INTRODUCTION

Endicott Research Group, Inc. has been designing and manufacturing "Smart Force" dc to ac inverters since the mid 1970's. Since the beginning, ERG Smart Force™ dc to ac inverters have been integrated into many different applications within various types of systems. Many interfacing problems and questions have been solved and answered over the years. This application note is intended to answer some of the most commonly asked questions and to provide a reference point for applications using the ERG Smart Force™ dc to ac inverters.

Each topic will be handled on two levels. The first will be the generic level, supplying overall guidelines helpful in solving problems or situations. Second; will be some specific examples (in most cases with values) intended to provide a concrete starting point.

The solutions and suggestions presented are not intended to be absolutes, just a feasible solution. The simple, durable nature of the ERG Smart Force™ inverters tolerates an endless variety of different external control loops which can enhance the overall performance of the inverter powered EL lamp system.

WHAT'S SMART FORCE ANYWAY?

The phrase "Smart Force" is merely a clever way to describe the relationship between the ERG's dc to ac inverter and the electroluminescent lamp (EL lamp) it was designed to power. They function together as a compensating integrated system.

An EL lamp is electrically a capacitor. This electroluminescent capacitor converts electrical energy into visible light, with the amount of light output directly proportional to the power delivered to the EL lamp. Since a capacitor blocks direct current, power is delivered to the EL lamp using alternating current. The typically small capacitance values of most EL lamps require a high ac voltage and/or frequency to deliver enough power to produce the desired amount of light output required by the overall application. An EL lamp can also be characterized as a "**light emitting capacitor**".
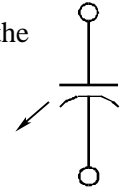
A dc to ac inverter is a means of producing high ac voltage required by EL lamps, from a low voltage dc power source.

The ERG Smart Force™ dc to ac inverter, together with the capacitance of the EL lamp forms a resonating oscillator, which allows the voltage and frequency applied to the EL lamp to change as the overall impedance of the EL lamp changes. As an electroluminescent lamp ages its impedance increases, reducing the power delivered and the light output. The resonating circuit formed by the ERG Smart Force™ inverter and the EL lamp(s) allows the output voltage and frequency to increase as the impedance of the EL lamp increases, producing a higher power level delivered and therefore increasing the light output. This increasing voltage and frequency across the EL lamp will increase the useful life and flatten the brightness vs. time relationship of the EL lamp.

The resonating output of the Smart Force™ inverter when powering an EL lamp produces a quasi-sinusoidal waveform with a higher overall efficiency.
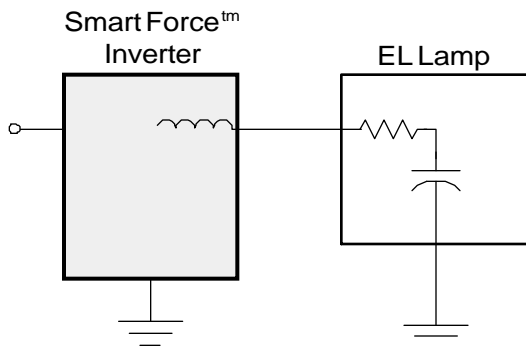

Figure 1.
Smart Force™ inverter and EL lamp

THE EQUIVALENT LOAD

It is very useful throughout the inverter design and selection process to assign a fixed impedance value to the EL lamp(s). This fixed impedance value is called the equivalent load. The equivalent load is a simplified, two component, circuit which very closely emulates the impedance of the EL lamp(s), which represents the total load to the inverter.

A parallel capacitor and resistor has been chosen as the equivalent load. The same impedance can certainly be represented by a series R-C circuit, but the parallel configuration allows for the equivalent load to be easily connected to the inverter.

DETERMINING THE EQUIVALENT LOAD

Measuring the capacitance of an EL lamp on an impedance bridge can produce erroneous readings because most impedance bridges operate at 1 kilo-hertz and apply less than one volt to the device being tested. The impedance of an EL lamp(s) needs to be determined at the nominal operating frequency (usually 400 to 600 hertz) and the nominal operating voltage, for the equivalent load to be accurate.
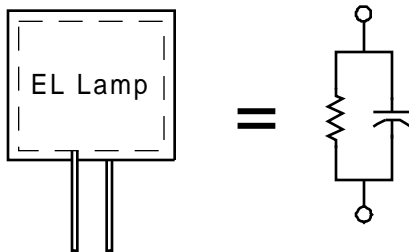

Figure 2.
Equivalent load

SUBSTITUTION METHOD

A straight forward and accurate method for determining the impedance of an EL lamp, under its normal operating conditions, is the substitution method. A brief description of the substitution method is as follows:

The EL lamp(s) to be tested should be connected to an ERG Smart Force™ inverter and the input voltage to the inverter adjusted so the operating frequency is at the nominal design frequency. The output voltage (rms) and frequency should be recorded.

With power removed from the inverter, the EL lamps(s) should be replaced by an adjustable resistor and adjustable capacitor connected in a parallel configuration. With power applied to the inverter, with the same dc input voltage as when it was powering the EL lamp, the resistance and capacitance should be adjusted to produce <u>exactly</u> the same output voltage and frequency recorded when the inverter was connected to the EL lamp(s). There is only one unique combination of resistance and capacitance values which will produce exactly the same voltage and frequency.

Note: A larger capacitance produces a lower frequency and a higher resistance value produces a higher output voltage when connected to the inverter.

INPUT SWITCHING

In applications where the EL lamp(s) are used to supplement ambient light, power can be conserved and the useful life of the EL lamp can be extended, if the EL lamp is lit only when it is necessary. Power can be removed from the EL lamp by removing power from the input of the inverter. The resonating nature of the Smart Force™ inverter and the EL lamp forces the output waveform to start or stop only at or about zero crossing (zero volts). This prevents sharp and distorted output waveforms which may create RFI or EMI.

There are several methods of switching the input of the dc to ac inverter on and off. The best method depends on the type of system and the overall objectives of the system. However, the EL lamp should <u>never</u> be switched on and off between the dc to ac inverter and the EL lamp. Removing the EL lamp from the inverter will cause the inverter to operate with no capacitance, causing the frequency to increase many times greater than the nominal design frequency. Operating in this mode (no load) will produce a very distorted

waveform at an elevated frequency and voltage, resulting in unpredictable operation.

The ERG Smart Force™ inverters are switching power supplies requiring current peaks from the input power source. These peak currents must be taken into consideration when selecting and biasing an input switching transistor. Although the exact input peak current value is dependent on many factors (source impedance etc.), a good estimate for the peak input current is four times the maximum average dc input current.

$$Ipeak = Iin (max) \times 4$$

Where: Ipeak = peak input current
Iin = average dc input current

Using this estimated value for the peak input current will insure the input switching transistor will always be into saturation. The addition of the input switching transistor should not fundamentally alter the performance of the inverter and EL lamp system.

