2N5941 (SILICON)
2N5942

The RF Line

NPN SILICON RF POWER TRANSISTORS

. . . designed primarily for applications as a high-power linear amplifier from 2.0 to 30 MHz, in single sideband mobile, marine and base station equipment.

- Specified 28 Volt, 30 MHz Characteristics –
  Output Power = 40 W (PEP) – 2N5941
  = 80 W (PEP) – 2N5942
  Minimum Gain = 13 dB
  Efficiency = 40%
  Intermodulation Distortion = –30 dB (Max)
- Isothermal-Resistor Design Results in Rugged Device
- 2N5942 Available as Matched Pairs for Push-Pull Amplifier Applications

MATCHING PROCEDURE

In the push-pull circuit configuration two device parameters are critical for optimum circuit performance. These parameters are $V_{BE(on)}$ and h_{FE}. Both parameters can be guaranteed by measuring I_{CQ} of the devices and selecting pairs with a $\Delta I_{CQ} \leqslant 10$ mAdc.

Actual I_{CQ} matching is performed in the 2N5942 test circuit with a V_{CE} equal to 28 Volts. The base bias supply is adjusted to set I_{CQ} equal to 40 mAdc using a reference standard 2N5942. The I_{CQ} of all production 2N5942 transistors is measured using this base bias supply setting. The production 2N5942's are tested and categorized in ranges of 10 mAdc. Finally, the devices are stocked as pairs with a guaranteed $\Delta I_{CQ} \leqslant 10$ mAdc.

***MAXIMUM RATINGS**

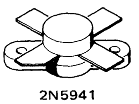
Rating	Symbol	2N5941	2N5942	Unit
Collector-Emitter Voltage	V_{CEO}	35		Vdc
Collector-Base Voltage	V_{CBO}	65		Vdc
Emitter-Base Voltage	V_{EBO}	4.0		Vdc
Collector Current – Continuous	I_C	6.0	12	Adc
Total Device Dissipation @ $T_C = 25°C$ Derate above 25°C	P_D	80 0.457	140 0.8	Watts W/°C
Storage Temperature Range	T_{stg}	–65 to +200		°C

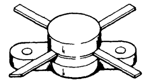
*Indicates JEDEC Registered Data

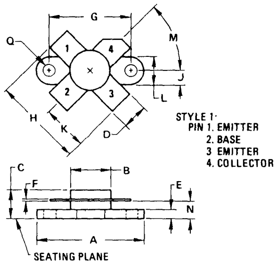
These devices are designed for RF operation. The total device dissipation rating applies only when the devices are operated as RF amplifiers.

40 W (PEP)–30 MHz – 2N5941
80 W (PEP)–30 MHz – 2N5942

RF POWER TRANSISTORS
NPN SILICON


2N5941

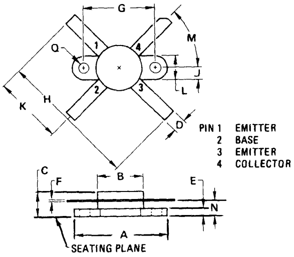

2N5942



2N5941

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	24.64	24.89	0.970	0.980
B	9.47	9.73	0.373	0.383
C	6.07	7.14	0.239	0 281
D	5.59	5.84	0.220	0.230
E	2 16	2.67	0 085	0.105
F	0.10	0.15	0.004	0.006
G	18.29	18.54	0.720	0.730
H	21.59	22.10	0 850	0.870
J	3.12	3.23	0.123	0.127
K	10.80	11.05	0.425	0.435
L	6.22	6.48	0.245	0.255
M	40°	50°	40°	50°
N	3.81	4.57	0.150	0.180
Q	2.97	3.12	0.117	0.123

CASE 211-01



2N5942

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	24.64	24.89	0.970	0.980
B	11.81	12.07	0.465	0.475
C	5.82	6.73	0.229	0.265
D	2.16	3.94	0.085	0.155
E	2.13	2.54	0.084	0.100
F	0.10	0.15	0.004	0.006
G	18.29	18.54	0.720	0.730
H	35.56	38.10	1.400	1.500
J	3.12	3.23	0.123	0.127
K	17.78	19.05	0.700	0.750
L	6.22	6.48	0.245	0.255
M	40°	50°	40°	50°
N	3.66	4.32	0 144	0.170
Q	2.97	3.12	0.117	0.123

