CHAPTER II

Inverters and Converters

2.1 Inverter Circuits

An inverter circuit is used to convert a dc input voltage to an ac output voltage. Subsequent rectification of the inverter ac output results in dc-to-dc conversion, or a converter circuit. In converters, output frequency and waveshape of the basic inverter output are relatively unimportant, except as they relate to efficiency of the converter and the filtering of the rectified output. When designing inverters, however, these and other characteristics must be specified before the proper circuit can be chosen.

Some inverter characteristics which may be important in various applications are listed in Table 2-1. It is the function of the inverter specifications to indicate which are important to the use intended, and to state, via tolerances, how critical each of these is expected to be. Obviously, the greater the number of controlled characteristics required and the tighter the tolerances, the more difficult and costly the design will be. In the absence of specifications requiring emphasis on other characteristics, inverters are usually designed for highest efficiency. Achievement of very precise frequency and output performance, etc. is usually at the expense of efficiency as well as circuit simplicity.

Semiconductor devices used in inverters are of two types, thyristor (generally SCR) and transistor. Some designs, of course, use both devices. Present day SCR inverters work best in an input voltage range from 50 to 600 volts dc and an input current range from 1 to 20 amperes. Transistor inverters are generally used with lower input voltages of about 1 to 100 volts and higher input currents (1 to 100 A). The typical output voltage of both types is a square wave which may be filtered to obtain a sine wave if necessary. The normal range of output power is from 1 watt to 1 kilowatt. The range of output frequencies normally encountered is 60 hertz to 100 kilohertz. The output voltage can be almost any value; it is determined by the input voltage and the output transformer turns ratio. Elaborate inverter circuits can be devised to extend the range of these characteristics. Series and parallel connections and time-sharing techniques are among those commonly used.

TABLE 2-I

COMMONLY SPECIFIED INVERTER CHARACTERISTICS

Input voltage: range and nominal
Output power
Output voltage
Output frequency accuracy
Regulation of output voltage and frequency vs. load and input voltage
Load power factor
Output waveform
Harmonic distortion of output, if sinusoidal, vs. load, power factor, input voltage
Overall efficiency vs. loading
Operating environments (Temperature, etc.)
Size and Weight
Protection required (as against shorted output, reversed polarity input, etc.)

SCR inverters can be conveniently categorized by identifying the method used to commutate or switch off the devices. Series-commutated inverters make use of a capacitor in series with the load to bring the load current to zero and turn off the appropriate SCR. When the capacitor is in parallel with the load, it is used to reverse the anode voltage on an SCR to turn the device off. This arrangement is called a parallel-commutated inverter. Finally, the inpulse-commutated inverter makes use of an auxiliary LC tank to store an impulse of energy that will be used to turn off the SCRs.

Transistor inverters may be identified by their feedback. In current-feedback inverters, a portion of the load current is fed back to drive the transistor base circuit. The voltage-feedback inverter samples a portion of the output voltage and uses it for transistor base drive. Finally, the hybrid inverter makes use of both types of feedback.

These circuits, both thyristor and transistor, have unique characteristics which make them desirable for specific applications. One circuit may have high efficiency while another may give excellent frequency regulation. The sections which follow will explain the theory of operation of these circuits as an aid to design. These sections will also describe the advantages and disadvantages of each circuit in an attempt to fit the circuit to a particular application.

The final section in this chapter contains a representative sample of practical inverter circuits. The circuits can be used as is or modified as desired.

2.2 Series-Commutated SCR Inverters

The basic circuit for series-commutated SCR inverters is shown in Figure 2-1. Capacitors C1 and C2 are equal and inductor L is center tapped. Resistor R is the load resistor through which a sine wave of current is to flow. The operation of the inverter starts with both SCRs off and with $E_S/2$ volts on each capacitor. When Q1 is turned on, the voltage across the upper half of L will be $E_S/2$. Current will start to flow as C1 discharges and C2 charges through the load and the upper half of L (see waveform in Figure 2-2). Current will be a maximum when the voltage across L reaches zero. With negligible load, the voltage across C1 will be zero and C2 will have charged to the battery voltage. Now as the field of inductor L collapses, C1 will be charged to $-0.5\ E_S$ and C2 to $+1.5\ E_S$ (reference battery ground). When the current drops to zero, Q2 is turned on and the voltage across the lower half of L will be $1.5\ E_S$. Autotransformer action induces this same voltage in the upper winding and causes Q1 to be reverse biased by twice the battery voltage E_S. This insures that Q1 will turn off very quickly. Now current will again start to flow but in the reverse direction as C2 discharges and C1 charges through the load and

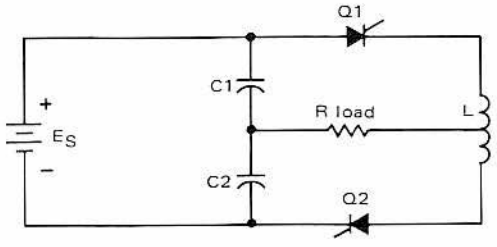


Figure 2-1 — Series-Commutated SCR Inverter

the lower half of L. This time the inductor L will charge C2 to $-1.5\ E_S$ and C1 to $+2.5\ E_S$. The cycle is now complete. The average voltage across C1 and C2 will remain $E_S/2$ but the peak voltage will continue to increase until the positive alternation becomes equal to the negative alternation. The amount of load resistance will be the limiting factor for this final value of capacitor voltage.

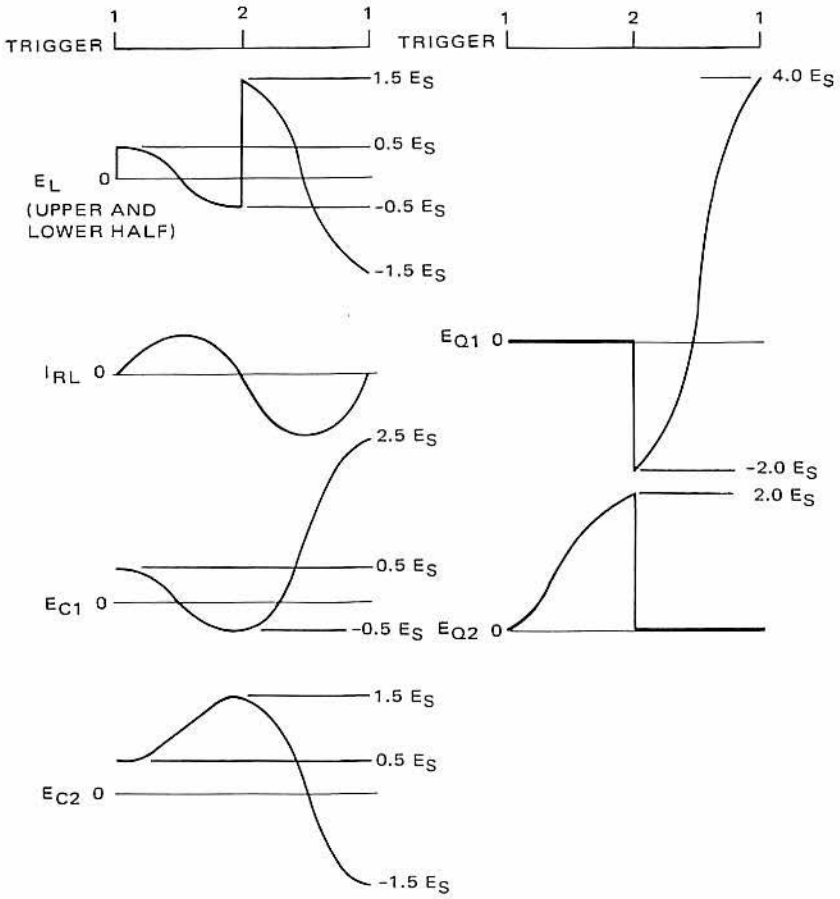


Figure 2-2 — Waveforms of Series-Commutated SCR Inverter

The peak value of capacitor voltage can be found using*

$$E_C = \frac{E_S}{2} \times \frac{(1 + e^{-\pi/2Q})}{(1 - e^{-\pi/2Q})},$$

where $Q = \frac{\sqrt{L'/C}}{R} \geqslant 1/2,$

$L' = L/4$ (half of load coil),

and $C = C1 + C2$ (sum of capacitors),

where the units are ohms, microfarads and microhenries.

The resonant frequency is determined by the values of L' and C:

$$f_R = \frac{1}{2\pi\sqrt{L'C}}$$

The circuit can be controlled solely by operation of the thyristor gates and operation above or below resonance is possible. The maximum frequency occurs when the circuit turn-off time has decreased to the value required by the characteristics of the SCR. The peak load voltage equals E_C/Q and becomes about 0.6 E_S with Q = 4. Four is the optimum value for factor Q although the circuit will operate with any value of Q greater than 1/2. This means that the load resistance may be varied from twice the circuit impedance ($R = 2\sqrt{L'/C}$) to zero, but that a good choice for R is one-quarter of the circuit impedance ($R = 1/4\sqrt{L'/C}$). As resistance increases above this value the sine wave output becomes distorted. Critical damping occurs at the upper limit where the thyristors fail to commutate (switch off). Lower values of resistance increase the reactive voltages and decrease the load voltage. If the circuit components were rated at higher voltages the load could be short circuited.

The series inverter is the easiest way to obtain a sine wave output voltage for a resistive load. Because a series inverter is self-commutating, it is not necessary to remove the input voltage to stop the circuit. Operation can be started and stopped by controlling the trigger pulses. It can also be designed so that a short circuit in the load will not destroy any components. Output voltage regulation, however, is generally quite poor for variations in the load.

The highest frequency of operation is generally limited by thyristor turn-off time to about 10 kilohertz. It is possible to increase this upper

*Bedford, B. D. and R. G Hoft, *Principles of Inverter Circuits*. John Wiley and Sons, Inc. 1964.

frequency limit by an order of magnitude using the circuit shown in Figure 2-3. If the thyristors are triggered in the sequence indicated by their numbering, each device will have one cycle to turn off. New limitations will be present with this circuit, the most predominate of which is the rate of rise of forward voltage.

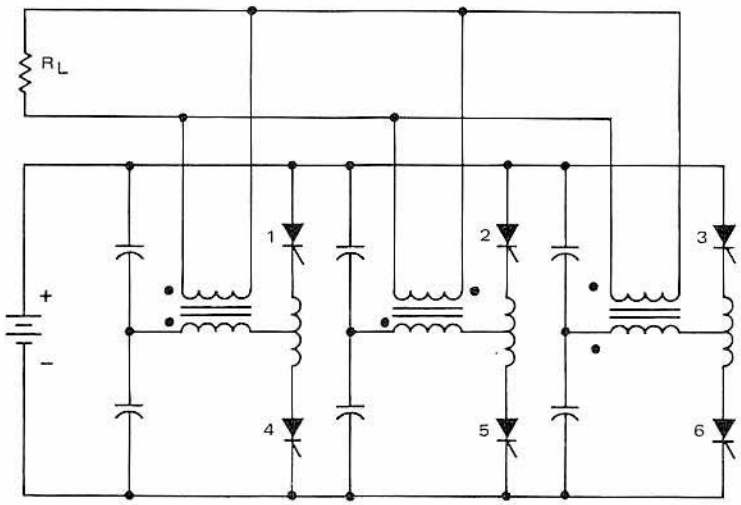


Figure 2-3 – Series-Commutated Time-Sharing SCR Inverter

2.3 Parallel-Commutated SCR Inverters

The basic circuit for parallel-commutated SCR inverters is shown in Figure 2-4, with waveforms taken from the circuit shown in Figure 2-5. SCR pair Q1 and Q2 is triggered alternately with pair Q3 and Q4 to produce a square wave across load resistor R (Figure 2-5D). The voltage across Q1 and Q2 is E_{12} and is shown positive when current flow is from Q1 through R to Q2. The voltage across R is E_R and is shown positive when the left side is positive with respect to the right. When Q1 and Q2 are turned on, the battery voltage, E_S will appear across inductor L, and current will start to flow. Current will flow from E_S through L, Q1, C, R, and Q2. At this point, there will be a constant current flow through L approximately equal to E_S/R (the voltage across R is E_S minus the sum of the voltage drops across Q1 and Q2.) During this time, the total voltage across Q1 and Q2 is approximately 1 V as shown by E_{12}. When Q3 and Q4 are turned on, C will begin to discharge. One path of discharge current will be through Q1 and Q3; another will be through Q4 and Q2. Reverse

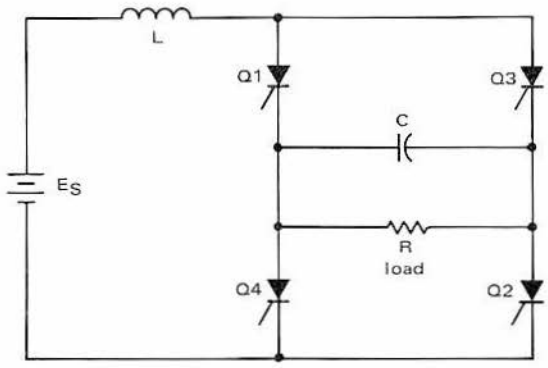


Figure 2-4 — Parallel-Commutated SCR Inverter

current will flow in Q1 and Q2 until the stored internal charge is removed and the devices cease conducting. Current through L will now be diverted from Q1, R, and Q2 to Q3, C, and Q4, and will begin to increase (see Figure 2-5B). The load voltage E_R is held positive by C and will not become negative until the current flowing through Q3 and Q4 charges C to E_S in the reverse direction (positive on the right). During the time E_R remains positive, E_{12} remains negative, and Q1 and Q2 are able to recover their forward blocking ability. So when E_R becomes negative, Q1 and Q2 will remain off, and E_{12} will go positive. Current through L reaches a maximum when E_R is approximately equal to E_S. The collapsing magnetic field will now cause a slight negative overshoot on E_R. Finally, a constant current will flow through L, and E_S will appear in reverse across R. A similar sequence of events will occur when Q1 and Q2 are triggered and E_R again becomes positive.

The design of this circuit would begin with the selection of the input voltage and load. The next step would be to choose the SCRs and a trigger circuit to meet the power and frequency requirements. Then values for the commutating capacitor and inductor should be determined: let the R-C time constant be twice the turn-off time (t_{off}). Then $R\,C = 2\,t_{off}$ and $C = 2\,t_{off}/R$. Finally let the L-R time constant be equal to the R-C time constant to obtain critical damping. Then $L/R = CR$ and $L = CR^2$.

If the inductance is reduced by a factor of three, the circuit will be underdamped.* The load voltage shown as E_{RU} in Figure 2-5E will result. Smaller inductance would cause more ringing and the circuit would turn itself off following commutation.

*Mapham, Neville "An SCR Inverter with Good Regulation and Sine Wave Output," *IEEE Transactions* IGA-3 No. 2 Mar/Apr 67.

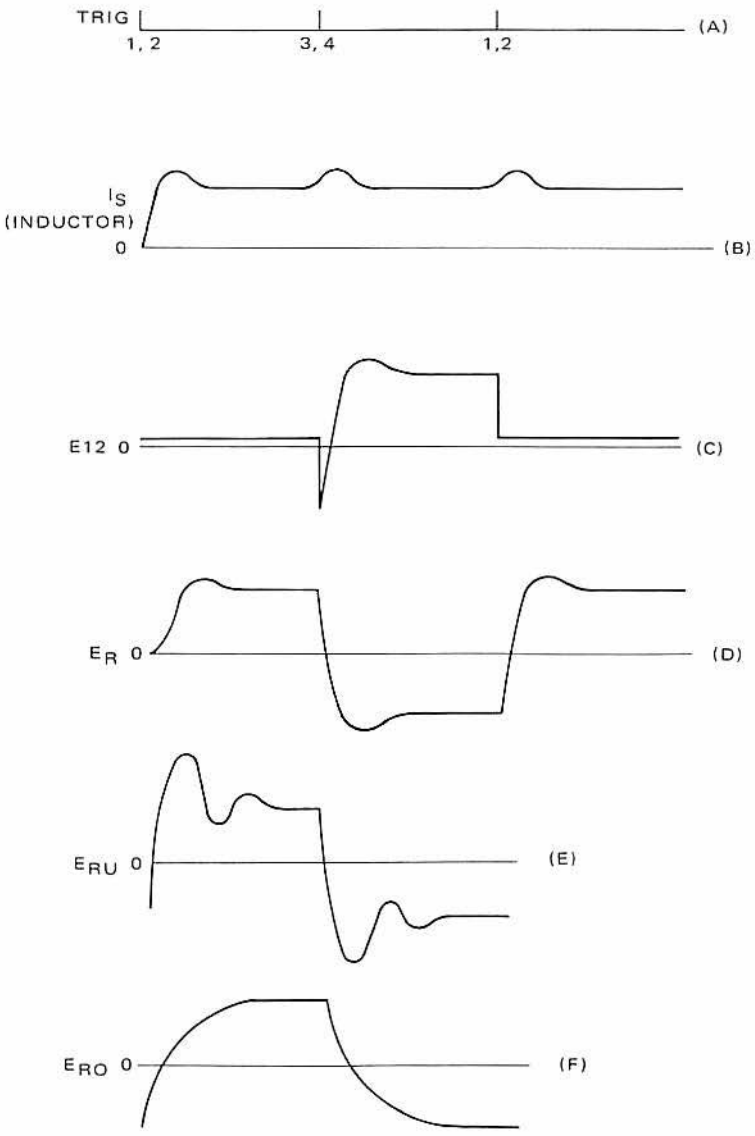


Figure 2-5 – Waveforms of Parallel-Commutated SCR Inverter

An overdamped load voltage is shown in Figure 2-5F as E_{RO}. The overdamped load voltage occurs when the inductance is increased by a factor of four.* Therefore, the actual value of the inductance should not be greater than 4L nor less than L/3. If the load is to be fixed, L should be chosen for critical damping. If the load is to be variable choose C for minimum load (R_{min}) and L for overdamping ($L = 4\,CR^2_{min}$). The load resistance can then be increased by a factor of 3.4 before the circuit will ring off. Any decrease in resistance would tend to shorten the turn-off time and commutation would then become unreliable.

It is possible to obtain any output voltage by replacing load resistor R with an output transformer. If the primary of this transformer has a center tap, SCRs Q1 and Q3 can be removed. The circuit would then appear as shown in Figure 2-6. In this case both C′ and R′ must be reflected across one-half of the transformer primary and the values to be used are $C = 4C'$ and $R = \left(\frac{n_1}{n_2}\right)^2 R'$.

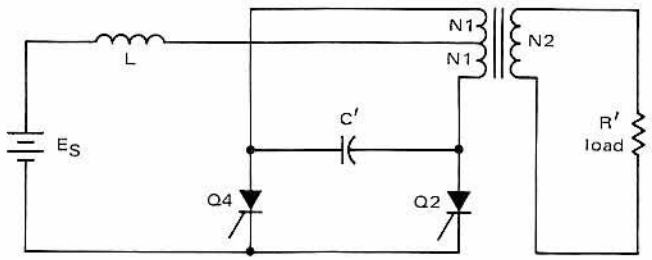


Figure 2-6 — Parallel-Commutated SCR Inverter with Center-Tapped Transformer Load

This approach to a parallel inverter is about the simplest way to obtain a square wave from an SCR inverter. Even the triggering is simplified since both SCRs have a common ground. However, the output waveform will always have an exponential leading edge and, the waveform is also affected, as we have shown, by variations in load. Because the turn-off time can represent a considerable portion of each alternation, the operating frequency will normally be less than 2 kilohertz for most available SCRs.