The circuit in figure 3 allows the inverter to be "on" when the control line is taken to ground. The biasing resistors should be selected to provide adequate peak collector current through the transistor while maintaining the proper turn-on voltage for the base of the transistor.

Figure 4 illustrates switching the ground side of the input using a NPN transistor. Again, the maximum peak input current must be taken into consideration when selecting the biasing resistor
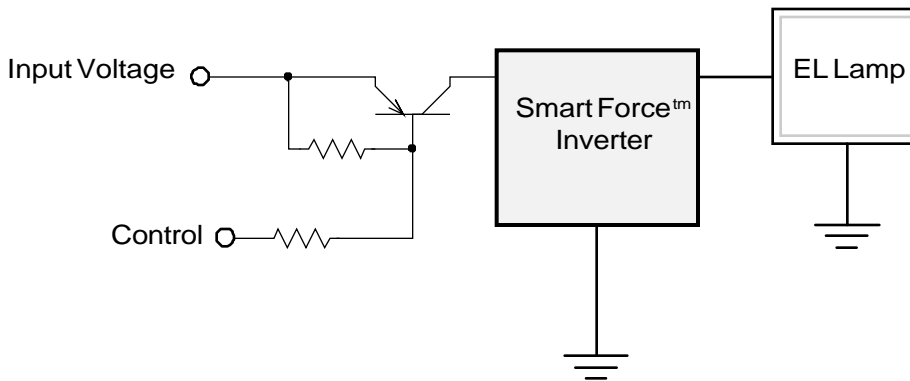

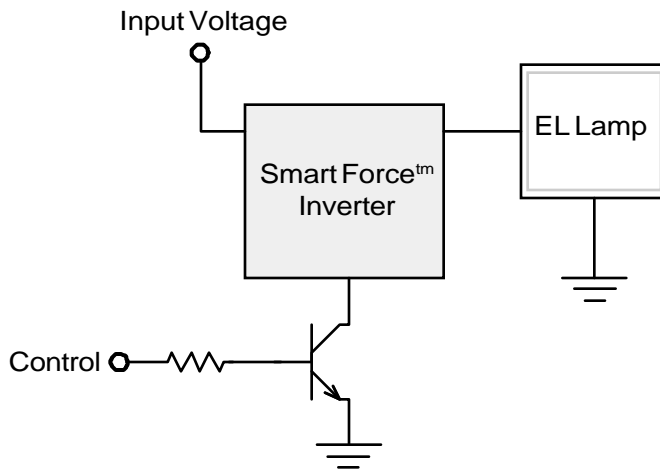Figure 3.
Input switching using a PNP transistor

Figure 4.
Input switching using a NPN transistor

for the transistor. The presence of the return current from the ac output may cause this configuration to be unstable under light current conditions; adding a small by-pass capacitor will improve the stability.

DIMMING

The brightness required for an EL lamp may not be an absolute value. Aging of the EL lamp, operating temperature, ambient light and operator preference can all determine the amount of light output which is required to make the system functional. Allowing the brightness of the EL lamp to be changed by the system user can not only provide the proper brightness level under all operating conditions, but will also extend the useful life of the EL lamp.

Varying the dc input voltage into the Smart Force™ dc to ac inverters varies the output voltage and frequency across the EL lamp. The wide input tolerance of the Smart Force™ inverter can result in more than a 5 to 1 ratio in brightness adjustment (the brightness is a function of the square of the applied voltage, and directly proportional to the frequency). This wide brightness variation is more than adequate for the majority of applications using an EL lamp.

The nominal or optimum output brightness level should be selected at the approximate mid-point of the adjustment range when powering a new EL lamp. The available potential brightness increase, within the circuit, can extend the useful life of the EL lamp dramatically.
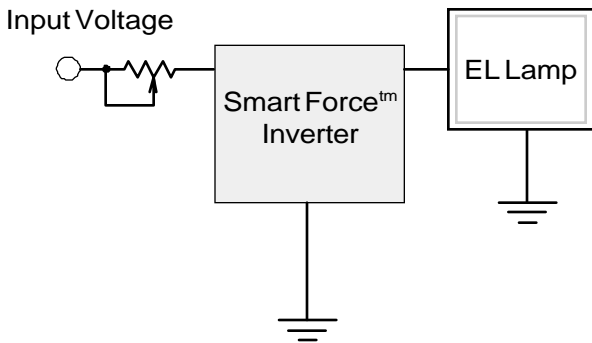
ANALOG DIMMING

Analog dimming of the EL lamp is straight forward; vary the input voltage to the inverter and the brightness of the EL lamp varies. Adding a two terminal potentiometer (see figure 5) in series with the input to the inverter will drop the input voltage in a controllable and predictable manner. The maximum resistance value of the two terminal potentiometer should be low enough to allow the inverter to continue to oscillate when the resistance is adjusted to its maximum resistance value. This prevents the inherent hysteresis of the inverter from becoming a factor during the normal operation of the system. Since the input current into the inverter is a function of the input voltage, the addition of the two-terminal potentiometer has only a slight increase in the overall power consumption of the system, and is more efficient than varying the inverter input voltage using an adjustable linear regulator.

To produce a linear brightness variation using a two terminal potentiometer a logarithmic taper is required.

In the selection of the potentiometer attention should be given to the peak input current, which is approximately four times the maximum average dc input current.

Using a linear three terminal potentiometer (see figure 6), with the center pin supplying current to

Figure 5.
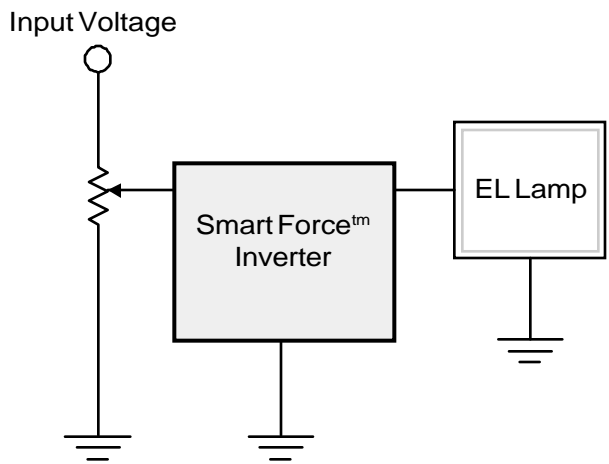Analog dimming using two terminal potentiometer

Figure 6.
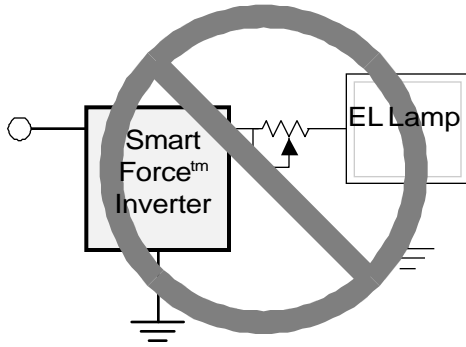Analog dimming using three terminal potentiometer

Figure 7.

the inverter, produces a more linear brightness versus adjustment relationship. However, the potentiometer must be larger (higher resistance value) with increased overall power losses.

