from JETEC release #1658A, Feb. 3, 1958

6861

TRAVELING-WAVE TUBE

6.5 db Noise Figure | **Low-Noise Amplifier Type for Receiver Applications 2700 to 3500 Mc** | **25 db Gain**

TENTATIVE DATA

RCA-6861 is a low-noise, low-level traveling-wave amplifier tube of the helix-transmission-line type. Operating in the frequency range from 2700 to 3500 megacycles per second, the 6861 is intended for use in the input stage of radar, scatter propagation, and other microwave receivers, and in if amplifier service. Characteristics of the 6861 include a noise figure of 6.5 db and a gain of approximately 25 db.

Featured in the design of the 6861 is a special type of electron gun. This gun deamplifies noise generated in the electron beam with the result that a low noise figure is obtained over the entire operating frequency range of the tube without readjustment of tube operating conditions. In addition, the use of a metal shell allows the rf-input and rf-output transducers to be permanently set in position during manufacture of the tube for optimum performance.

PRINCIPLES OF OPERATION

The structural arrangement of the 6861, shown in Fig. 1, incorporates an electron gun which produces an electron beam; a helix transmission line (slow-wave structure) which propagates a microwave signal in a manner that permits interaction between the beam and the signal; a collector which removes the unused beam energy; transducers which introduce and remove the signal; and an attenuator which isolates the input and output sections of the slow-wave structure to prevent oscillations. All of the components mentioned above, with the exception of the transducers, are contained within an evacuated glass envelope. The input and output transducers, with their semirigid 50-ohm coaxial lines, are adjusted and locked in position within the metal shell to insure proper location with respect to the helix. The metal shell also facilitates mounting of the tube in the magnetic field required to focus the electron beam. The magnetic field may be provided by a permanent magnet, or by a solenoid as illustrated in Fig. 1.

The amplification provided by a traveling-wave tube is produced by interaction of the electron beam and the signal on the slow-wave structure (helix) in the following manner. The velocity of the electron beam entering the helix from the gun is determined by the dc helix voltage. A strong magnetic field whose axis coincides with the axis of the helix confines the electrons to a cylindrical beam whose diameter approaches the inside diameter of the helix. A signal wave introduced onto the helix at the end nearest the gun travels circumferentially along the helix at approximately the velocity of light, although its velocity in the axial, or beam, direction is reduced by the pitch-to-circumference ratio of the helix. When the helix voltage is properly adjusted, the velocity of the beam electrons is made slightly greater than the axial velocity of the rf signal.

The electric field produced by the rf signal moving along the helix affects the velocity of the electrons in the beam in such a manner that beam velocity is slightly reduced by the time the beam reaches the end of the helix. This deceleration of the beam is accompanied by a transfer of beam energy to rf electric-field energy, with the result that the signal is amplified.

GENERAL DATA

Electrical:

Heater, for Unipotential Cathode:

Voltage (AC or DC)	5.0 ± 5%	volts
Current at 5 volts	0.65	amp

Starting Current: The maximum instantaneous starting current must never exceed 4.0 amperes even momentarily.

Cathode Heating Time	1 min.	minute
Frequency Range	2700 to 3500	Mc
Cold Insertion Loss	80	db

Mechanical:

Mounting Position	Any
Cooling	Natural
Maximum Overall Length	19-3/8"

Shell Diameter	1.375" ± 0.005"
Base	Octal 8-Pin
Collector Connector	Birnbach No.403 Banana Jack
RF Connectors:	
Input	Type N UG-18B/U Plug
Output	Type N UG-18B/U Plug
Weight	1-1/2 lbs

Maximum and Minimum Ratings, *Absolute Values*:

DC COLLECTOR VOLTAGE	500 max.	volts
DC HELIX VOLTAGE	500 max.	volts
DC GRID-No.4 VOLTAGE	500 max.	volts
DC GRID-No.3 VOLTAGE	300 max.	volts
DC GRID-No.2 VOLTAGE	75 max.	volts
DC GRID-No.1 VOLTAGE	20 max.	volts
DC COLLECTOR CURRENT	500 max.	μamp
DC HELIX CURRENT	5 max.▲	μamp
MAGNETIC FIELD STRENGTH	400 min.●	gausses
PEAK RF POWER INPUT	100 max.	watts
AVERAGE RF POWER INPUT	0.4 max.	watt
METAL-SHELL TEMPERATURE (At hottest point)	175 max.	°C

Typical Operation at 3100 Mc:

DC Collector Voltage	400	volts
DC Helix Voltage	375	volts
DC Grid-No.4 Voltage	200	volts
DC Grid-No.3 Voltage	40	volts
DC Grid-No.2 Voltage (Approx.)	20	volts
DC Grid-No.1 Voltage	0	volts
DC Collector Current	150	μamp
DC Helix Current	0.5	μamp
DC Grid-No.4 Current, DC Grid-No.3 Current, DC Grid-No.2 Current, DC Grid-No.1 Current	each less than 1	μamp
Magnetic Field Strength†	525 ± 5%	gausses
Gain (Low Level)	25	db
Power Output (Saturated)	1.0	mw
Noise Figure	6.5	db

Characteristics Range Values for Equipment Design:

	Note	*Min.*	*Max.*	
Heater Current	1	0.45	0.85	amp
Input VSWR (Non-operating)	2	-	1.7	
Output VSWR (Non-operating)	2	-	2.0	
DC Helix Voltage	3	350	390	volts
DC Grid-No.4 Voltage	3	160	275	volts
DC Grid-No.3 Voltage	3	20	50	volts
Saturated Power Output	3	0.25	-	mw
Gain	3	20	-	db
Noise Figure	3	-	7.0	db

Note 1: With heater voltage of 5.0 volts.