*See Reference Four.

2.4 Impulse-Commutated SCR Inverters

The basic circuit for impulse-commutated SCR inverters is shown in Figure 2-7. Battery voltages E1 and E2 are equal. Either thyristor Q3 or Q1 must be triggered first to store turn-off energy in capacitor C1. Assume Q3 is triggered first. Current will flow from battery E1 through inductor L1, capacitor C1, and load resistor R1. When this current ceases to flow, C1 will be charged to E1 (positive on the side connected to L1) and Q3 will turn off. Q4 can be turned on next and current will then flow from E2 through R1 and Q4. At this point the battery side of R1 will be positive, and C1 will remain charged as before. Using this condition, we can now refer to the waveforms in Figure 2-8A. A trigger pulse is applied to Q1. The capacitor current is initially zero. E_R, the voltage on resistor R1, is positive and the capacitor voltage, E_C, is negative. Both are approximately equal to E1. The current flowing through R1 (I_L) is approximately equal to E1/R1. C1 will now discharge a sine wave pulse of current through L1, Q1, E2 and R1. As I_C increases toward the value of load current I_L (shown dotted), the current through Q4 will decrease to zero at t1. When I_C exceeds I_L, E_R will increase until diode D2 is forward biased. The amount of I_C that exceeds I_L will therefore flow through D2. During this time, Q4 is reversed biased by D2 and will turn off. When I_C is maximum, E_C is zero and energy is now stored in the magnetic field of L1. As this field collapses, I_C will decrease below I_L and D2 will become reverse biased at t2. Now charging current will flow from E2 through R1, C1, L1, and Q1, and E_R will decrease. When C1 becomes charged at t3 to E2, E_R will be zero, and Q1 will turn off. The triggering of Q2 and Q3 will create a similar sequence of events for the negative alternation of load voltage (E_R).

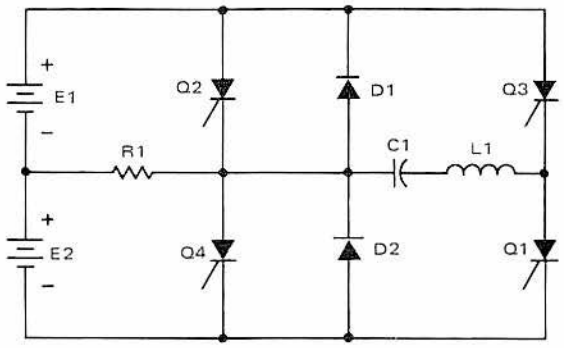


Figure 2-7 — Impulse-Commutated SCR Inverter

An alternate triggering sequence is shown in Figure 2-8B. Q1 has just been triggered; E_C is negative and Q4 is on. During the time D2 is forward biased, I_C exceeds I_L, and Q4 is recovering its blocking capability. At the point where I_C decreases below I_L, the turn off of Q4 is completed and Q2 may be triggered. The load voltage E_R will reverse instantaneously at this point. Since Q2 was triggered before I_C reached zero, Q1 will still be on. This means that charging current for C1 will now flow from both E2 and E1 through Q2, C1, L1, and Q1. The net result is that the final voltage on C1 will be about double that of the previous operation.

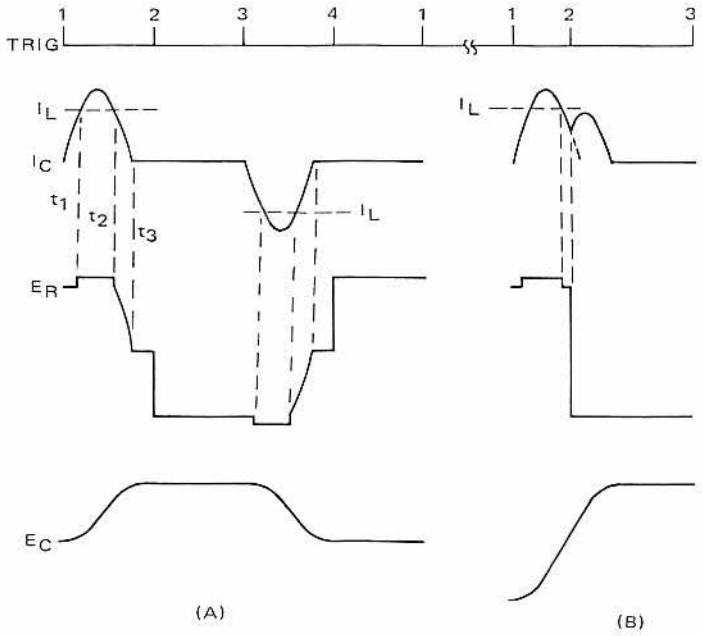


Figure 2-8 – Waveforms of Impulse-Commutated SCR Inverter

In the design of this circuit, the supply voltage and load are selected first. The center-tapped supply may be obtained by connecting two capacitors in series across a single dc supply. Any value of load voltage may be obtained by using an output transformer. After the thyristors and diodes have been selected, a triggering circuit can be designed. A variable-time ring counter is often a good choice. Finally, values for L1 and C1 must be determined. Let I_C be 1.5 I_L, and the pulse width ($\pi\sqrt{LC}$) be at least double the turn-off time ($2\,t_o$) because this pulse shape requires the least

energy.* Since I_C is determined by E_C and the characteristic impedance (Z_o), we obtain

$$1.\quad I_C = \frac{E_c}{\sqrt{L/C}} = 1.5\, I_L \text{ or } Z_o = \sqrt{L/C} = \frac{E_c}{1.5\, I_L},$$

where E_c is either equal to E1 or 2E1 depending on the mode of operation. The remaining condition is

$$2.\quad \pi\sqrt{LC} = 2\, t_o \text{ or } f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{4} t_o,$$

where f is the resonant frequency. Knowing f and Z_o, values for L1 and C1 may now be obtained directly from a reactance chart.

In the mode of operation shown in Figure 2-8A, turn off can occur at any time. This means that the output voltage can be pulse-width modulated. In the mode of 2-8B, a near-perfect square wave and fast switching and no overshoots is obtained. Very little power is lost in the commutating circuit so the circuit is very efficient. The circuit can be operated with no load and with a reactive load. The limiting value of load current (I_L) is that chosen for use in equation (1). Commutation becomes unreliable for load currents which exceed this value. It is possible to operate this circuit with any frequency up to about 25 kHz. This limit is imposed by a typical turn-off-time requirement of 20 μs. The one disadvantage of this circuit is that it requires four thyristors and a fairly complex triggering circuit.

2.5 Current-Feedback Transistor Inverters

The basic current-feedback, two-transformer transistor inverter is shown in Figure 2-9. Possible modifications include the use of NPN transistors (with proper power supply polarity) and/or common collectors, with feedback windings in the emitters. In the circuit of Figure 2-9, feedback transformer T1 functions as a current transformer to provide base drive current proportional to collector current. If Q1 is assumed to be conducting, $I_{B1} \approx (N_C/N_B)\, I_{C1}$. This flow of base current causes a voltage drop in the base circuit of Q1. In the absence of other series voltage drops, the voltage developed will be the V_{BE} of the conducting transistor and voltage

*Bedford, B. D. and R. G. Hoff, *Principle of Inverter Circuits*. John Wiley and Sons, Inc. 1964.

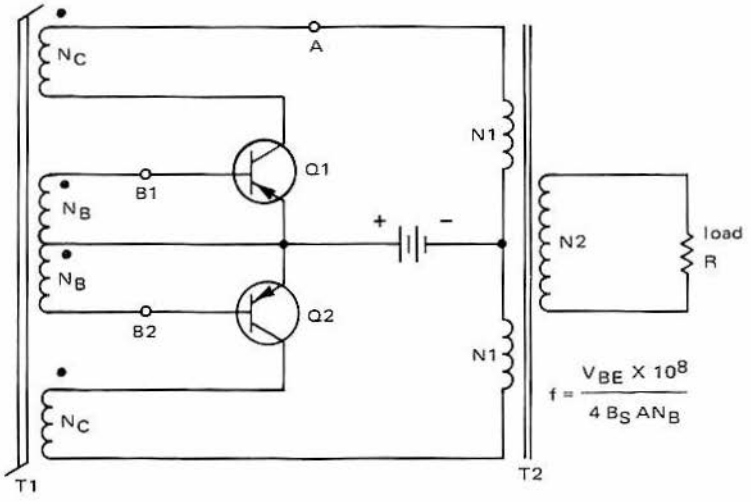


Figure 2-9 — Current-Feedback Two-Transformer Transistor Inverter

across N_B will be clamped at V_{BE}. This voltage across N_B determines how long it will take T1 to saturate and establishes the operating frequency of the inverter according to equation (1), where $V = V_{BE}$, $N = N_B$, and $\beta_s A$ is the flux capacity of the core of T1:

$$f = \frac{V \times 10^8}{4 \beta_s A N} . \qquad (1)$$

β_s is the maximum flux density in gauss

A is core area in cm^2.

When T1 saturates, the conducting transistor Q1 loses base drive, and the inverter switches to the other transistor.

Collector current I_C results in $H_1 = \frac{I_C N_C}{\ell}$ where ℓ is core magnetic path length. Prior to core saturation, only a small portion of this applied magnetic-field intensity is required for core magnetization, and current induced in base winding N_B will be approximately $(N_C/N_B)\, I_C$. As the core saturates, increasing current required for core magnetization detracts from the available base drive, causing the conducting transistor to turn off, and the other transistor to switch on regeneratively.

Because V_{BE} is relatively insensitive to inverter input voltage and load current, the frequency of the basic current feedback inverter (Figure 2-9) is correspondingly independent of input and load. However, the following precautions are necessary: The duration of the half period associated with conduction of each transistor is proportional to the V_{BE} of that respective transistor. To avoid half-period asymmetry which would result in net direct current in transformer T2, it is recommended that the two transistors be matched for V_{BE}. Further, since V_{BE} is typically one volt or less, considerable deviation from calculated frequency can be caused by even tenths of a volt of base-circuit I-R drops such as may be caused by appreciable series resistance in winding N_B. Empirical adjustment of the number of turns (N_B) is generally easier than taking winding resistance into account in the original calculation.

Current-feedback inverters are easily adapted to stabilization or control of inverter frequency by the addition of controlled series voltage drops in the base circuits. Several possibilities are shown in Figure 2-10. In each case, frequency is proportional to the sum of V_{BE} and the added series voltage drop.

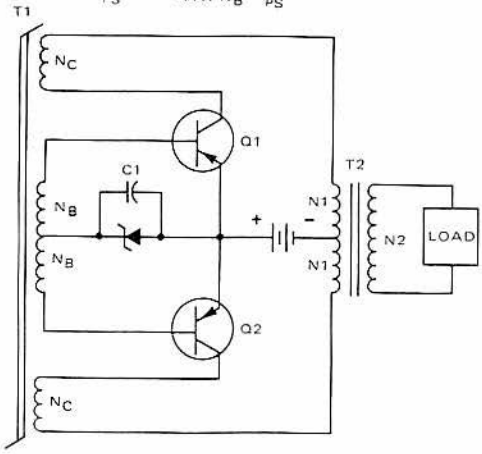
In Figure 2-10A, a zener diode in series with V_{BE} reduces the effect on frequency of variations in V_{BE} due to changing load or temperature. If V_{BE} is small compared to zener voltage V_Z, good frequency accuracy is possible.

A diode in series with the drive circuit is used in Figure 2-10B to compensate for the negative temperature coefficient of β_s, and provide almost constant frequency over a wide temperature range. A resistor in series with the base of the transistor may be used to obtain a series voltage that will provide a frequency proportional to $V_{BE} + I_B R_B$. With a variable resistor, as shown in Figure 2-10C, frequencies over a range exceeding ten to one have been observed. Also, frequency variation or precise frequency control may be obtained by using a voltage-regulating transistor in the feedback circuit, as shown in Figure 2-10D.

In adding series voltage to the base circuit, care must be taken not to exceed BV_{EBO} of the nonconducting transistor, or a protective external diode must be placed in the base circuit. In the configurations shown in Figure 2-10, which have series elements common to both base circuits, reverse emitter-base voltage will be twice the induced series voltage plus V_{BE} of the conducting device. Common-collector circuits or other configurations having independent series elements in each base circuit will result in emitter-base reverse bias equal to the series voltage plus V_{BE}. Note, however, that when independent series elements are used, the voltages

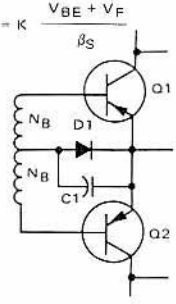
(a) "CURRENT FEEDBACK" INVERTER CIRCUIT MODIFICATION USING ZENER DIODE TO STABILIZE INVERTER FREQUENCY

$$f = \frac{(V_{BE} + V_Z)}{\beta_S} \times \frac{10^8}{4\,A1\,N_B} = \frac{K}{\beta_S}(V_{BE} + V_Z)$$



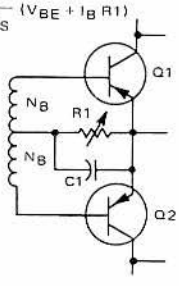
(b) MODIFICATION USING SERIES FORWARD DIODE TO COMPENSATE FOR NEGATIVE TEMPERATURE COEFFICIENT OF β_S

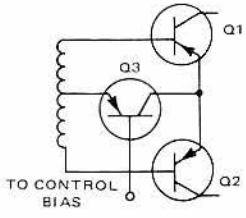
$$f = K\,\frac{V_{BE} + V_F}{\beta_S}$$



(c) USING RESISTOR TO VARY INVERTER FREQUENCY

$$f = \frac{K}{\beta_S}(V_{BE} + I_B R1)$$





$$f = \frac{K}{\beta_S}(V_{BE} + V_{CE_3})$$

(d) USING SERIES-PASS TRANSISTOR TO VARY OR STABILIZE INVERTER FREQUENCY

Figure 2-10 — Stabilized Current-Feedback Inverters

developed across each should be equal, so that the two half cycles are of equal duration.

Some means must generally be provided to assure starting of current feedback inverters. Frequently, introduction of a slight circuit imbalance is adequate to initiate regenerative conduction of one transistor and begin oscillation. Such imbalance may consist of a resistor from point A to point B1 in Figure 2-9, or a capacitor from A to B2. For severe starting requirements, more sophisticated starting means, such as the circuit of Figure 2-11, may be used.

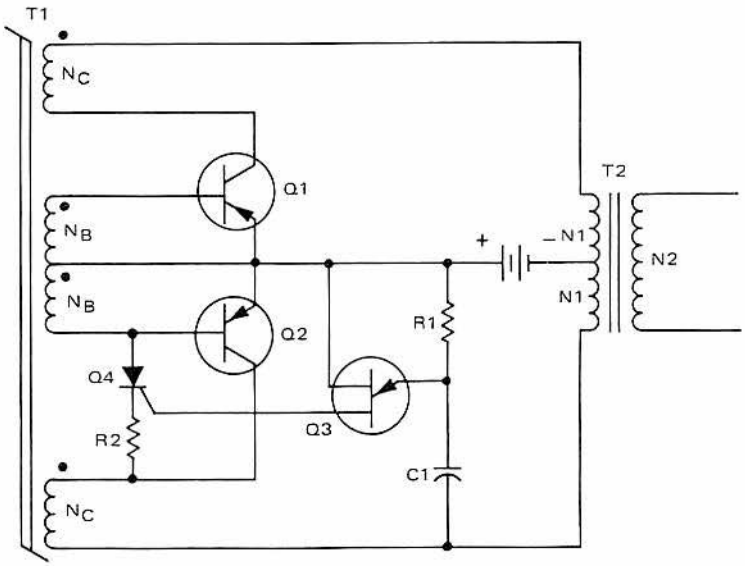


Figure 2-11 — Current-Feedback Inverter with Starting Circuit

In the circuit of Figure 2-11, inverter starting is accomplished by turning on SCR Q4, causing current to flow through the emitter-base diode of Q2, and thus turning Q2 on. When Q2 turns on, the collector-base junction of Q2 becomes forward biased and Q4 is commutated off. Q4 is triggered by the discharge of C1 through unijunction transistor Q3 when the voltage on C1 becomes adequate to fire the unijunction. Resistor R2 limits both gate and anode current of Q4. If the time constant of R1 and C1 is long compared to the inverter half period, the starting circuit will not fire after the inverter starts, and very little loss of efficiency will result from use of the starting circuit.

Simplifications in the starting circuit of Figure 2-11 may be adequate for many applications. For example, if Q4 were eliminated, and base one of the unijunction were connected to the collector of Q2, discharge of C1 would be through the Q2 feedback winding N_C. Q2 would be biased on by current-feedback action of transformer T1. For NPN circuits, unijunction base one may be connected directly to the base of an inverter transistor, and discharge of C1 would provide starting base current to the transistor.

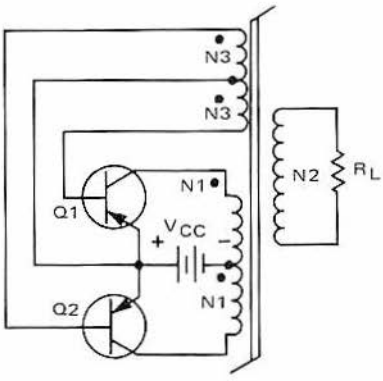
Note that because high output current results in proportionately high base current, current-feedback inverters start well into a full load, or even a somewhat-capacitive load. On the other hand, starting into inductive loads is difficult. This is the converse of voltage-feedback inverters, which start well into light or inductive loads, but with difficulty into full or capacitive load. Low input voltage does not detract from starting performance of current-feedback inverters.

For applications involving varying loads or a range of input supply voltages, current-feedback inverters are more efficient than voltage-feedback inverter because of the proportionality between base current and output current in current-feedback inverters. Conventional voltage-feedback inverters must be designed to provide adequate base drive at full load and minimum input voltage. As loading is reduced, voltage feedback and its associated losses remain constant in magnitude and represent an increasing share of input power. As the input voltage is increased from its minimum value, drive losses increase, again detracting from efficiency. The combination of light load and high input voltage may result in very inefficient operation. A further inefficiency of voltage-feedback inverters is that base resistors or other dissipative means must usually be provided to control base current.