Never add anything between the inverter and EL lamp for dimming.

DIGITAL DIMMING

The ERG Smart Force™ inverter is a "ringing-choke" type oscillator, which takes energy from the input power source very rapidly then releases the energy, via the output, in a much slower, controlled manner. This type of circuit will continue the output discharge even if power is removed from the input during the discharge cycle. This characteristic prevents switching output peaks and allows the output to resemble a

zero-crossing detector (allowing turn-on or turn-off at or near zero).

When the input supply voltage of the inverter is controlled with a pulse width modulated signal (see figure 8), the brightness of the EL lamp can be controlled from 0% to 100% in distinctive steps. The number of brightness levels is determined by the fundamental frequency of the pulse width modulator and the operating frequency of the inverter.

When using this type of dimming control, the fundamental frequency of the pulse width modulator should be slightly above the "flicker" point of the human eye. This low frequency (70 to 100 hertz) will allow a greater number of brightness levels, while still allowing the EL lamp to operate at a nominal frequency of 400 hertz. The number of distinct brightness levels is the operating frequency of the inverter divided by the pulse width modulation frequency + 1 (off condition).

$$\text{No. of brightness levels} = \frac{\text{inverter frequency}}{\text{PWM frequency}} + 1$$

With a pulse width modulator frequency of 70 hertz, a minimum of 6 steps are possible, including off . This is more than adequate for most applications. If more brightness steps are required, a dc to ac inverter with a higher frequency can be ordered.
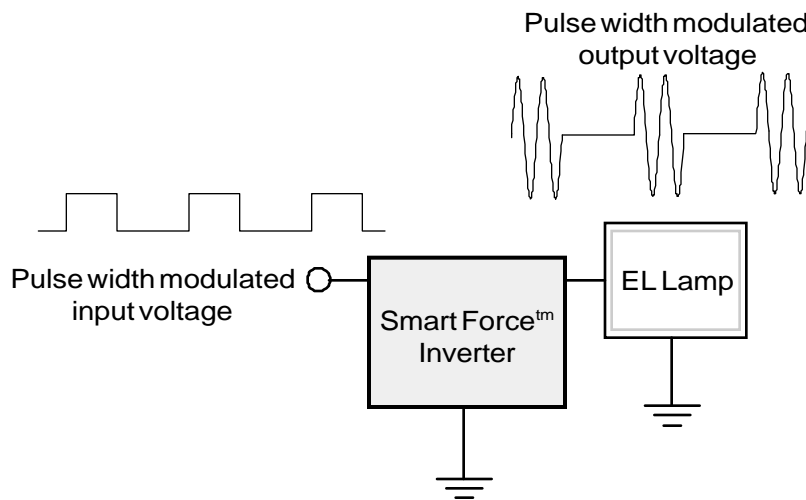

Figure 8.
Pulse width modulated dimming

PARALLEL OPERATION, EL LAMPS AND INVERTERS

EL LAMPS

More than one EL lamp can be connected in parallel to a single inverter. The total impedance presented to the inverter is the sum of the impedance of each individual EL lamp.

For example, if a 4 square inch EL lamp, with an equivalent impedance of .02 uf in parallel with 100,000 ohms is connected in parallel to another EL lamp, with an equivalent impedance of .04 uf in parallel with 50,000 ohms, the total impedance is .06 uf in parallel with 33,333 ohms. The total impedance is merely the parallel combination of the capacitors in parallel with the parallel combination of the resistors.

Any number of EL lamps may be connected in parallel as long as the inverter used is designed around the total impedance of all the EL lamps. When paralleling EL lamps, just to keep things consistent, it is suggested that the polarity (foil side to foil side) of each lamp be the same, if application permits.

SMART FORCE INVERTERS

ERG Smart Force™ dc to ac inverters can be connected in parallel to power larger total areas of EL. The total load capacity of all the inverters connected in parallel are added directly. The operating frequency and output voltage of the inverters in parallel are determined by the total load impedance and the total output impedance of all the paralleled inverters. Despite each individual inverter having its own typical operating frequency, the output waveform of the inverters connected in parallel is completely synchronized.

For example, two Smart Force™ ERG inverters each designed to power 20 square inches of EL lamp(s) will power 40 square inches to the same voltage and frequency when connected in parallel.

The inverters should be connected in phase, with each pin connected to exactly the same pin on the other inverter. Only inverters with the same part number should be connected in parallel.
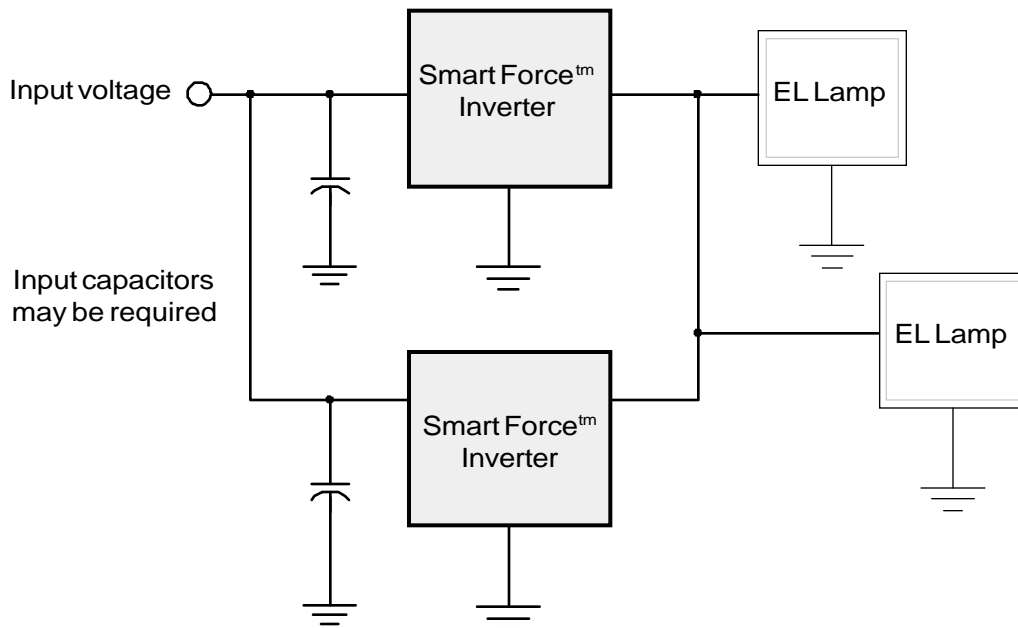

Figure 9.
Two Smart Force™ inverters connected in parallel

SMART FORCE INVERTER VALIDATION

Despite all the efforts to insure that the inverter and EL lamps are compatible when installed into the final system, the EL lamp may still be too bright. An EL lamp which is too bright is often an indication that the inverter and EL lamp are not properly matched. If a grossly mismatched condition is not corrected, it can shorten the useful life of the EL lamp or cause the inverter to be audibly noisy.

