



## The New -hp- 15-21 KMC 10 MW Signal Generator

**T**HE NEW -hp- 15-21 kilomegacycle signal generator is designed as a general-purpose instrument which will give engineers working in the 15-21 kmc region the same conveniences and accuracy that have led to the wide acceptance of the other -hp- microwave generators. To this end the generator provides at least 10 milliwatts (+10 dbm) of maximum output over its complete frequency range, is direct-reading in frequency to within 1%, has a direct-reading, accurate 100 db output attenuator, and is provided with a flexible modulator which gives pulse, square-wave or f-m modulation.

SEE ALSO:  
 "Waveform Effects  
 on Voltmeters," p. 3

A block diagram of the circuit arrangement of the new generator is shown in Fig. 2. The oscillator uses a type V40B reflex klystron operating with an external waveguide resonator which is tuned by a non-contacting type plunger. The number of times the oscillator is tuned through its frequency range is thus essentially independent of tube life. As in the other -hp-

generators, a direct-reading frequency dial is obtained by mechanically tracking the resonator plunger with repeller voltage. The frequency range is covered by using parts of two modes, and mode switching is performed automatically by the repeller tracking mechanism. The klystron temperatures are kept at a low value by drawing air through the louvred portion of the front panel directly across the tube and resonator.

R-f power from the klystron is fed to a simple uncalibrated attenuator. This attenuator serves as the power set control and permits the attenuator output to be standardized to the nominal maximum output value of 10 milliwatts (in practice, at least 20 milliwatts are usually obtainable). The power level at the attenuator output is then monitored by a temperature- and sensitivity-compensated thermistor bridge. The power sample for the bridge is split from the main output by a specially-designed directional coupler of the -hp- multi-hole type<sup>1,2</sup>.

Following the directional coupler is the main output attenuator which is of the rotary type<sup>3</sup>. This type of attenuator has advantages in that it is not sensitive to frequency in this range, has an attenuation which is controlled by a mathematical law, is accurate, and is mechanically practical to construct. Since the attenuation range of a single attenuator is less than that desirable in a quality signal generator, however, the attenuator used is formed from two rotary



Fig. 1. New -hp- Model 628A Signal Generator operates from 15 to 21 kmc, provides at least 10 milliwatts over complete band.

<sup>1</sup> E. F. Barnett and J. K. Hunton, "A Precision Directional Coupler Using Multi-Hole Coupling," *Hewlett-Packard Journal*, Volume 3, No. 7-8, March-April, 1952.

<sup>2</sup> E. F. Barnett, "More About the -hp- Precision Directional Couplers," *Hewlett-Packard Journal*, Vol. 4, No. 5-6, January-February, 1953.

<sup>3</sup> B. P. Hand, "A Precision Wave Guide Attenuator Which Obeys a Mathematical Law," *Hewlett-Packard Journal*, Vol. 6, No. 5, January, 1955.

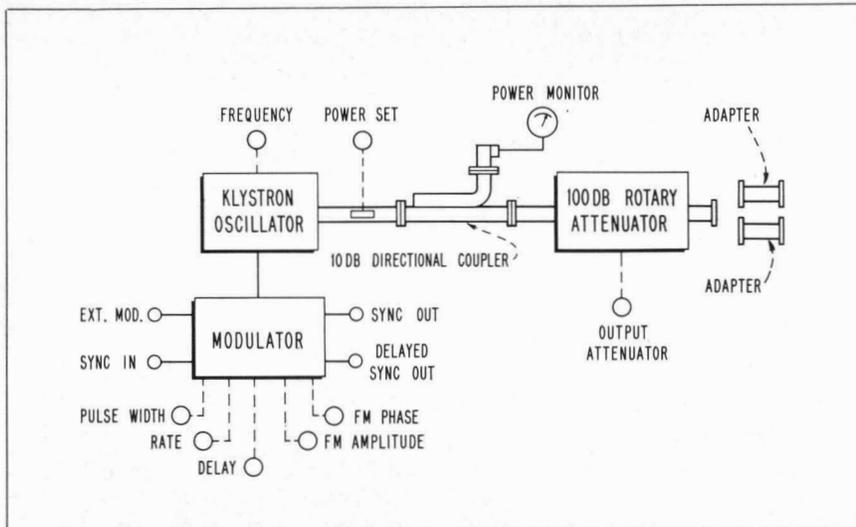


Fig. 2. Basic circuit arrangement of -hp- 628A Signal Generator.

attenuators which are driven from a common gear drive and operate as a single unit. This arrangement results in an attenuator which is calibrated over a 100 db range to an accuracy of  $\pm 2\%$  of its db reading at any frequency in the generator's range.