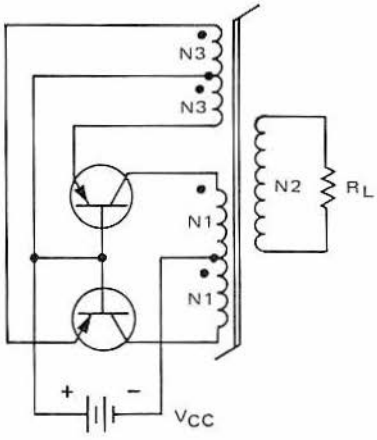
2.6 Voltage Feedback Transistor Inverters

One-Transformer-Inverter Operation

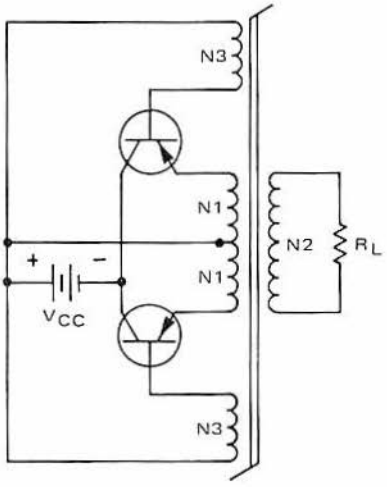
Operational theory common to most transistor inverters may be illustrated by considering the basic over-driven, push-pull, transformer-coupled transistor oscillator circuit of Figure 2-12A, and the transformer B-H curve of Figure 2-13. Assume that transistor Q1 is nonconducting, Q2 conducting, and the transformer saturated at point J on the B-H curve. When Q1 starts to conduct, the voltage developed across the primary windings (N1) induces voltage in the feedback windings (N3) which drives Q1 into saturation rapidly and turns Q2 off. When this transition is completed, constant voltage, $V_P = V_{CC} - V_{CE(sat)}$, is applied to N1. Since



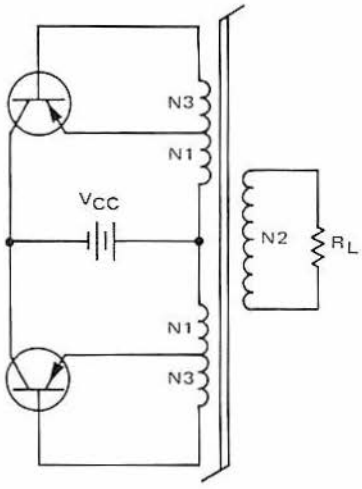
(a) COMMON-EMITTER CIRCUIT



(b) COMMON-BASE CIRCUIT



(c) COMMON-COLLECTOR CIRCUIT (N3>N1)



(d) AUTOTRANSFORMER COMMON-COLLECTOR CIRCUIT

Figure 2-12 – Basic One-Transformer Inverter Circuits

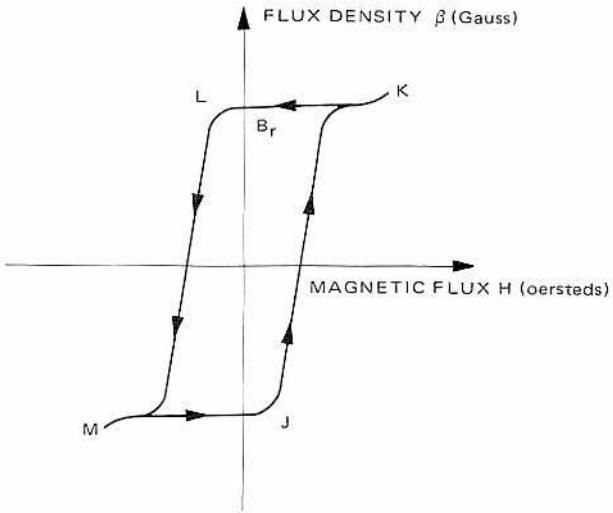


Figure 2-13 – Transformer B-H Curve

$\frac{d\phi}{dt} = \frac{V_P}{N1}$, flux ϕ must increase in the transformer core at a constant rate, causing flux density $B = \phi/A$ to increase from point J toward point K on the B-H curve. As long as the core remains nonsaturated, magnetization current i_m ($= H/N1$) is small, but as saturation (point K) is approached, high magnetization current i_m is required to keep $\frac{d\phi}{dt}$ constant. When reflected load current, plus this sharply increasing magnetization current, exceeds the collector current which Q1 can supply (with the drive available), Q1 begins to come out of saturation causing V_P to decrease. The feedback voltage (V_{FB}) and collector current (I_C) decrease regeneratively, turning Q1 off and ending the half cycle.

As flux in the transformer core collapses from point K to point B_r, voltage which biases transistor Q2 into conduction and initiates the next half cycle is induced in the winding. The operation is similar to the first half cycle except that supply voltage (less $V_{CE(sat)}$) is applied to the other half of the primary, causing a reversal of polarity in the induced output voltage. Q2 conducts until the core is driven into negative saturation at point M on the B-H curve. As flux collapses from M to J, the full cycle is completed.

Typical voltage and current waveforms for a one-transformer inverter are shown in Figure 2-14. It can be seen from the waveforms of

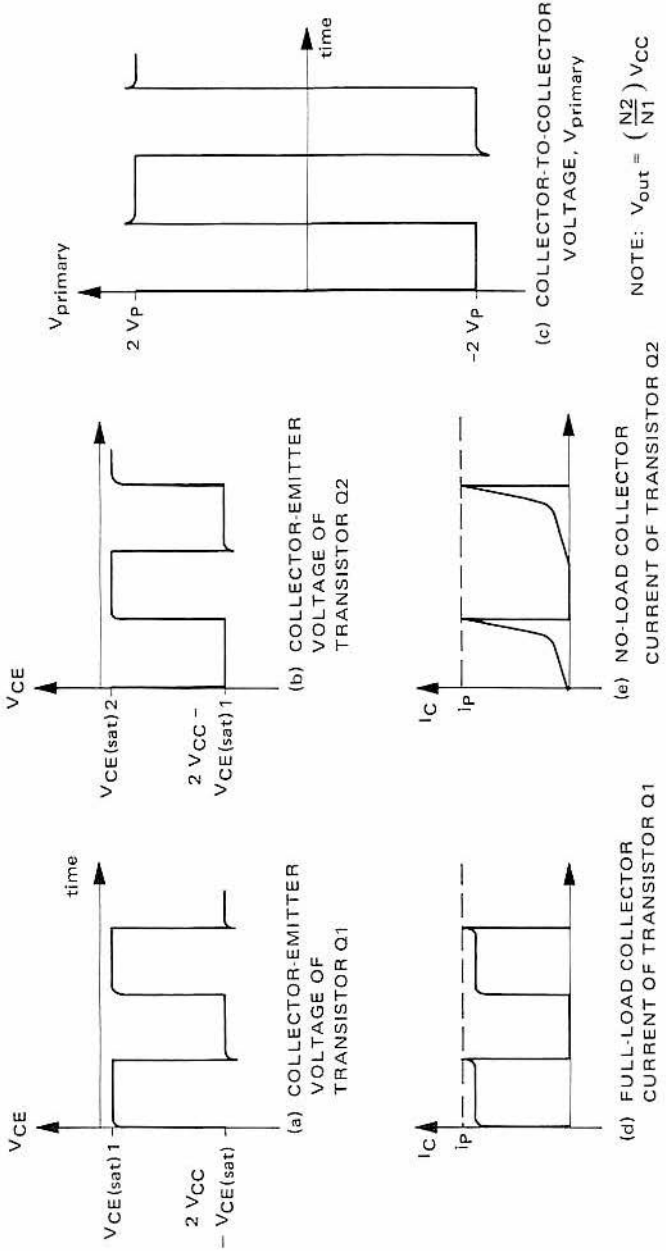


Figure 2-14 – Typical Voltage and Current Waveforms for One-Transistor Inverter

collector-to-emitter voltage that, in the off condition, each device is subjected to a voltage approximately equal to twice the supply voltage plus any induced voltage that may occur in the circuit due to leakage inductance, etc. Also significant is the fact that the same maximum collector current i_p is required for switching action whether this current is primarily reflected load current, as in Figure 2-14D, or totally magnetization current, as in 2-14E. This will obviously limit efficiency at low output loads.

Operating frequency of the inverter is determined by the voltage V_p and by the saturation characteristics of the transformer core according to the relationship, $f = \frac{V_P \times 10^8}{4\beta_S A N_1}$ Hz. β_S is saturated flux density in gauss, A is cross-sectional area of the core in cm^2, and N_1 is the number of turns on one half of the primary.

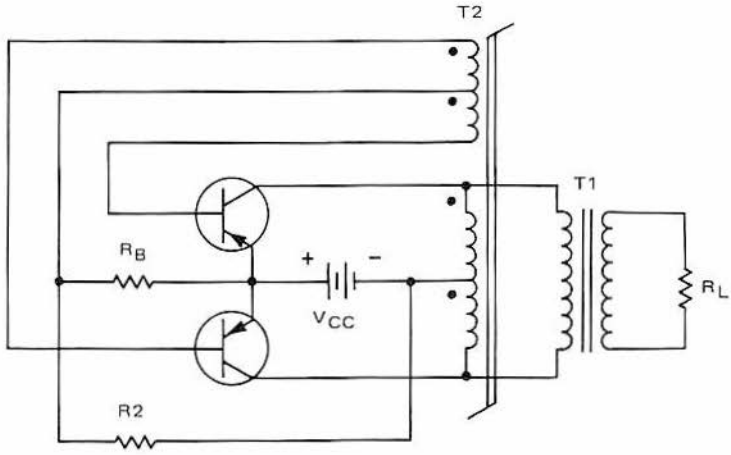
Two-Transformer Inverters

At high load currents, high frequency, and high output power, it becomes increasingly difficult to design and build a one-transformer inverter in which the transformer fulfills the dual role of frequency control and efficient transformation of output voltage satisfactorily. For this reason, the two-transformer inverter designs of Figure 2-15 are advantageous in many applications. Operation of two-transformer inverters is similar to that of one-transformer inverters except that in a two-transformer circuit (Figure 2-15), only the small feedback transformer T2 need be saturated. Since the magnetization current of T2 is small, high current levels due to transformer saturation currents are reduced significantly compared to one-transformer design, as is device stress due to these transformer saturation current levels. (Compare Figure 2-16 with Figures 2-14D and 2-14E.) Furthermore, use of a conventional output transformer with normal core material permits lower transformer costs as well as higher efficiency.

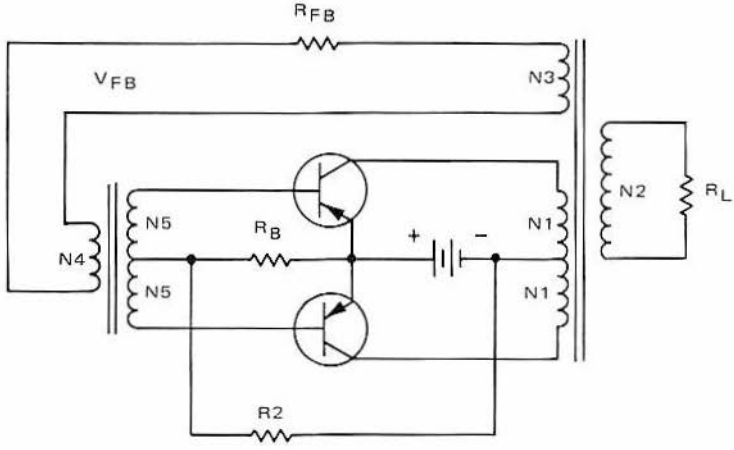
Another major advantage of two-transformer inverter designs (circuits similar to Figure 2-15) is that the inverter frequency is determined by V_{FB}. This voltage can be regulated to provide a constant frequency or can be changed with a variable resistor for R_{FB} to provide variable frequency output.

Bridge Inverters and Series-Connected Inverters

Inverters such as the bridge circuits of Figure 2-17, and the series-connected inverter of Figure 2-19, are useful when input voltage exceeds transistor voltage capabilities. The bridge arrangements apply the supply voltage across each transistor, instead of applying approximately twice the



(a) TWO-TRANSFORMER INVERTER WITH SIMPLE OUTPUT TRANSFORMER T1



(b) TWO-TRANSFORMER INVERTER HAVING EASILY REGULATED V_{FB}

Figure 2-15 – Typical Two-Transformer Inverters

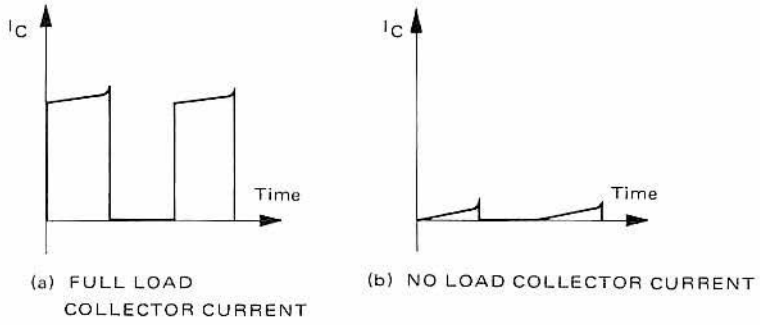


Figure 2-16 — Collector-Current Waveforms for Two-Transformer Inverter

supply voltage as in simple push-pull circuits. This reduction in voltage to which each device is subjected is true of all circuits of Figure 2-17, but in the half-bridge circuit of Figure 2-17C, transistor current must double to maintain the original output power.

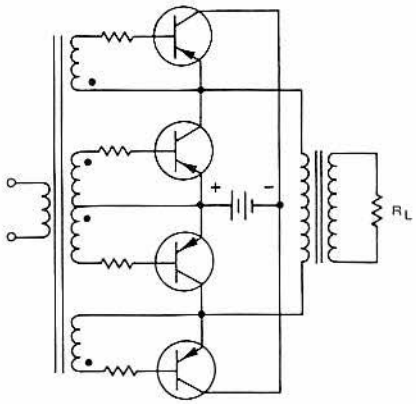
In considering bridge inverters, the designer should be aware of a problem tolerable in simple inverters but of major significance in bridge connections. This has to do with the current-voltage excursions of the devices as the circuit switches. If the previously nonconducting side of the circuit turns on before the other side is completely off, both high voltage and high current may be imposed on the transistors, and their safe areas may be exceeded. Additionally, high transients may be generated. The problem may be somewhat alleviated by reducing device "on" drive, by device protection against transients, or by compensating base-drive networks which retard turn on of the nonconducting device. One possibility is to use a driven bridge having the input waveforms of Figure 2-18.

In the circuit of Figure 2-19, n simple inverters connected in series divide the supply voltage equally so that each device is required to withstand $\frac{2\,V_{CC}}{n}$. The magnetic circuit requires that the voltage divide equally among the series stages.

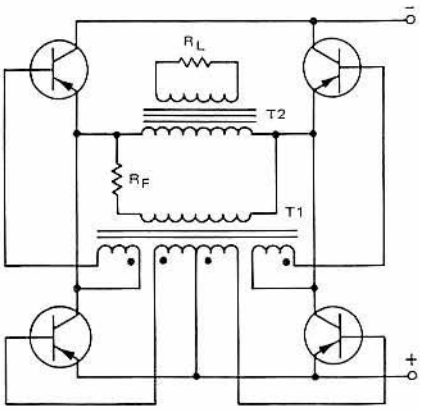
Each of the basic approaches summarized above has a unique combination of advantages and disadvantages which should be considered in light of the design requirements.

Inverter Starting Circuits

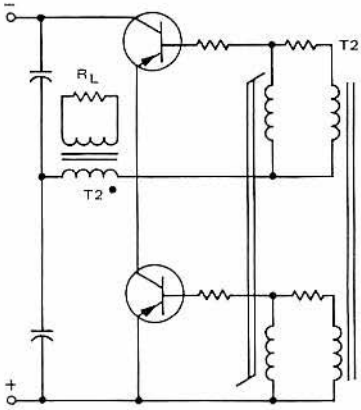
In general, the basic circuits of Figure 2-12 and their derivatives (including basic two-transformer inverters) will not oscillate readily unless some means is provided to begin oscillation. This is especially true at full load and low temperature, the most severe starting condition for resistive



(a) DRIVEN BRIDGE-CONNECTED OUTPUT STAGE



(b) SELF-OSCILLATING TWO-TRANSFORMER FULL-BRIDGE INVERTER



(c) HALF-BRIDGE INVERTER WITH SATURABLE-BASE INDUCTORS

Figure 2-17 — Typical Bridge Inverter Circuits

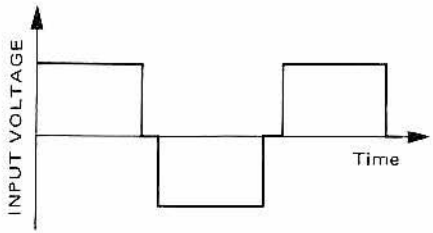


Figure 2-18 — Typical Magnetic-Amplifier-Output Waveform Used as Bridge-Inverter Input Prevents Simultaneous Conduction of Both Inverter-Circuit Halves During Conduction

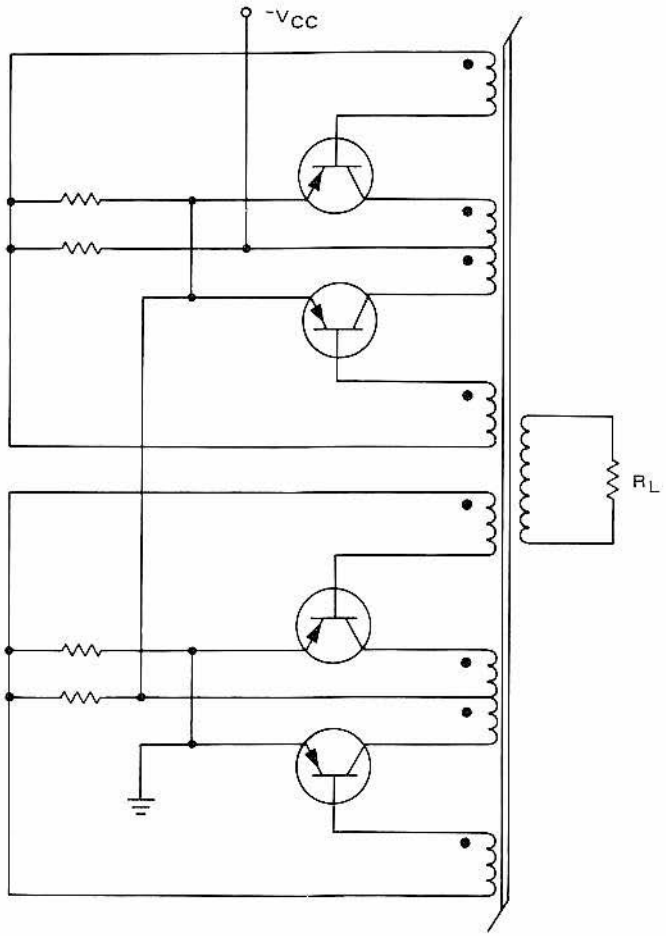


Figure 2-19 — Series-Connected Inverter for High DC Input Voltages

loads. The discussion of basic inverter operation assumed that one of the transistors was conducting, which will start the oscillation. The function of the starting circuit is to ensure this condition.