Note 2: Measured at specified connector over the frequency range of 2700 to 3500 Mc.

Note 3: Adjusted for optimum noise figure with a magnetic field of 525 gausses, signal frequency of 3100 Mc, and heater voltage of 5 volts.

▲ During alignment of the tube in the magnetic focusing field, the helix current may exceed this value for short periods, but should never exceed 25 μamp.

● This value of field strength will focus the electron beam, but noise figure will not be optimum.

† For RCA Solenoid, Type MW-4900.

OPERATING CONSIDERATIONS

The *maximum ratings* shown in the tabulated data are limiting values above which the serviceability of the 6861 may be impaired from the viewpoint of life and satisfactory performance. Therefore, in order not to exceed these absolute ratings, the equipment designer has the responsibility of determining an average design value for each rating below the absolute value of that rating by an amount such that the absolute values will never be exceeded under any usual condition of supply-voltage variation, load variation, or manufacturing variation in the equipment itself.

The *rated values for collector voltage, helix voltage, grid-No.4 voltage, and grid-No.3 voltage are high enough to be dangerous to the user.* Care should be taken during adjustment of circuits, especially when exposed circuit parts are at high dc potential.

The *power supply* for the 6861 should be capable of holding ripple voltage sufficiently low to prevent phase distortion, and should have adequate regulation to prevent a change in operating conditions which might increase the noise figure. A suggested power-supply circuit for use with the 6861 is shown in Fig.2. Provision should be made for monitoring helix current, collector current, and cathode current.

The rated *heater voltage* of 5.0 volts should be applied for at least 1 minute to allow the cathode to reach normal operating temperature before voltages are applied to the other electrodes.

The *magnetic field* required for focusing the electron beam of the 6861 may be obtained from a solenoid or permanent magnet capable of providing a uniform field of 525 gausses over the length of the tube axis starting 2 inches from the groove near the base end of the metal shell and continuing for at least 9 inches along the tube axis.

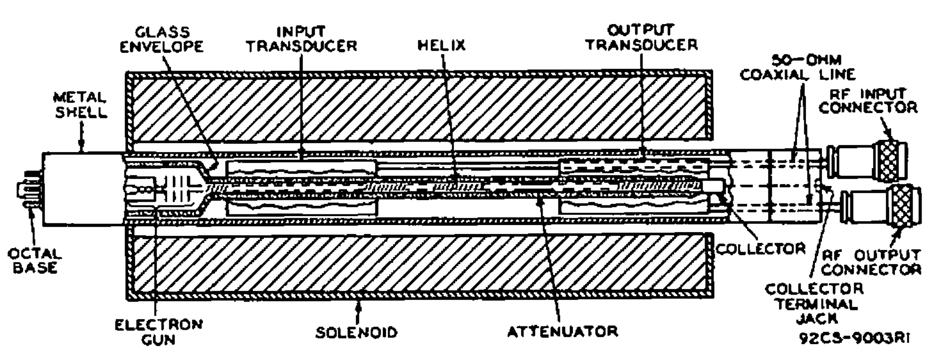
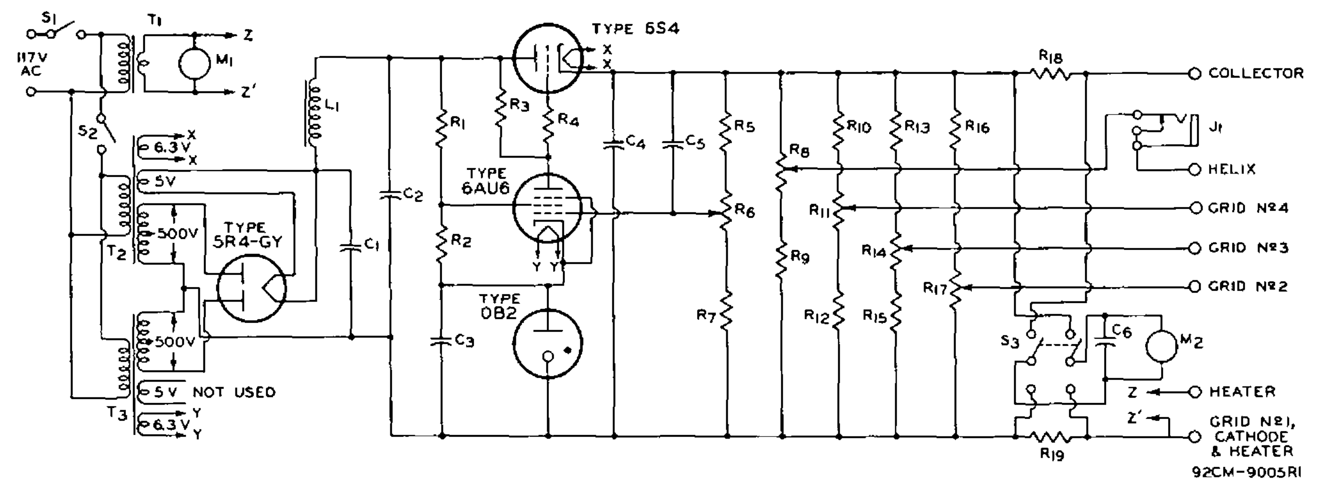