The generator power is delivered in RETMA type WR51 wave guide (0.510" x 0.255" inner dimensions) which is terminated at the panel in a flat cover flange. To permit this size guide to be used, where desired, with 12.4-18 kmc WR62 (RG-91/U) size guide or with 18-26.5 kmc WR42 (RG-53/U) size guide, two special adapters are provided with the equipment. A wave guide cap chained to the panel is provided to exclude foreign objects during non-use periods.

The output match of the generator is such that power reflection

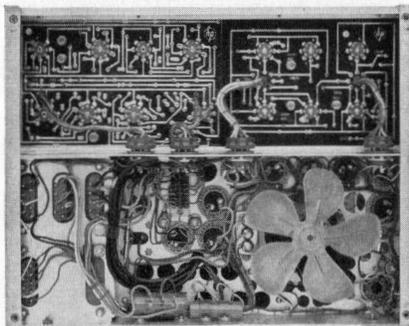


Fig. 3. Back of chassis view of new generator. Etched circuit construction contributes to clean layout and good accessibility to components.

from a flat load is inconsequential. At levels below 0 dbm, the VSWR looking into the generator does not exceed 1.2, corresponding to a power reflection of less than 0.8%. At higher outputs the VSWR of the generator rises but does not exceed approximately 2.

The klystron is repeller-modulated from a modulator which is designed to provide pulse, square-wave or swept operation. On pulse and square-wave modulation, the repetition frequency is adjustable from 40 to 4,000 cps by means of direct-reading controls. A direct-reading control is also provided for adjusting the pulse width from 0.5 to 10 microseconds.

On f-m operation the klystron is swept at the power line frequency. Deviations up to  $\pm 5$  megacycles are obtainable with the deviation control. The sweep voltage is also provided at a panel jack for operating an oscilloscope and the phase of the modulation is adjustable over a range approaching  $\pm 90^\circ$  to accommodate the oscilloscope display.

On pulse and square-wave operation, the modulator provides two sync out pulses of positive polarity. One of these is approximately coincident with the leading edge of the r-f pulse. The second can be adjusted to occur anywhere in the range from 3 to 300 microseconds in advance of the r-f pulse. Both pulses have am-

plitudes of at least 25 volts and rise times of less than 0.5 microsecond across loads as low as 1000 ohms shunted by 500 micromicrofarads.

#### GENERAL

Constructionally, considerable care has been taken to achieve a good order of mechanical performance. Etched circuit type construction is used to obtain a clean, open layout. All circuit adjustments are made with screwdriver type controls. Components are substantially derated to obtain a long life.

