM modulation.
19. **BURST OFF/ON Switch.** Selects external or internal burst gate. Continuous output is obtained with switch in the OFF position and no external burst gate is applied.
20. **START/STOP Switch.** Enables adjustment of the starting and stopping sweep frequencies. The actual adjustment is performed by the SWEEP START and SWEEP STOP controls (29 and 27). START/STOP selection is enabled only when the SET/RUN switch (21) is set to SET.
21. **RUN/SET Switch.** Selects sweep set or sweep run operation. In the SETposition, the starting or ending sweep frequency is continuously present at the output. In the RUN position, the generator sweeps between the low and the high frequencies at a rate set by the SWEEPTIME control.
22. **SWEEP EXT/INT Switch.** When engaged (INT) enables the sweep mode of operation. Sweep rate is controlled by SWEEP TIME control (25) and sweep length is controlled by the SWEEPSTOP control (27) and the start frequency is controlled by the SWEEPSTART control (29). When released (EXT), allows external control of generator output frequency by a DC voltage input at the VCG/MOD INPUT jack (12).
23. **SWEEP LIN/LOG Switch.** When engaged (LOG) selects logarithmic sweep characteristic and when released (LIN) selects a linear sweep characteristic.
24. **CNTR INT/EXT Switch.** Selects the input source for the counter input.
25. **SWEEPTIME Control.** In sweep mode, rotation determines amount of time to sweep from the start frequency to the stop frequency.
26. **FINE FREQUENCY Control.** Vernier adjustment of the output frequency for ease of setting frequency.
27. **SWEEP STOP Control.** Adjusts the ending sweep frequency.
28. **COARSE FREQUENCY Control.** Coarse adjustment of the output frequency from 0.1 to 1 times the selected range.
29. **SWEEP START Control.** Adjusts the starting sweep frequency.
30. **GATE LED.** Indicates when the frequency counter display is updated. When the 200K through 20M ranges are selected, the LED will flash 10 times per second (every 0.1 seconds). When the 20 through 20K ranges are selected, the LED will flash every 10 seconds. As the LED turns off, the display is updated.

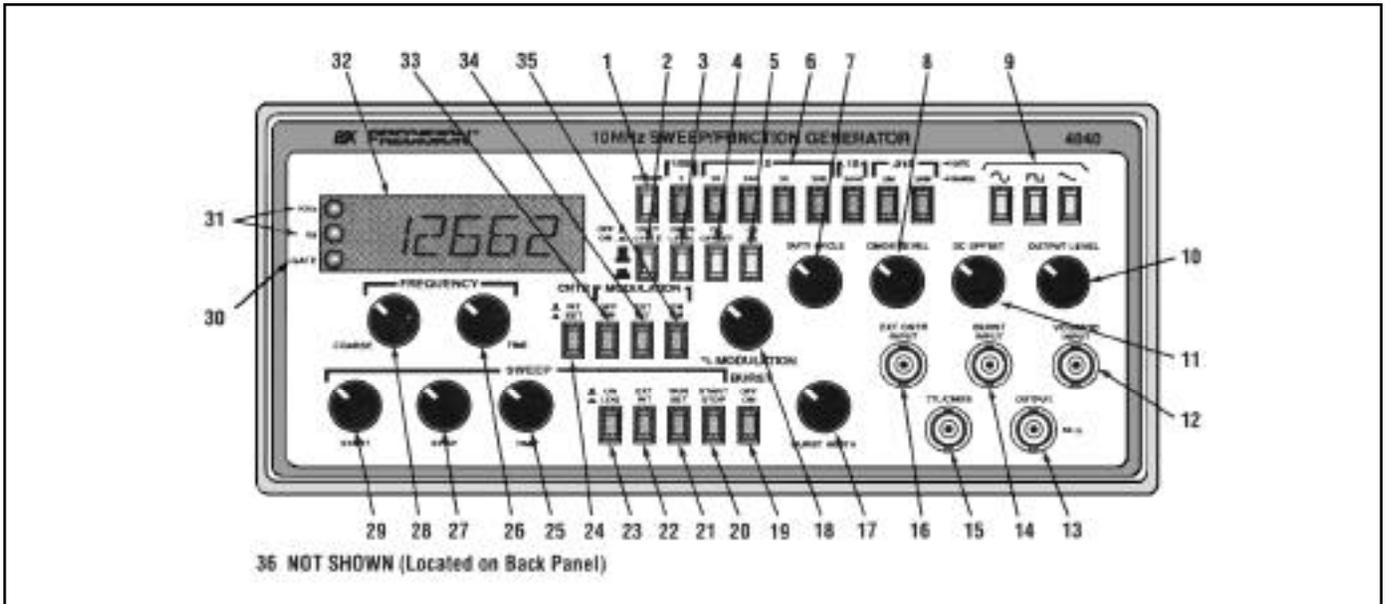


Fig. 1 Typical function generator front panel.

- 31. Hz and KHz LED.** Indicates whether the counter is reading in Hz or KHz.
- 33. MODULATION ON/OFF Switch.** Enables or disables modulation of the generator.
- 35. MODULATION FM/AM Switch.** Selects Frequency modulation or Amplitude modulation.
- 32. COUNTER DISPLAY.** Displays frequency of internally generated waveform, or external signal when CNTR EXT is selected.
- 34. MODULATION EXT/INT Switch.** Selects whether generator modulation is from the internal 1 KHz source or from a signal applied to the VCG/MOD INPUT jack.
- 36. GCVOUTPUT.** (Located on back panel) Generator control voltage output. Voltage is proportional to the generator frequency. When Sweep mode is selected sweep voltage is present at this jack for connection to an oscilloscope.

## FUNCTION GENERATOR BASICS

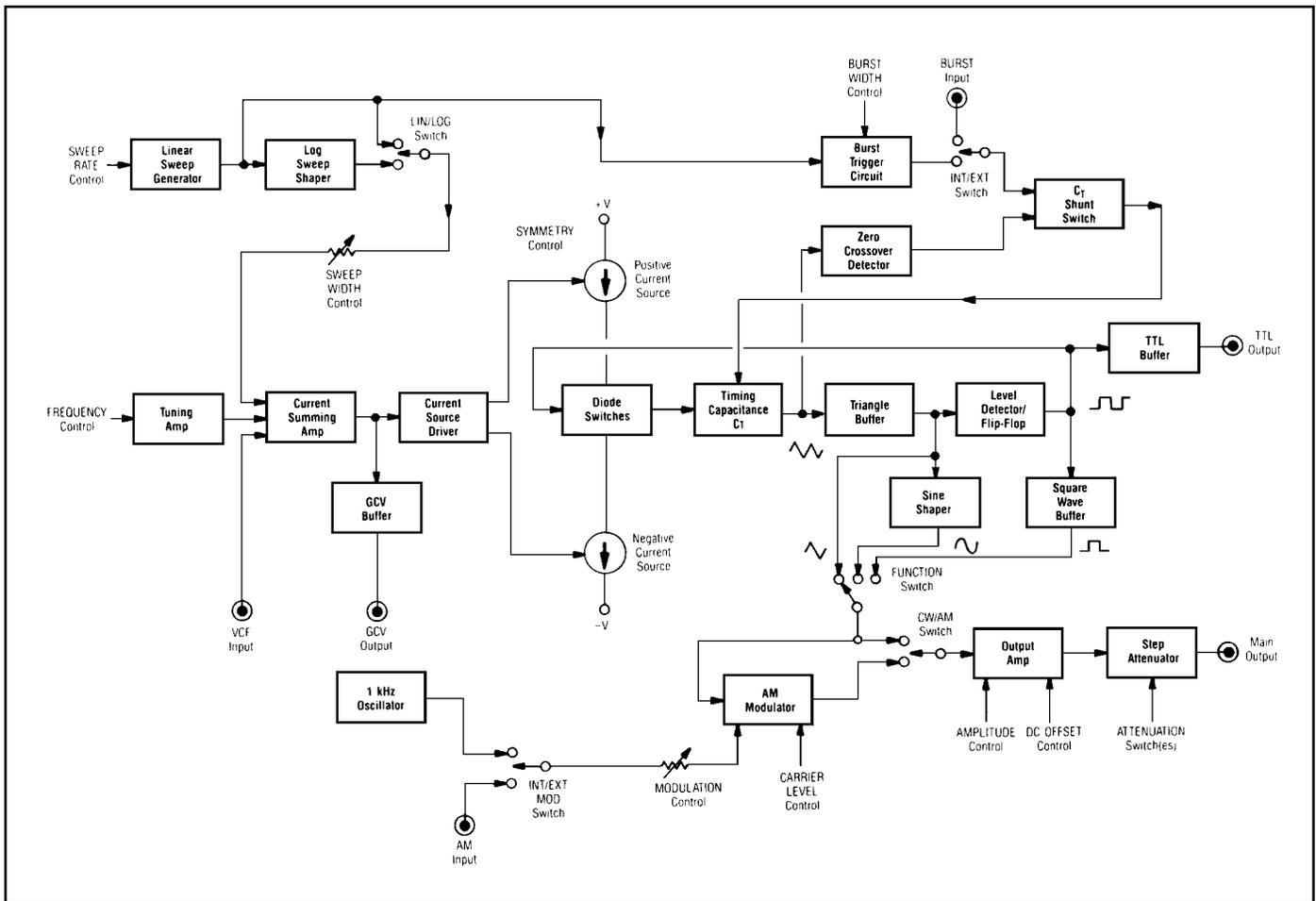


Fig. 2 Block diagram of typical function generator circuitry.

The following discussion deals with the fundamentals of function generator operation on a block diagram level. While the individual blocks may be implemented in various ways depending on the particular generator, the general principles described are somewhat universal, especially those pertaining to the basic generator loop. For the discussion, refer to Fig. 2, which depicts the block diagram of a unit with features similar to those of the hypothetical generator presented in the TYPICAL CONTROLS section of this guidebook.

### Input Circuits

While in the strictest technical sense, a function generator does not require a signal input in the manner of a counter or oscilloscope, its internal circuitry nevertheless does possess a "front end". The basic input is the DC voltage developed across the FREQUENCY control. As seen in Fig. 2, this is buffered by a tuning amp which preserves linearity of

the control. This signal is then combined with other inputs, such as the instantaneous voltages from the VCF (voltage-controlled frequency) jack, and the sweep circuit, in a current-summing amplifier. The resulting output, which is a summation of all pertinent controls and inputs, is used to control the current sources in the main generator loop. In some units, it is also buffered and offered as a GCV (generator-controlled voltage) output.