Fig.1 - Schematic Arrangement of Type 6861 with Associated Solenoid.



C1 C2: 8 µf, electrolytic, 800 volts
C3: 0.5 µf, 600 volts
C4: 8 µf, electrolytic, 600 volts
C5: 0.05 µf, 600 volts
C6: 25 µf, 50 volts
J: Closed-circuit jack (for helix-current meter)
L: 12 henries at 80 ma; Thordarson T20C53, or equivalent
M1: AC voltmeter, 0-10 volts
M2: DC microammeter, 0-500 µa
R1: 25000 ohms, 25 watts
R2: 10000 ohms, 10 watts
R3: 1 megohm, 1 watt
R4: 100 ohms, 1 watt
R5: 390000 ohms, 2 watts
R6: 100000-ohm potentiometer, 2 watts
R7: 100000 ohms, 2 watts

R8: 50000-ohm potentiometer, 2 watts
R9: 200000 ohms, 2 watts
R10: 82000 ohms, 2 watts
R11: 100000-ohm potentiometer, 2 watts
R12: 100000 ohms, 2 watts
R13: 100000 ohms, 10 watts
R14: 15000-ohm potentiometer, 2 watts
R15: 4700 ohms, 1 watt
R16: 100000 ohms, 10 watts
R17: 10000-ohm potentiometer, 2 watts
R18 R19: Meter shunt for 1 ma full scale
S1: SPST switch (heater circuit)
S2: SPST switch (high-voltage supply)
S3: DPDT switch
T1: Filament transformer, 5.0v, 3a
T2 T3: Power transformer, Thordarson T22R00, or equivalent

Fig. 2 - Suggested Power-Supply Circuit for Type 6861.

Mounting. The magnetic focusing device used with the 6861 should provide means both for centering the tube in the magnetic field and for locking the tube in position. Provision should be made for natural circulation of air around the tube.

The circumferential groove in the metal shell near the base end of the 6861 is designed to receive a resilient ring used with a clamping device to hold the tube longitudinally in its magnetic focusing field.

A keyway is provided to permit accurate angular location of the 6861 in its magnetic focusing field, and locking the tube against rotation.

After the tube has been inserted in the magnetic focusing field and locked in position, attach an octal socket to the tube base and make connections to the collector jack and to the rf-input and rf-output connectors.

The *base pins* of the 6861 fit a standard octal 8-contact socket. Connection to the *collector terminal jack* may be made with a standard-size banana-type plug. Both *rf-input and rf-output terminals* of the 6861 employ semirigid 50-ohm coaxial lines having type N UG-188/U connectors.

Initial Alignment Procedure

Apply rated heater voltage to the 6861 for one minute. Then connect operating voltages as shown under *Typical Operation* to all other tube electrodes except grid No. 2. Grid-No. 2 voltage may then be applied, and increased until cathode current reaches approximately 50 microamperes.

If the tube is incorrectly aligned within the magnetic field, some of the beam current will be drawn to the helix and increase the helix current. The axial alignment of the 6861 within the magnetic focusing field should then be adjusted to produce a minimum value of helix current. Grid-No. 2 voltage should then be increased until collector current is approximately 150 microamperes. Readjust alignment of the tube and magnetic focusing field until a minimum value of helix current is again obtained. Helix current of the 6861 when properly aligned in the magnetic focusing field is usually less than one microampere. Collector current should be checked to see if it is essentially the same as cathode current. Such a condition is another indication that the tube is properly aligned in the magnetic field. If a solenoid is used to supply the magnetic focusing field, check the solenoid current and readjust it, if necessary, to obtain the specified field-strength value.

The above alignment procedure need not be repeated so long as the adjustments are not disturbed.