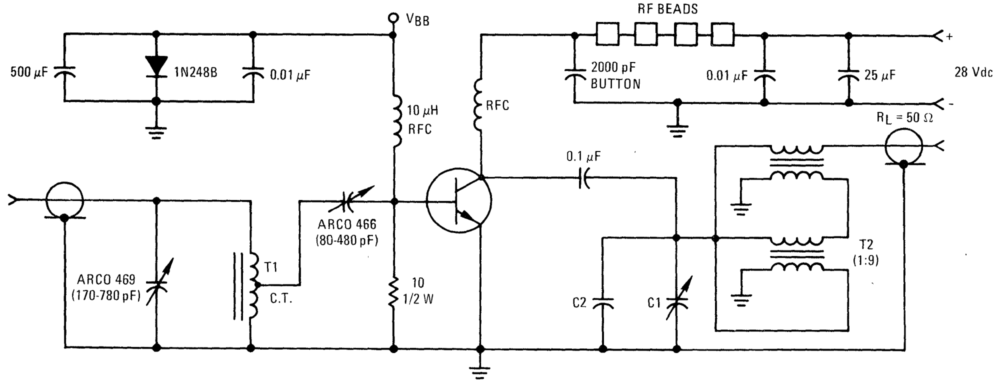
CASE 211-02

***ELECTRICAL CHARACTERISTICS** ($T_C = 25^{\circ}C$ unless otherwise noted)

Characteristic		Symbol	Min	Max	Unit
OFF CHARACTERISTICS					
Collector-Emitter Breakdown Voltage (I_C = 100 mAdc, I_B = 0)		BV_{CEO}	35	–	Vdc
Collector-Emitter Breakdown Voltage (I_C = 100 mAdc, V_{BE} = 0)		BV_{CES}	65	–	Vdc
Emitter-Base Breakdown Voltage (I_E = 1.0 mAdc, I_C = 0)		BV_{EBO}	4.0	–	Vdc
Collector Cutoff Current (V_{CE} = 28 Vdc, V_{BE} = 0, T_C = +55°C)	2N5941 2N5942	I_{CES}	– –	5.0 10	mAdc
ON CHARACTERISTICS					
DC Current Gain		h_{FE}			–
(I_C = 0.5 Adc, V_{CE} = 5.0 Vdc)	2N5941		10	–	
(I_C = 1.0 Adc, V_{CE} = 5.0 Vdc)	2N5942		10	–	
DYNAMIC CHARACTERISTICS					
Current-Gain—Bandwidth Product		f_T			MHz
(I_C = 0.25 Adc, V_{CE} = 15 Vdc, f = 50 MHz)	2N5941		50	–	
(I_C = 0.5 Adc, V_{CE} = 15 Vdc, f = 50 MHz)	2N5942		50	–	
Output Capacitance (V_{CB} = 28 Vdc, I_E = 0, f = 1.0 MHz)	2N5941 2N5942	C_{ob}	– –	125 250	pF
FUNCTIONAL TEST					
Common-Emitter Amplifier Power Gain (Figure 1)		G_{PE}			dB
(P_{out} = 40 W (PEP), I_C = 1.78 Adc (Max), V_{CC} = 28 Vdc, f_1 = 30 MHz, f_2 = 30.001 MHz)	2N5941		13	–	
(P_{out} = 80 W (PEP), I_C = 3.575 Adc (Max), V_{CC} = 28 Vdc, f_1 = 30 MHz, f_2 = 30.001 MHz)	2N5942		13	–	
Intermodulation Distortion Ratio (Figure 1)		IMD			dB
(P_{out} = 40 W (PEP), I_C = 1.78 Adc (Max), V_{CC} = 28 Vdc, f_1 = 30 MHz, f_2 = 30.001 MHz)	2N5941		–	-30	
(P_{out} = 80 W (PEP), I_C = 3.575 Adc (Max), V_{CC} = 28 Vdc f_1 = 30 MHz, f_2 = 30.001 MHz)	2N5942		–	-30	
Collector Efficiency		η			%
(P_{out} = 40 W (PEP), I_C = 1.78 Adc (Max), V_{CC} = 28 Vdc, f_1 = 30 MHz, f_2 = 30.001 MHz)	2N5941		40	–	
(P_{out} = 80 W (PEP), I_C = 3.575 Adc (Max), V_{CC} = 28 Vdc, f_1 = 30 MHz, f_2 = 30.001 MHz)	2N5942		40	–	

* Indicates JEDEC Registered Data.