It is recommended that the final inverter design or part number selected and final EL lamp design or formulation be validated before production begins. Before production, EL lamps should be connected to the proper inverter with the nominal input voltage applied to the input of the inverter; the output voltage and frequency should be within approximately +/- 20 % of their nominal values. If the output voltage or frequency is more than +/-20% from nominal, the part number of the inverter selected may have to be re-evaluated.

The minimum input voltage to the inverter should also be verified. When the inverter is loaded properly, it should start to oscillate (when the input voltage is increased starting from 0 volts) at less than the minimum input voltage specified for that inverter. If the minimum starting voltage is higher than the minimum input voltage, cold temperature operation at low input voltages may be jeopardized.

Note: When an inverter fails to operate due to cold ambient temperature or low input voltage, the input current goes to zero and no permanent damage is done to the inverter. When the inverter is subjected to the proper input voltage and temperature, the unit will function normally.

TEMPERATURE

The capacitance (impedance) of a typical EL lamp is very dependent on the ambient temperature. In very general terms, a typical EL lamp (foil EL lamps used for basis) has a positive temperature coefficient with a tolerance as high as +/- 25% when operated from -40 degrees Celsius to +85 degrees Celsius. This change in load impedance will change the output voltage and frequency of the inverter as the operating temperature changes.

Fortunately the temperature characteristics of the EL lamp are off-setting. When the ambient temperature is high, the impedance of the EL lamp is lower. Thus, more output current is being drawn from the inverter to produce a higher brightness. The output current capacity of the inverter is limited and the inverter's output voltage and frequency will drop, producing almost a constant current to the EL Lamp. This overload condition, due to high ambient temperature, will not effect the minimum voltage operation of the inverter since starting is not a problem at high ambient temperatures.

At low ambient temperatures the impedance of the EL lamp is higher, allowing the inverter output voltage and frequency to increase, producing almost a constant current through the EL lamp. The decreased loading at colder operating temperature improves the inverter starting characteristics.

Curves showing output versus temperature, with an EL lamp and an equivalent load, are included for reference.
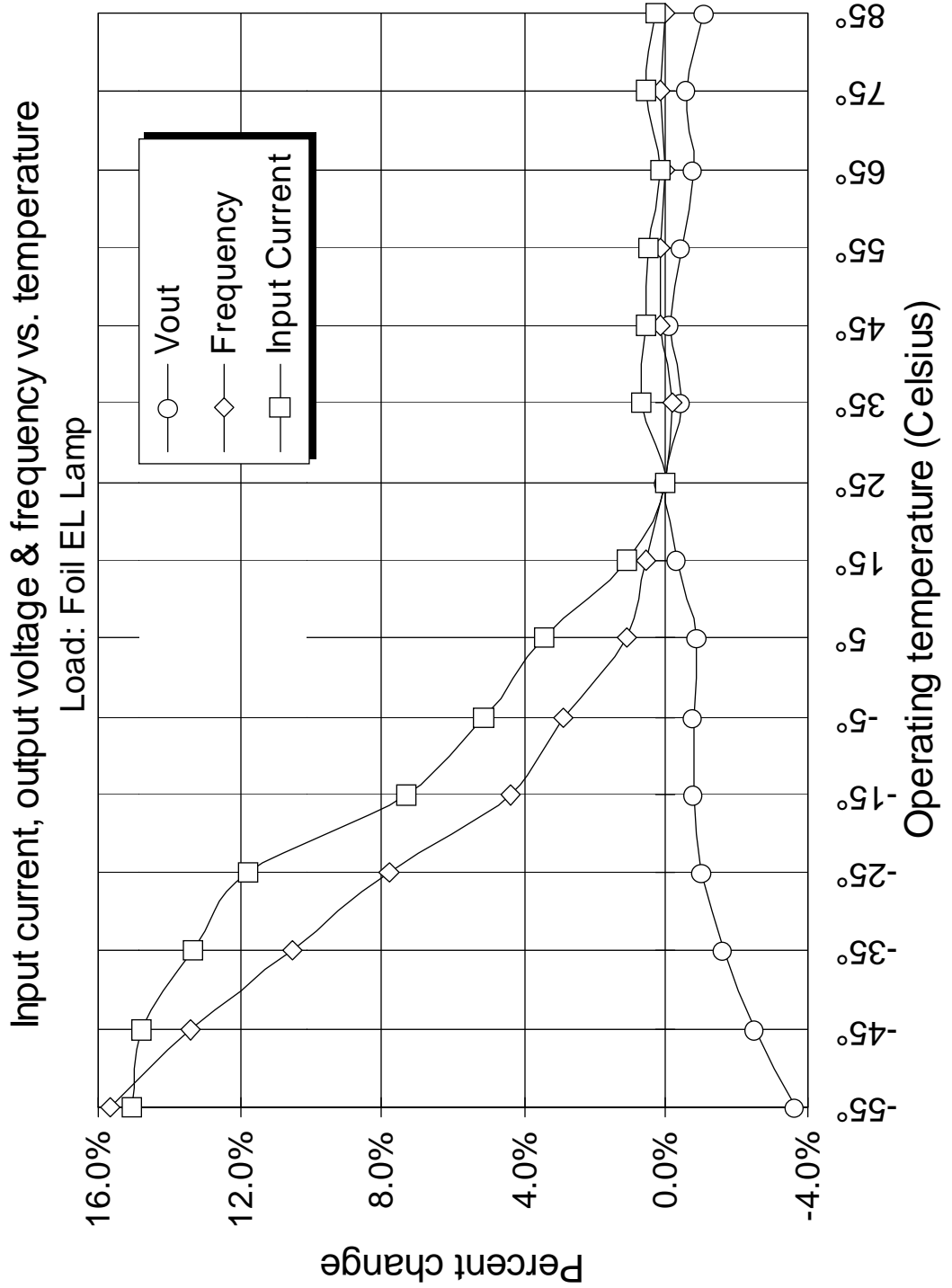
LPS09-3-3

Input current, output voltage & frequency vs. temperature
Load: .06uf in parallel with 33,333 ohms