Lowest-Noise-Figure Adjustment Procedure

In order to operate the 6861 at the lowest noise figure, it is necessary to adjust the electrode voltages as follows: With the 6861 connected in its circuit, and with either noise input or signal input, adjust the helix voltage to give maximum output at the operating frequency. This value of helix voltage simultaneously produces optimum tube gain and lowest noise figure. Next, with no input signal, vary dc grid-No.3 and grid-No.4 supply voltages alternately until the receiver output reaches a minimum value. The voltages are now adjusted to operate the 6861 at its lowest noise figure for the particular frequency to which the equipment is tuned. If the strength of the magnetic focusing field changes, it will be necessary to repeat the above adjustment procedure with regard to grid-No.3 and grid-No.4 voltage.

Noise-Figure Characteristics

Noise-figure characteristics of the 6861 for different electrode voltages are shown in Figs.3 through 5. The effect of collector-current value on noise figure is shown in Fig.6. The effect of magnetic-focusing field-strength value on noise figure is given in Fig.7, while typical noise-figure variation over the operating frequency range of the 6861 is shown in Fig.8.

Noise Figure

Noise figure (sometimes called noise factor) of an amplifier or a tube is fundamentally a measure of the noise added to the signal by the amplifier or tube, i.e., the ratio of the total noise power delivered by the device to its output termination to the portion thereof arising from noise developed by the input termination.

The noise figure (F) expressed as a power ratio may be written as

$$F = \frac{\frac{S_i}{N_i}}{\frac{S_o}{N_o}} \text{ or } \frac{S_i}{S_o} \cdot \frac{N_o}{N_i} \qquad (1)$$

where S_i = signal input power to device

S_o = signal output power delivered by device

N_i = noise power developed by input termination of device

N_o = noise power delivered by device to output termination

Since $\frac{S_o}{S_i}$ is equal to the gain (G) of the device,

Eq.(1) becomes

$$F = \frac{1}{G} \cdot \frac{N_o}{N_i} \qquad (2)$$

The values for G and N_o can be measured. The value for N_i is calculated from the relation

$$N_i = kTB$$

where k = 1.38×10^{-23} joules/°K (Boltzman's constant)

T = absolute temperature of noise signal source in °K

B = bandwidth of device in cycles/second

Determination of Noise Figure

The noise-figure values in this bulletin were determined using the equipment arrangement of Fig.9, in the following manner:

The operating conditions of the 6861 were adjusted to provide lowest noise figure. Then, with the gas-tube noise source operating and with approximately 40 db of rf attenuation inserted between the noise source and the 6861, the receiver gain was adjusted to provide a convenient value of output. Next, the 40 db of rf attenuation between the noise source and the 6861 was removed and the precision if attenuator was adjusted to add attenuation until the receiver output reached its previous value with 40 db of rf attenuation. The power ratio equivalent to the if attenuation thus added is inversely proportional to the noise generated in the traveling-wave tube.

The power ratio corresponding to the added if attenuation, the effective noise-temperature ratio of the noise source, the insertion loss of the noise source, and the circuit loss between the noise source and the input to the traveling-wave tube all enter into the measurement of noise figure, as follows:

$$F = \frac{\left(\frac{T_B}{T_o} - 1\right)\left(\frac{L-1}{L}\right)}{(A)\ (Y-1)} \qquad (3)$$

where $\frac{T_B}{T_o}$ = effective noise-temperature ratio of gas-tube noise source

L = the power ratio corresponding to the noise-source insertion loss

A = the power ratio equivalent to the circuit loss between noise source and 6861

Y = power ratio corresponding to the attenuation added in precision if attenuator

The value of the first term in the numerator of Eq.(3) is equivalent to 15.28 db for an argon-bulb waveguide-type noise source. This type does not require any temperature compensation. The values of A and L for the equipment used are equivalent to 0.54 db and 15 db, respectively.

Converting these db values into power ratios and substituting them in Eq.(3) gives

$$F = \frac{28.9}{(Y-1)} \qquad (4)$$

To express Eq.(4) in decibels, it is necessary to take 10 times the common logarithm of the power ratio. Hence,