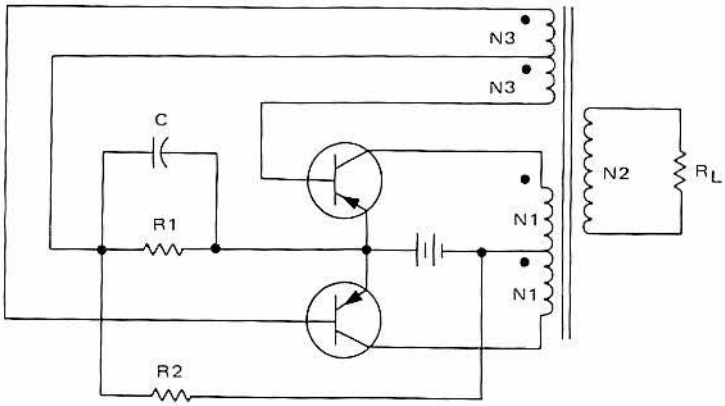
A simple, commonly used starting circuit is shown schematically in Figure 2-20A. In this circuit R1 and R2 form a simple voltage divider to bias the transistors to conduction before oscillation starts. A good rule of thumb for the base starting bias developed by this circuit is to use 0.3 volts for germanium transistors and 0.5 volts for silicon. This voltage, V_B, is equal to $\frac{R1\ V_{CC}}{R1 + R2}$. Since R1 occurs in the feedback circuit in series with the base of each circuit half, R1 must not exceed R_B, which is equal to $\frac{V_{FB} - V_{EB}}{I_B}$. If R1 is set equal to R_B, then R1 and R2 are uniquely determined for any given starting bias. The resistance of R2 is uniquely determined for any given starting bias. The value of R2 may be adjusted if starting is not satisfactory. The advantage of this straightforward starting technique is that only resistors need to be added to the circuit, but it has the disadvantage of additional power dissipation, which may become excessive in high power circuits.

An improved, but somewhat more costly, starting circuit is the diode self-starting circuit shown in Figure 2-20B. This circuit dissipates less power than its resistive counterpart and is less temperature dependent. Operation is similar to resistive starting, but when power is first applied the bases of the transistors are driven negative by full supply voltage and oscillation starts rapidly.

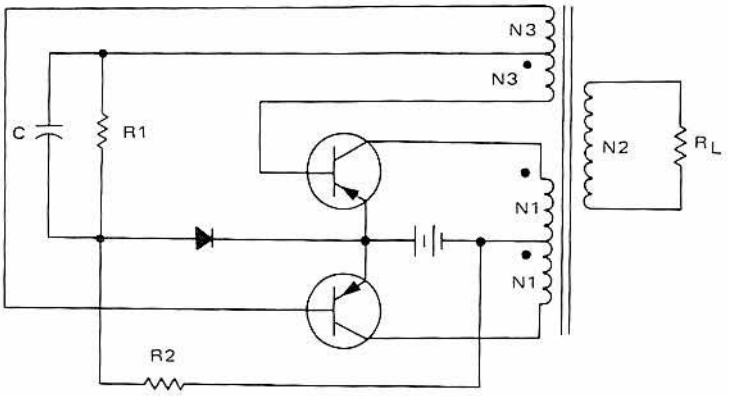
Capacitive filters, starting motors or incandescent lamps may temporarily present extremely high loads to inverters during the starting period. Starting with such loads is often simplified somewhat by using a driven inverter, and this approach may be preferable to the circuit complications needed to assure self-oscillation.

Conclusion

Transistor voltage-feedback inverters provide many advantages in conversion of direct current to alternating current. The basic two-transistor, one-transformer design has excellent efficiency and performance, but is inferior to a two-transistor inverter at power outputs in excess of 100 watts or if precise frequency is required. Design requirements are dictated by inverter specifications, and modifications to the basic circuit probably will be necessary to achieve precisely controlled frequency or output voltage.



(a) SIMPLE RESISTIVE SELF–STARTING CIRCUIT WITH SPEED-UP CAPACITOR ACROSS R1



(b) DIODE SELF-STARTING CIRCUIT

Figure 2-20 – Starting Circuits for Transistor Inverters

2.7 Hybrid Feedback Inverters

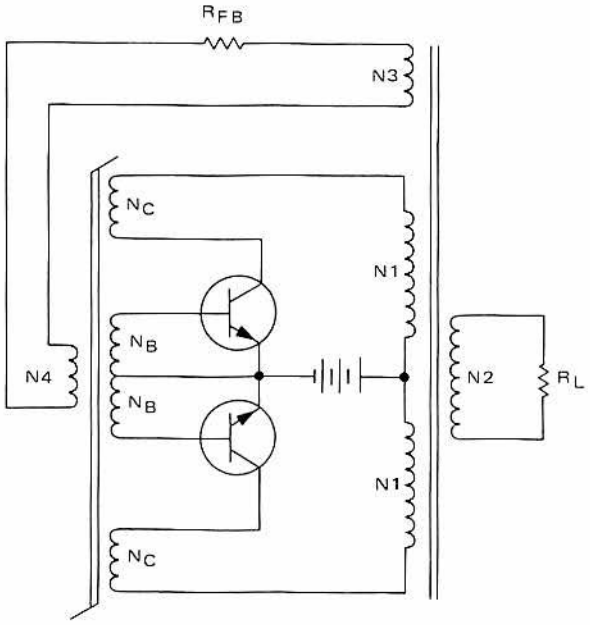
It has been noted that current-feedback inverters have some advantages over voltage-feedback inverters. The frequency of a current-feedback inverter is almost independent of supply voltage and load, and its efficiency is nearly constant over a wide range of load because its base current is proportional to load current. This constant forced gain also enhances the overload capability of current-feedback inverters. Current-feedback inverters operate well with low input voltage. They start well into full loads, but are difficult to start into light or inductive loads, and shut down with open output. They can be operated into center-tapped resistive loads as well as into transformers.

Voltage-feedback inverters start well into light or inductive loads, but are difficult to start into full or capacitive loads, and shut down automatically if their output is shorted. The frequency of voltage-feedback inverters is determined by feedback voltage and therefore is usually proportional to input voltage. Because base drive is constant with respect to load, voltage-feedback inverters are comparatively inefficient at low load. Base drive increases with increasing input voltage, and decreases efficiency if input voltage ranges widely.

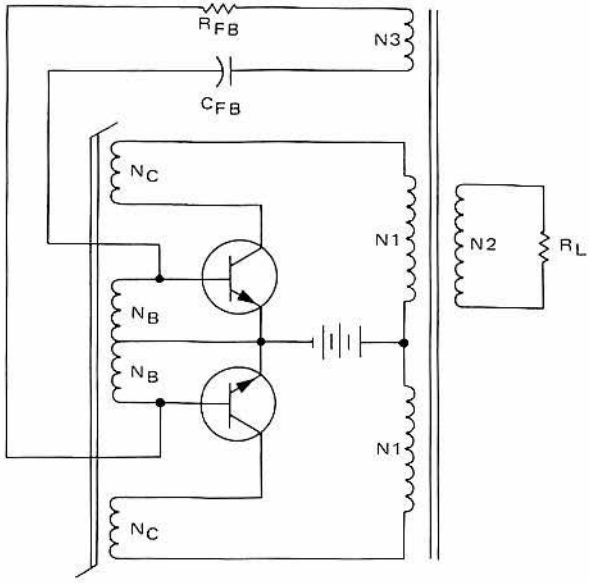
By combining current feedback and voltage feedback in a single inverter, it is possible to obtain many of the advantages of each type of feedback. For example, the hybrid inverter of Figure 2-21A has voltage feedback added to the basic current-feedback inverter. Although the polarity of N4 could be arranged to obtain differential feedback, additive feedback is assumed in the following discussion. The relative contributions of N4 and N_C to total drive may be varied, depending upon the characteristics desired.

The combination or hybrid feedback results in excellent starting over a full range of loads, including reactive loads. Frequency stability with changing input voltage and changing load is essentially that of the current-feedback inverter. As previously discussed for current-feedback inverters, a resistor, rectifier, zener diode or other series element may be placed in the base circuits for additional control of inverter frequency. Low-load efficiency and overload capability are improved over the voltage-feedback inverter since base current is still somewhat proportional to load current. Hybrid inverters operate well over an extremely wide range of input voltage. Either common-emitter or common-collector NPN or PNP transistors can be used in hybrid-feedback configurations.

The modification of hybrid feedback shown in Figure 2-21B, was found to be useful with inductive and light loads. Because of capacitor C_{FB} in the voltage feedback loop, the voltage feedback is maintained only



(a) CURRENT FEEDBACK + VOLTAGE FEEDBACK



(b) CURRENT FEEDBACK + "BOOSTER" FEEDBACK

Figure 21 — Hybrid-Feedback Two-Transformer Inverter

during the first portion of each half cycle. Each time the inverter switches, a pulse of current from the voltage feedback "booster" circuit consisting of R_{FB}, C_{FB} and N3 is injected at the base of the transistor being turned on. This supplemental current adds to the base current from the current-feedback transformer to assist transistor switching. If the load is inductive, it also serves to maintain bias until collector current is adequate to provide the feedback needed to sustain conduction. At low loads (low current in N_C), the booster circuit is adequate to provide oscillation. At full load, regular current-feedback operation predominates and the booster circuit has little effect on the inverter operation.

2.8 SCR Inverter with Well-Regulated, Sine-Wave Output 165 Vdc - 120 Vac, 800 W, 400 Hz

The 800 watt, 400 hertz series-commutated SCR inverter shown in Figure 2-22 is designed to operate with an input of 165 volts. The output voltage is 125 volts rms and the waveform is a sine wave. This circuit is probably the best sine-wave inverter known today. The output voltage is extremely well regulated for variations in load, the frequency is independent of normal load and input voltage variations, and the circuit itself can be designed to operate over a wide range of frequencies and output power levels.

The 800 watt limit imposed on this circuit is actually a device limitation. The circuit was tested at 1000 watts for efficiency, and the load was then reduced to 3 ohms before the thyristors failed to commutate. The 3 ohm load represents almost 5 kilowatts of output power. The circuit will also operate at the other extreme of no load. The actual operating range of output power is 0 to 800 watts with an input of 165 volts dc.

Efficiency and output voltage are plotted as a function of output power in Figure 2-23. Efficiency increases with power from 5% at 30 watts to 60% at 800 watts. This shows that the best efficiency is obtained with full load. The output voltage decreases slightly as output power is increased. The voltage dropped from 127.5 V at no load to 125.0 V at full load. This means that output voltage will decrease by only 0.3 volts for every 100 watt increase in load. Frequency was not plotted because it does not vary with load. The frequency remains 400 hertz over the full range of output power. The waveform itself is also quite good over this range; there is no perceptible distortion of the sine wave as viewed on an oscilloscope.

At full load, the input current is about 9 A. If the trigger circuit were externally driven, the inverter circuit would operate with an input voltage of 25 volts dc. The zener will start to lose regulation in this circuit

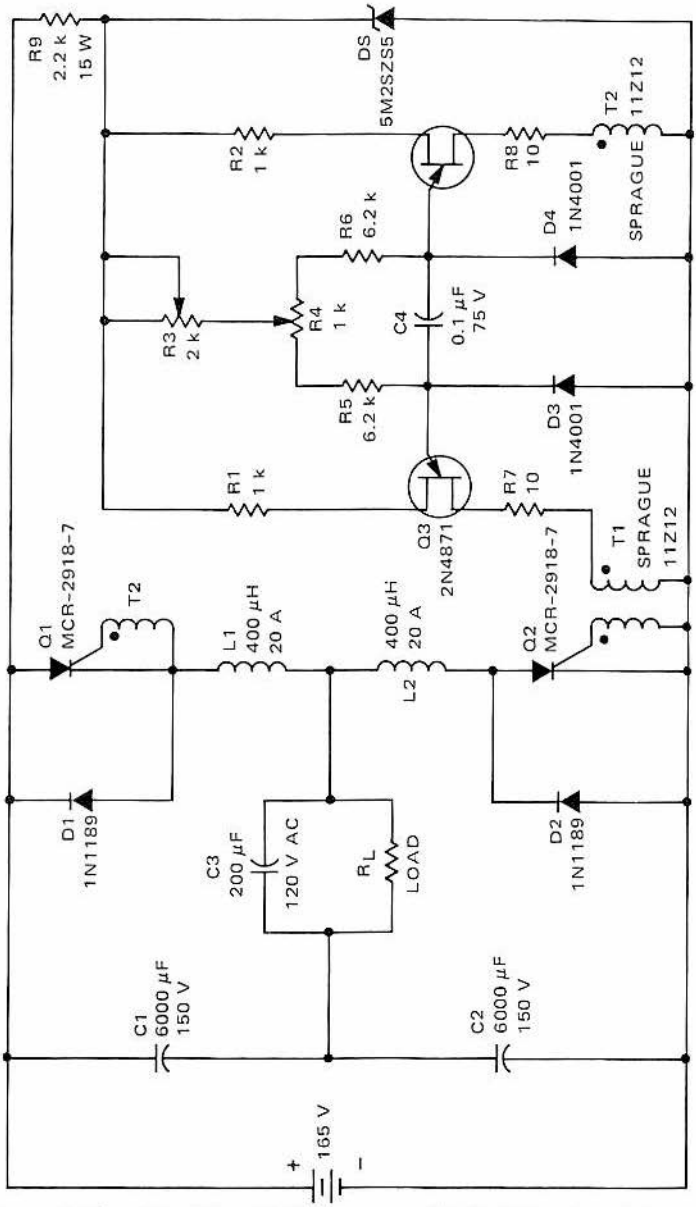


Figure 2-22 — Sine-Wave SCR Inverter with Well-Regulated Output. 165 Vdc-120 Vac, 800 W, 400 Hz

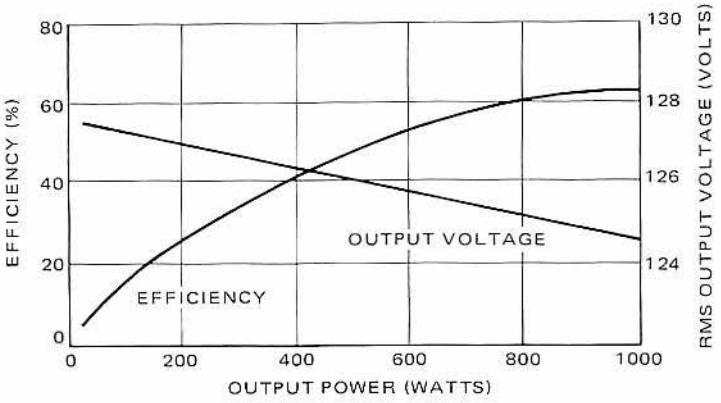


Figure 2-23 – Performance Curves for Series-Commutated SCR Inverter in Figure 2-22

at about 75 volts input. Between 75 and 165 volts input, the output frequency remains 400 hertz. Output power and output voltage, however, will vary with the input. The peak output voltage remains approximately equal to the input voltage. This means that the rms output is about 0.7 times the input voltage.

This circuit does differ from the basic series inverter: Diodes D1 and D2 are connected across the thyristors Q1 and Q2. Inductors L1 and L2 do not have a common core and the resonant frequency is higher than the operating frequency. The circuit is discussed in more detail in Reference 6.

2.9 Basic Sine-Wave Inverter 28 Vdc - 110 Vac, 40 W, 400 Hz

The 40 watt, 400 hertz series-commutated SCR sine-wave inverter shown in Figure 2-24 is designed for an input of 28 volts dc. The output voltage is 110 volts rms. The circuit is quite simple; it uses a capacitor and inductor on the output to produce the sine-wave output. It may be operated above or below resonance without any commutation problems. The circuit is driven by a pair of unijunction transistors, and the frequency regulation is excellent for variations in both input voltage and load. The circuit can be operated indefinitely into either an open- or short-circuited load. The output voltage and power are affected by variations in circuit Q and will change with variations in load resistance.

Figure 2-25 shows the effect of variations in load resistance on frequency, efficiency, power, and output voltage. The load resistance was

increased from 50 to 500 ohms with a 28 volt dc input. Frequency increases slightly with resistance but the overall regulation is better than 5%. The output voltage varies considerably with load; it increases from about 30 to 130 volts rms. If it is desirable to keep output voltage within a certain range, the load resistance must be limited accordingly. The maximum transfer of power occurs with a load resistance of 290 ohms and the output power at this point is approximately 42 watts. Variations in resistance above and below this power cause the power to decrease. Efficiency increases with increasing load resistance from about 20% to 60%. At 250 ohms, the efficiency is slightly better than 40%.

In Figure 2-26, output voltage and frequency are plotted as a function of input voltage, with a constant load of 250 ohms. As the input voltage is increased from 15 to 30 volts, the output voltage increases linearly from about 50 to 110 volts. Doubling the input voltage also causes the output voltage to double. The output frequency decreases from 415 to 395 hertz over this same range of input voltage. Frequency regulation is again better than 5%.

The nominal input voltage is 28 volts dc. Variations of ±10% are the allowable limit. Input current will vary with load from 2 A at 500 ohms to 6 A with a short circuit (0 Ω load resistance). The operating range of load

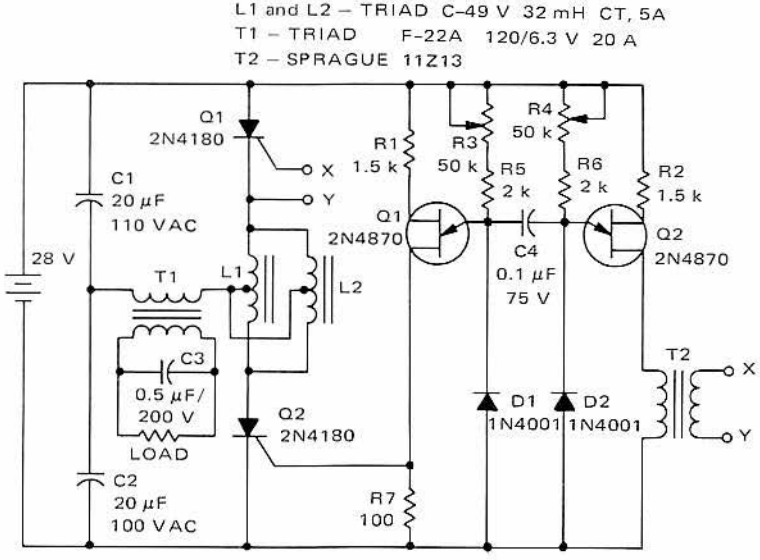


Figure 2-24 – Basic Sine-Wave SCR Inverter. 28 Vdc to 110 Vac, 40 W, 400 Hz

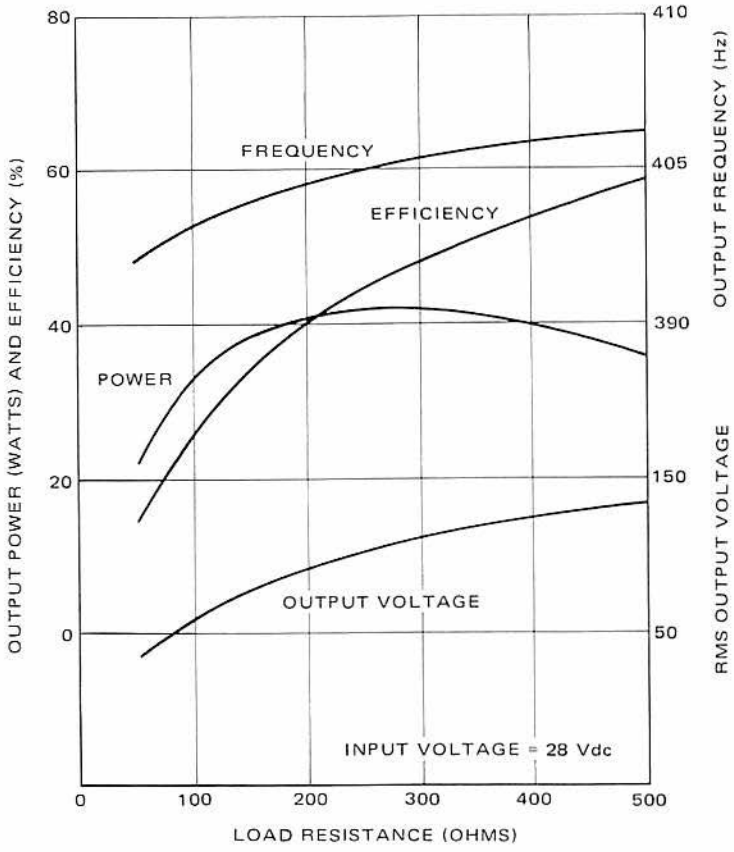


Figure 2-25 – Performance of SCR Sine-Wave Inverter in Figure 2-24 for Varying Load

resistance should be from 200 to 300 ohms in order to obtain ±10% output voltage regulation.