### Basic Generator Loop

The basic waveform of a function generator is a triangle wave, developed by alternately charging and discharging a capacitance  $C_T$  via two constant current sources. This capacitance is the heart of the function generator; the capacitors used are chosen for such highly desirable qualities as low dissipation factor, low temperature coefficient, and long-term capacitance stability.  $C_T$  is usually implemented by multiple capacitors, one for each frequency band, but this discussion will

refer to it as a single component for simplicity.

As seen in Fig. 2, the output of the current-summing amp is applied to the current source driver, which governs the amount of current in the two sources. This, in turn, determines the charge/discharge rate of  $C_T$ , and, ultimately, the frequency of the triangle wave.

The charge/discharge cycle is regulated by a feedback scheme wherein the capacitor voltage is buffered and applied to a level detector/flip-flop which changes state whenever one of two thresholds is reached. The resulting highs and lows are fed back to a diode switching arrangement which connects the capacitor to one of the two current sources.

Figs. 3 and 4 provide detailed looks at two implementations of the basic generator loop. In Fig. 3, the two current sources are

each of the same value, "I". The diode switching arrangement, which usually consists of a four-diode bridge, is represented figuratively by a double-pole, double-throw switch controlled by the flip-flop output. In the position shown, "AD", the flip-flop is in the low state, and it sinks all current from the positive source. The negative current source, on the other hand, is connected to the capacitor and is discharging it at this point in time. When the capacitor voltage reaches the low threshold of the flip-flop, the "switch" will change to position "BC". Then the positive current source will feed the capacitor, while the negative source sinks current from the flip-flop's "high".

Fig. 4 presents a simpler "switch" arrangement, usually implemented merely by two diodes. Here, however, the positive current source delivers twice the current of the negative source. In position "A", as shown, the flip-flop output is low, and it sinks all the positive current. The negative current source, which is always connected to the capacitor, is discharging it at a current rate of "I". In position "B", produced by a "high" from the flip-flop, both sources are connected to the capacitor, resulting in a net current of "I" into it. The capacitor is thus charging at a rate equal to its previous discharge rate.

Variations in symmetry can be achieved by altering the amount of current flow in one of the current sources. Coarse changes in frequency (range changes) can be effected by altering the flow in both sources, or by changing the value of  $C_T$ . Some generators drastically change  $C_T$  by applying the triangle waveform, inverted, to the opposite end of the capacitor, thus producing an effective capacitance "multiplier".

### Function Selection

Most generators offer three output functions: triangle, square, and sine wave. The triangle is simply the buffered output of the capacitor voltage, passed to a final output amplifier. The square wave is obtained by taking the TTL output of the level detector/flip-flop, shifting its DC bias for symmetry about zero, and sending it to the output amp. The sine wave is produced by applying the buffered triangle to a sine shaper, which may consist of a transistor array or several diode bridges. The resulting sinusoidal waveform is sent to the output amp. The FUNCTION switch determines which of the three waveforms is selected.

### Output Stages

The output amplifier may be a simple circuit with relatively few transistors, or it may be a complex configuration incorporating

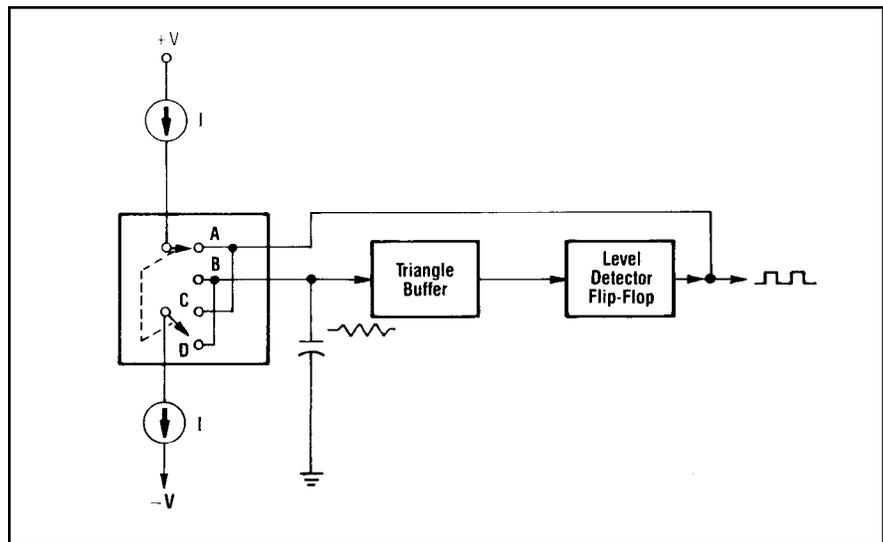


FIG. 3 Basic Generator Loop.

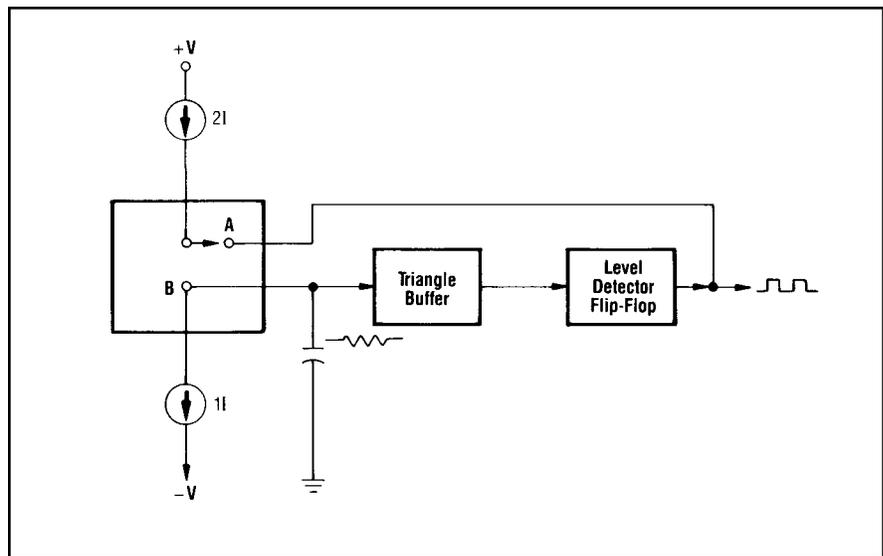


FIG. 4. Basic Generator Loop - Alternate Implementation.

separate pre-amp and power amp sections. In either case, the output AMPLITUDE control is usually a gain adjustment in this amplifier. Similarly, the DC OFFSET control is implemented as a bias adjustment in this circuit.

The attenuator, if one is provided, is a set of precision resistances selected to provide a prescribed amount of attenuation without changing the output impedance (typically 50  $\Omega$ ).

### Additional Circuitry

The preceding discussion describes the basic circuits required in all function generators. However, many units are equipped with additional features, which are included in Fig. 2. A discussion of these features follows.

### Sweep Circuit

The output frequency of the generator is determined by the various signals applied to the current summing amp. To produce a frequency sweep, a ramp voltage must be applied. This can be externally generated and fed into the VCF input, or can be created internally, as follows.

As shown in Fig. 2, a sweep generator produces a linear ramp whose repetition rate is governed by the SWEEP RATE control. The ramp is fed to a circuit which changes it from linear to logarithmic. Both waveforms are applied to the LIN/LOG switch, which selects one and passes it to the current summing amp.

Width of the frequency sweep is directly related to the width of the ramp. This can be

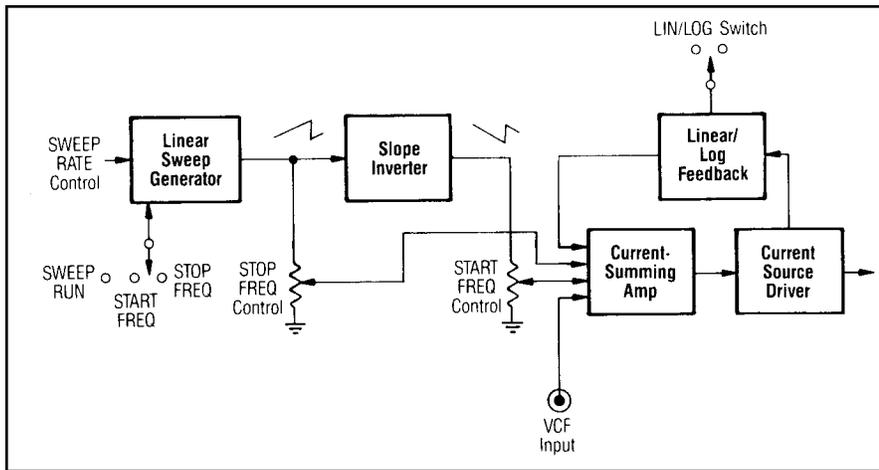


FIG. 5. Sweep circuit - alternate implementation.

controlled in one of two ways. The simpler implementation, as shown in Fig. 2, is a SWEEP WIDTH pot in series with the ramp output. This method of adjustment usually requires the use of an oscilloscope, monitoring either the actual output frequency or the output of the current summing amp, at the GCV jack.

A more elaborate sweep system is presented in Fig. 5. In this system, the output of the ramp generator is passed through an inverter, producing a ramp with the same endpoints but with inverted slope. Additionally, the ramp generator can be switched off and held at each of the two endpoints indefinitely. In both cases, because of the inverter, one of the two pots, START FREQ or STOP FREQ, has maximum voltage at its top, while the other has zero. This enables each of the frequency limits to be set without the sweep running. When the sweep circuit is restarted, the summation of the two opposite ramps forms a single ramp which runs from the START FREQ setting to the STOP FREQ setting, regardless of direction. Feedback from the current source driver is

used to produce a linear or log sweep. This system has the advantages of more accurate settability of endpoints, and sweep capability in either direction.

**Gated Burst Circuit**

Gated burst operation, or on-off switching of the generator output, is performed by a shunt switch circuit which prevents the main timing capacitor  $C_T$  from charging. As shown in Fig. 2, this shunt switch is controlled by two sources, the gating signal and a zero crossover detector.

The gating signal can be either external, from the BURST IN jack, or internal. It is common to utilize the internal sweep circuit for this purpose. As seen in the figure, the linear ramp from the sweep generator is fed to a trigger circuit, essentially a Schmitt trigger with its threshold set by the BURST WIDTH control. Varying the threshold results in a varying length pulse at the same repetition rate as the sweep generator. It is thus common to utilize the SWEEP RATE control to also adjust the internal burst rate.