$$F \text{ (in db)} = 10 \log_{10}\left(\frac{28.9}{Y-1}\right) \qquad (5)$$

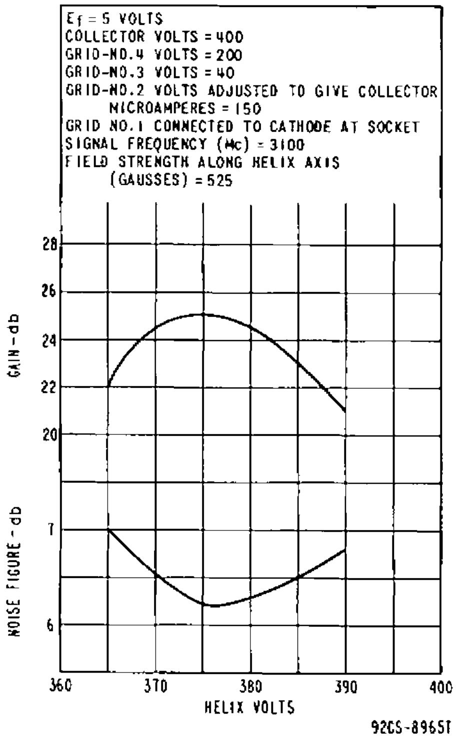


Fig. 3

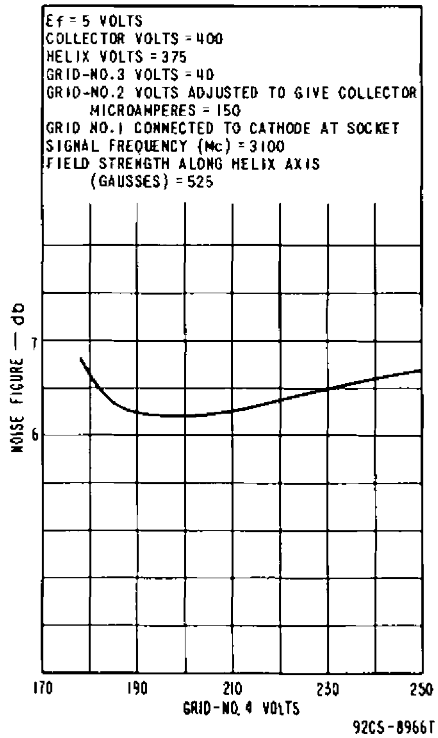


Fig. 4

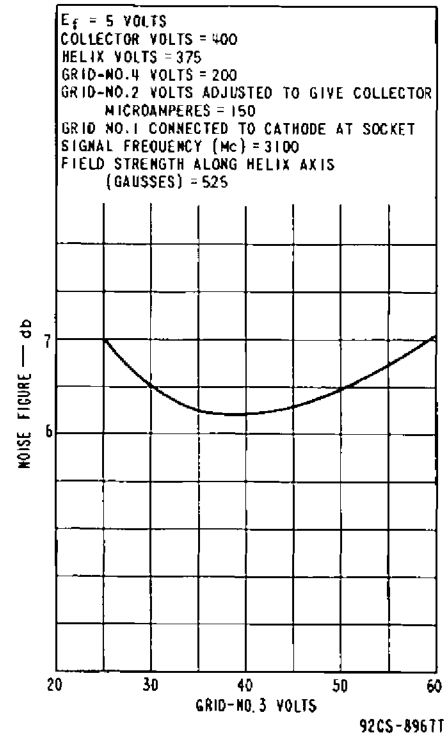


Fig. 5

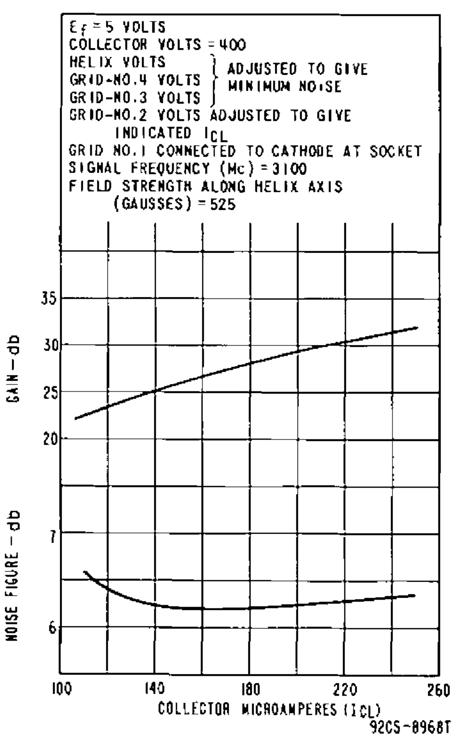


Fig. 6

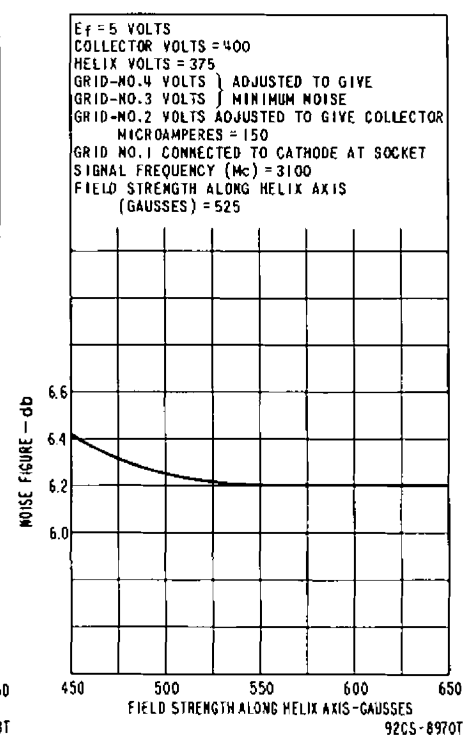


Fig. 7

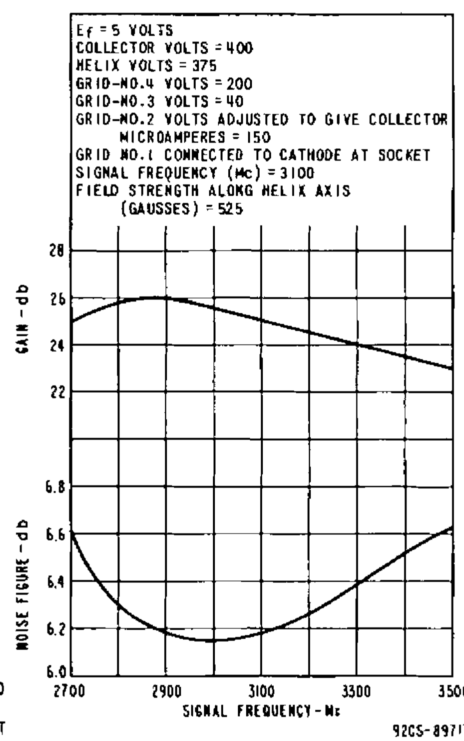


Fig. 8

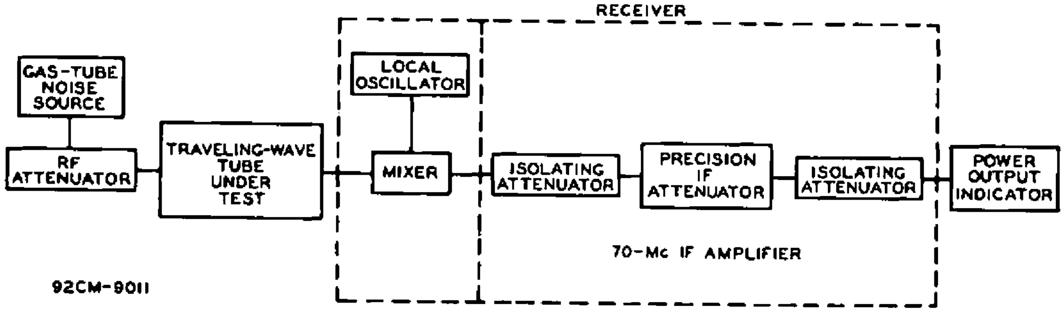


Fig. 9 - Block Diagram for Noise-Figure Measurements of Type 6861.

The value determined from Eq.(5) includes both tube noise and receiver noise. The relative effect due to receiver noise can be determined from

$$F_{1,2} = F_1 + \frac{F_2 - 1}{G_1} \qquad (6)$$

where $F_{1,2}$ is noise figure of two networks in cascade

F_1 is noise figure of first network (consisting of traveling-wave tube)

F_2 is noise figure of second network

G_1 is the gain of the first network

In this equation, all values are expressed as power ratios.

If F_2 is small or if G_1 is large, the value of the second term becomes so small that it can be neglected. In measurements on the 6861, F_2 was equal to a power ratio of 20, and G_1 was equal to a power gain of 315. Consequently, the second term in Eq.(6) was equal to a power ratio of 0.06 as compared to a power ratio of about 4.5 for F_1. Hence, the contribution by the second network to the measured noise figure is negligible.