2.10 Driven Inverter with Stable Frequency Output 24 Vdc - 45 Vac, 120 W, 400 Hz

A simple means to approximately double a voltage is to use the parallel-commutated SCR inverter shown in Figure 2-27. The nominal input voltage for this circuit is 24 Vdc, but input voltage may be varied from 10 to 28 Vdc. Output power is typically 120 watts but can be increased to approximately 150 watts with 28 Vdc input. The output voltage is a 45 V, 400 Hz square wave. This voltage is independent of load

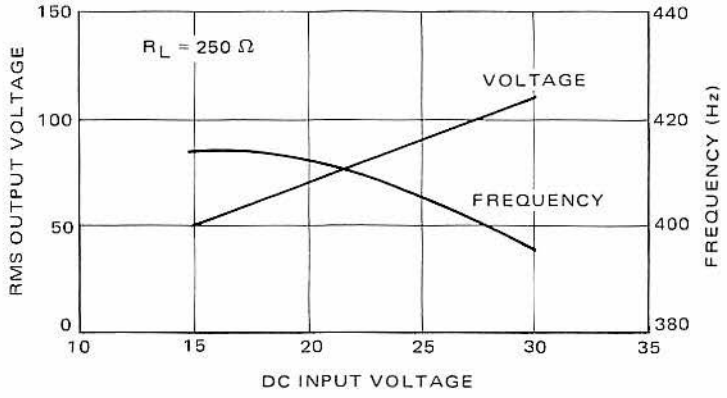


Figure 2-26 — Performance of SCR Sine-Wave Inverter in Figure 2-24 for Varying Input

current but does vary with the input voltage. A capacitive load is required to commutate the thyristors properly. Load power factor in this circuit is about 0.9.

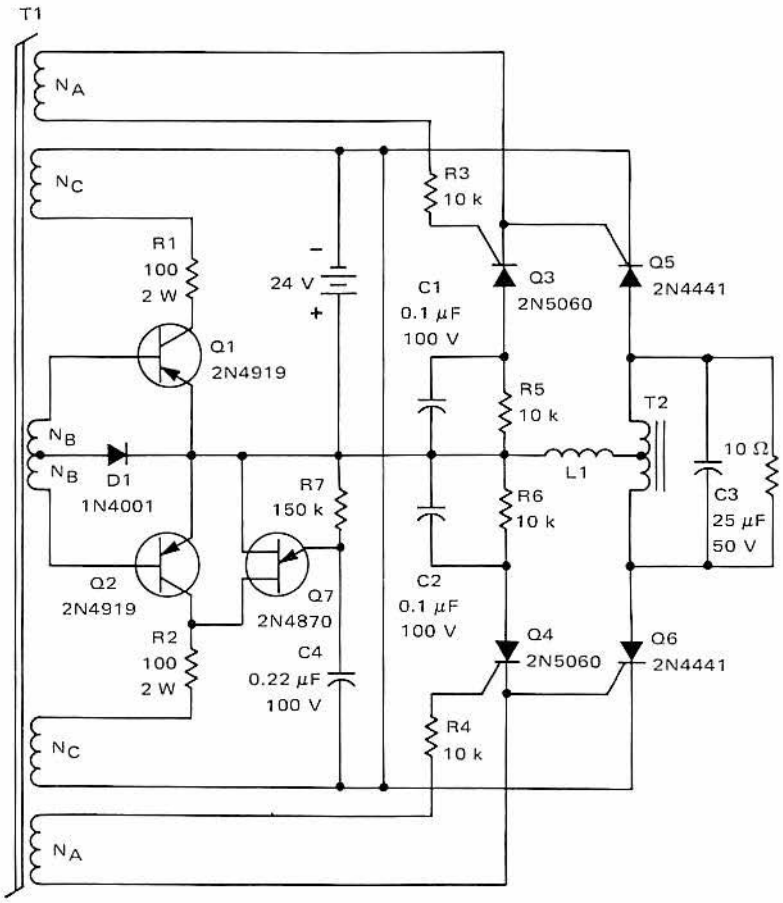
Load current does affect the output voltage waveform of this circuit. The leading and lagging edges rise and fall exponentially. As load current decreases, the rise and fall times increase. A certain amount of rise and fall time is necessary for commutation. The minimum load for this circuit is ten ohms, resulting in a maximum load current of 2.4 A.

The magnitude of the input voltage does not affect the output-voltage rise and fall times but will, as stated before, affect output voltage magnitude.

Since this is a driven inverter, the output frequency is not affected by changes in the load. Frequency is also very stable for variations in input voltage. Frequency stability is maintained by the voltage drops of diode D1 and the base-emitter junctions of Q1 or Q2, which are relatively independent of current variations.

The overall efficiency of this circuit is approximately 70%, resulting in power losses low enough that this inverter can be used in ambient temperatures from 0°C to +60°C if heat sinks with thermal resistance of less than 3°C per watt are used for Q1, Q2, Q5, and Q6.

The circuit is actually an inverter-driven inverter. The drive circuit is a current-feedback inverter with a UJT starting network. Additional windings on the small timing transformer drive a pair of sensitive-gate SCRs. These SCRs drive the main parallel-commutated inverter, which supplies power to the load.



TRANSFORMERS

T1 – ARNOLD CORE 6T-5340-D1
N_A + N_B 83 TURNS EACH #30 WIRE
N_C 8 TURNS #26 WIRE

T2 – PHOENIX TRANSFORMER PX2677
350 V, 1 kVA, 1 kHz
INDUCTOR

INDUCTOR

L1 – PHOENIX TRANSFORMER PX1710 2 mH, 30 A

Figure 2-27 – Driven SCR Inverter.
24 Vdc-45 Vac, 120 W, 400 Hz

The value of inductor L1 was chosen to provide a damped output waveform with no overshoot. If the waveform is not critical, this value may be reduced to as low as 80 μH. This not only reduces the weight of the reactive components but will improve efficiency as well. This circuit is subject to damage from short circuits or overloads. In either case, both thyristors Q5 and Q6 will fail to commutate, permitting sufficient current to be drawn from the line to destroy them unless suitable protection is provided.

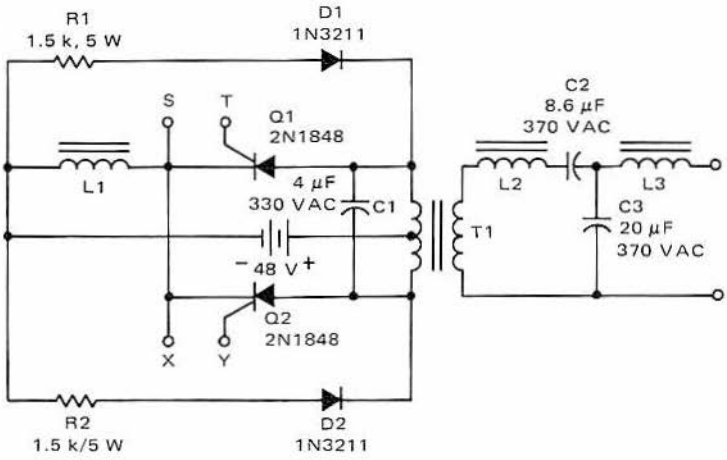
2.11 Sine-Wave Inverter with Stable Output Frequency 48 Vdc - 120 Vac, 100 W, 60 Hz

A 100 watt, 60 hertz parallel-commutated SCR inverter requiring a 48 volt dc input is shown in Figure 2-28. It was designed by the Forest Electric Company and is commercially available as the Felco Model W-1694. The output voltage is a 120 volt rms sine wave. The output frequency is extremely stable for variations in load and input voltage, since the drive circuit is a frequency-controlled inverter. The drive circuit and the main inverter both use the same input voltage, but the drive-circuit input is regulated by the combination of resistor R5 and zener diode D5. The 62 V zener diodes, D3 and D4, have been placed across the input to suppress voltage transients.

The performance curves shown in Figure 2-29 were taken with a fixed load of 92 watts (with 48 volts dc input). Variations in efficiency, frequency, and output voltage are plotted as a function of input voltage. The frequency decreases by 0.6 hertz when the input voltage is increased by 10 volts. In other words, a 10% change in input voltage causes the frequency to vary by only 0.5%. The efficiency remains at about 60% over this range of input voltage. However, the output voltage does increase in almost direct porportion to the input. That is, a ±10% change in input voltage will cause the output voltage to vary by approximately ±10%.

Additional performance information is shown in Figure 2-30 for a smaller load (79 watts at 48 V input). The frequency and output voltage regulation are identical to Figure 2-29 but the efficiency shows a noticeable decrease as the input voltage is increased. It drops from 59% at 43 volts to 56% at 53 volts.

An interesting comparison can be made between Figures 2-29 and 2-30. The frequency at 92 watts (Figure 2-29) is identical to the frequency at 79 watts (Figure 2-30), with 48 V input. The frequency at these points is 60.3 hertz and is not dependent on the load. The output voltage, however, does increase from 120 to 123 volts as the load is decreased. This



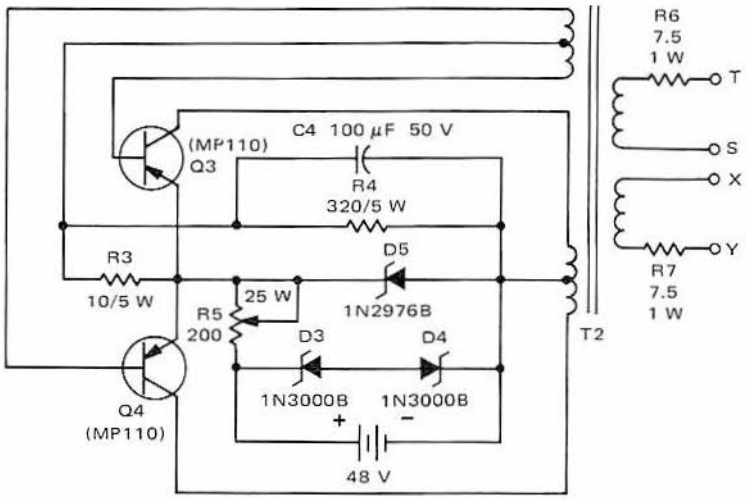
INDUCTORS

L1 – FOREST ELECTRIC W-1708
L2 – FOREST ELECTRIC W-1706
L3 – FOREST ELECTRIC W-1707

TRANSFORMERS

T1,T2 – FOREST ELECTRIC W-1705
T2 – FOREST ELECTRIC W-1704

Figure 2-28A – SCR Inverter with Stable Output Voltage and Frequency. 28 Vdc - 120 Vac, 100W, 60 Hz. Drive Circuit in Figure 2-28B. Felco Model W-1694 Inverter



INDUCTORS

L1 – FOREST ELECTRIC W-1708
L2 – FOREST ELECTRIC W-1706
L3 – FOREST ELECTRIC W-1707

TRANSFORMERS

T1, T2– FOREST ELECTRIC W-1705
T2 – FOREST ELECTRIC W-1704

Figure 2-28B – Inverter Drive Circuit for Inverter in Figure 2-28A

means that a 5 watt increase in load would cause the output voltage to decrease by nearly 1 volt. Efficiency also varies with load. At 79 watts the efficiency is 57.5%, but this increases to 60.3% at 92 watts.

The output power may be increased to 150 VA with lagging power factor as low at 0.84. The total harmonic distortion will be about 6%. The permissible input voltage variation is ±10%, as shown on the curves. The maximum input current will be approximately 6 A. Best frequency regulation is obtained by setting resistor R5 to its maximum resistance of 200 Ω. The setting can be reduced to about 100 Ω if the frequency changes when the input voltage is decreased to its minimum value.

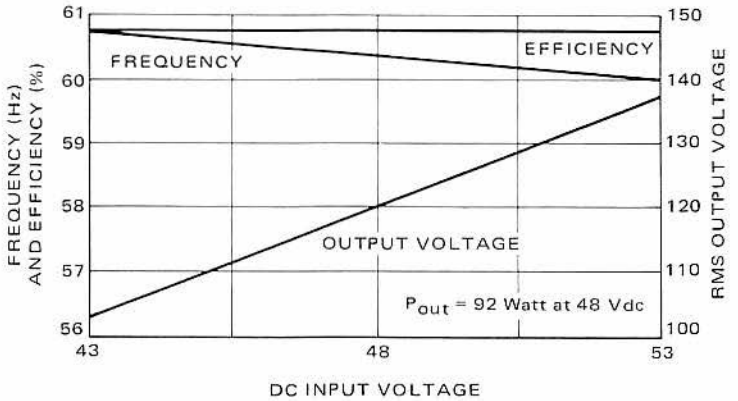


Figure 2-29 – Performance Curves for Inverter of Figure 2-28 at P_o = 92 W

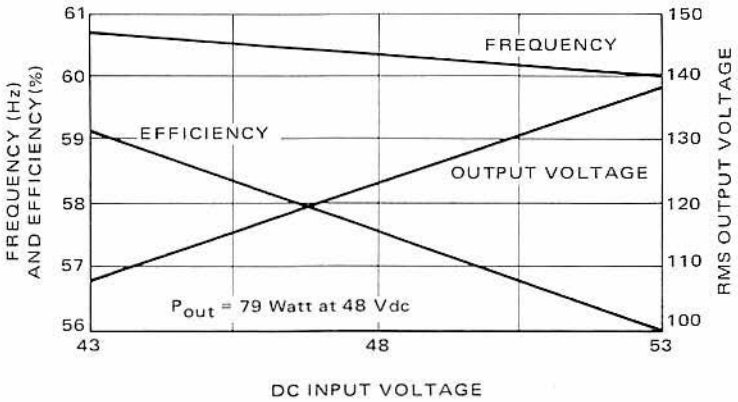


Figure 2-30 – Performance Curves for Inverter of Figure 2-28 at P_o = 79 W

The design of the sine-wave output filter is covered in "A Filter for SCR Commutation and Harmonic Attenuation in High Power Inverters," in *Communications and Electronics,* May, 1963, by Richard R. Ott.

2.12 SCR Inverter with Stable Output Voltage and Frequency 28 Vdc - 12 Vac, 60 W, 465 Hz

The 60 watt, 465 hertz impulse-commutated SCR inverter shown in Figure 2-31 requires 28 Vdc input. The output square-wave voltage and frequency are well regulated for variations in load. This particular output frequency can be used to drive a 400 Hz sine-wave transformer. Efficiency and output power are relatively low compared to SCR inverters operating from higher voltages because of the SCR forward voltage drop. The 2N4441-44 thyristor series will handle from 50 to 600 volts. If the remaining components were rated at 600 volts, a 400 Vdc supply could be used. This would increase the output power capability to nearly 2 kilowatts.

Variations in efficiency, frequency, and output voltage are shown in Figure 2-32. Output voltage decreases as the load increases. The no-load-to-full-load regulation is better than 10%. In other words, the output voltage will decrease by about 0.1 volt for an increase in output power of 6 watts.

Frequency regulation is better than 2%. The frequency tends to increase with load. The increase is approximately 1 hertz for each 10 watt increase in output power. Potentiometers R13 and R14 are used to make adjustments to the output waveform. Resistor R14 determines the balance between positive and negative alternations. The tap is therefore normally set midway for equally timed alternations. Resistor R13 is used to adjust the frequency; it was set for maximum resistance for this test. Frequency can be increased by decreasing the resistance.

The efficiency of this circuit also increases with load. At 2 watts the efficiency is about 10%. This increases to 65% at full load (60 watts). Most of the power lost in this circuit does not depend on load. This includes power in the trigger circuits and in the commutating elements, capacitor C3 and inductor L1. Because of this fact, the best efficiencies can be realized by operating at full load.

The maximum input current is 4 A. Input voltage can be reduced to 20 volts and the circuit will operate with no load. The maximum load is approximately 75 watts. The load resistance at this point is about 1.5 ohms. The circuit will not commutate (switch) with lower values of load resistance.

The commutating inductor, L1, is larger than necessary because a smaller inductor was not available. The design value for L1 is about 20 μH.