The zero crossover detector monitors the triangle voltage on timing capacitor  $C_T$  and causes the burst interval to start and stop at the zero point. This insures that the gated output consists of integral whole- or half-cycles, depending on the particular generator.

**AM Circuit**

After the desired waveform is selected by the FUNCTION switch, but before it is applied to the output amplifier, it may be routed through an amplitude modulation circuit, as shown in Fig. 2. The AM circuit generally consists of a single IC which performs the modulation, and possibly some discrete transistor circuitry for DC level shifting.

One of two modulation sources can usually be selected, either external or internal. The internal source is commonly a 1 kHz sine wave.

**TTL Output**

This output is simply the buffered signal from the level detector/flip-flop, which toggles each time the basic triangle waveform reaches one of the two flip-flop thresholds. The input to the buffer is already TTL-level; the buffer usually consists of one or more NAND gates which increase the fan-out and prevent loading on the output of the level detector/flip-flop.

**FM Modulation**

FM modulation is achieved by applying an external signal to the VCF input, which is fed directly to the current summing amp. The output frequency is a function of the current summer's output, which is, in turn, dependent on the FREQ-dial setting, the sweep generator, and the VCF input. If the sweep circuit is turned off, then excursions above and below zero volts on the VCF input will produce frequency deviation around the operating frequency set by the FREQ dial.

## APPLICATIONS

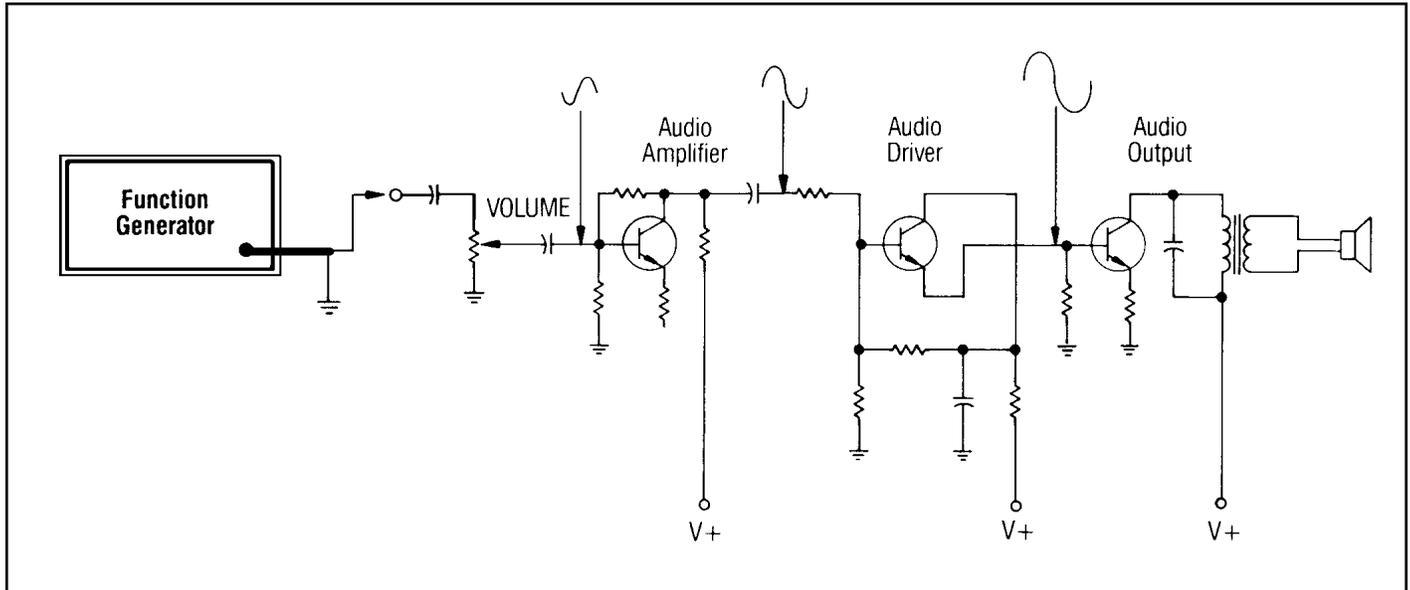


FIG. 6. Possible signal tracing points in a simple amplifier.

## INTRODUCTION

Because of the wide range of function generators currently available, and the wide array of features which they offer, the inventive user can undoubtedly devise many more applications than can be covered here. Therefore, this section endeavors to cover some basic applications using features found on the hypothetical generator presented in the TYPICAL CONTROLS section of this guidebook. It is hoped that the user can utilize these basic ideas, perhaps improvising or improving upon them as the particular situation dictates. The reader should note that these descriptions have been generalized to some degree to account for differences in specific generators.

## TROUBLESHOOTING BY SIGNAL TRACING

One of the most common methods of troubleshooting defective audio equipment is to inject a signal from a function generator at the input of the device under test. An oscilloscope is then used to check the output at each stage, starting nearest the input and moving toward the output. The stage which has no output or distorted output is presumed to be defective. A typical application is presented in Fig. 6. The input signal is usually a sine wave of low enough amplitude so as not to

produce undesired clipping in later stages. Also, there is usually no DC offset present, although, as shown in the figure, most amplifiers incorporate an input capacitor to block any DC component.

The technique is equally applicable to non-audio equipment. Most function generators can produce signals up to 1 MHz, with some models capable of 5 MHz or higher.

## TROUBLESHOOTING BY SIGNAL SUBSTITUTION

A variation on the signal tracing technique is to inject an audio signal at various points in the circuit under test, to substitute for the normal signal. In this technique, the signal is first injected nearest the speaker and is moved toward the audio input one stage at a time until no sound is heard from the speaker. The stage that produces no sound is presumed to be defective.

One precaution: make sure that the DC offset matches the normal operating voltage at each point of signal injection. Improper DC offset could bias a normally operating stage to cutoff and make it appear defective; it could also damage the circuit under test. A coupling capacitor may be used to block the DC offset and allow the signal to float at the DC level of the point of injection if desired.

The signal amplitude should simulate the normal signal levels used in the circuit where signal is being injected.

This technique is also applicable to non-audio equipment. Connect an oscilloscope, voltmeter, or any other device which will indicate the presence or absence of output.

If the equipment under test is already handling one or more signals that could be confused with the test signal, use sweep or tone burst operation on the function generator to produce unique sounds or signals. These should be easily distinguishable from any other signals that may be present.

## USING A FUNCTION GENERATOR AS A BIAS AND SIGNALSOURCE

Most modern function generators are able to superimpose a DC offset voltage on their AC signal output. As shown in Fig. 7, this capability can be used to bias a transistor amplifier under test as well as furnish the AC component of the input signal. By observing the amplifier output on an oscilloscope, the amplitude and bias of the transistor can be optimized for maximum undistorted output. By varying the DC offset, the effects of various types of bias (class A, B, and C) can be determined.

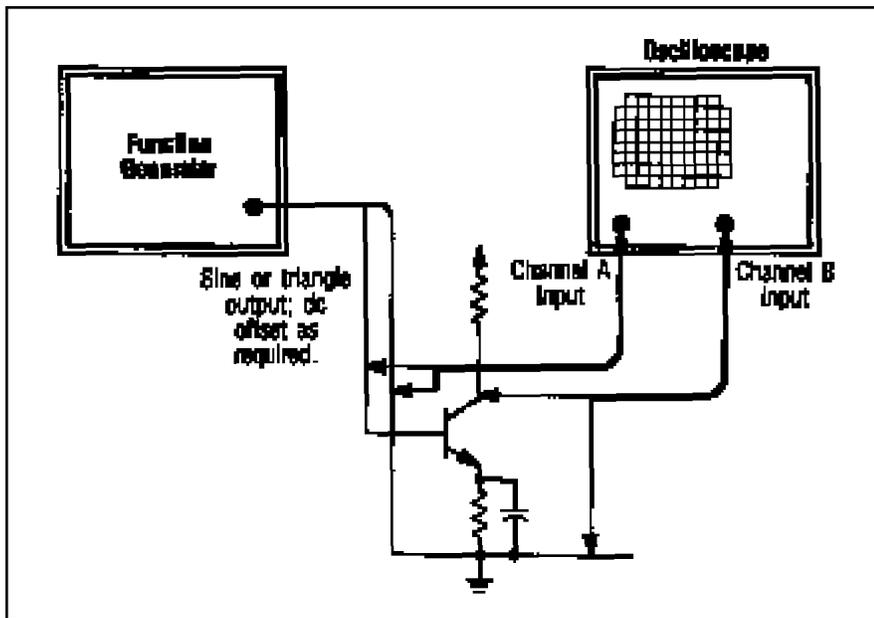


FIG. 7. Use of a function generator as combined bias supply and signal source.

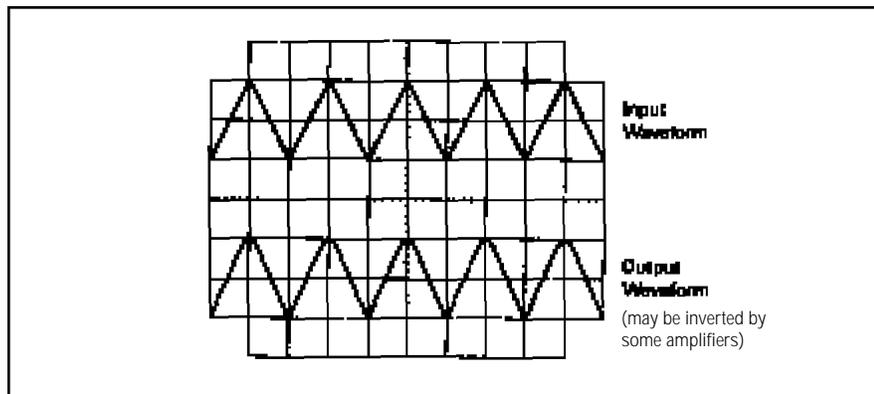


FIG. 8. Amplifier overload characteristics.