-Wm. D. Myers

#### SPECIFICATIONS

##### -hp- MODEL 628A SHF SIGNAL GENERATOR

- FREQUENCY RANGE: 15,000 to 21,000 mc.
  - FREQUENCY CALIBRATION: Dial direct reading in megacycles. Accuracy better than  $\pm 1\%$ .
  - OUTPUT RANGE: 10 mw to 1  $\mu\text{w}$ . (Plus 10 dbm to -90 dbm, 0 dbm = 1 mw.) Attenuator dial directly calibrated in output dbm. SWR less than 2 at +10 dbm; 1.2 at 0 dbm and lower.
  - OUTPUT MONITOR ACCURACY: Better than  $\pm 1$  db.
  - OUTPUT ATTENUATOR ACCURACY: Better than  $\pm 2\%$  of attenuation in db introduced by output attenuator.
  - OUTPUT CONNECTOR: 0.590 inches by 0.335 inches (external) wave guide with WR51 Flat Cover Flange.
  - LEAKAGE: Less than minimum calibrated signal generator output.
  - MODULATION: Internal or external pulsed, FM or square wave.
  - INTERNAL PULSE MODULATION: Repetition rate variable from 40 to 4,000 cps. Pulse width variable 0.5 to 10 microseconds.
  - SYNC OUT SIGNAL: 20 to 50 volts amplitude into 1,000 ohm load. Better than one microsecond rise time. (1) Simultaneous with r-f pulse—positive. (2) In advance of r-f pulse—positive, variable 3 to 300 microseconds.
  - EXTERNAL SYNCHRONIZATION: (1) Sine wave, 40 to 4,000 cps, amplitude 5 to 50 volts rms. (2) Pulse signals 0 to 4,000 cps, 5 to 50 volts amplitude, positive or negative. Pulse width 0.5 to 5 microseconds. Rise time 0.1 to 1 microsecond.
  - INTERNAL SQUARE WAVE MODULATION: Variable 40 to 4,000 cps controlled by "pulse rate" control.
  - INTERNAL FREQUENCY MODULATION: Power line frequency, deviation up to  $\pm 5$  mc.
  - EXTERNAL PULSE MODULATION: Pulse Requirements: Amplitude 15 to 70 volts peak positive or negative; width 0.5 to 2500 microseconds.
  - EXTERNAL FREQUENCY MODULATION: Provides capacitive coupling to repeller of klystron. Maximum deviation approximately  $\pm 5$  mc.
  - POWER SOURCE: 115 volts  $\pm 10\%$ , 50/60 cps, approx. 200 watts.
  - SIZE: Cabinet Mount: 16 $\frac{3}{4}$ " wide, 13 $\frac{1}{2}$ " high, 12" deep.
  - WEIGHT: Net 65 lbs.; shipping weight 105 lbs.
  - ACCESSORIES FURNISHED: (a) N to P Band wave guide adapter, WR51 to WR62 guide. (b) N to K Band wave guide adapter, WR51 to WR42 guide. (c) Power cord. (d) Two each AC-16K Video Cable Assemblies.
  - PRICE: -hp- Model 628A SHF Signal Generator, 15-21 kmc, \$3,000.00 f.o.b. Palo Alto, California.
- Data subject to change without notice.

# Some Effects of Waveform on VTVM Readings

(Conclusion)

## EXTREMES OF ERROR, PEAK-READING METERS

With peak-reading type meters, the limits of error can theoretically range from 100% low to infinitely high. Consider, for example, the pulse waveform shown in Fig. 8. This waveform can be shown to have an rms value

$$E_{rms} = E\sqrt{\delta(1-\delta)}$$

where  $\delta$  is the duty cycle  $t/\tau$ . Since the actual meter deflection is proportional to the peak value of the waveform, the ratio of  $E_{peak}$  to  $E_{rms}$  will show the operation of the meter

$$\frac{E_{peak}}{E_{rms}} = \frac{E(1-\delta)}{E\sqrt{\delta(1-\delta)}} = \sqrt{\frac{1-\delta}{\delta}}$$

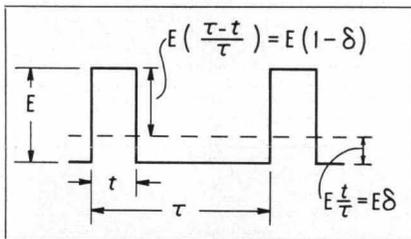


Fig. 8. Pulse waveform defining values used in text.

Thus, if the waveform has a low value for  $\delta$ , the duty cycle, the meter reading will, in the limit, be infinitely high. If the duty cycle has a relatively large value approaching unity (i.e., the pulses will become what are usually considered to be negative pulses), the meter reading will approach zero or be 100% low.

## HARMONICS WITH PEAK-READING METERS

Since the deflection of a peak-reading meter is proportional to the peak of the applied waveform, the maximum reading will be obtained on such a meter when the relative phases of the wave components are such that a peak of the harmonic coincides with the peak of the fundamental. The maximum reading for a given magnitude of harmonic will thus be the same regardless of the order of the harmonic. The ratio of this maximum to the fundamental is plotted as the upper curve in Fig. 9.

The minimum value that the peak can have will be obtained when a peak of the harmonic is in phase opposition to the peak of the fundamental. The lowest minimum peak values will be obtained with low order harmonics. As the order of the harmonic is increased, the minimum peak value will increase until it approaches as a limit

the maximum peak value, i.e., when the fundamental and harmonic peaks coincide. The reason that the minimum reading finally increases as the amount of the harmonic is increased is that the harmonic ultimately causes neighboring peaks to be formed (see Fig. 6[a]). These are what the meter then responds to, and their amplitude increases with increased harmonic. The higher this order,  $n$ , of the harmonic, the smaller is the percentage  $\left(\frac{100}{n^2}\right)$  at which these peaks first form.