FIGURE 1 — 30 MHz TEST CIRCUIT



V_{BB} adjusted for I_{CQ}. 2N5941 – 20 mAdc (I_{CQ} = Quiescent
2N5942 – 40 mAdc Collector Current)

RFC. 20 TURNS #12 AWG ENAMELED WIRE CLOSE WOUND IN 2 LAYERS, 1/4" I.D.
T1: 20 TURNS #24 AWG WIRE WOUND ON MICRO-METALS T37-7 TOROID CORE CENTER TAPPED.
T2: 1:9 XFMR; 6 TURNS OF 2 TWISTED PAIRS OF #28 AWG ENAMELED WIRE. (8 CRESTS PER INCH) BIFILAR WOUND ON EACH OF 2 SEPARATE BALUN CORES. (Stackpole #57-1503, No. 14 Material) Interconnected as shown
RF BEADS. FERROXCUBE #56-590-65/3B

C1 – 2N5941 – 80-480 pF, ARCO 466 or Equiv
2N5942 – 170-780 pF, ARCO 469 or Equiv
C2 – 2N5941 – 220 pF
2N5942 – 330 pF

LINEAR OUTPUT POWER versus FREQUENCY

FIGURE 2 — 2N5941

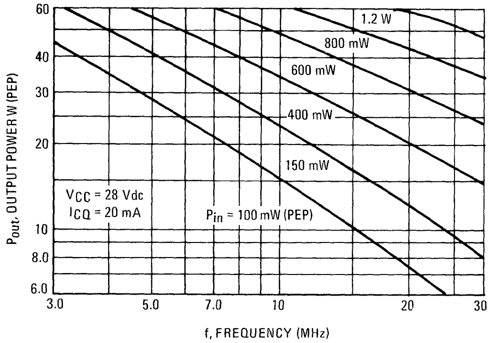
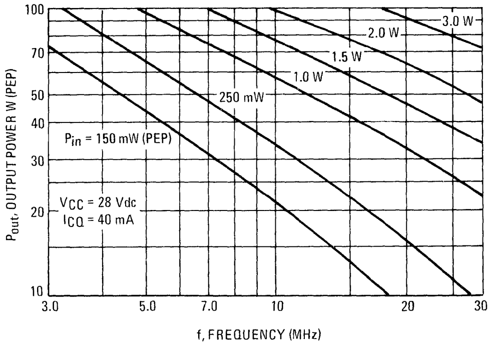


FIGURE 3 — 2N5942



OUTPUT POWER versus INPUT POWER

FIGURE 4 — 2N5941

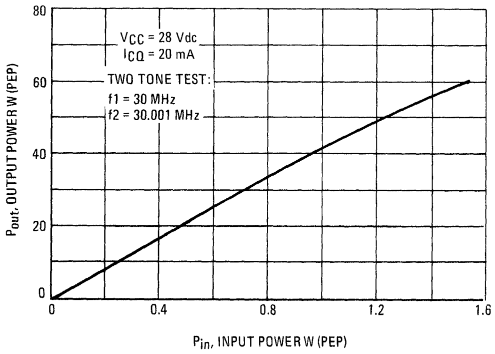


FIGURE 5 — 2N5942

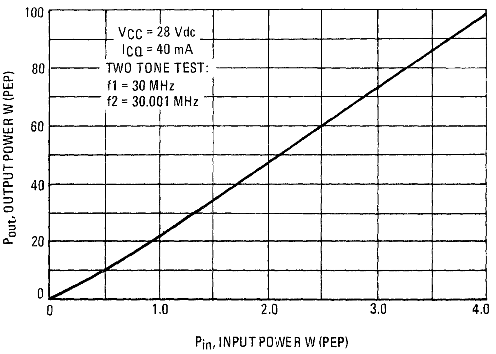


FIGURE 6 — 2N5941

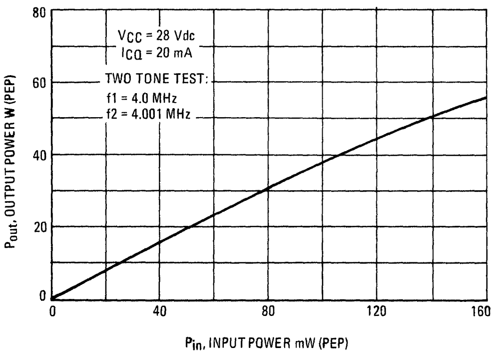
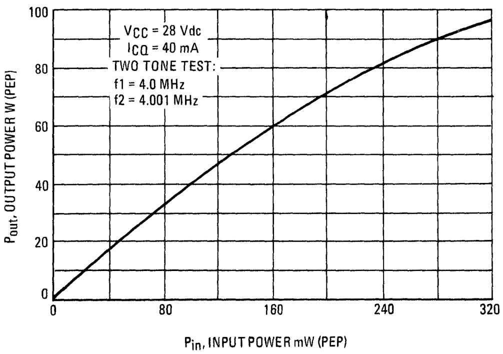