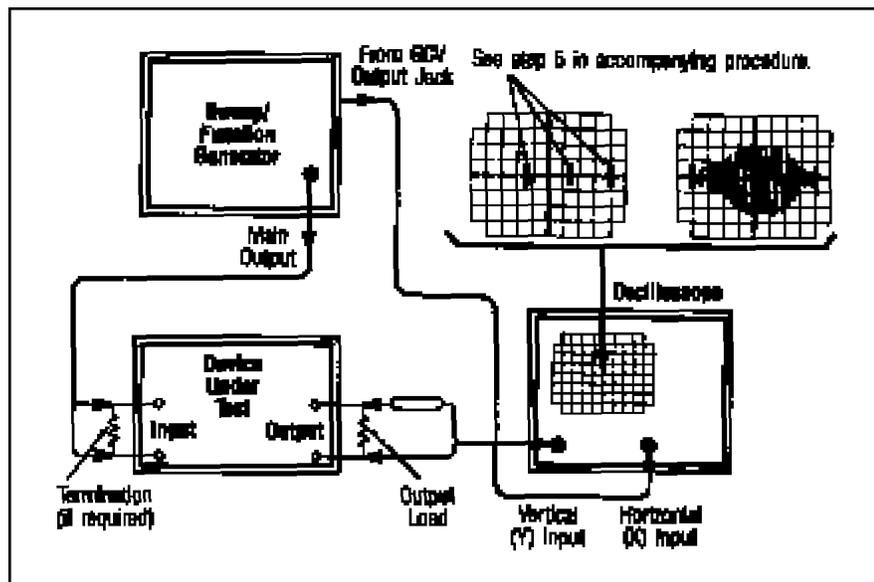


FIG. 9. Frequency response test set-up and measurement.

**AMPLIFIER OVERLOAD CHARACTERISTICS**

The overload point for some amplifiers is difficult to determine using a sine wave input. The triangle waveform is ideal for this type of test because any departure from absolute linearity is readily detectable. Using the triangle output, the peak overload condition for an amplifier can be easily determined. This overload condition is shown in Fig. 8.

**FREQUENCY RESPONSE MEASUREMENTS, LINEAR DISPLAY**

**Introduction**

Function generators with sweep capability are ideal for checking the frequency response of such devices as amplifiers, bass and treble controls, bandpass filters, low or high pass filters, coupling networks, speakers and speaker enclosures, IF amplifier strips, tuned circuits, notch filters, and any impedance network. Since the range of modern function generators is at least 1 MHz and higher, they can provide the means for measuring, adjusting, and analyzing the response of any active or passive device up to that range.

In addition to internal sweep, many generators feature a VCF input which permits sweep control by sine waves or other special patterns. Also, many units enable the entire audio range of 20 Hz to 20 kHz to be covered in one single sweep for convenience.

**Test Set-up**

The following procedure, along with Fig. 9, describes the typical set-up and method for measuring frequency response.

1. Select the desired frequency range on the generator.
2. Connect a cable from the GCV output jack on the generator to the horizontal (X) input of the oscilloscope.
3. Set the oscilloscope for X-Y operation, and select DC coupling for the X input.
4. With the generator's sweep turned off, vary the basic operating frequency of the unit. The GCV output will cause the dot on the scope screen to deviate from left to right. Direction of the deviation depends on the particular generator. Some move to the right as frequency is increased, and some to the left.
5. Use a grease pencil or china marker and

mark the location of the dot on the screen for all frequencies of interest within the sweep, as shown in the figure.

6. Turn on the sweep and adjust the sweep width and starting controls for a trace which encompasses all of the desired markers on the screen. Adjust the sweep rate control for a flicker-free display.
7. Connect the output of the generator to the input of the circuit being tested. If necessary, insert a termination for impedance matching between the generator output and the input of the device under test. This is not needed if the input and output impedances already match, e.g. both are 50 .
8. Connect the vertical (Y) input of the oscilloscope to measure the voltage across the output load of the circuit being tested.
9. Select sine, triangle, or square wave as appropriate. Sine wave signal is most commonly used for frequency response checks.
10. On most generators, linear and logarithmic sweep will both produce a linear display, because the GCV output voltage becomes linear or logarithmic along with the sweep. The log mode is nevertheless sometimes preferred because it does not sweep through the low frequencies as rapidly. A method of obtaining a true logarithmic display is discussed in the next section.
11. Set the amplitude of the generator output and the vertical gain of the scope for convenient viewing height of the displayed waveform. Be sure to keep the signal below the clipping level of the circuit being tested. To insure against clipping start with a very low signal level and increase signal amplitude until the highest peak on the display no longer increases in height as the amplitude control is increased. Then reduce amplitude slightly below that point.

### The Frequency Response Display

When using a conventional oscilloscope probe, the display will be an envelope such as shown in Fig. 10. The relative gain or attenuation of all frequencies within the swept band is displayed. The display may be analyzed for acceptable or unacceptable frequency response characteristics. In wideband amplifiers, the objective is usually to maintain a flat frequency response over the widest possi-

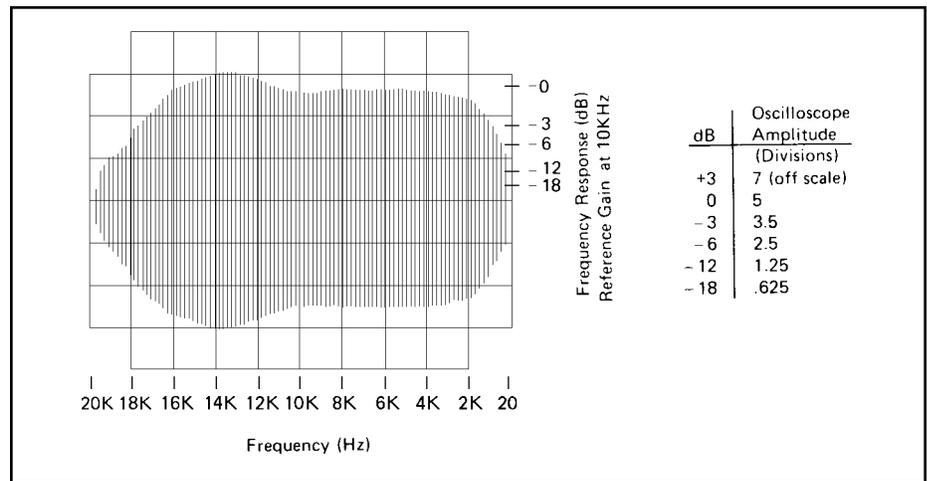


FIG. 10. Typical audio amplifier response display.

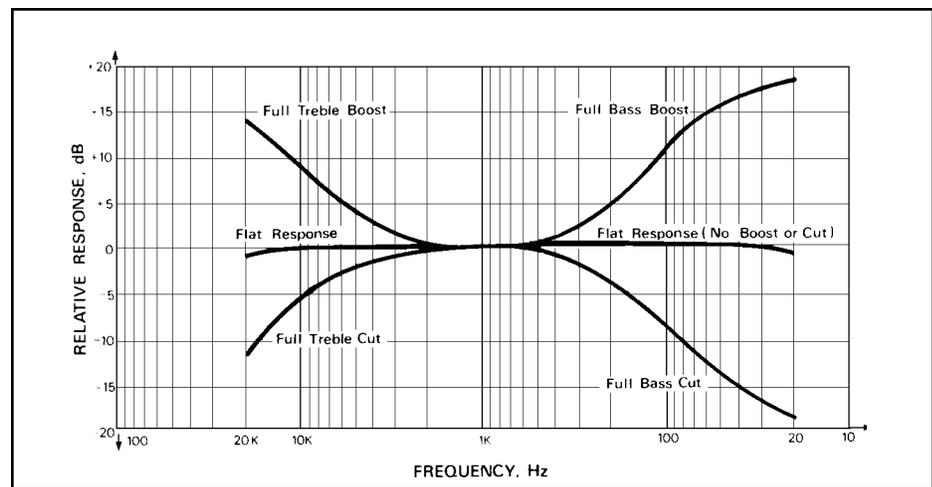


FIG. 11. Effects on audio frequency response by varying tone controls.

ble bandwidth. Frequency response displays of filters and coupling networks show the cut-off frequency and the sharpness of the cutoff. The frequency response display is often the basis for alignment of RF circuits (Figs. 16 and 17). The display also may be analyzed to determine the center frequency of bandpass, symmetry of bandpass, bandwidth, gain or signal amplitude, Q, and rejection of adjacent frequencies.

### Tone Control Test

If an audio amplifier under test is equipped with bass and treble controls, the effects of these controls on overall response can be determined by running frequency response tests while adjusting the controls throughout the range of adjustment. Fig. 11 illustrates some typical responses (note: graph is logarithmic).

### FREQUENCY RESPONSE MEASUREMENTS, LINEAR/LOG DISPLAY

#### Introduction

Most sweep generators are equipped with logarithmic and linear sweep capability. Logarithmic frequency response curves are quite common on specification sheets for amplifiers and other equipment. Whereas linear characteristics give more resolution of high frequency response, log displays give a more detailed picture of the low frequency end. Sometimes it is desirable to use both methods in examining frequency response characteristics of a device.

A difficulty is encountered in trying to generate a log characteristic using the GCV output, as stated in the previous section. Since this output is proportional to frequency, it becomes linear or logarithmic along with the sweep. Using it as a horizontal deflection signal for a scope results in a display that is always linear, whether the sweep itself is linear or logarithmic.