The two lower curves in Fig. 9 show the error possible when the phases of the second or third harmonics are such as to cause the minimum possible reading of the meter. Higher harmonics will give minimum reading curves that progressively approach the curve for the maximum possible reading.

If the error in Fig. 9 for a peak-reading meter is compared with that in Figs. 3 and 5 for an average-reading meter, the superiority of the average-reading meter in approximating the true rms value of the waveform will at once be apparent.

## AVERAGE AND PEAK METERS WITH A-M WAVES

If an average meter is being used to measure an amplitude-modulated wave, the meter will, if the modula-

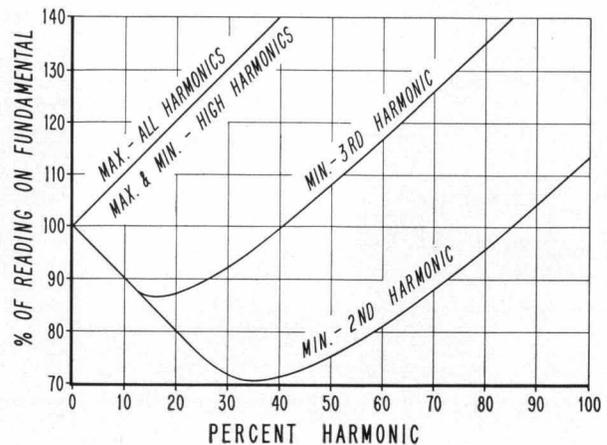


Fig. 9. Curves showing maximum and minimum readings possible on peak-reading meter when applied wave consists of fundamental with various amounts of harmonic content.

tion is linear, read the rms of the average or unmodulated carrier.

A peak meter will read the rms value of the peak r-f amplitude.

The two meters can thus be combined to make readings of the percentage modulation of the modulated wave, because percent modulation is equal to  $100 \left\{ \left( \frac{E_{peak}}{E_{average}} \right) - 1 \right\}$ .

## AVERAGE AND PEAK METERS WITH HUM

It often happens that a small amount of hum is combined with the voltage to be measured. When the frequency to be measured is relatively high with respect to the hum frequency, a small amount of hum such as 10% will increase the reading of an average type meter by about one-half as much as it would increase the reading of a true rms meter. (Thus, 10% hum will give a reading which is 1.0025 times the reading without hum, i.e., an increase of only  $\frac{1}{4}\%$ .)

A peak-reading meter, on the other hand, will add the hum voltage linearly to the desired voltage. The meter reading will thus be high by an amount approximately equal to the hum amplitude (10% hum will result in a meter reading of 110%).

## AVERAGE METERS WITH GAUSSIAN NOISE

The voltage of thermal noise is characterized by a probability dis-

tribution which is of gaussian shape. Shot noise will also have a gaussian probability distribution if the average number of shots per second is much greater than the bandwidth in cycles per second. Impulse noise behaves as shot noise only if the impulses are totally independent and occur at random times. Rectified gaussian noise as obtained from an envelope detector does not have a gaussian distribution.

The indication of an average-reading meter on noise can be calculated as follows. The rectified d-c voltage  $V_o$  from noise will be

$$V_o = \int_{-\infty}^{\infty} V_p(V) dV = 2 \int_0^{\infty} V_p(V) dV$$

where the second integral follows from the first if  $p(V)$  is symmetrical about zero.

If the noise is gaussian, the probability  $p(V)dV$  that the instantaneous voltage lies between  $V$  and  $V + dV$  is:

$$p(V)dV = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{V^2}{2\sigma^2}} dV$$

where  $\sigma$  is the rms noise voltage. Substituting this into the expression for  $V_o$  gives

$$V_o = \frac{2}{\sigma\sqrt{2\pi}} \int_0^{\infty} V e^{-\frac{V^2}{2\sigma^2}} dV$$

$$= \frac{2\sigma}{\sqrt{2\pi}}$$

Since the meter is calibrated to read the rms value of a sine wave, the indicated voltage  $V_i = 1.11$  (i.e.,  $\frac{\pi}{2\sqrt{2}}$ ) times  $V_o$ , where  $V_o$  is the average or rectified value. Thus,

$$\frac{V_i}{\sigma} = \frac{\sqrt{\pi}}{2}$$

$$= 0.886 \text{ or } -1.05 \text{ db}$$

Average-reading meters thus read 1 db low on gaussian noise provided that no overload occurs on the peaks.