Similarly, in terms of decibels, the contribution by the second network to the measured noise figure is less than 0.06 db.

Preamplifier in Radar Receivers

In the usual type of radar system, a portion of the transmitter pulse leaks through the TR tube to the crystal mixer in the receiver, overloads the crystal, and gradually impairs its performance. If, however, the crystal is preceded by the 6861 in a preamplifier stage, the traveling-wave tube serves as a crystal-protection device because of its saturation characteristic shown in Fig.10. From this curve, it will be noted that the saturated power output of the 6861 is about 1 milliwatt which will not harm the crystal. Therefore, the spike-leakage limit of the TR tube can be eased and thus eliminate the need for supplying "keep-alive" voltage to the TR tube. Furthermore, the ability of the 6861 to withstand an rf peak power input of as much as 250 watts or an average power input of as much as 1 watt makes it possible to employ a TR tube with lower attenuation.

Additional advantages offered by the 6861 in a preamplifier stage include: (1) reduction of the overall noise figure of the radar receiver; (2) improved receiver recovery time; (3) better TR tube life, and (4) reduction of local oscillator radiation. All of these advantages contribute to improved radar-system operation.

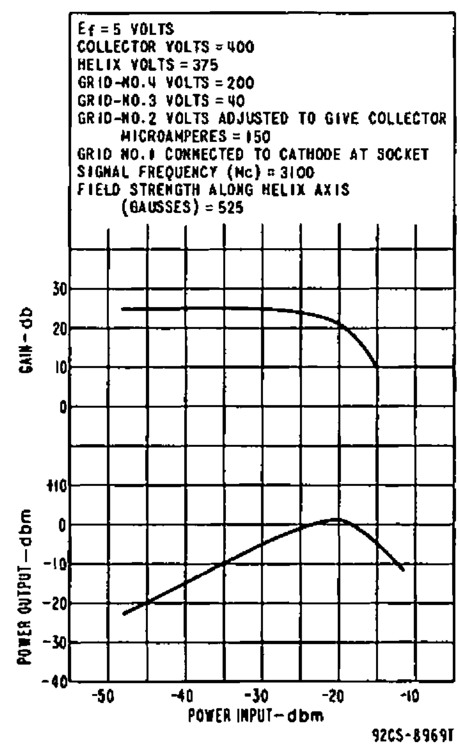


Fig. 10 - Saturation Characteristics of Type 6861.