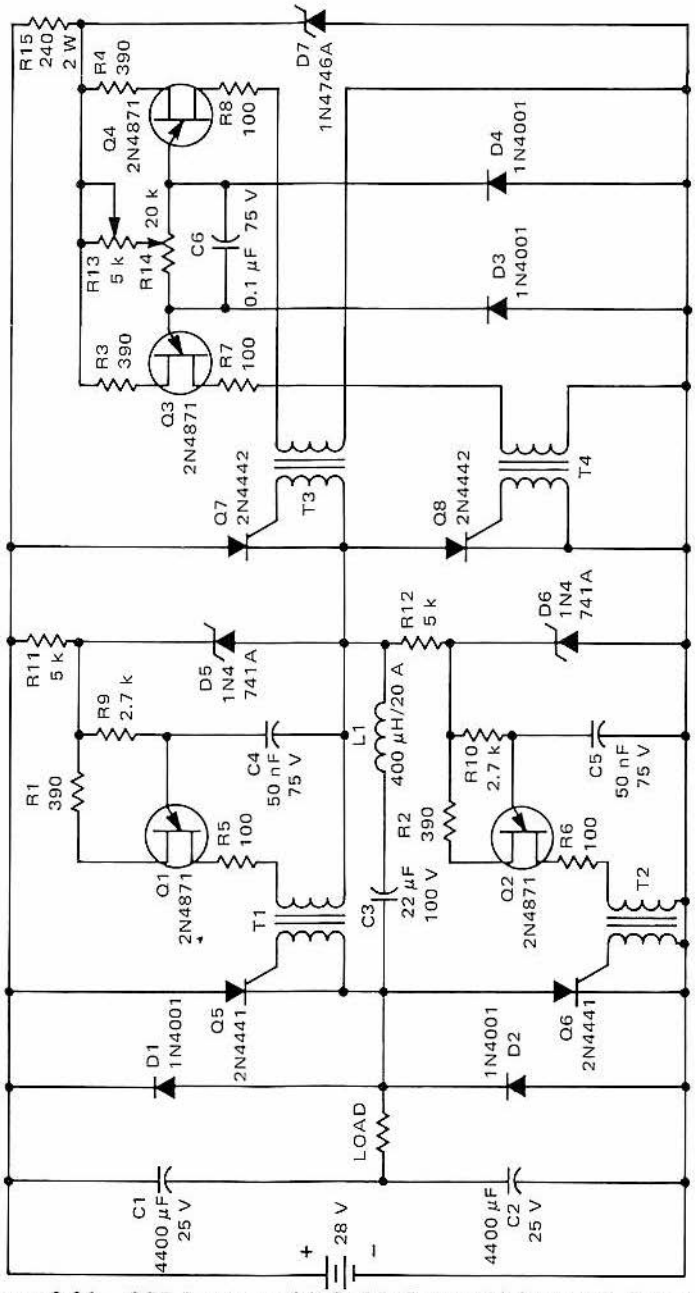


Figure 2-31 – SCR Inverter with Stable Output Voltage and Frequency. 28 Vdc-12 Vac, 60 W, 465 Hz

Lower-resistance loads could be commutated if this value had been available. Output power could have been increased to approximately 200 watts. There would also be a disadvantage in this case. Timing of the trigger circuits involving transistors Q1 and Q2 would be more critical. Instability here could cause either early or late firing. With full load, it is possible that both of these cases would prevent commutation. When the load is not commutated from Q5 to Q6, both thyristors remain on. The result is that they would then draw excessive current and destroy themselves.

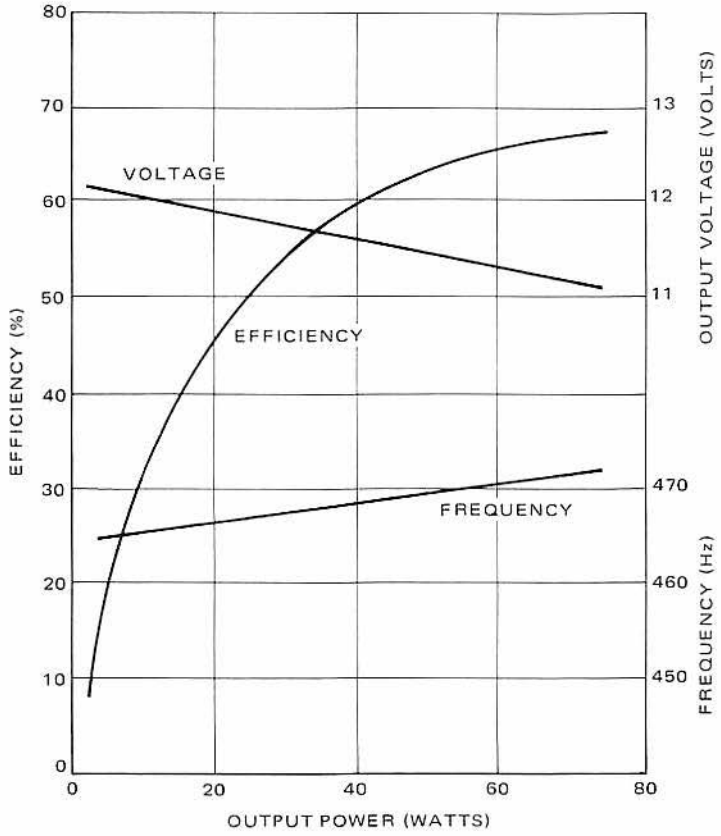
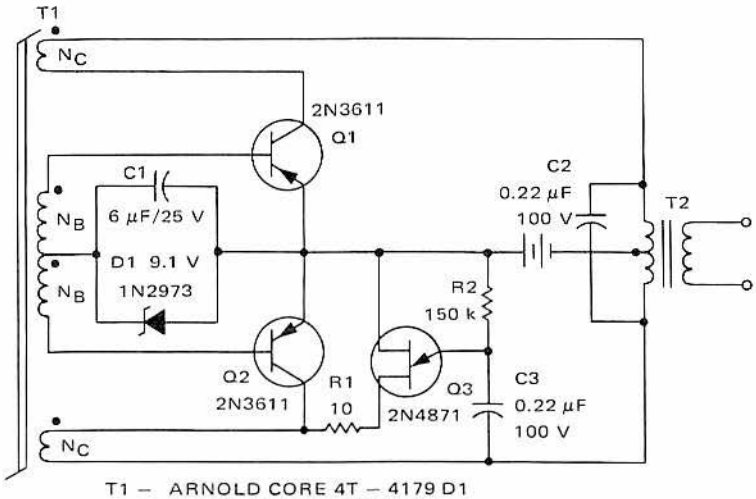


Figure 2-32 – Performance Curves for Inverter of Figure 2-31

2.13 Transistor Inverter with Stable Output Frequency 12 Vdc - 110 Vac, 40 W, 400 Hz

A 40 watt, 400 Hz current-feedback inverter designed for 12 volt input is shown in Figure 2-33. The output voltage is a 110 volt square wave whose frequency is extremely stable and almost unaffected by changes in input voltage and output power. In Figure 2-34 the percent change in frequency is plotted as a function of input voltage for various loads. It can be seen that if the input voltage is varied ±25% at full load (40 watts), the frequency will change by less than ±2%. When the load was reduced to 6 watts, the nominal output frequency dropped to 390 hertz. However, at this reduced load, there was virtually no variation in frequency as the input voltage was varied by ±25%.

Input voltage is nominally 12 Vdc. It is possible to operate the circuit with input voltages as low as 6 Vdc and as high as 20 Vdc. The main function of capacitor C2 is to suppress switching transients caused by leakage inductances. It will also suppress any power-supply spikes at the input. There is no provision for filtering input ripple voltage or for regulating the input voltage. It is therefore desirable to keep input-voltage changes to minimum to obtain a clean, well-regulated output voltage waveform.



T1 – ARNOLD CORE 4T – 4179 D1
N_B 200 TURNS #20 WIRE
N_C 20 TURNS THREE #16 WIRES IN PARALLEL
T2 – TRANSFORMER 110-24 VCT FELCO VJ-1
(PRODUCT OF FOREST ELECTRIC CO.)

Figure 2-33 – Transistor Inverter with Stable Output Frequency. 12 Vdc-110 Vac, 40 W, 400 Hz

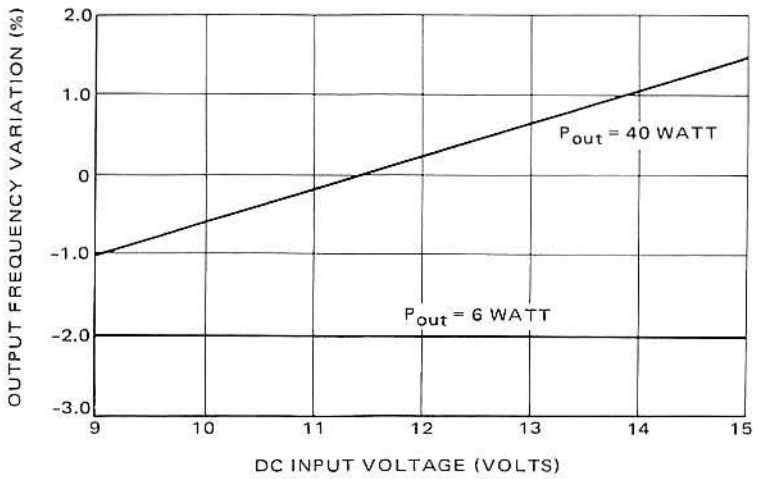


Figure 2-34 – Output Frequency versus Input Voltage for Inverter of Figure 2-33

Nominal input current is 4 A but can vary from 240 mA to 7 A depending on the input voltage and the output load. This means that if the input voltage is 12 V, the permissible range of output current will be from 25 mA to 760 mA. Capacitive loads are permissible if the load surge current is less than 1.5 A.

Circuit efficiency is approximately 80%. Power is purposely sacrificed in the zener diode to obtain frequency stability. Decreasing the zener voltage would improve efficiency.

A unijunction transistor, Q3, is used to start the inverter. Its output voltage pulse causes current to flow into the lower collector winding of transformer T1. Transformer action then creates the base current which turns transistor Q2 on.

In a low-voltage inverter such as this, the $V_{CE(sat)}$ of the transistors used should be low for good efficiency and output voltage regulation. Because the zener voltage adds to the reverse base-emitter voltage drop, a high V_{BE} rating is necessary. The 2N3611 germanium power transistor was chosen mainly because it fulfilled these requirements. In addition, it met the following specifications imposed by the circuit: V_{CES} over 28 V, h_{fe} greater than 10 with I_C - 4 A, V_{BE} over 10 V, and $V_{CE(sat)}$ less than 1 V with I_C - 4 A. The $V_{BE(sat)}$ must be small in relation to the zener voltage; it must also change very little as input voltage and load current vary to obtain good frequency stability. For changes in collector current

from 3 to 5 A, the change in $V_{BE(sat)}$ is only 0.1 V or 1% of the zener voltage.

The ambient temperature range of the circuit is from 0°C to 70°C without a heat sink and from 0°C to 100°C with a heat sink on transistors Q1 and Q2. The thermal resistance of the heat sink should be no more than 3°C per watt.

2.14 Low Voltage Input High-Current Inverter 2 Vdc - 35 Vac, 80 W, 1 kHz

The 80 watt, 1 kHz current-feedback inverter shown in Figure 2-35 requires an input of 2 volts dc. The output voltage increases only 30% when the load is reduced from full to one-fourth load. Figure 2-36 shows the effects of load changes on both output voltage and efficiency.

Efficiency also varies with load but remains quite high even at full load, as illustrated in Figure 2-36. Maximum efficiency of 87% occurs with a 30 watt load. As the load is increased to 80 watts, efficiency drops slightly to about 70%.

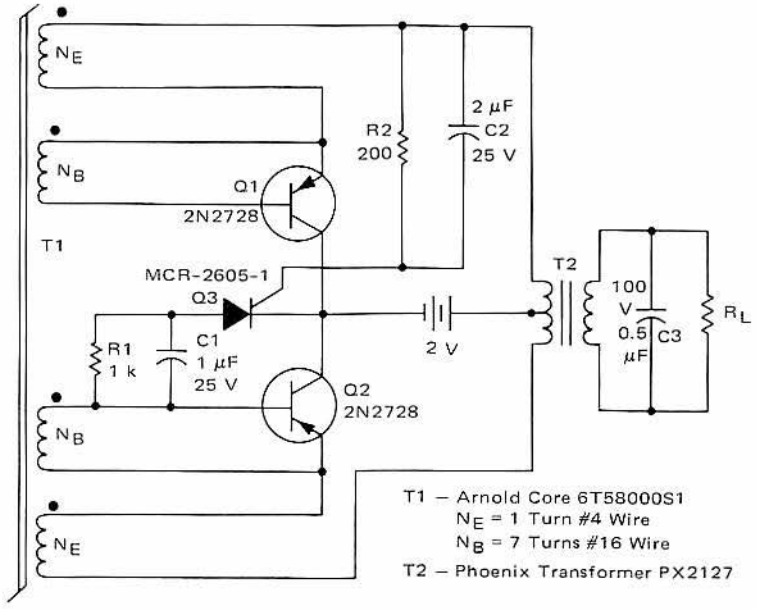


Figure 2-35 – Low-Voltage Input, High-Current Inverter. 2 Vdc-35 Vac, 80 W, 1 kHz

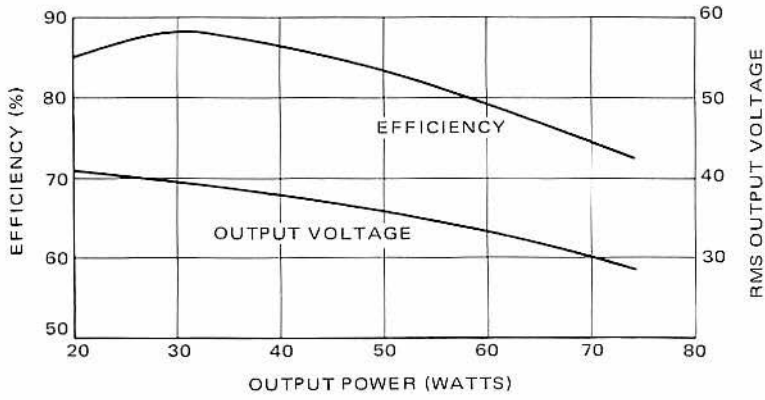


Figure 2-36 – Performance of Inverter in Figure 2-35

The allowable range of input current is 10 to 50 amperes. This means that with an input voltage of 2 V, the output load can be varied from 20 to 80 watts. It is also possible to vary the input voltage from 1.5 to 2.5 V. The frequency is slightly dependent on the load since the resulting change in collector current will cause the forward base-emitter voltage drop to change. However, as input current is increased from 10 to 50 A, the frequency will increase only 20%. In a more practical case, if the load is doubled, the frequency will change by less than 10% (100 Hz.)

The starting circuit for this inverter consists of R1, C1, R2, C2 and Q3. When supply voltage is first applied, both gate and anode of the thyristor are positive with respect to the cathode. This turns the thyristor on and provides base current to start transistor Q2. Saturation of Q2 commutates Q3. After starting of the inverter, the thyristor cannot turn on. When Q2 is on, the anode is reversed biased, and when Q1 conducts, gate voltage is too low to fire Q3 since $V_{CE(sat)}$ is less than 0.1 volt at $I_C = 50$ A.

The operating temperature range of this circuit is 0 to 75°C when Q1 and Q2 are mounted on a heat sink with thermal resistance of less than 3.0°C per watt. Only one heat sink is needed because the cases (collectors) of the two transistors are common electrically. The heat sink must be capable of cooling both transistors.

2.15 High Power Inverter 28 Vdc - 110 Vac, 2 kW, 580 Hz

The 2 kilowatt, 580 hertz current-feedback inverter shown in Figure 2-37 requires an input of 28 volts dc. Its output voltage is a square wave

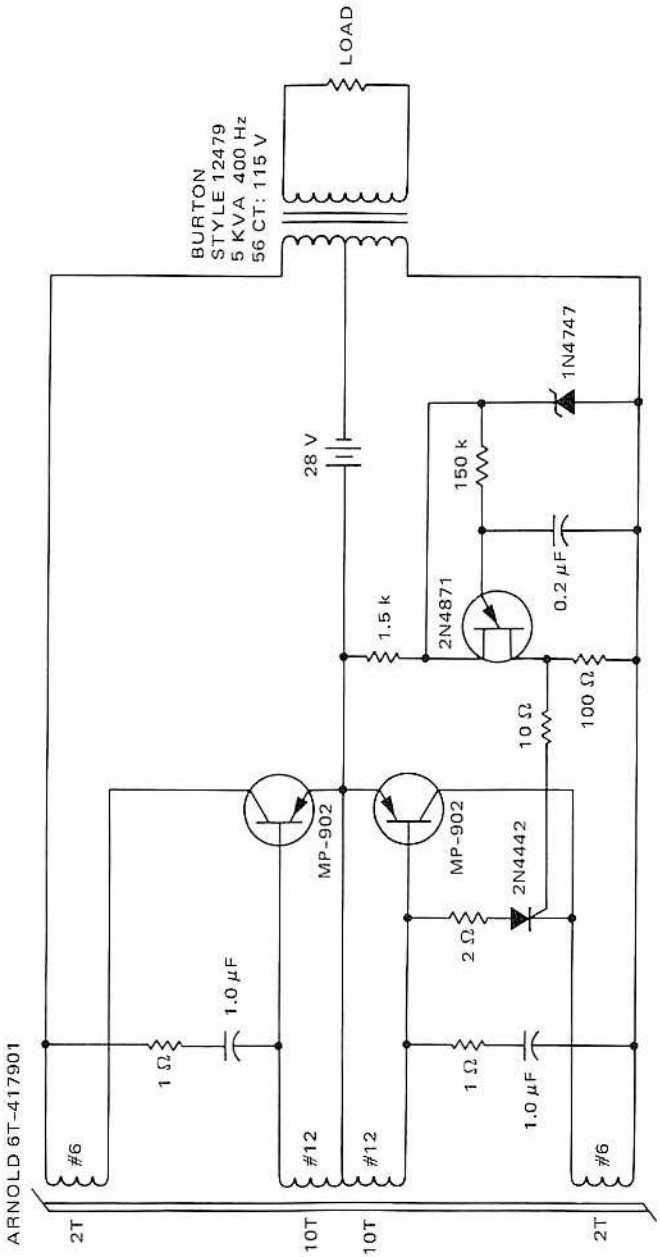


Figure 2-37 – High Power Inverter. 28 Vdc-110 Vac, 2 kW, 580 Hz

whose peak magnitude is approximately 100 volts. The output voltage regulation and efficiency are excellent for variations in load. The circuit was designed basically for high power and high efficiency. No attempt has been made to stabilize frequency. If it becomes desirable to operate this inverter at 400 hertz, Figure 2-38 can be used to determine the appropriate limit for output power. For instance, if the load is allowed to vary from 500 to 1000 watts, the frequency will increase only 70 hertz (from 360 to 430 Hz). The output voltage over this range decreases only 3 volts (from 113 to 110 V). Another advantage is gained by operating between 500 and 1000 watts: efficiency is greater than 90% in this range.

With the input voltage held constant at 28 volts dc, the variations in output voltage, frequency, and efficiency are plotted as functions of output power in Figure 2-38. Output power was varied from 125 watts to full load of 2050 watts. The output voltage decreased from 114 to 98 volts which means that the regulation is better than 20%. It takes more than a 100 W increase in load power to decrease the output voltage by 1 volt. Frequency, on the other hand, jumped from 260 to 580 hertz which means that it more than doubled as the output power was increased from very low load to full load. The increase in frequency is approximately 20 hertz for each 100 W increase in load. The efficiency of this circuit remains high over the entire range of output power. At 125 W output, efficiency is 77%. It increases to 93% at 500 watts and then decreases again to 82% at full load.