FIGURE 7 — 2N5942



INTERMODULATION DISTORTION versus OUTPUT POWER

(f1 = 30 MHz, f2 = 30.001 MHz)

FIGURE 8 – 2N5941

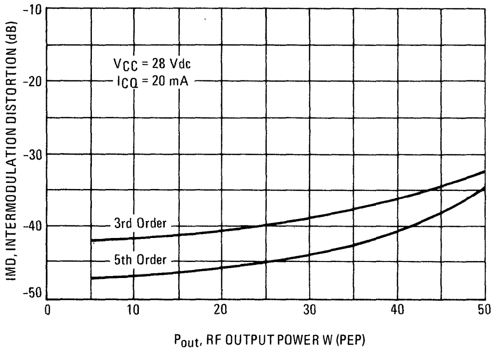
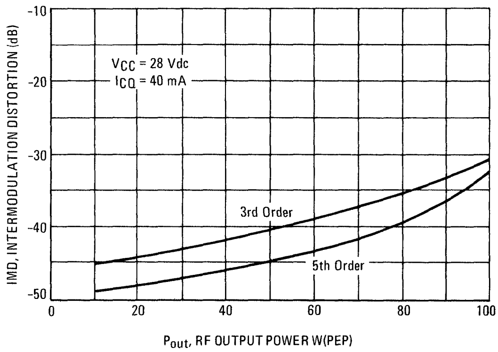


FIGURE 9 – 2N5942



LINEAR OUTPUT POWER versus SUPPLY VOLTAGE

(f1 = 30 MHz, f2 = 30.001 MHz)

FIGURE 10 – 2N5941

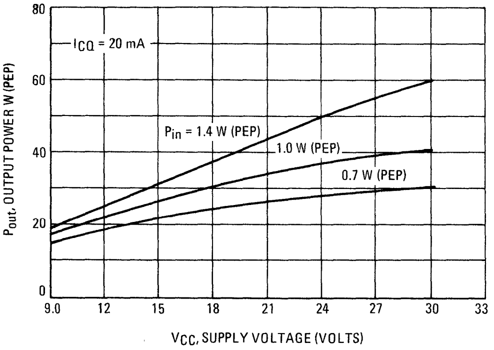


FIGURE 11 – 2N5942

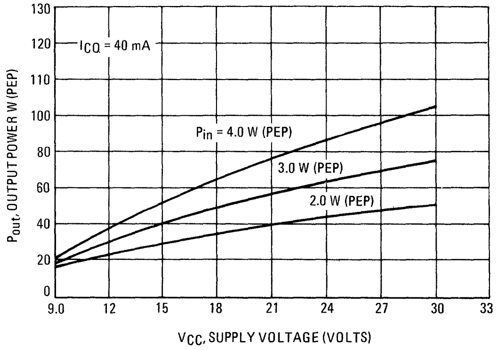


FIGURE 12 – 2N5941

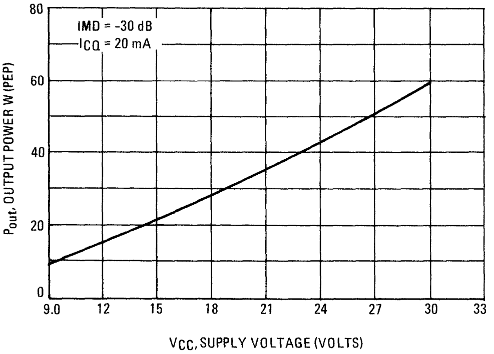
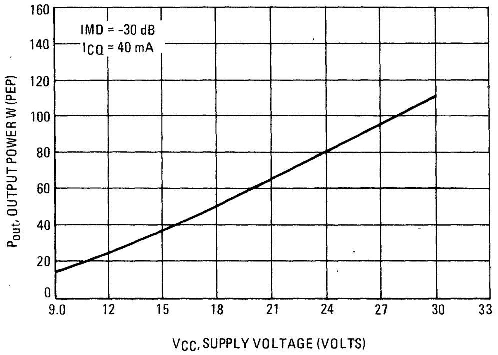