Phase-Sensitive Applications

When the 6861 is used in a phase-sensitive radar system or in a microwave relay system where frequency-modulated information is amplified, even a small amount of phase distortion can adversely affect performance. The following table shows for each tube electrode the values of rms ripple voltage which will cause a peak-to-peak change in rf phase of approximately 1 degree.

Tube Electrode	Typical Operating DC Volts	Approx. RMS Ripple Volts For Peak-to-Peak Phase Shift of 1°
Grid No. 1	0	0.1
Grid No. 2	20	0.1
Grid No. 3	40	0.5
Grid No. 4	200	3.5
Helix	375	0.024
Collector	400	6.7

For the RCA Solenoid Type MW-4900 operated at 100 volts dc, a peak-to-peak change in rf phase of approximately 1° will be caused by an rms ripple voltage of 7.7 volts.

Input Matching Considerations

In general, the *voltage standing wave ratio* (VSWR) will increase as the electron-beam current of the tube is increased. This "hot VSWR" is a direct function of gain and can be attributed to reflections of the amplified wave at a discontinuity along the slow-wave structure. In contrast, the VSWR with no voltages applied to the tube, is referred to as the "cold VSWR". This "cold VSWR" determines the transfer of input signal energy to the helix and, therefore, the noise figure of the 6861 is not degraded by the "hot VSWR". In general, it will be found that when the input to the 6861 is adjusted for optimum matching under "cold" conditions, the same adjustment will provide optimum matching under "hot" conditions. Fig. 11 shows a typical input-matching characteristic of the 6861 under "cold" conditions.

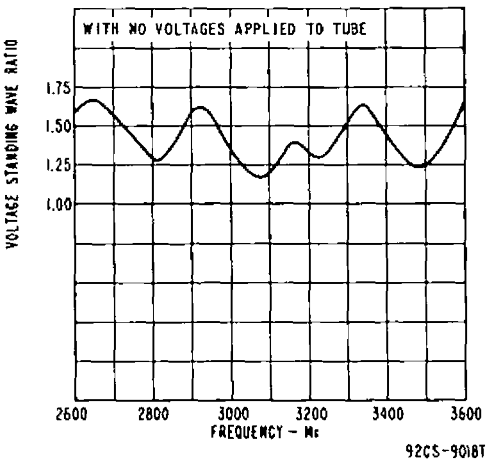


Fig. 11 – Input-Matching Characteristic of Type 6861.

Amplifier-Design Considerations

Amplifier design requires consideration not only of the amplification obtained at each fre-

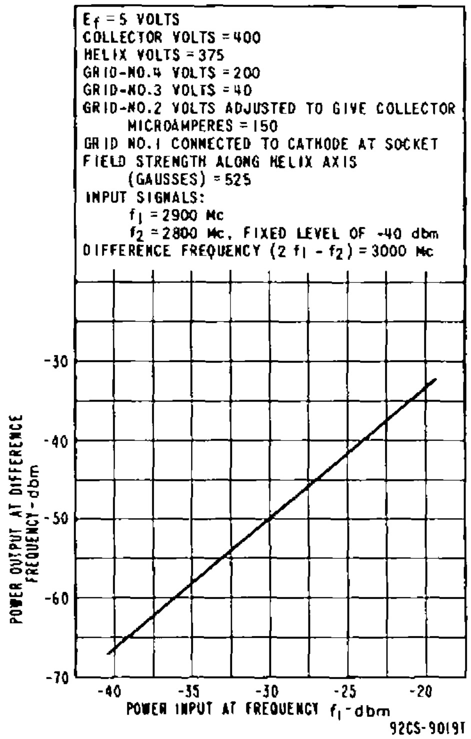


Fig. 12 - Intermodulation Characteristic of Type 6861.

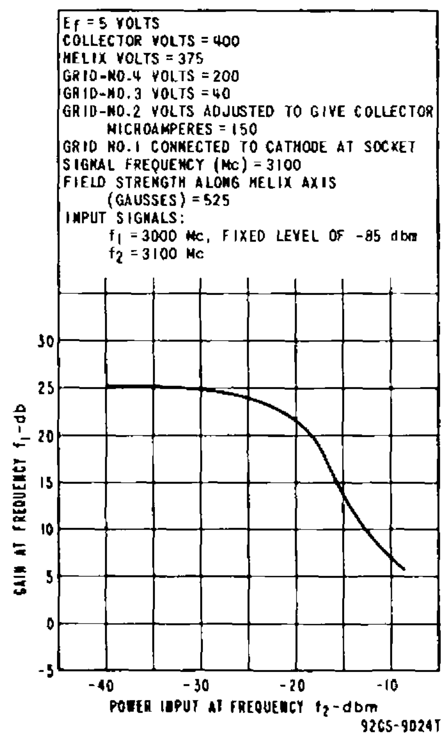


Fig. 13 - Cross-Modulation Characteristic of Type 6861.

quency in the band, but also of such factors as linearity of response at high signal levels (see Fig.10); intermodulation (see Fig.12); and cross-modulation (see Fig.13). At low levels of input signal, the second harmonic output is relatively low. When the input to the 6861 is increased toward its saturation level, the non-linear response increases until the tube output at the second harmonic exceeds the input at the fundamental frequency. Under such conditions, the tube operates as a frequency doubler.