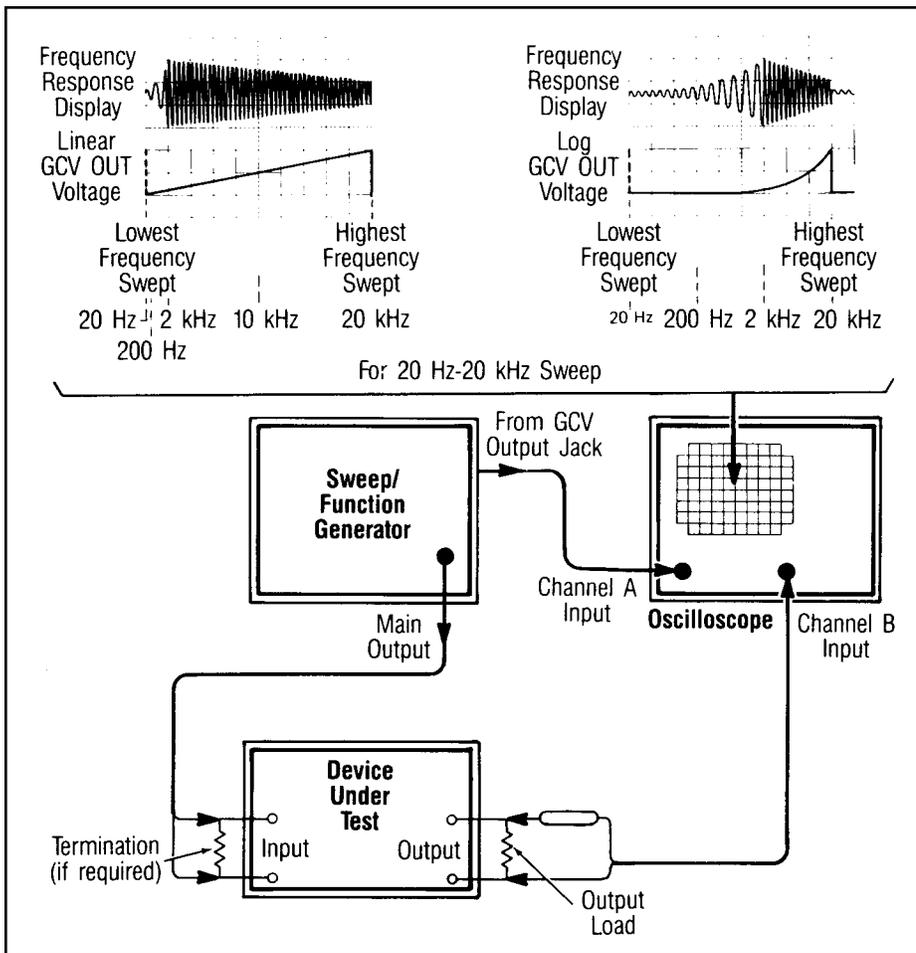


Fig. 12 Frequency response measurement, linear/log display method.

NOTE

Some generators have separate start frequency and stop frequency controls, which facilitate setting of sweep endpoints. However, the procedure of steps 3, 5, and 6 is still advisable. Moreover, on some units, these controls are uncalibrated during logarithmic sweeps. In that case, the procedure is still necessary.

8. Return the frequency dial on the generator to the sweep starting frequency, and turn the sweep mode on, selecting linear or log sweep as desired.
9. Initially, set the sweep rate so that it is high enough for one or more cycles of sawtooth waveform to be displayed, either linear or log, like the bottom traces in Fig. 12. Set the oscilloscope to trigger on the GCV waveform (channel A in this example). Note: direction of the ramp depends on the particular generator.
10. Adjust the sweep width so that the sawtooth ramps between the two screen positions chosen in steps 5 and 6. The generator is now sweeping between the two desired frequencies.
11. Adjust the sweep rate to attain the desired repetition rate. For viewing convenience, the highest possible setting is desirable. However, it must be set low enough to obtain a few cycles at the lowest frequencies being swept.

This difficulty is overcome by using the normal time base of the scope for horizontal deflection, rather than the GCV output. Since this deflection signal is always linear with respect to time, then the true nature of the sweep (linear or log) is displayed. Drawbacks are a somewhat more difficult determination of exact frequency points on the scope, and, depending on the generator, a possible reversal of display from the method used earlier.

**Procedure**

Refer to Fig. 12.

1. Connect the GCV output of the generator to a vertical input of the oscilloscope, as shown in the figure. Though not used for horizontal deflection, the GCV output is nevertheless useful in setting and determining frequency points on the display.
2. Select the desired frequency range on the generator.
3. Set the generator for continuous run mode, and set the frequency dial for the desired starting frequency of the sweep.
4. Use DC coupling for the scope input to which the GCV output is connected. Initially, select only that channel and adjust the scope controls to display a flat trace. Use automatic sync on triggered sweep scopes.
5. Use the oscilloscope vertical position control to locate the trace at a convenient vertical reference point. Note: if the GCV voltage increases with increased frequency, the trace should be located near the bottom of the screen; otherwise, locate it close to the top. Check the manufacturer's manual for the particular generator.
6. Now set the generator to run at the desired ending frequency of the sweep. Without readjusting the vertical position control, adjust the vertical gain controls of the oscilloscope (step and vernier) so that the new trace is located at a convenient point vertically opposite the point used in step 5.
7. Repeat steps 3, 5, and 6 as required to attain the two desired vertical positions for start and stop references.

12. Readjust the oscilloscope sweep speed to display one cycle of the sweep voltage waveform, and spread it out over some convenient number of horizontal divisions. Each division can later serve as a frequency marker if the corresponding frequency is calculated. For example, the first display in Fig. 12 shows a 20 Hz to 20 kHz linear sweep display spread over 10 divisions. The difference between the lowest and highest frequency is almost 20 kHz. Therefore, starting from the left of the display at 20 Hz, each division equals a frequency increase of 2 kHz. When log display is used, markers between the lowest and highest frequencies must be scaled logarithmically. The second display in Fig. 12 shows a 1000:1 log sweep display spread over nine horizontal divisions. Each three divisions equals a decade of frequency change; that is, after three divisions, the frequency has increased one decade or 10:1 (from 20 Hz to 200 Hz), after six divisions it has increased another decade or 100:1 (to 2 kHz), and after nine divisions, another decade, or 1000:1 (to 20 kHz).

13. Connect the output of the generator to the input of the device under test. Use a termination, if necessary, to match the input impedance of the device to the output impedance of the generator.
14. Set the scope to display both channels simultaneously. Adjust the GCV waveform so that it occupies a smaller vertical space, as in the figure. Do not, however, readjust the time base.
15. Adjust the signal amplitude of the function generator, and adjust the vertical gain controls for the other channel of the scope, to obtain a display similar to that of the figure. Be sure to keep the signal amplitude of the generator below the clipping level of the circuit being tested. To prevent clipping, start with a low signal level from the generator and increase signal amplitude until the highest peak on the display no longer increases as input amplitude is increased. Then reduce amplitude slightly below that point.
16. You may switch from linear to logarithmic mode, or vice versa. In doing so, you may wish to readjust the time base for more convenient frequency markers. Note also that on some generators, the start and stop points of the sweep (as indicated by the ramp ends) may vary slightly between the row modes. If so, you may wish to start again at step 3.

**FREQUENCY RESPONSE USING A DIGITAL-STORAGE OSCILLOSCOPE**

The advent of digital-storage oscilloscopes, or DSO's, facilitates the frequency response measurements discussed in the last section. With a conventional scope, the generator's sweep rate must be kept fast enough to avoid flicker, but slow enough to provide at least a few cycles at the low end of the sweep. A DSO, on the other hand, can be set up to trigger on a single cycle of a relatively slow GCV waveform. This permits a sweep through the desired frequency range that is slow enough to permit adequate response of the circuit under test for all frequencies in the sweep. Moreover, many DSO's permit downloading of their stored display to computers, printers, etc., thus permitting a permanent record of the test.

The procedure for frequency response testing on a DSO is essentially the same as that discussed in the last section, where the time base of the scope is used for horizontal deflection. However, the DSO needs only to be triggered by a single cycle. Many DSO's are "hybrid" analog-digital types, which

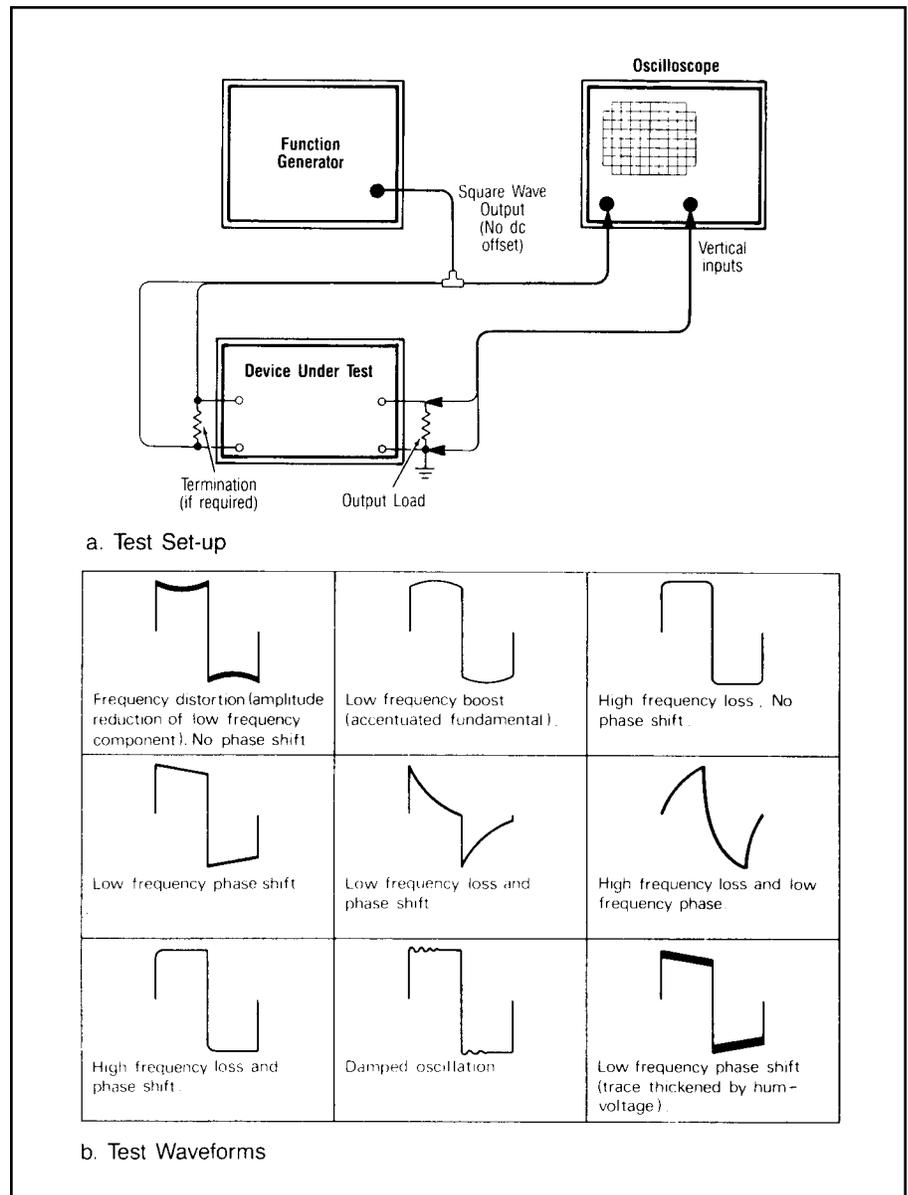


Fig. 13. Amplifier performance evaluation using square waves.

means that frequency limits and triggering levels can be set using GCV output of the function generator, in the same fashion as for analog scopes. The scope is then switched to digital storage mode, and "armed" to trigger on the next GCV cycle, in "single-cycle" mode. Some function generators also facilitate this set-up by providing a MANUAL switch which causes a single sweep to be initiated manually.