LPS09-3-3

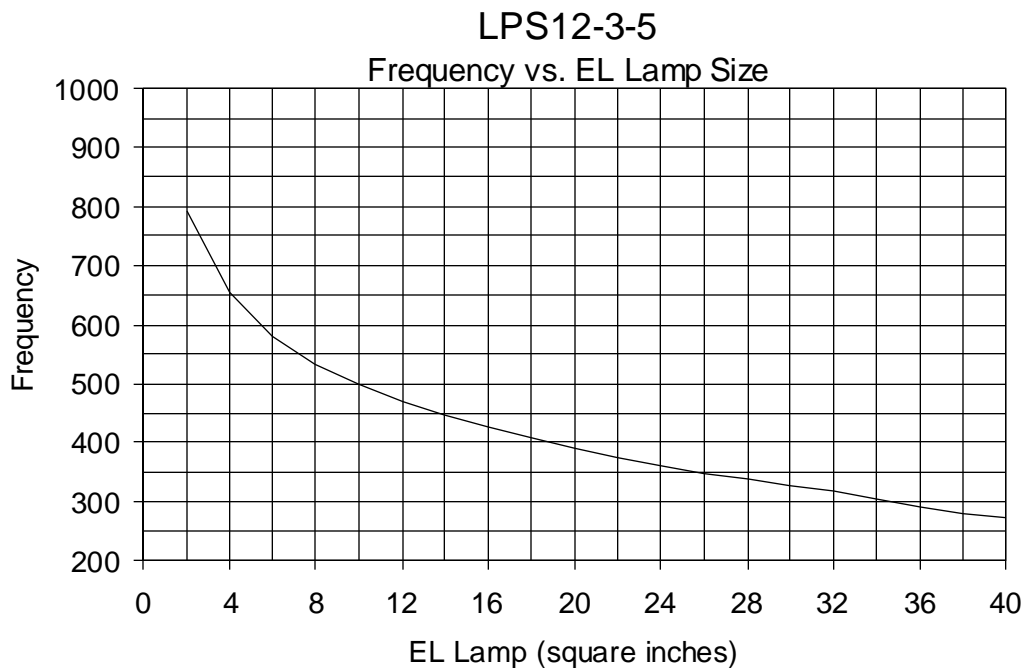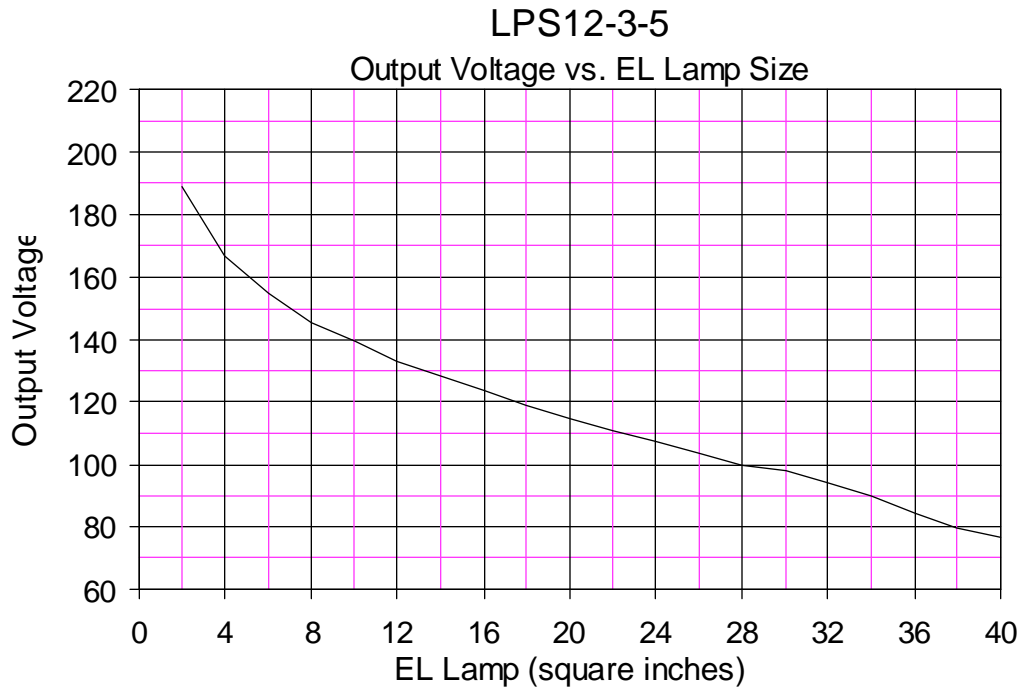**Input current, output voltage & frequency vs. temperature**
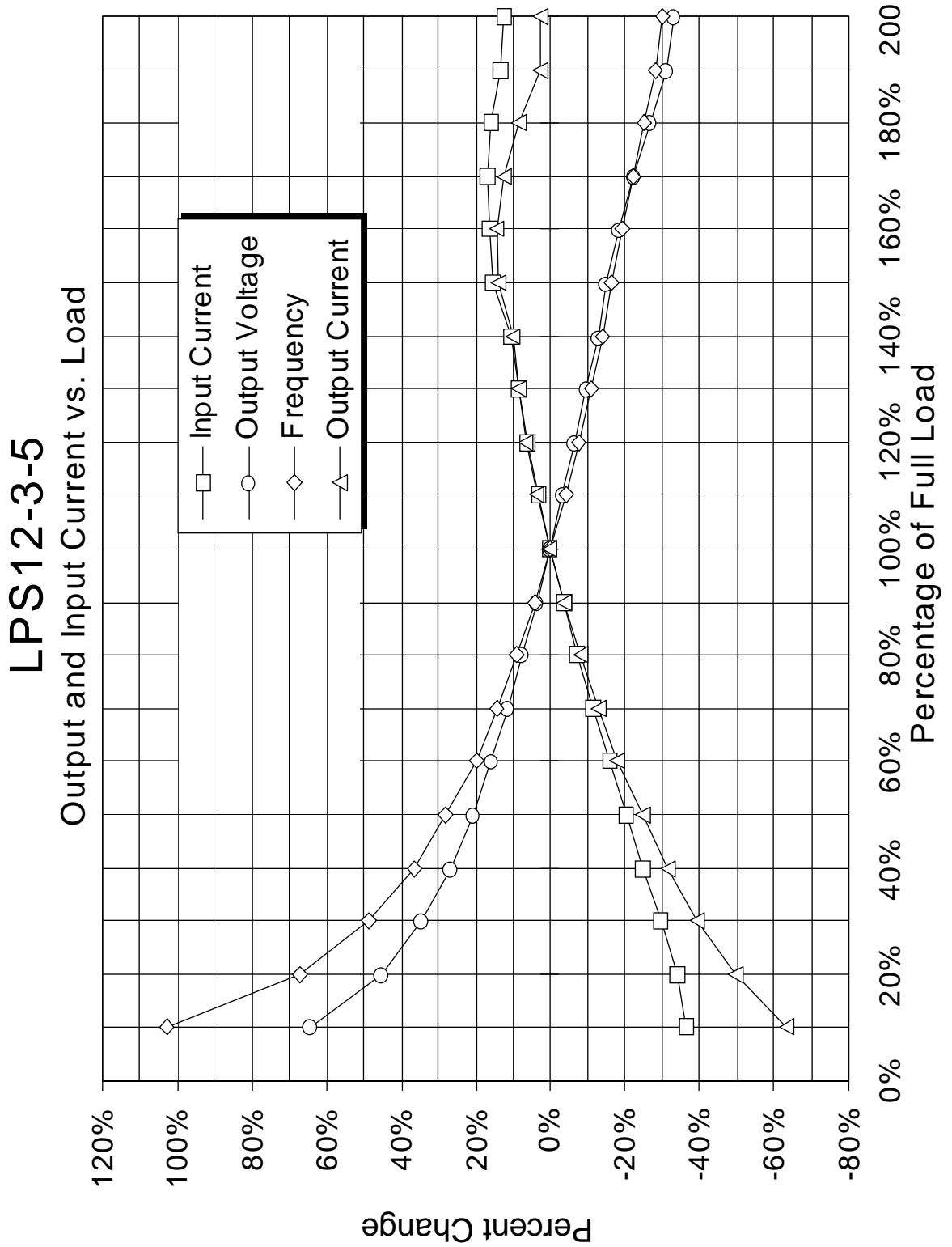
Load: Foil EL Lamp
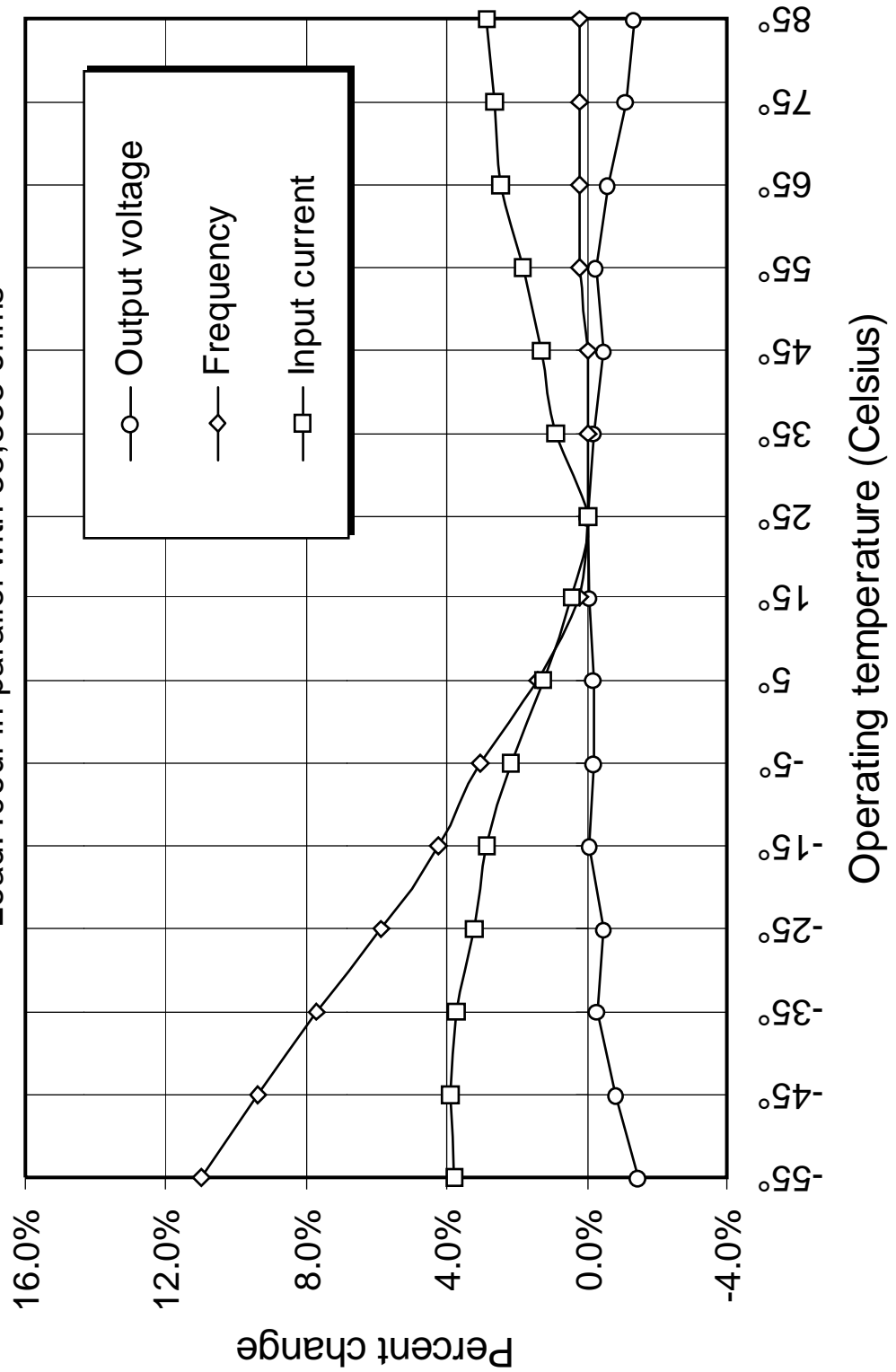
LOAD REGULATION