The performance curves in Figure 2-39 were obtained with a con-

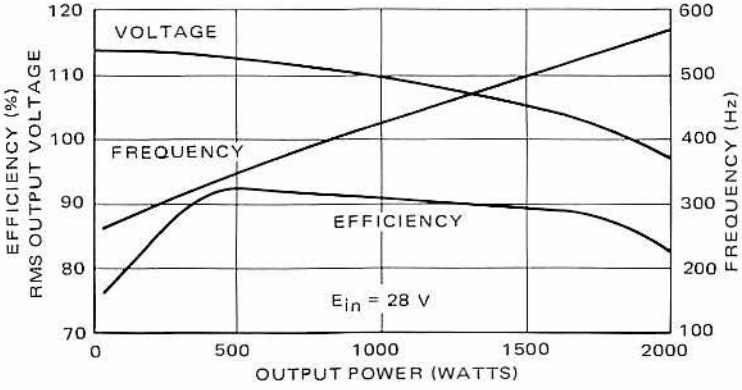


Figure 2-38 – Performance of High-Power Inverter of Figure 2-37 for Varying Output Power

stant load of about 5 ohms, which represent 2 kilowatts or full load with a 28 volt dc input. The variations of output voltage, frequency, and efficiency are plotted as a function of input voltage. The input voltage was varied from 5 to 32 volts dc, a factor of about six. As could be expected, the output voltage did nearly the same; it increased by a factor of six from 18 to 115 volts. The increase in frequency was not as drastic; it only increased from 340 to 610 hertz which means that it did not even double. Efficiency again remains quite high as input voltage is varied; it remains constant at 82% from 15 to 28 volts but decreases rapidly beyond these limits.

A special feature of this circuit is the ac network connected to each base. This is a "booster" type of voltage feedback which provides additional base drive during switching. The nominal input voltage is 28 volts dc but the circuit can be operated with voltages from 24 to 32 V. Starting is unreliable at lower voltages. The maximum input current is 100 A.

In general, the power transistors used in this circuit must have low $V_{CE(sat)}$ and adequate current gain at I_C = 100 A. The MP902 germanium transistor has an extremely low $V_{CE(sat)}$ of 0.5 V but the gain at I_C = 150 A is only 5. The bases were driven with a low forced gain, 5 instead of 10, to insure good operation at I_C = 100 A. The most critical requirement was for a clamped inductive safe operating area of 70 V with 100 A current. The test point which insures that this specification is met is at 55 V and 150 A.

The load resistance can be varied from 100 to 5 ohms. Higher resis-

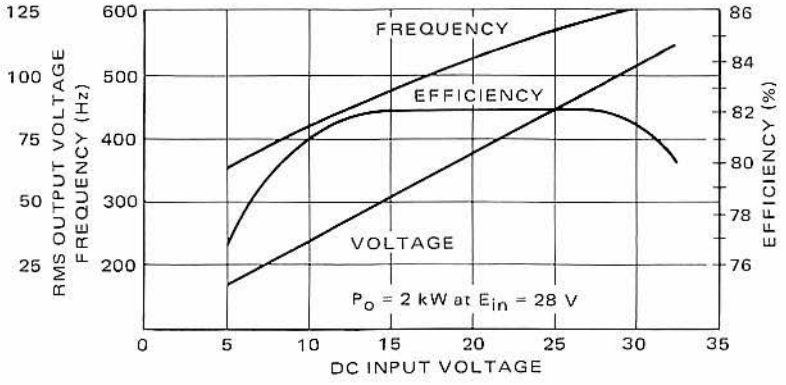


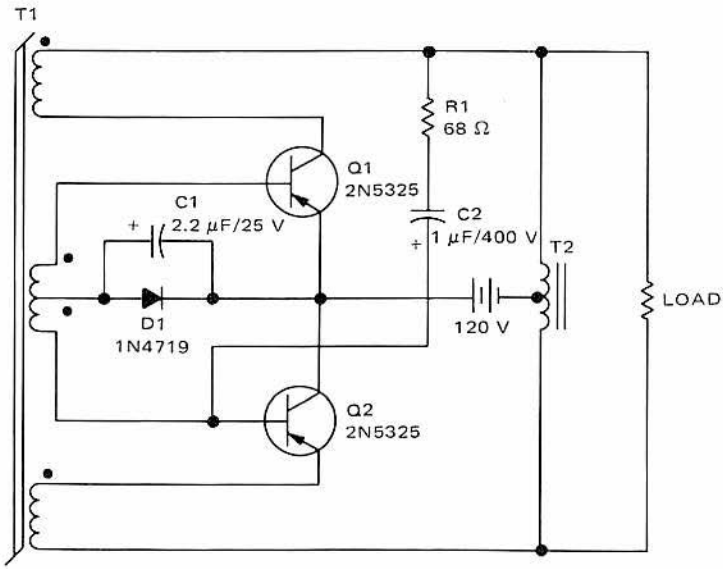
Figure 2-39 – Performance of Inverter of Figure 2-38 for Varying Input Voltage

tances tend to make starting difficult. Lower resistances can cause the power transistors to pull out of saturation, which can destroy them. The power transistors were mounted side by side on a silicone-greased heat sink (Wakefield MN-2131-6.0 without insert). Without forced air cooling, the circuit can be operated at ambient temperatures up to 55°C at full load.

2.16 High Efficiency Inverter 120 Vdc - 240 Vac, 1 kW, 1200 Hz

The nominal input voltage of the current-feedback inverter shown in Figure 2-40 is 120 Vdc, but it can be operated with an input voltage greater than 20 V but less than 160 V. The output voltage is a 1200 Hz, 240 V square wave (with 120 V input.) Output current is about 4 A, but the transistors can handle up to 5 A in the load.

The efficiency of this circuit is excellent. Figure 2-41 shows that efficiency is 92% at 1000 watt output. Frequency stability is also very good. In Figure 2-42, it is shown that a 6:1 change in input voltage will



T1 – ARNOLD CORE 6T 4168S1
46T OF #23 FOR EACH BASE WINDING
5T OF 3 #18 FOR EACH COLLECTOR WINDING
T2 – PHOENIX TRANSFORMER PX-2677

Figure 2-40 – High-Efficiency Inverter. 120 Vdc-240 Vac, 1 kW, 1200 Hz

shift the frequency by only 20%. Variation in load impedance produces similar results. Voltage regulation is less than 2% when the load is varied from no load to full load. However, the output voltage will change in direct proportion to the input voltage unless a preregulator stage is used.

Even though this circuit is self-excited, it will fail safe if either input voltage or load is removed. That is, one transistor will not remain on and burn out. However, there is no current limiting and the transistors can be damaged by a short circuit in the load. There are no starting limitations for the circuit. It can be started into a full load or a capacitive input load up to the surge rating capability of the transistor.

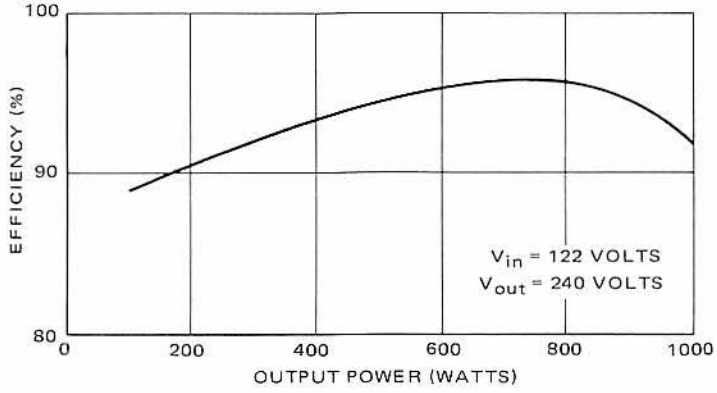


Figure 2-41 — Efficiency versus Output Power for High-Efficiency Inverter of Figure 2-40

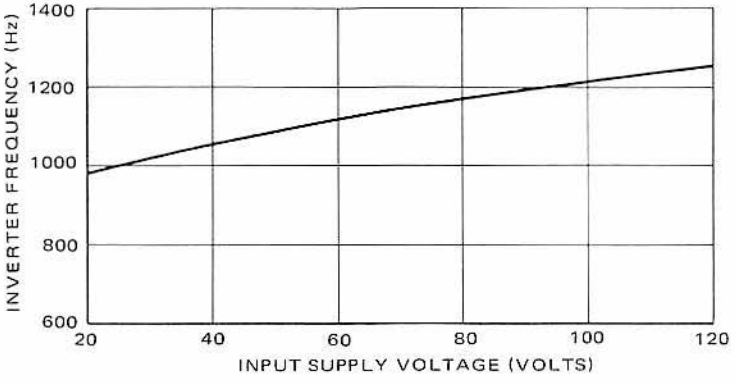


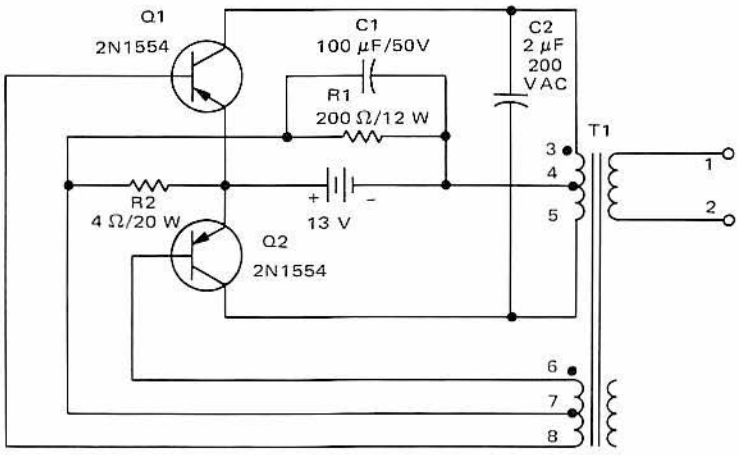
Figure 2-42 — Frequency versus Input Voltage for High-Efficiency Inverter of Figure 2-40

If the transistors are mounted on a heat sink with a thermal resistance of less than 3°C per watt, the ambient temperature range will be from 0 to 80°C.

2.17 One-Transformer, Car-Battery-to-AC-Line-Voltage Inverter 13 Vdc - 115 Vac, 180 W, 60 Hz

The schematic of a 180 watt, 60 hertz voltage-feedback inverter designed for 13 volt dc input is shown in Figure 2-43. The output of this inverter is a 113 volt square wave; its magnitude varies with load and input voltage. Figure 2-44 shows that as load is increased, the voltage will decrease. The voltage regulation from no load to full load (180 watts) is less than 30%. This means that it takes a 6 watt increase in load to decrease the output voltage by 1 volt. A corresponding curve of output voltage versus input voltage is shown in Figure 2-45. As input voltage increases, the output also increases. However, a change in input voltage of ±11.5% (±1.5 V) will only cause the output voltage to vary by ±7.5%. This is a ratio of about 2 to 3.

Output frequency is even more stable than the output voltage. In Figure 2-44, it can be seen that frequency decreases linearly as the load is increased. The change in frequency from no load to full load is slightly less than 12%. This means that it takes a 30 watt increase in load to decrease the frequency by approximately 1 hertz. Frequency also varies with input



T1 – Forest Electric VJ-18

Figure 2-43 – Car Battery-to-Line-Voltage Inverter. 13 Vdc-115 Vac, 180 W, 60 Hz. Felco Model TR-181

voltage as shown in Figure 2-45. Here a change in input voltage of ±11.5% produces about the same change in frequency (±12%).

The curve of efficiency versus output power is shown in Figure 2-44. Efficiency increases from about 60% at 40 watts to 75% at full load. This is a good figure for a one-transformer inverter.

The operating range of input voltage is from 12 to 14 volts. Input current can vary from 2 to 20 A. This means that it is possible to operate a load of 200 watts with 14 volt input as shown in Figure 2-45. It is also possible to operate with no load. Loads in excess of 200 watts and short circuits can destroy the transistors and should be avoided.

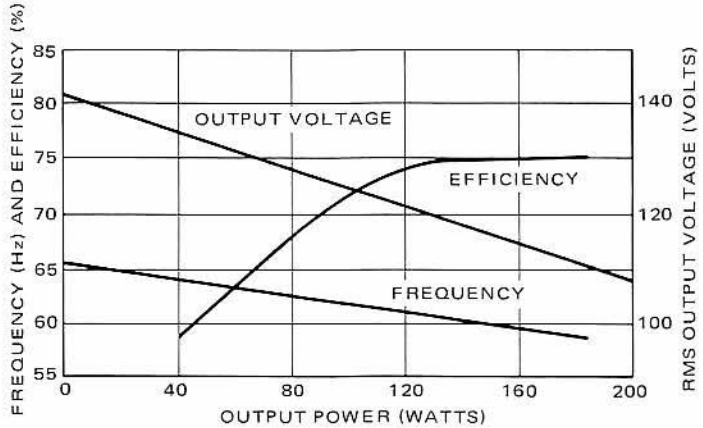


Figure 2-44 — Performance of Inverter in Figure 2-43 as a Function of Output Power

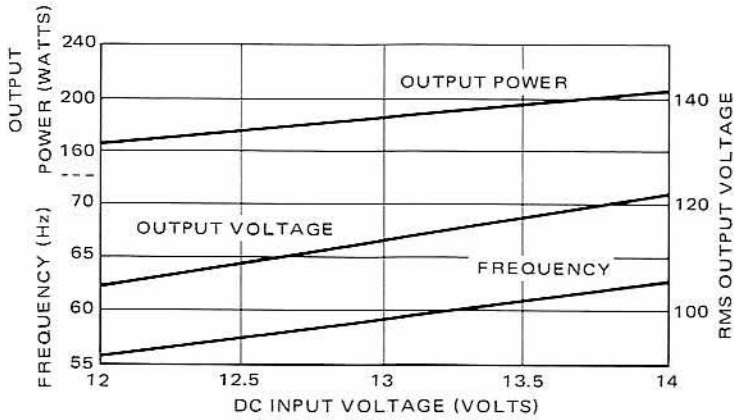


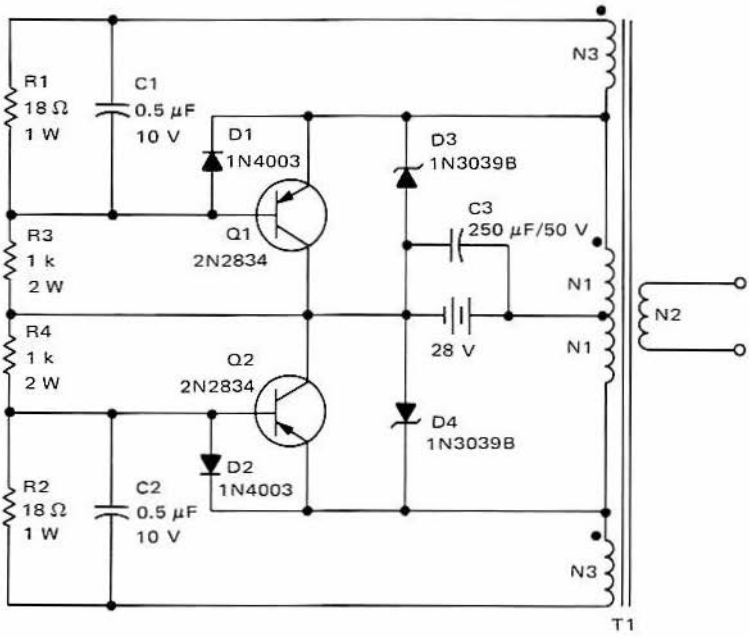
Figure 2-45 — Performance of Inverter in Figure 2-43 as a Function of Input Voltage

The 2N2152 germanium power transistor was chosen for this inverter because of its low cost and low $V_{CE(sat)}$. Specifically, the transistor has a $V_{CE(sat)}$ of 0.3 V at an I_C of 25 A and costs less than $3.00. Other specifications necessary were h_{fe} greater than 10 at $I_C = 25$ A, V_{CES} of 45 V, and V_{EB} greater than 8 V because of the drop across R2 in the base-emitter circuit.

The circuit can be operated in ambient temperatures from 0 to 60°C. The transistors should be mounted on heat sinks with thermal resistances of about 3°C per watt.

2.18 Efficient, High Frequency Inverter 28 Vdc - 52 Vac, 100 W, 15 kHz

The 100 watt, 15 kHz voltage-feedback inverter shown in Figure 2-46 requires 28 volt dc input. The output voltage is a square wave with a magnitude of 52 volts rms.



T1 – ARNOLD CORE GT-5502-D500
N1 26 TURNS OF AWG #14 WIRE
N2 52 TURNS OF AWG #14 WIRE
N3 3 TURNS OF AWG #22 WIRE

Figure 2-46 – Efficient, High-Frequency Inverter. 28 Vdc-52 Vac, 100 W, 15 kHz

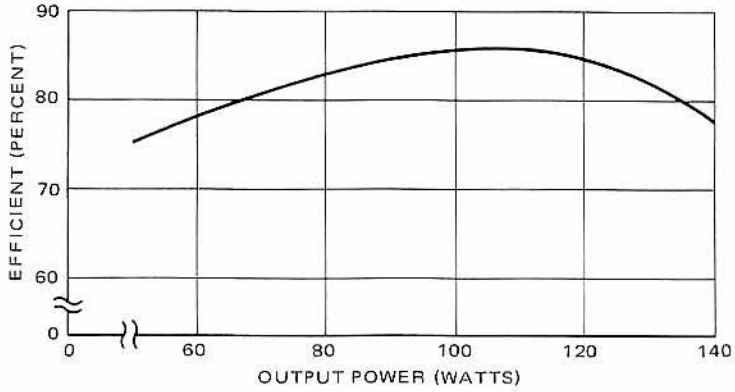


Figure 2-47 — Efficiency versus Output Power for Inverter of Figure 2-46

The frequency stability of this circuit is excellent. Frequency is dependent only on input voltage and not load. Any variation in output power will not affect the frequency. However, a 10% increase in input voltage will cause a 10% change in frequency. In other words, if the input voltage increases by 1 volt, the output frequency will increase by approximately 500 hertz.

The efficiency, as shown in Figure 2-47, is quite high. It reaches a maximum of 85% at approximately 100 watts. Even at 50 watts of output power, the efficiency drops only slightly to about 75%. This would be higher if there were a way to reduce the base drive as the output power decreases.

The output voltage, like frequency, is well regulated for changes in load. Figure 2-48 shows that the output voltage remains constant as the load is increased from 50 to 100 watts. The transistors are not fully saturated above this point and the output voltage starts to decrease at higher power levels. The output voltage, however, is affected by changes in input voltage. The output transformer almost doubles the input voltage. The output voltage can be increased or decreased by adding or subtracting turns from secondary winding N2.

The output power is nominally 100 watts but the inverter can be operated at any level from no load to this value. The output transformer will overheat at higher power levels, but the transistors will handle 140 watts of output power. The fast switching speed of the transistors permits efficient switching at 15 kHz. The range of output power could be increased to this value if the tape-wound core in transformer T2 were re-

placed by a ferrite core. Diodes D1 and D2 were used to protect the base-emitter junctions of Q1 and Q2 from reverse voltage.

Input voltage variations of ±10% will not affect the output significantly. At full load (100 watts) the input current will be 4 A.

Both transistors can be mounted on a single heat sink with the collectors uninsulated. The thermal resistance of the sink should be 3°C per watt or less. The ambient temperature may then be allowed to vary from 0 to 60°C.

Since this is a high-frequency inverter, it is excellent for applications which require minimum size and weight.