FIGURE 13 – 2N5942



PARALLEL EQUIVALENT INPUT RESISTANCE versus FREQUENCY

FIGURE 14 — 2N5941

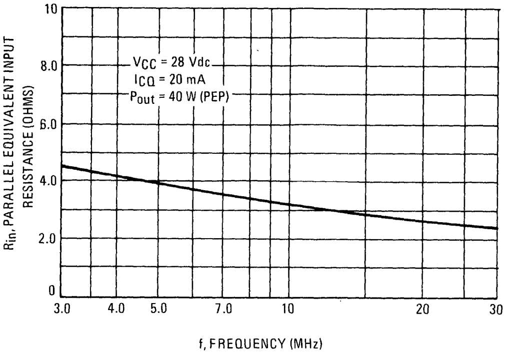
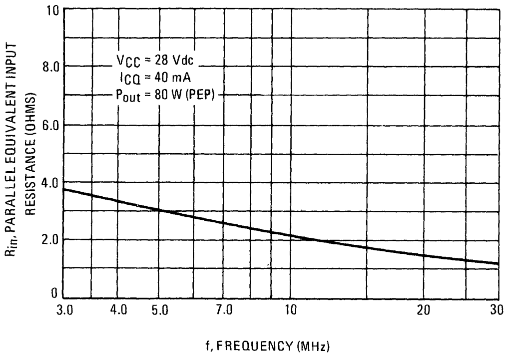


FIGURE 15 — 2N5942



PARALLEL EQUIVALENT INPUT CAPACITANCE versus FREQUENCY

FIGURE 16 — 2N5941

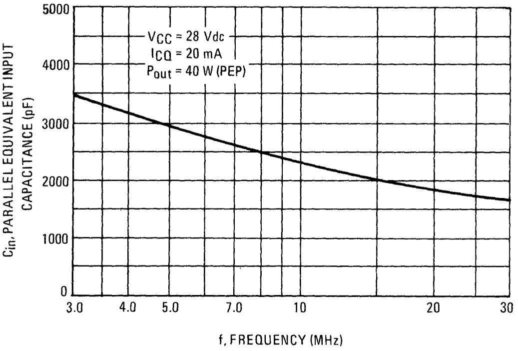
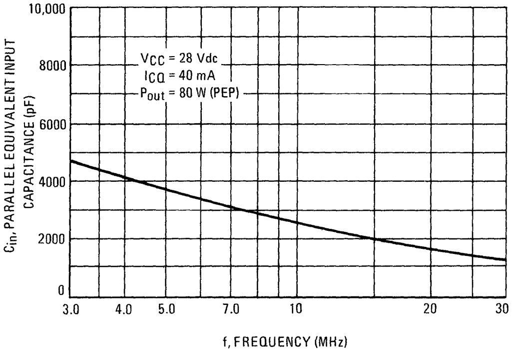


FIGURE 17 — 2N5942



PARALLEL EQUIVALENT OUTPUT CAPACITANCE versus FREQUENCY

FIGURE 18 — 2N5941

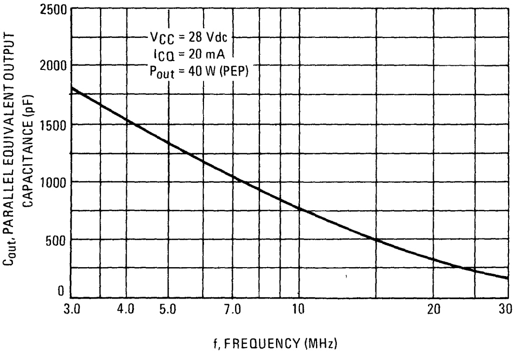
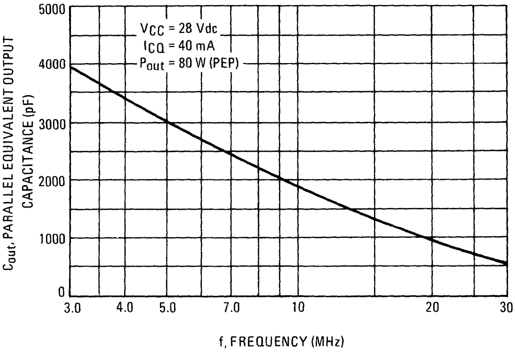