The ERG Smart Force™ inverter, when connected to an EL lamp, forms a resonating oscillator designed to produce a specific output voltage at a desired frequency. By definition a resonating oscillator has very poor load regulation, with both the voltage and frequency being very load dependent. Included is an output versus load curve for a median Smart Force™ inverter, with the load varied from 10% to 200% of full load. This curve illustrates the output voltage and frequency are linear and predictable above 50% of full load to well over 150% of full load. This curve can be used as a reference for applications where the load on the inverter varies.

LPS12-3-5
Output Voltage vs. EL Lamp Size

LPS12-3-5
Frequency vs. EL Lamp Size

LPS12-3-5

Output and Input Current vs. Load

EL LAMP SEGMENT SWITCHING

Some applications using multiple EL lamps require that the EL lamps or lamp segments be selectively switched on and off. In this type of application, or any application where the load on the inverter is not constant, particular care must be exercised to insure the output voltage of the inverter does not exceed the breakdown limits of the switching devices controlling the EL lamps or lamp segments.

Documenting the output voltage versus load and verifying the end points under a low load and high line condition will allow the output voltage to traverse in a controlled operating window which, by design, will be within the voltage rating of the output switching device(s).

TRIAC SEGMENT SWITCHING

A triac can be used to activate an EL lamp or lamp segment from a low level logic voltage. The triac, connected closest to ground is connected in series with the EL lamp or segment to be controlled. Since the electric parameters for most

triacs are centered around line voltage and frequency (120 and 220 volts at 50 or 60 Hertz) and cycle by cycle switching, the effectiveness of any triac must be confirmed empirically before being designed into the system. Generally triacs perform better, and are easier to use with light loads at higher frequency than at heavier loads and lower frequencies.

Since the output voltage of the inverter is dependent on the load, a dummy load should be added in parallel with the EL lamp segments to prevent the output voltage from becoming too high. The value of the dummy load should be selected to minimize the change in EL brightness as the number of EL lamps or segments change.