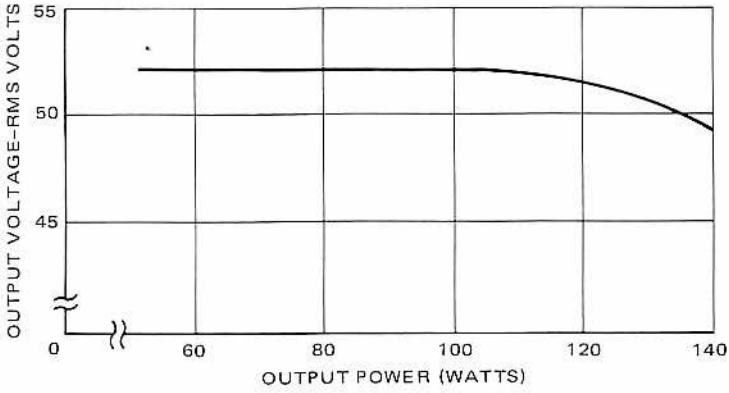


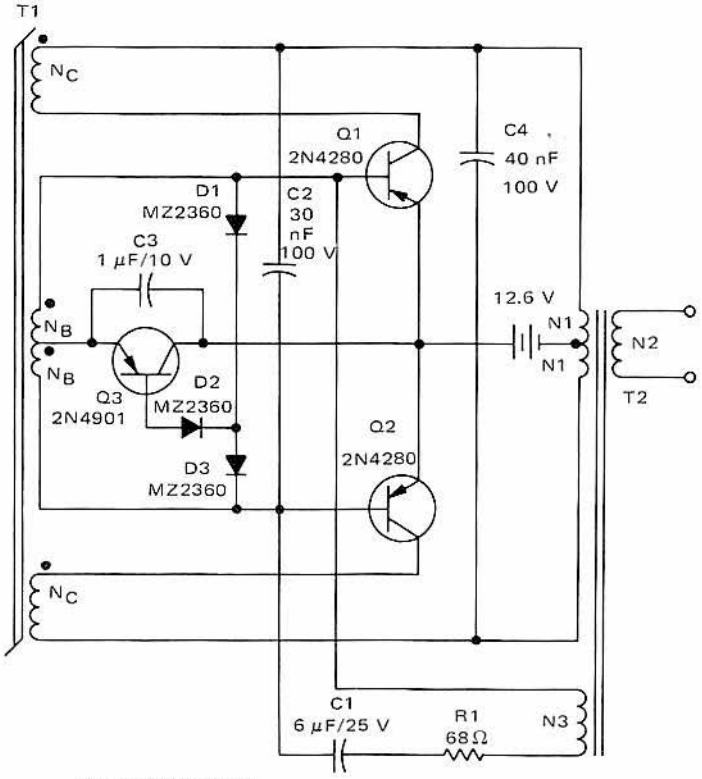
Figure 2-48 – Output Voltage versus Output Power for Inverter of Figure 2-46

2.19 Efficient Inverter with Good Output Regulation 12 Vdc - 115 Vac, 400 W, 400 Hz

The 400 watt, 400 hertz hybrid-feedback inverter in Figure 2-49 furnishes a 115 volt square wave output with a 12 V input. Figure 2-50 shows the output voltage variation with load. As load is reduced to 50 watts, the voltage increases by 10%. Voltage regulation is therefore quite good. The curves were taken with the input voltage constant at 12.6 volts; input voltage changes will affect the output voltage. An increase in input voltage will cause the output to increase.

The efficiency of this circuit is high; it remains greater than 85% for the entire range of output power. In Figure 2-50 the efficiency is shown reaching 89% with a 200 watt load.

The nominal input voltage is 12.6 volts dc, but the input voltage may be allowed to vary from 10 to 14 volts. The output load may be varied from no load to a maximum of 400 watts. As the load is varied over this range, the input current will increase from 0.75 to 40 A. Loads that exceed 400 watts, and output short circuits, can damage power transistors Q1 and Q2. This inverter will operate into both resistive and inductive loads. It has been used with fluorescent and incandescent lights, and a 400 hertz, 90 watt motor.



TRANSFORMERS
T1 — ARNOLD CORE 6T 7699D1
N_B 54 TURNS #20 WIRE
N_C 3 TURNS TWO #12 WIRES IN PARALLEL
T2 — ARNOLD CORE 3T 6464-L4
N1 12 TURNS TWO #12 WIRES IN PARALLEL
N2 120 TURNS #16 WIRE
N3 7 TURNS #20 WIRE

Figure 2-49 — Hybrid-Feedback Inverter with Good Output Regulation. 12 Vdc-115 Vac, 400 W, 400 Hz

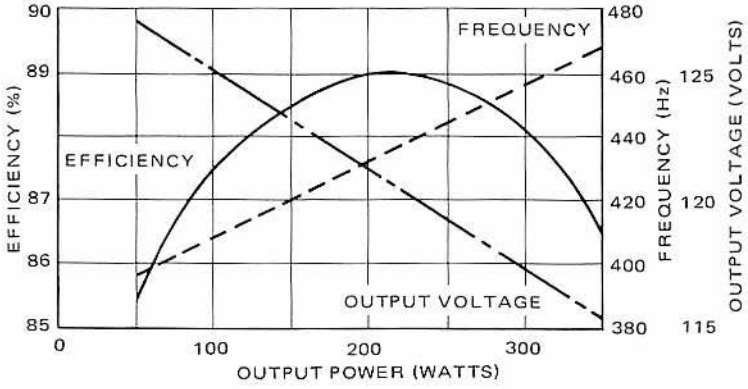


Figure 2-50 — Performance of Inverter of Figure 2-49

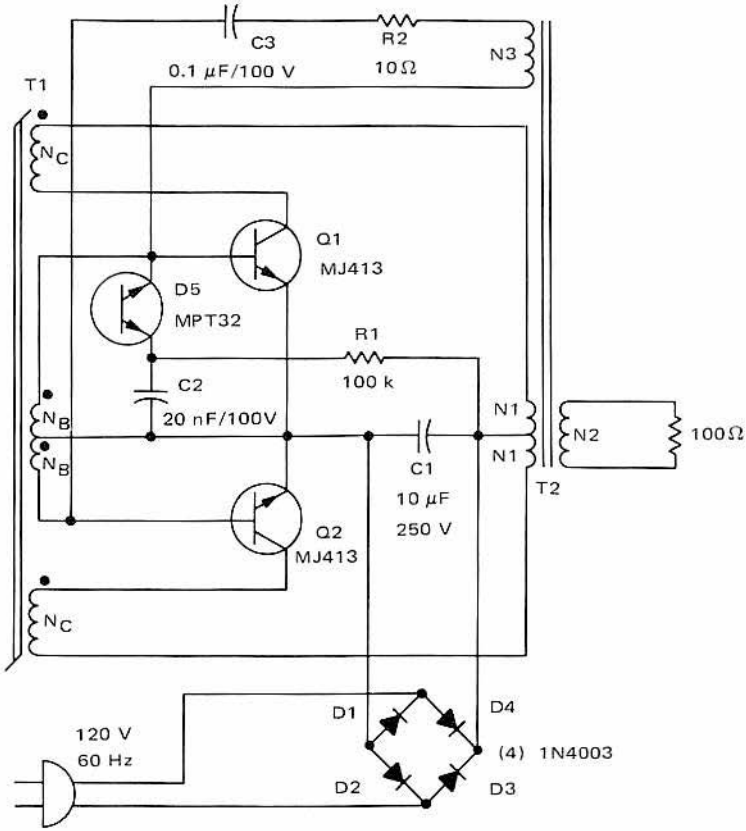
The output frequency is slightly dependent on load and input voltage. Figure 2-50 shows an output frequency of 470 hertz at 350 watts; it decreases to 400 hertz at 50 watts. For a 7-to-1 reduction in load, the frequency decreases by only 15%. The base-emitter voltage, which would normally determine frequency, decreases from 0.63 to 0.40 volts over this range of output power. However, the voltage across winding N_B only decreases from 1.8 to 1.6 volts because of frequency-stabilizing transistor Q3.

The circuit was originally operated without feedback-winding N3. Efficiency dropped off at light loads and it would not start without a load. However, the output frequency regulation remained the same and the range of variation was lowered by about 30 hertz. That is, the frequency at 350 watts was 435 hertz, and it dropped to 378 hertz at 50 watts.

The output frequency can be decreased in another way if desired. It turns out that each additional turn on winding N_B will lower the frequency by 10 hertz. In order to obtain sufficient current gain at 400 watts, winding N_B must be limited to 62 turns. This means that up to eight turns may be added. This would decrease the frequency by 80 hertz. With a 400 watt load, output frequency would then decrease from 480 to an even 400 hertz.

2.20 Line-Operated, High Frequency Inverter 120 Vac - 120 Vac, 200 W, 15 kHz

Figure 2-51 shows a 200 watt, 15 kHz, line-operated hybrid-feedback inverter. It is designed for an input voltage of 120 V at 60 Hz. In order to keep size to a minimum, there is very little filtering of the recti-



TRANSFORMERS

T1 – CORE – MAGNETICS INC. #80623-1/2D-080
N_B 15 TURNS OF AWG #26 WIRE
N_C 3 TURNS OF AWG #22 WIRE

T2 – CORE – ARNOLD GT-5800-D1
N1 100 TURNS OF 3 AWG #22 WIRES
N2 104 TURNS OF 3 AWG #19 WIRES
N3 7 TURNS OF AWG #26 WIRE

Figure 2-51 – Line-Operated, High-Frequency Inverter. 120 Vac-120 Vac, 200 W, 15 kHz

fied input. This means that the voltage across C1 varies from 10 to 150 and back to 10 volts during each alternation of the input voltage. This makes the output voltage an amplitude-modulated 15 kHz square wave. Because the additional turns on the output winding compensate for the internal voltage drops, the output voltage magnitude remains 120 V rms. The output voltage is unaffected by changes in load but will vary with input voltage.

The output frequency is dependent on both input voltage and output load as shown in Figure 2-52. With a 100 ohm load, a dc voltage was connected across C1. As the voltage varied from 120 to 70 V, the frequency changed by less than 1%. Below 70 V, the frequency begins to increase as shown. With a 100 Vdc input and variable load, similar changes in frequency occur. That is, with an increase in load from 40 to 80 watts, the frequency change was less than 1%. Above 80 watts, the frequency again increases as shown.

Output power is nominally 150 watts, but the circuit may be operated with loads between 2 watts and 200 watts. At the nominal load, efficiency is 88%.

This inverter was developed for an application which required isolation from the line with minimum size and weight. Better frequency stability can be obtained with increased input filtering. The voltage across C1 should ideally be kept above 70 V. It can also be seen that variations in load will affect frequency unless the output power is kept below 80 watts.

The hybrid feedback used in this circuit is useful with inductive

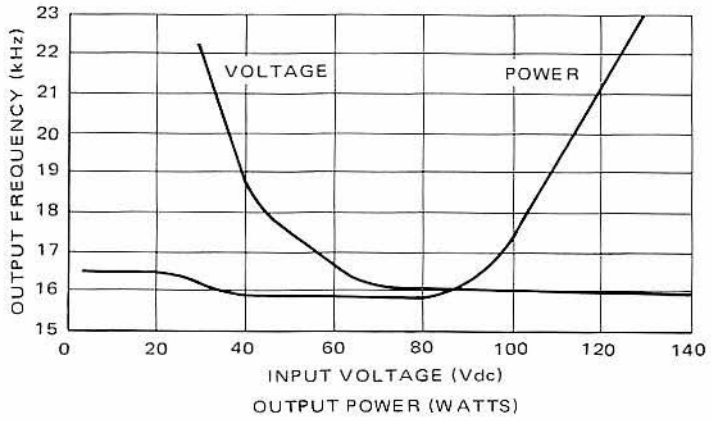


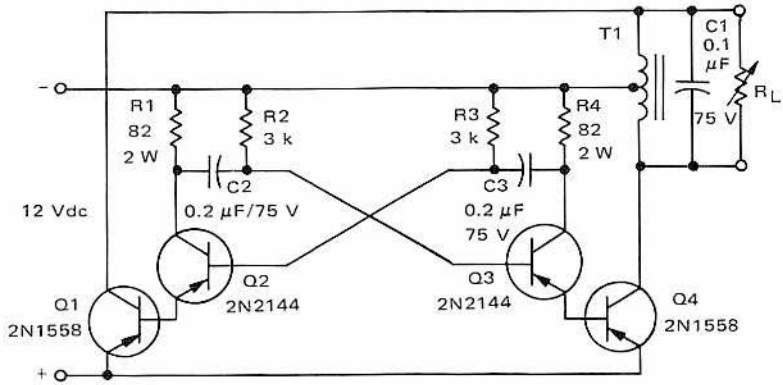
Figure 2-52 — Output Frequency versus Input Voltage and Output Power for Inverter of Figure 2-51

loads, and with light loads. Because of capacitor C3 in the voltage feedback loop, the voltage feedback is maintained only during the first portion of each half cycle. Each time the inverter switches, a pulse of current from the voltage feedback or "booster" circuit consisting of R2, C3, and N3 is injected at the base of the transistor being turned on. This supplemental current adds to the base current from the current feedback transformer to assist transistor switching. If the load is inductive, it also serves to maintain bias until collector current is adequate to provide the feedback needed to sustain conduction. At low loads (low current in N_C), the booster circuit is adequate to provide oscillation. At full load, regular current-feedback operation predominates and the booster circuit has little effect on the inverter operation.

2.21 Multivibrator-Driven Inverter 12 Vdc - 20 Vac, 50 W, 1 kHz

The 50 watt, 1 kHz, driven inverter shown in Figure 2-53 requires a 12 volt dc input. The output voltage is a square wave with an rms magnitude of 20 volts. The inverter is driven by a free-running multivibrator which provides excellent frequency regulation for variations in both input voltage and load.

In driven inverters, switching of the output power transistors is accomplished by multivibrator drive rather than by feedback from the output transformer. Multivibrator driven transistor inverters are useful for precision systems requiring carefully controlled frequency, waveform, etc.,



T1 – Phoenix Transformer PX2677

Figure 2-53 – Multivibrator-Driven Inverter. 12 Vdc-20 Vac, 50 W, 1 kHz

and for load independent systems. Load-independent systems are especially attractive for reactive loads, and when transient or starting conditions impose loads which would cause self-oscillating inverters to shut down or operate abnormally. Power requirements of the multivibrator are largely offset by lack of output transformer saturation and elimination of the feedback drive. The multivibrator-driven inverter is not inherently less efficient than a self-oscillating inverter, but use of the driven power stage as a linear amplifier rather than as a saturated switch will result in high dissipation in the transistors and low system efficiency.

Figure 2-54 shows the effect of variations in load on output voltage, efficiency, and frequency. Output power is varied from about 10 to 70 watts. Frequency increases with load from 1030 to 1080 hertz. Frequency regulation is better than 5% and frequency increases by only 1 hertz as the load is increased by 1 watt. Output voltage decreases with load by almost 4 volts. This is just less than 20% regulation and means that the output voltage will decrease about 1 volt for a 20 watt increase in load. Efficiency is about 36% at 10 watts and 64% at 50 watts. This drops again to about 56% as the load is further increased to 70 watts.

Figure 2-55 shows the effect of variations in input voltage on output frequency. As the input voltage ranges from 10 to 14 volts, frequency decreases from 1090 to 1040 hertz. Regulation here is again better than 5% and frequency increases approximately 10 hertz per volt. Below 10 volts, the increase in frequency is more pronounced but the circuit is not normally operated in this range.

Figure 2-56 shows the effect of variations in input voltage on the output voltage magnitude. As the input is increased from 10 to 14 volts, or

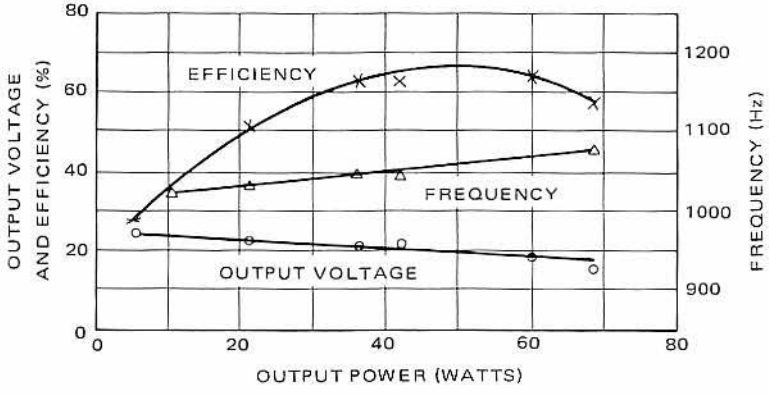


Figure 2-54 — Performance of the Inverter in Figure 2-53 as a Function of Output Power

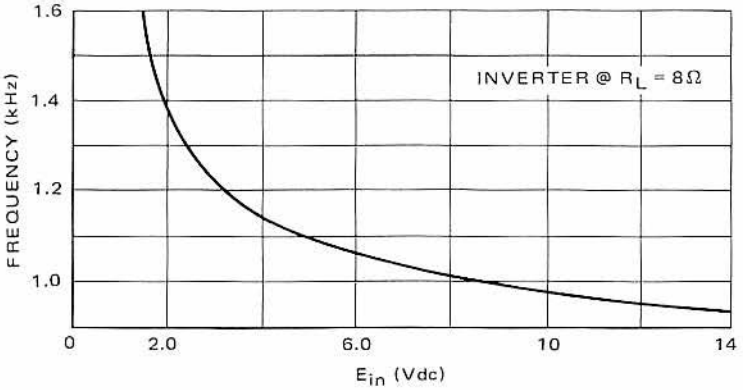


Figure 2-55 – Frequency versus Input Voltage for the Inverter of Figure 2-53

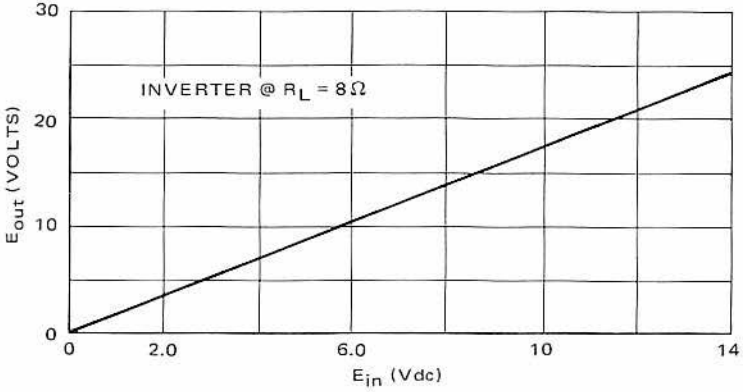


Figure 2-56 – Output Voltage versus Input Voltage for the Inverter of Figure 2-53

about 40%, the output does nearly the same. That is, the output voltage increases from 17 to 24 volts rms, just less than 40%.

Output power may be varied from 10 to 70 watts. The maximum input current will be 10 A dc. Input voltage is normally 12 volts with an operating tolerance of ±2 volts dc. The circuit will operate with input voltages as low as 2 volts dc, but the frequency regulation will be poor (see Figure 2-55). The nominal load resistance is 8 ohms and this corresponds to 50 watts of output power. With 4 ohms in the load, the output power will be about 70 watts. This represents the minimum amount of load resistance. If load is increased beyond this point, transistor Q1 and Q4 come out of saturation and may be destroyed.

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