FIGURE 19 — 2N5942



COLLECTOR CURRENT versus BASE-EMITTER VOLTAGE

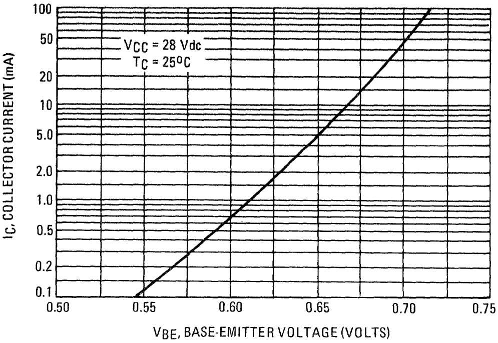


FIGURE 20 – 2N5941

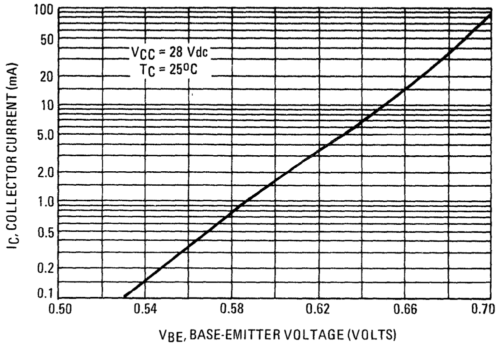


FIGURE 21 – 2N5942

SAFE OPERATING AREA

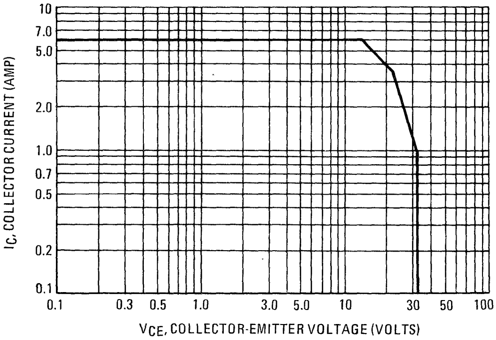


FIGURE 22 – 2N5941

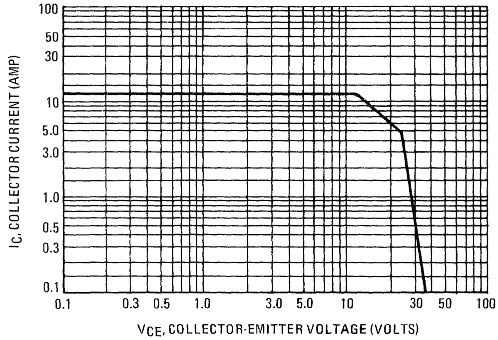
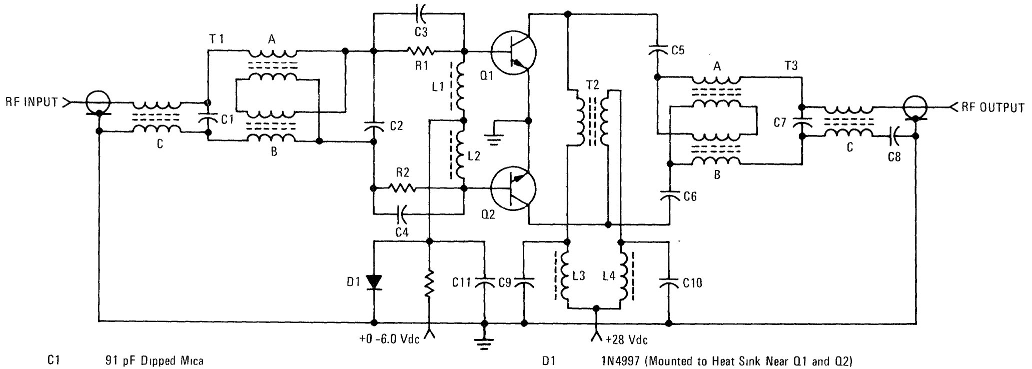


FIGURE 23 – 2N5942

FIGURE 24 – PUSH-PULL 120-WATT PEP, 2-30 MHz LINEAR AMPLIFIER

G_{PE} = 13.5 dB, IMD = -31 dB (Typ)



C1	91 pF Dipped Mica
C2	680 pF Dipped Mica
C3,C4	3900 pF Ceramic (Total Lead Length to Bases Not to Exceed 3/4")
C5,C6	0.047 μF Polyester Film (Total Lead Length to Collectors Not to Exceed 1/2")
C7	27 pF Dipped Mica
C8	3300 pF Ceramic
C9,C10	0.33 μF Ceramic
C11	500 μF, 6.0 Volt Electrolytic
R1,R2	5.0 Ohm, (Two 10 Ohm, 1/2 Watt Carbon Resistors in Parrallel)
R3	20 Ohms, 10 Watts
L1,L2	10 μH Molded Chokes
L3,L4	FERROXCUBE VK200 19/4B (or 6 Ferrite Beads on #20 AWG)
D1	1N4997 (Mounted to Heat Sink Near Q1 and Q2)
Q1,Q2	2N5942 Matched Pair
T1	A and B Consist of 5 Turns of 4 Pairs of #32 AWG loosely twisted, Enameled Wires Wound on the Outer Toroids of INDIANA GENERAL TV Antenna Balum Core F684-1. C = 2 Pairs of #32 AWG Wound on the Inner Toroid of the Balum Core
T2	Collector Choke, 4 Turns, 2 Twisted Pairs of #22 AWG Enameled Wire (4 Twists Per Inch), Wound on INDIANA GENERAL F627-8Q1 or Equivalent Toroid.
T3	A and B Consist of 5 Turns, 2 Twisted Pairs of #24 AWG, C Consists of 10 Turns, 1 Twisted Pair of #24 AWG Enameled Wire. (All Winding 6 Twists Per Inch) Core = INDIANA GENERAL F624-19Q1 or Equivalent.