**AMPLIFIER PERFORMANCE EVALUATION USING SQUARE WAVES**

Standard sine wave frequency response curves do not give a full evaluation of amplifier transient response. The square wave, because of its high harmonic content, yields

much information regarding amplifier performance, when used in conjunction with an oscilloscope.

1. Use the test set-up of Fig. 13a. When using square waves, it is essential to place a termination at the input of the device under test which matches the output impedance of the generator (in most cases 50 ). This eliminates ringing effects generated by the fast rise times. This termination is not required if the two impedances already match.
2. Using the triangle output of the generator, set amplitude so that there is no signal clipping over the range of frequencies to be used.

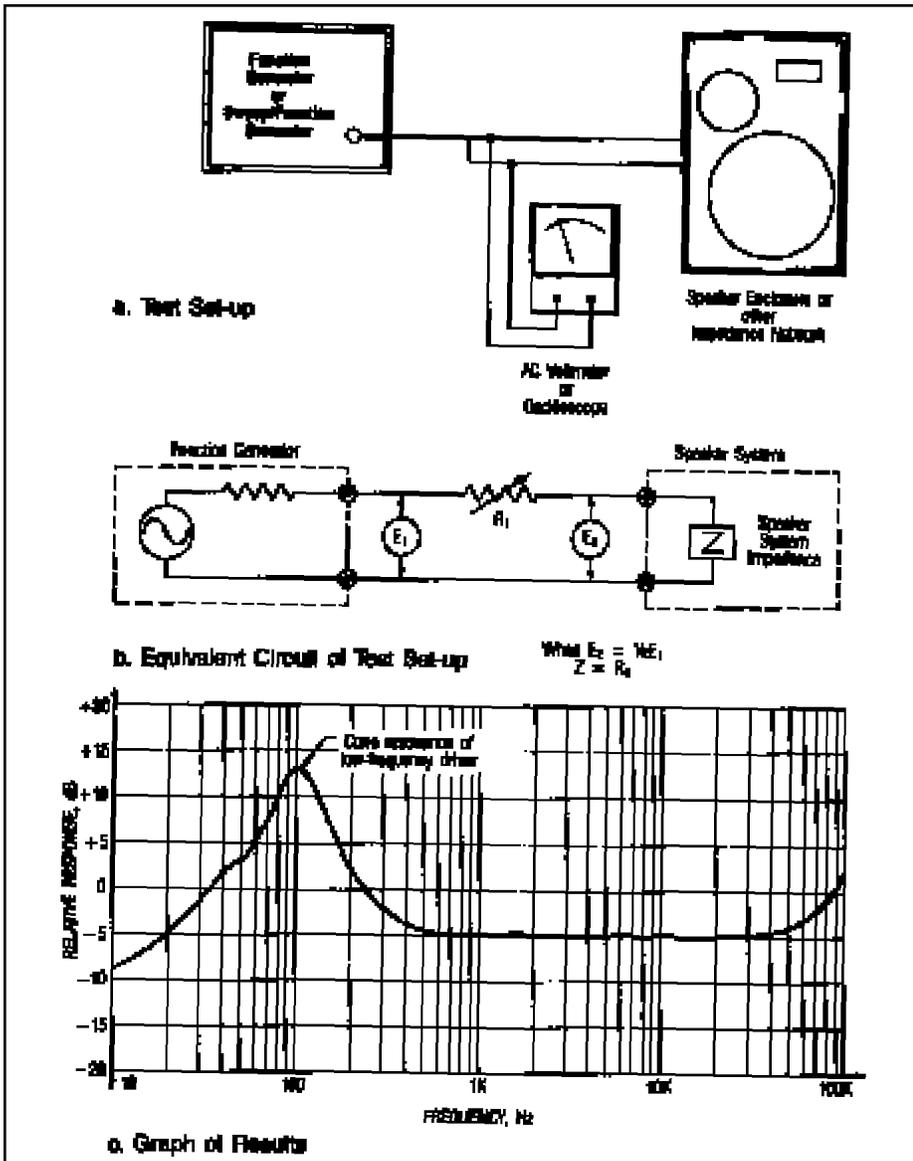


Fig. 14. Testing speaker systems and impedance networks.

3. Select the square wave output and adjust the frequency to several check points within the passband of the device under test, such as 20 Hz, 1 kHz, and 10 kHz.
4. At each frequency checkpoint the waveform obtained at the output of the device under test provides information regarding its performance with respect to the frequency of the square wave input. Fig. 13b indicates the possible waveforms obtained and the interpretation of their characteristics.

Square wave evaluation is not practical for narrow-band amplifiers. The restricted bandwidth of the amplifier cannot reproduce all frequency components of the square wave in the proper phase and amplitude relationships.

**TESTING SPEAKERS AND IMPEDANCE NETWORKS**

A function generator can be used to provide information regarding the input impedance of a speaker or any other impedance network vs. frequency. In addition, the resonant frequency of the network can be determined.

1. Connect equipment as shown in Fig. 14a. The oscilloscope may be used to verify that the function generator is not in a clipping condition.
2. If the voltmeter method is used, vary the generator frequency over the full range of interest and log the voltage measured at the speaker terminals vs. frequency. The dB scales of an AC voltmeter are convenient for converting this information to standard response units.

3. If the oscilloscope method is used, use sweep operation for frequency response measurement.
4. In speaker testing, a pronounced increase of voltage will occur at some low frequency. This is the resonant frequency of the speaker system (Fig. 14c). The speaker enclosure will modify the results obtained from the same speaker without an enclosure. A properly designed enclosure will produce a small peak on each side of the peak obtained without an enclosure. The enclosure designer can use the response characteristics to evaluate the effects of varying port sizes, damping materials, and other basic enclosure factors.
5. In testing other impedance networks, resonance will not necessarily occur at low frequency. However, as resonance is approached, the signal level will increase. The impedance of the network can be measured at resonance, or at other frequencies if desired as follows:

- a. Connect a non-inductive variable resistor in series with the impedance network as shown in Fig. 14b.
- b. Measure the voltage at points E1 and E2 respectively and adjust variable resistor R1 so that voltage E2 equals one half of voltage E1.
- c. The impedance of the network equals the resistance of variable resistor R1.

**NOTES ON AMPLITUDE MODULATION**

Amplitude modulation, or AM, is the varying of the amplitude of one signal in accordance with the amplitude of another, lower-frequency, signal. Many function generators allow the user to amplitude-modulate the main output via either an external or internal modulation source. Refer to Fig. 15. The top left waveform represents the unmodulated output of the generator. The two waveforms immediately below it show the output carrier with 50% and 100% modulation, respectively, where percentage is calculated using the formula shown. The amount of modulation is typically adjusted by a front panel control which affects both the internal and external source. The fourth waveform shows the results of overmodulation (greater than 100%), which is an undesirable condition.

The waveforms in the right column of Fig. 15 represent a mode of AM known as

suppressed carrier. When a signal is amplitude-modulated, two “sidebands” are created on either side of the carrier frequency. Each of these sidebands contains all of the modulating information; consequently, either the carrier alone or the carrier and one sideband can be suppressed for reduced power consumption by the radio transmitter. These two modes of operation are known as double-sideband (DSB) and single-sideband (SSB), respectively. Some function generators provide a carrier level control which allows partial or complete suppression of the carrier for double-sideband operation. The figure shows the generator output for partial and complete carrier suppression, with and without modulation.

**AM RECEIVER ALIGNMENT**

1. Use the test set-up of Fig. 16, with the generator set to produce a linear sweep display.
2. If a precise center frequency and bandwidth is required, a frequency counter should be used during set-up. Function generators with built-in frequency counters (digital display) simplify this step. Before sweep operation begins, set the frequency dial on the generator to obtain the desired frequencies of interest on the counter and place markers on the oscilloscope screen using a grease pencil or china marker.
3. The signal can be injected either at the mixer (455 kHz) or at the antenna, depending on the frequency capability of the generator. When injecting the 455 kHz signal at the mixer input, the local oscillator must be disabled.
4. When the IF response is observed at the input to the AM detector, an RF detector probe is required unless a demodulated point is specified by the manufacturer.
5. The IF amplifier tuning adjustments can be performed as required to obtain the desired IF response curve. Often, each tuned circuit is adjusted for maximum amplitude at the IF center frequency. However, some IF amplifiers are stagger-tuned to achieve the desired bandwidth.

External sweep may be used if desired for sine wave or other sweep patterns. Connect the external sweep voltage source to the VCF input jack of the generator. The external sweep voltage should also be applied to the horizontal input of the oscilloscope. To set up frequency markers, a variable DC power supply may be fed into the VCF input jack and

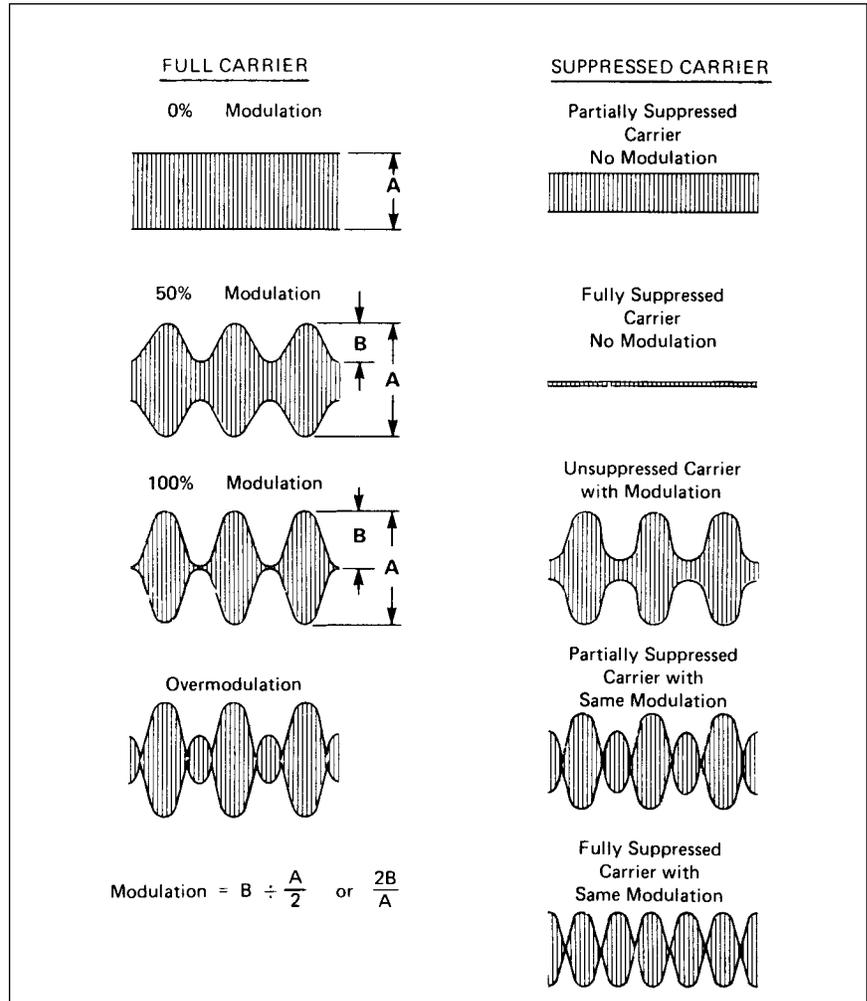


Fig. 15. AM modulation and suppressed carrier waveforms.