Notes On Associated Microwave Circuitry

A low-noise traveling-wave tube used in a superheterodyne circuit will cause a 3 db degradation in noise figure unless a filter is used at the output of the traveling-wave tube to remove noise generated at the image frequency.

Whenever the output of the 6861 is connected to a filter, signals in the reject band of the filter are reflected back into the tube. As these signals travel back through the tube, they suffer little attenuation until they are absorbed by the attenuator. Should there be appreciable reflection from the attenuator or another discontinuity inside the traveling-wave tube, oscillations may occur, depending on the gain within the tube from the attenuator or discontinuity to the output end of the tube.

The 6861 is designed to be short-circuit stable, i.e., the power reflected from a short-circuited output termination will be insufficient to cause oscillation when the 6861 is operating at a normal value of beam current. If the beam current is increased sufficiently above this value, the gain of the tube will increase until oscillation takes place.

When a high-gain microwave amplifier tube such as the traveling-wave tube is employed, special care must be taken to prevent distortion or oscillations resulting from feedback through circuitry external to the tube. Some types of filters may show satisfactory attenuation characteristics in and near the frequency band of interest. However, oscillations can still occur due to "holes" in the filter characteristic at frequencies outside the band of interest. Attenuation of filters should therefore be checked over wide bands and the holes, if any, can then be filled by supplementary, simple filters.

Our engineers are ready to assist you in the circuit applications of the RCA-6861. For further information, write to Commercial Engineering, RCA, Harrison, New Jersey, giving complete details as to the proposed service.

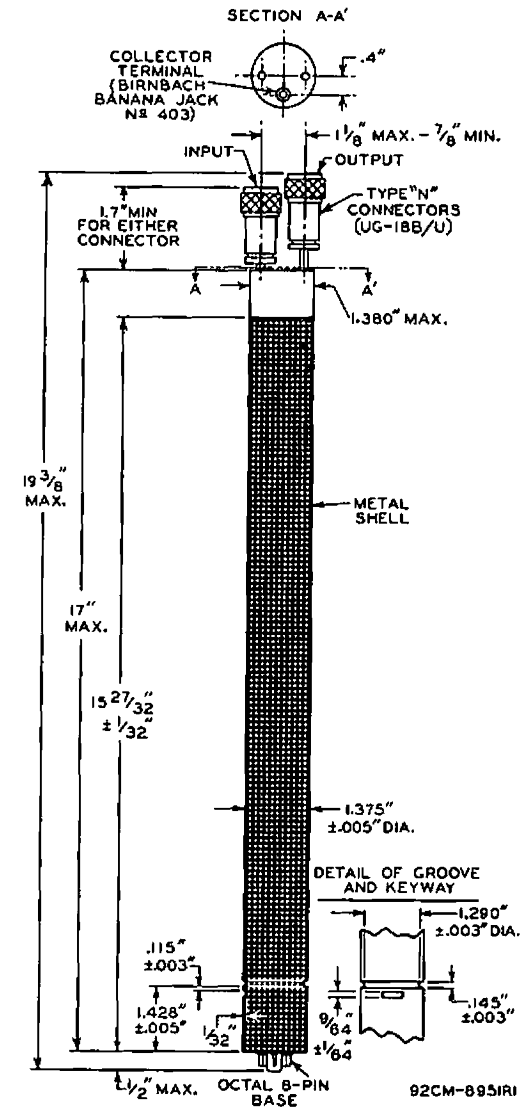
REFERENCES

J. R. Pierce, *"Traveling-Wave Tubes"*, D. Van Nostrand Co., Inc.

R. W. Peter, *"Low-Noise Traveling-Wave Amplifier"*, RCA Review, September, 1952.

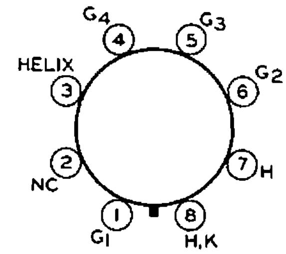
W. W. Mumford, *"A Broad-Band Microwave Noise Source"*, Bell System Technical Journal, October, 1949.

DIMENSIONAL OUTLINE



SOCKET CONNECTIONS

Bottom View



PIN 1: GRID No.1	PIN 5: GRID No.3
PIN 2: NO CONNECTION	PIN 6: GRID No.2
PIN 3: HELIX	PIN 7: HEATER
PIN 4: GRID No.4	PIN 8: HEATER, CATHODE