FIRST QUADRANT OPERATION (POSITIVE)

When the triac is inserted into the circuit so it is operated in the first quadrant, main terminal 2 (MT2) is connected to ground, the triac conducts when a positive current is flowing through the gate. Proper switching should be verified at both temperature and voltage extremes.
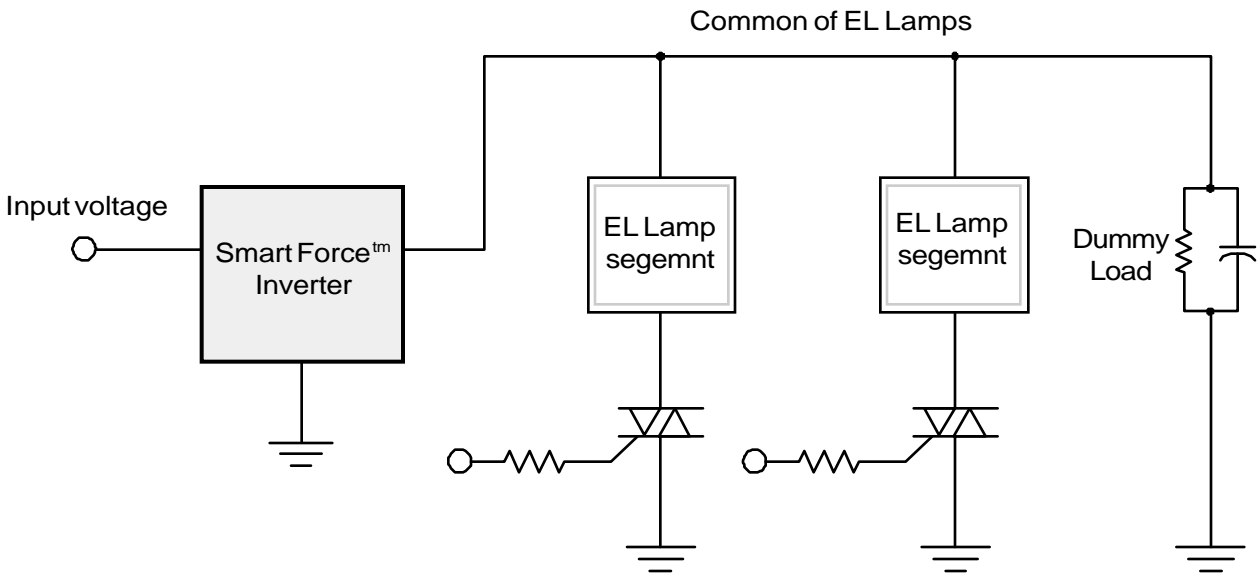

Figure 9.
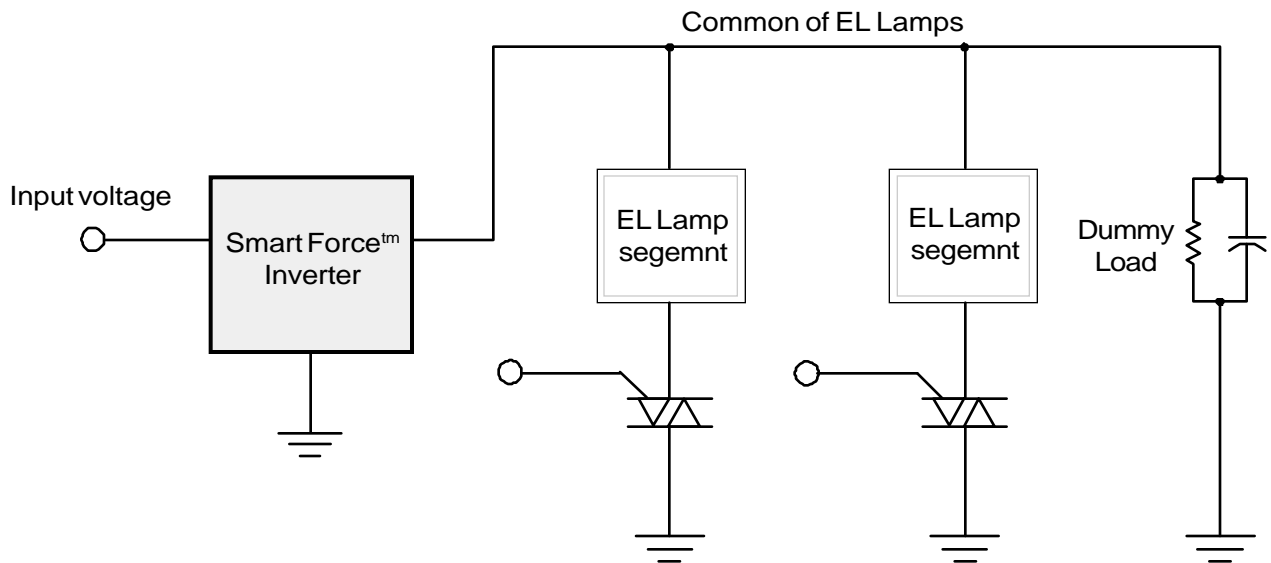El lamp segment switching, first quadrant

THIRD QUADRANT OPERATION (NEGATIVE)

If the triac is inserted into the circuit so main terminal 1 (MT1) is connected to ground, when the gate is connect to ground the triac will conduct. In this mode the gate of the triac is very sensitive and the gate current must be very small to stop the triac from conducting.

If all of the EL lamps or lamp segments are to be turned off during the normal operation of the system, the inverter should also be turned-off. This will reduce the requirements for pre-loading the output of the inverter.

Unlike input switching, if the output switching is not controlled, the triacs can turn-on at any point during the output waveform. This could produce very sharp rise and fall times, possibly generating unacceptable levels of RFI.

El lamp segment switching, third quadrant

INTERFERENCE

The inherently low operating frequency of the Smart Force™ dc to ac inverter (typically 400 to 600 hertz) and the sinusoidal nature of the output waveform produce very little radiated interference. Standard Smart Force™ inverters have been designed into radio equipment without having to add any shielding or special packaging considerations.

The switching nature and peak input current demands of the ERG Smart Force™ dc to ac inverters can produce unacceptable levels of reflected noise on the input voltage source. This problem generally occurs when the input voltage source has a high output impedance. This reflected electrical noise, because of the low fundamental frequency, contains fairly slow rise and fall times and can be reduced to acceptable levels with a small capacitor (10 uf - 100 uf) directly across the input of the inverter.

In very sensitive applications a small resistance can be added in series with the input of the inverter, before the capacitor, to further reduce the reflected input ripple. An inductor in series with the input is not recommended, the presence of this added inductance could change the oscillating characteristics of the inverter.

The typically small values of capacitance (as low as .01 uf) which the Smart Force™ dc to ac inverters are powering require a very high magnitude of

output inductance (greater than one henry), generating large magnetic fields inside the inverter. This magnetic field can interfere with surrounding components which may be sensitive to a magnetic fields (speakers, microphones, etc.). Generally the placement of the inverter with respect to the sensitive components will reduce or eliminate the interference.