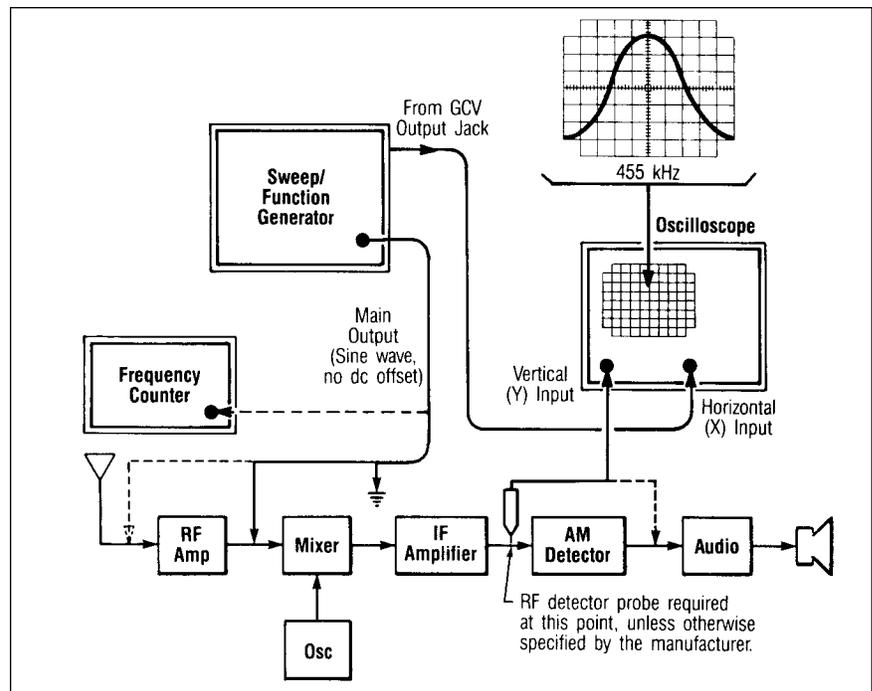


Fig. 16. AM receiver alignment

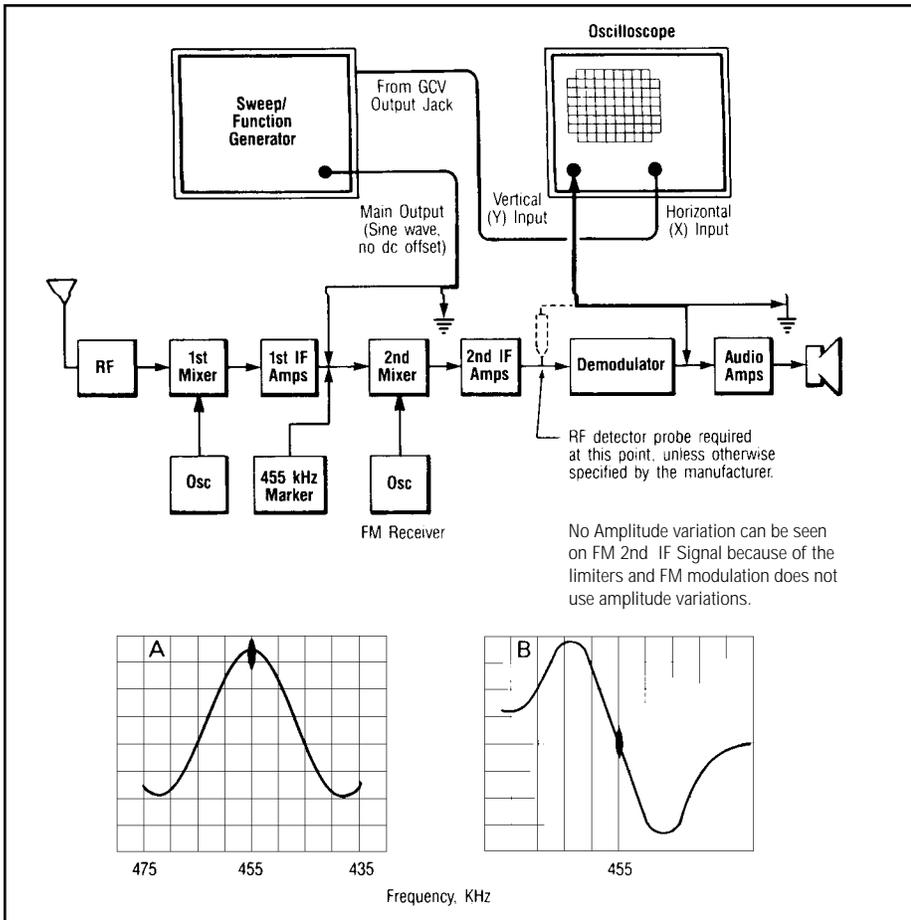


Fig. 17. Alignment of FM communications receiver IF's and discriminators

oscilloscope horizontal input, and a counter may be used to measure output frequency. However, even with external sweep operation, it may be more convenient in setting up frequency markers to use the GCVOUT voltage to drive the horizontal input of the oscilloscope, because it allows direct correlation between the oscilloscope display, frequency counter, and frequency dial of the generator.

**FM COMMUNICATIONS RECEIVER ALIGNMENT**

The test set-up of Fig. 17 can be used for alignment of FM communications receiver IF's and discriminators using the 455 kHz IF frequency. For accurate frequency adjustments, a 455 kHz crystal-controlled marker source should be used.

1. Use sweep operation and apply signal to the input of the 455 kHz IF section.
2. When signal at the output of the 455 kHz IF section is displayed, a response curve similar to Fig. 17a should be obtained. The marker "pip" should be in the center of the response curve.

3. When the output of the discriminator is displayed, a response curve similar to Fig. 17b should be obtained. The "S" curve should be balanced on each side of the marker "pip".

In some receivers the IF selectivity is "packaged", which means all adjustments are preset. In this case the receiver alignment can only be evaluated and verified without adjustment. Where the tuned circuits are adjustable, the manufacturer's procedure must be followed to ensure that the proper overall response is obtained.

**TESTING DIGITAL LOGIC CIRCUITS**

Modern function generators are well suited for testing digital logic circuits. They can supply square waves, pulses, or gated pulse trains. On many generators, these waveforms may be swept in frequency if desired. Using variable symmetry, narrow clock pulses can be supplied for breadboarding and design analysis. A dedicated TTL-level output is common on most modern units. Its frequency and symmetry can be varied along with that of the main output, but its output levels are

always correct for injection into TTL circuits without adjustment of offset or amplitude.

The standard square wave output of the generator can also be useful in determining logic thresholds for a particular TTL circuit. The user can start by applying a TTL-level signal, with proper DC offset, and then gradually decrease the amplitude until marginal operation is produced by the circuit under test. None: on most units, as amplitude is decreased, the DC offset will need to be continually readjusted also.

The square wave output is also useful for testing CMOS circuits, which may have logic levels varying from 3V to 18V, depending on the application. Some function generators have a CMOS output for convenience, but the main output can be set up to simulate CMOS signal conditions.

**PRESET FREQUENCY SELECTION**

In test and design work where several frequencies are to be used repeatedly, it is convenient to be able to preselect these frequencies with a minimum of effort. As shown in Fig. 18, the VCF feature of many function generators can be used together with preset voltages and a frequency selector switch.

1. Construct the circuit shown in Fig. 18. The voltage labeled "+V" should be a regulated voltage at or near the maximum safe input to the VCF input jack as recommended by the manufacturer. This limit indicates the voltage value required for maximum frequency spread on a given range. Note: applying a higher voltage will most likely damage the generator, and usually won't provide greater frequency coverage anyway.
2. Consult the instruction manual for the particular generator to determine whether its output frequency increases or decreases with an increase in the applied external voltage.
3. If the frequency increases with positive voltage changes, set the frequency dial to the bottom of its rotation (lowest frequency). If frequency decreases with positive voltage changes, set the dial to the top of its rotation. Since the VCF input is summed with the dial voltage, setting the dial to an end stop insures the the preselected frequencies will be repeatable.
4. Connect the circuit to the VCF input jack, and connect a frequency counter to the output of the generator.

5. With the frequency selector switch in the F1 position, adjust R1 for the desired frequency as observed on the counter. Repeat this for the other frequencies desired.
6. After the initial set-up, whenever this circuit is used for automatic frequency selection, the frequency dial on the generator must be placed at the same end of rotation for repeatability.

**DIGITALFREQUENCYSELECTION**

Frequencies can be switched electronically by using the set-up shown in Fig. 19. The preset voltages can be digitally selected and applied to the VCF input jack on the generator. Although provisions for two frequencies are shown, additional frequencies can be added using redundant circuits. This is convenient in frequency shift keying (FSK) systems.

As with "Preset Frequency Selection" above, "+V" in the circuit should be at or near the maximum safe limit specified for the VCF input jack by the manufacturer, and a counter should be connected to the generator output for initial frequency calibration. Whenever the circuit is used thereafter, the dial should be set to the same end stop for repeatability.

**TESTING TONE BURST DECODERS**

A tone burst decoder requires a specific tone frequency, such as 2250 Hz, for a specific minimum period of time, such as 120 milliseconds, before it will provide an output. This delay prevents voice signals or other random on-frequency signals from falsely activating the decoder. A function generator equipped with tone burst capability can generate the signals necessary to test the delay time, as well as the frequency response and sensitivity of tone burst decoders.