NOTE For more information on transformers, see AN-593, "Broadband Linear Power Amplifiers Using Push-Pull Transistors."

The maximum theoretical output from a 28 Volt push-pull amplifier, with a 1:4 output transformer, is 110-112 Watts, due to the limited voltage swing (assuming the transformer is a perfect 1:4). In most transmission line type transformers, the transformation ratio is usually higher, especially at the higher frequencies. Thus, depending on the amount of flat-topping that can be tolerated, and the compensation techniques of the transformer higher power outputs can be realized at reasonably low distortion. Ideally a 1:6 output transformer would be required for a power output of 150 Watt PEP.

APPLICATIONS INFORMATION

The 2N5941 and 2N5942 transistors are designed for linear power amplifier operation in the HF region (2 to 30 MHz). They feature guaranteed linear amplifier performance rather than the conventional performance demonstrated in a class C* amplifier.

Class C operation is inherently non-linear, but in many power amplifier applications non-linear operation does not present major problems. With a single frequency driving signal, the only spurious signals generated are harmonics and these can be suppressed in the amplifier tuned networks and output filter.

For single sideband (SSB), low level amplitude modulation (AM), and other types of complex signals, class C operation is generally not satisfactory. For instance, when a signal contains multiple frequencies at close spacings, odd-order non-linearities will generate spurious outputs which are within the passband of the tuned circuits and filters; therefore, the spurious outputs are not suppressed before they reach the antenna or other load. As a result, such complex signals require linear amplification if the amplified signal is to be free of spurious outputs.

A detailed analysis of spurious signals generated by non-linearities and linearity requirements of various applications is described in Chapter 12 of Reference 1.

The following discussion concerns itself with a detailed description of the 2N5941-2 characterization curves and general information on solid-state linear power amplifier design.

The Two-Tone Test

The 2N5941-42 functional test specification consists of a linear power amplifier test with guaranteed limits on power output, gain, efficiency, and intermodulation distortion (IMD) output levels. A two-tone test signal is used with the test amplifier as shown in Figure 1.

The two-tone test is one of many methods commonly used for testing linear amplifier performance. This test involves driving the amplifier with two RF signals, of equal amplitude, separated in frequency from each other by approximately 1 kHz.

When a two-tone test signal consisting of frequencies f_1 and f_2 is passed through a non-linear amplifier, odd order non-linearities generate spurious signals near the desired carrier. The level of these spurious signals provides a measure of the degree of non-linearity of the amplifier. This type of non-linearity is called intermodulation distortion (IMD). The spurious signals generated by IMD are further classified according to the exponential order of the amplifier non-linearity, i.e., 3rd order IMD products, 5th order IMD products, etc. The 3rd and 5th order IMD products are usually the most significant encountered with linear power amplifiers. Data on both 3rd and 5th order IMD are included in the 2N5941-42 characterization.

Third order IMD generates spurious signals near the operating frequency at frequencies $2f_1 - f_2$ and $2f_2 - f_1$; and 5th order IMD spurious signals are at frequencies $3f_1 - 2f_2$ and $3f_2 - 2f_1$.

Specifications and Characterization

The two-tone functional amplifier test is performed in a manner identical to the conventional class C functional test with two exceptions: a two-frequency signal is used in place of a single frequency, and amplifier linearity is added to the items tested and specified.

The functional test procedure for the 2N5941-42 requires driving the test amplifier with a two-frequency signal and measuring power output, gain, efficiency, and linearity.

Power output, gain, and efficiency measurement methods are the same for both linear and class C amplifiers.

Since a multiple frequency test signal has an instantaneous power level which varies with time, power levels are normally expressed in peak envelope power (PEP). This is the average power level of the envelope at its greatest amplitude point.