#### PEAK METERS WITH GAUSSIAN NOISE

The reading of a peak meter on gaussian noise depends on the efficiency of rectification, i.e., on the ratio of the resistance through which

the input capacitor is charged to that through which it is discharged. If the noise is extremely wide band compared with the reciprocal of the charge and discharge time constants of the meter, the reading will be steady and found as follows:

$$i_{\text{discharge}} = i_{\text{charge}}$$

$$\frac{V_o}{R_d} \cong \frac{1}{R_c} \int_{V_o}^{\infty} V_p(V) dV$$

where  $R_d$  = discharging resistance  
 $R_c$  = charging resistance  
 $V_o$  = rectified d-c value of noise

For gaussian noise this becomes

$$\frac{R_c}{R_d} = \frac{1}{\sigma V_o \sqrt{2\pi}} \int_{V_o}^{\infty} V e^{-\frac{V^2}{2\sigma^2}} dV$$

$$= \frac{1}{\sqrt{2\pi}} \frac{\sigma}{V_o} e^{-\frac{V_o^2}{2\sigma^2}}$$

$\frac{V_o}{\sigma}$  is the ratio of rectified d-c to the true rms of the noise. If the meter is calibrated to read rms on a sine wave, then  $V_o = \sqrt{2} V_i$  where  $V_i$  is the indicated rms. Hence

$$\frac{R_c}{R_d} = \frac{1}{2\sqrt{\pi}} \frac{\sigma}{V_i} e^{-\left(\frac{V_i}{\sigma}\right)^2}$$

$$\text{or } \frac{R_d}{R_c} = 2\sqrt{\pi} K e^{K^2}$$

where  $K = \frac{\text{indicated rms}}{\text{true rms}}$

The factor  $K$  is plotted as a function of  $R_d/R_c$  in Fig. 10. This curve allows one to estimate the correction factor to be applied to the reading of a peak meter to get the rms of a gaussian noise input. The approximate region of the curve applicable to the -bp- 410B is marked.

Although the curve is useful since it is quite flat in the region of interest, several considerations dictate that it should be used only for rough estimating. For one thing the charging resistance is rather uncertain in most cases since it depends on diode perveance and current. Further, with very high  $R_d/R_c$  the current drawn

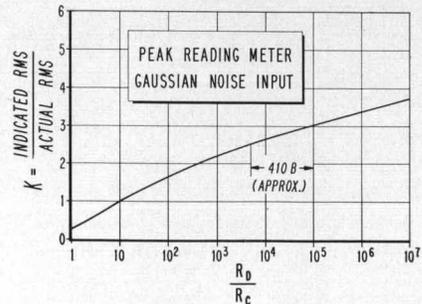


Fig. 10. Plot of correction factor for peak-reading meters when used to measure rms value of gaussian noise. Portion of curve applicable to -bp- Model 410 is marked. Curve should be used only for rough estimating.

by the diode is infrequent and large so that loading on the circuit by the meter tends to suppress the high peaks and decrease  $K$ . Finally, the curve is predicated on the probability distribution being gaussian out to the tips of the distribution. Any amplifier non-linearity will change the distribution.

#### AVERAGE METER WITH SINE WAVE AND NOISE

It frequently happens that one wishes to know the rms value of a sine wave corrupted by added gaussian noise. Even though the noise cannot be eliminated, the signal usually can.

From the readings of noise alone and of noise-plus-signal the rms value of the signal alone can be obtained from the curve in Fig. 11.

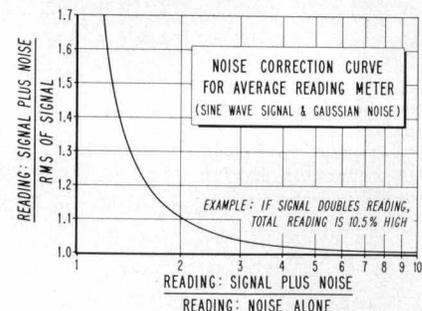


Fig. 11. Curve for obtaining rms value of sine wave in presence of gaussian noise as measured by average-reading meter.

This curve was computed from the expressions derived by W. R. Bennett and published in the Bell System Technical Journal for January, 1944 in an article entitled "Response of a Linear Rectifier to Signal and Noise".

-B. M. Oliver