The following procedure, along with Fig. 20, describes the typical testing method for these devices.

1. Connect equipment as shown in Fig. 20. With the generator initially in the continuous run mode, set its range and frequency to the decoder's acceptance frequency. This should be found in the manufacturer's service literature, or may be marked on the unit. Use a frequency counter if a high degree of accuracy is required.
2. Set the generator to tone burst mode, and select internal gating.

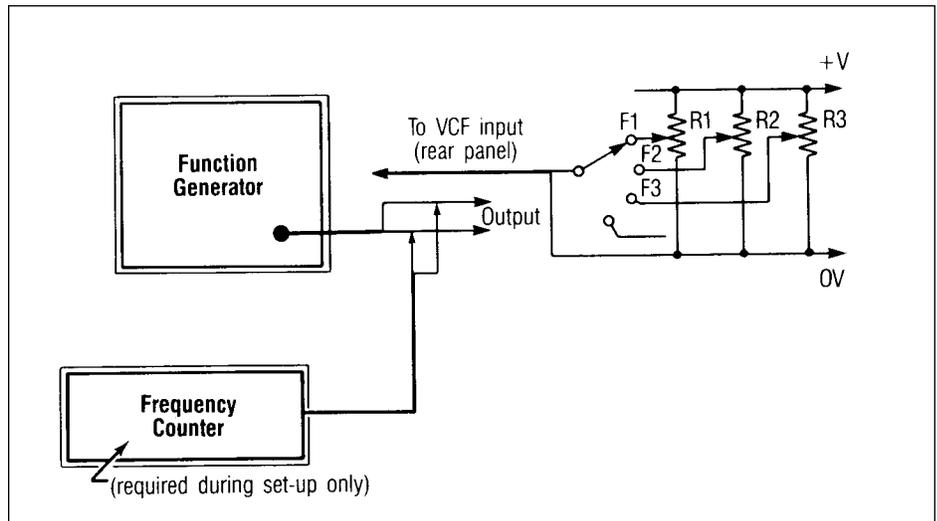


Fig. 18. Preset frequency selection.

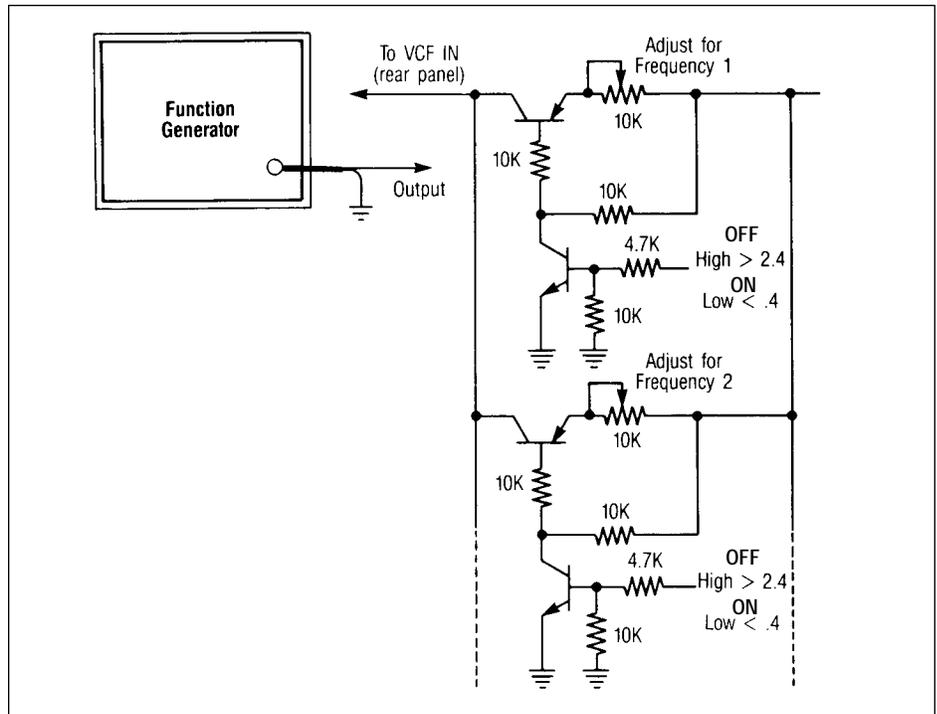


Fig. 19. Digitally programmed frequency selection.

3. Using a dual-trace oscilloscope, display the decoder input signal on one trace and its output on the other. Synchronize the scope to the beginning of the tone burst signal.
4. Adjust the duration of the tone burst to equal or slightly exceed the specified turn-on delay time of the unit under test.
5. Adjust the repetition rate of the tone burst, allowing sufficient time between bursts for the decoder to fully return to its

standby condition. The repetition period can be measured on the oscilloscope.

6. The decoder's turn-on delay period can also be measured on the scope. This is the time period from the beginning of the tone burst until the decoder output changes stated. Decoder turn-off delay can also be measured. This is the time period from the end of the tone burst until the decoder output reverts to the off state. Both intervals are shown in Fig. 20.

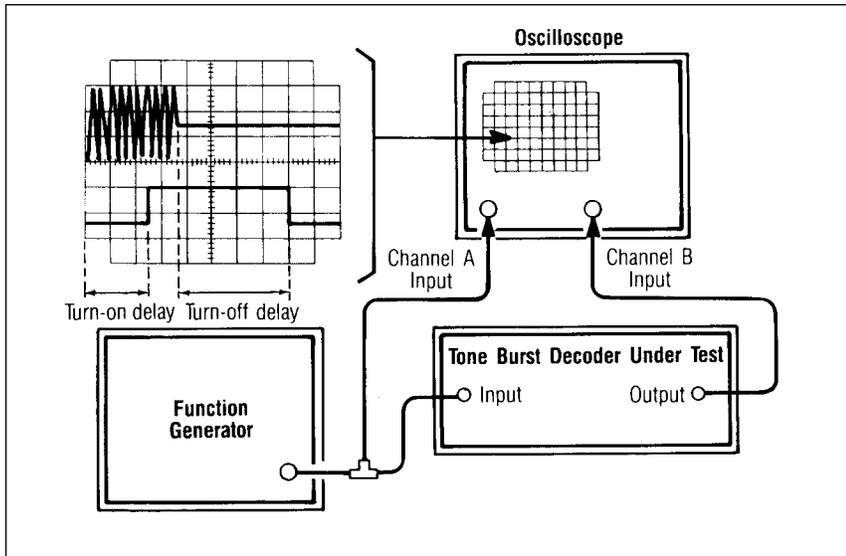


Fig. 20. Tone burst decoder testing.

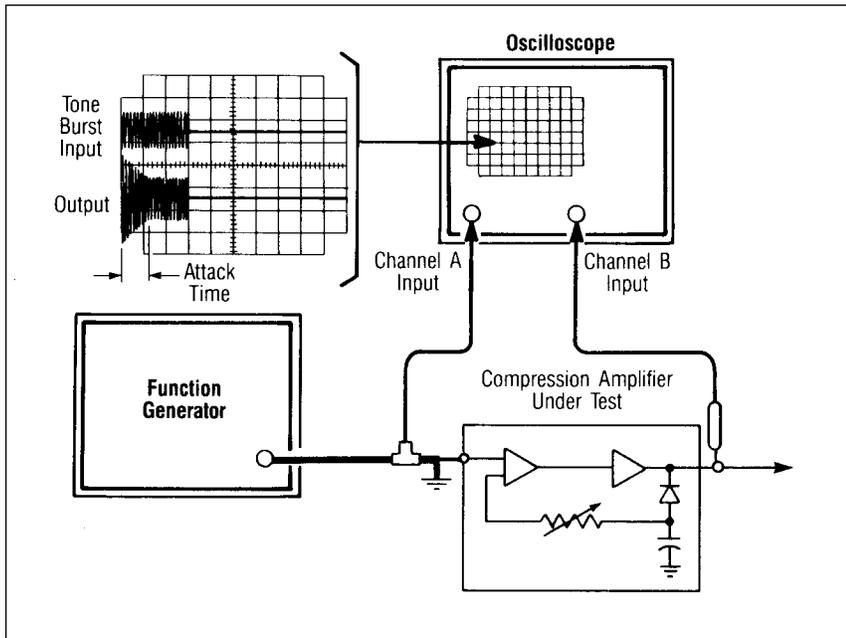


Fig. 21. Measuring attack time of a compression amplifier

**TESTING MODULATION LIMITERS AND COMPRESSION AMPLIFIERS**

Compression amplifiers are often used in communications equipment to provide better audibility over a wide range of input conditions. One very common application is modulation limiting in CB radio transmitters. Attack time, the time delay from initial application of signal until full compression takes effect, is a primary consideration in compression amplifiers. The tone burst output of many function generators can provide an effective method of testing attack time, which cannot be measured with continuous signal applied.

1. Connect equipment as shown in Fig. 21. Using a dual-trace oscilloscope, display the input of the compression amplifier on one trace and the output on the other trace.
2. Place the function generator in tone burst mode.
3. Observe the output waveform on the scope, synchronizing the display with the beginning of the tone burst. Note that the amplitude of the waveform is maximum at the beginning of the tone burst, and decreases until full compression takes effect. At that point, the amplitude becomes constant.
4. Allow enough tone burst width for full compression to take effect. Also allow sufficient time between tone bursts for the bias of the compression amplifier circuit to revert to the full gain state.
5. Using a calibrated time scale on the oscilloscope, measure the attack time, as shown in Fig. 21, and compare with the manufacturer's specifications.
6. The effectiveness of the compression amplifier also may be tested by applying various amplitude input tone bursts and measuring the output amplitude. Specifications for compression amplifiers are often stated in this manner. For example, "30 dB variation in input level will produce no more than 3 dB variation in output level".
7. Testing may be performed at various frequencies of the compression amplifier's passband.

7. Decoder sensitivity can be measured by varying the amplitude of the tone burst signal. Adjust the amplitude to the level that will barely activate the decoder output. That amplitude is the decoder's threshold sensitivity.
8. Alignment and off-frequency rejection may be checked by performing a fre-

quency response measurement on the tone burst decoder. Output frequency can be varied minutely up and down until the device begins to function marginally. At those points, the generator can be temporarily switched back to continuous run, and a counter used to determine the frequencies of interest.