When the test signal consists of multiple signals with equal amplitudes and different frequencies, the relationship of average power and PEP is given by the following expression:

$$\text{Average power} = \frac{\text{PEP}}{\text{N}}$$

where N = the number of input frequencies.

Therefore, when measuring the power level of a standard two-tone test signal, a true average reading power meter will indicate 1/2 the PEP of the signal.

Linearity is tested by measuring the amplitudes of the 3rd and 5th order IMD products. The ratio of one of the 3rd order products to one of the two desired frequencies is then expressed as a power ratio in decibels (dB). This is repeated for the 5th order products. The smaller of these two ratios (usually the 3rd order) is then included in the electrical characteristics specification as intermodulation distortion ratio (IMD).

2N5941-42 Performance Curves

Figures 2 through 7 show typical power output and gain characteristics versus frequency and/or input power. These curves are similar to those found on other RF power transistor data sheets with one exception, a two-frequency test signal was used rather than a single frequency signal.

The curves shown in Figures 8 and 9 are unique to transistors characterized for linear power amplifier service and show the typical IMD levels versus power output.

The 2N5941-42 feature guaranteed IMD performance at the -30 dB level. However, the designer may desire IMD greater or less than -30 dB for a particular application. Figures 8 and 9 provide data on IMD levels that can be expected as a function of output power.

Figures 10 and 11 show the variation in gain with dc supply voltage and provide data on gain only. They do not include information on IMD ratio.

Figures 12 and 13 reflect the power output that can be obtained at a fixed IMD ratio for operation with dc supply voltages other than 28 Vdc.

Figures 14 through 19 show the large signal impedance characteristics of the 2N5941-42. These are similar to curves shown on other Motorola data sheets except a two-frequency test signal was used rather than a single frequency signal.

It must be stressed that the data shown in Figures 14 through 19 do not represent y, z, h, s, or any standard two-port parameter set. The actual transistor impedance levels during normal operation in an amplifier are given. For a detailed discussion of RF power transistor large signal impedance, see Reference 2.

Linear Amplifier Design

The following is a discussion of some general design considerations for solid-state linear power amplifiers. While this is not a detailed analysis of linear amplifier design, some general guidelines are provided.

The major difference between linear power amplifiers and class C power amplifiers is in the dc bias circuitry. As stated in the introduction, class C operation usually involves a collector dc supply as

APPLICATIONS INFORMATION (continued)

the only bias voltage with $V_E = V_B = 0$. The collector current is zero until the input RF signal turns the transistor "on".

In contrast, a linear amplifier is normally operated with forward bias and some collector current flowing when no signal is present.

The magnitude of no-signal collector current and the bias circuitry may vary with the application. Optimum no-signal collector currents for the 2N5941 and 2N5942 were found to be approximately 20 mA and 40 mA respectively.

The key to bias circuitry for good linearity lies in maintaining the base-emitter dc voltage relatively constant as the RF signal amplitude varies. The inherent nature of a forward-biased RF power transistor is to bias itself "off" with increasing RF drive signal. Therefore, a constant voltage source is required for base voltage.

Temperature effects also complicate the situation, since V_{BE} decreases with increasing temperature.

A simple solution to the bias problem involves the use of a forward-biased diode mounted on the transistor heat sink for thermal coupling to the transistor. A sample of this technique is shown in the test circuit of Figure 1. The capacitor in parallel with the diode helps maintain a constant V_{BE} with RF drive and improves linearity, while the diode provides temperature compensation to prevent thermal runaway. It is also possible to use complex active circuitry for biasing, and some rather exotic schemes have been developed to provide the same results.

Another important consideration is the collector-output network. Normally, a network with low impedance to ground for harmonics provides better linearity than a network with high harmonic impedances; therefore, some experimentation with network configuration is in order. Proper impedance matching remains the primary factor in both input and output network design. Further, it must also be stressed that the collector load impedance should be designed for the PEP, not the average power output. See Chapter 13 of Reference 1 for a detailed discussion of network design considerations.

Feedback may also be employed to improve linearity and may take the form of either neutralization or negative RF feedback. The possibilities here are limited only by the designer's imagination. Of course, negative RF feedback involves a decrease in gain to improve linearity.

REFERENCES

1. Pappenfus, Bruene, Schoenike, "Single Sideband Principles and Circuits", McGraw-Hill.
2. Hejhall, "Systemizing RF Power Amplifier Design", Motorola Semiconductor Products Inc., Application Note AN-282A.

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*"Class C", as used here refers to operation with the no signal conditions $I_C = 0$, and $V_{BE} = 0$, and a theoretical conduction angle of less than 180°, even though the actual conduction angle may be more than 180°.