"H" PACKAGE

The "H" package is a larger, more powerful, version of the standard and "P" package Smart Force™ inverters. The "H" package offers 2 to 3 times the driving capability (depending on input voltage and EL lamp type) and has been added as a package suffix on all the standard inverter types. All of the standard electrical parameters are applicable to any inverter in the "H" package configuration.

An "H" package inverter can drive over 100 square inches of EL lamp, and when several are connected in parallel, total EL lamp lit areas of 300 or more square inches are possible.
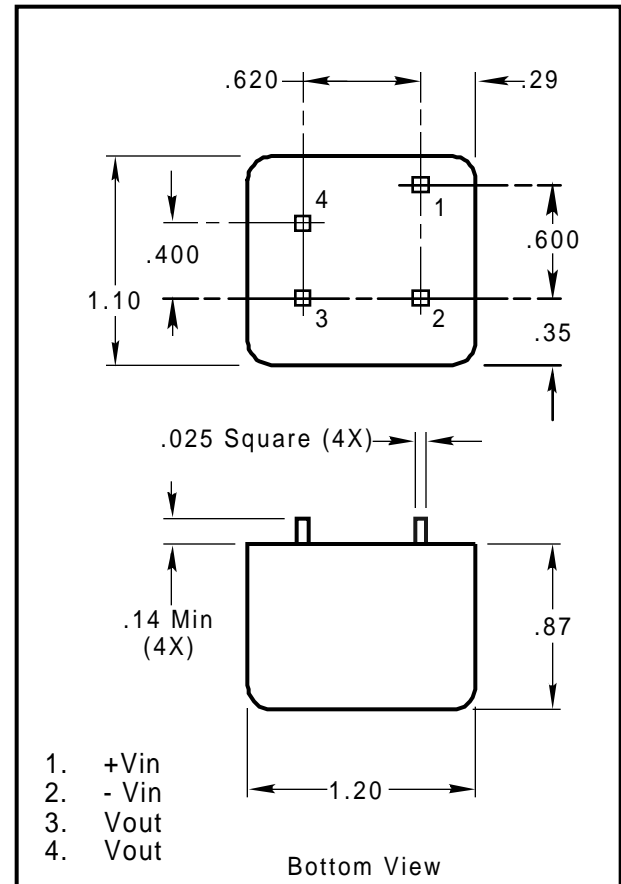

Figure 11.
"H" Package drawing

OPTICAL FEEDBACK

In applications where the brightness of the EL lamp must be maintained at, or controlled to a very specific brightness or energy level, adding an optical feedback loop to the inverter and EL lamp will provide a very stable and reproducible brightness level.

An optical pickup (photo transistor, cds cell, etc..) should be attached to the EL lamp being used in the system. If this is impractical, a smaller EL lamp of the same type connected in parallel with the main EL lamp can be used. This "sampling lamp" should be located in the same general area (exposing it to the same environment) as the main EL lamp. The signal from the optical pick-up can

be used to control the input voltage of the inverter (see analog or digital dimming).

With optical feedback the sampling lamp must be replaced whenever the main EL lamp is replaced.

AGING

The following will be a brief general discussion about EL lamp aging and its effect on the Smart Force™ dc to ac inverter.

The specific impedance characteristics versus time for any particular EL lamp(s) depends on many factors, including type, shape, brightness level and operating environment.
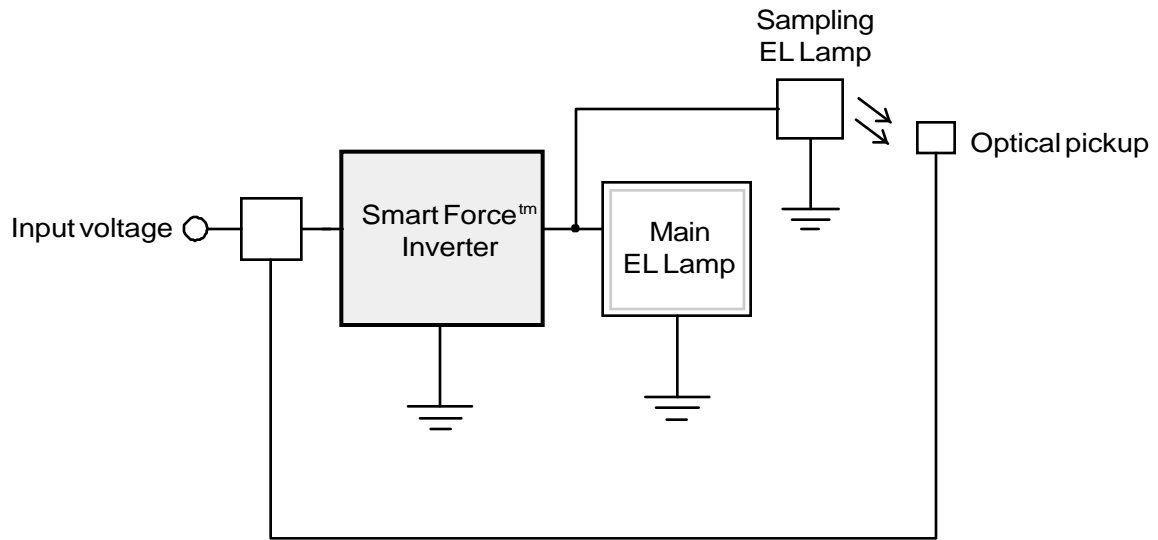
Figure 12.
Optical feedback block diagram

As an electroluminescent lamp ages the overall impedance of the EL lamp increases reducing the current. This results in decreased brightness. The resonating circuit formed by the Smart Force™ inverter and electroluminescent lamps allows the output voltage and frequency to increase over time. The inverter will increase its output voltage and frequency in an attempt to maintain constant current through the EL lamp.

The total increase, and rate of increase, in the output voltage and frequency is dependent on the change in impedance of the EL lamp. Different types of EL lamps change at different rates, and generally the harder an EL lamp is driven the greater the rate of impedance change. Usually when the EL lamp is at half brightness, the Smart Force™ inverter output voltage increases by approximately 20% and the frequency increases by approximately 10%.

The change in total impedance of an EL lamp, over time, is the vectorial sum of the change in capacitance and the change in the phase angle. Generally an EL lamp with a low initial phase angle will have a higher change in impedance (therefore more compensation) than an EL lamp with a high initial phase angle.

The aging curves illustrate the change in impedance and the change in the inverter output over time. The test was conducted (at room temperature) using an EL lamp with a typical phase angle (if there is such a thing) that had been pre-aged at the factory prior to shipment.

PRE-AGED EL LAMPS

Some EL manufacturers subject each EL lamp to a burn-in prior to shipment. These EL lamps exhibit a smaller amount of initial compensation during the first hours of operation. However, the rate of initial decay is lower.

Pre-aging the EL lamps either before or after they are installed into a system can minimize the total amount of light decay over time because it minimizes or eliminates the rapid change during the early hours of operation.
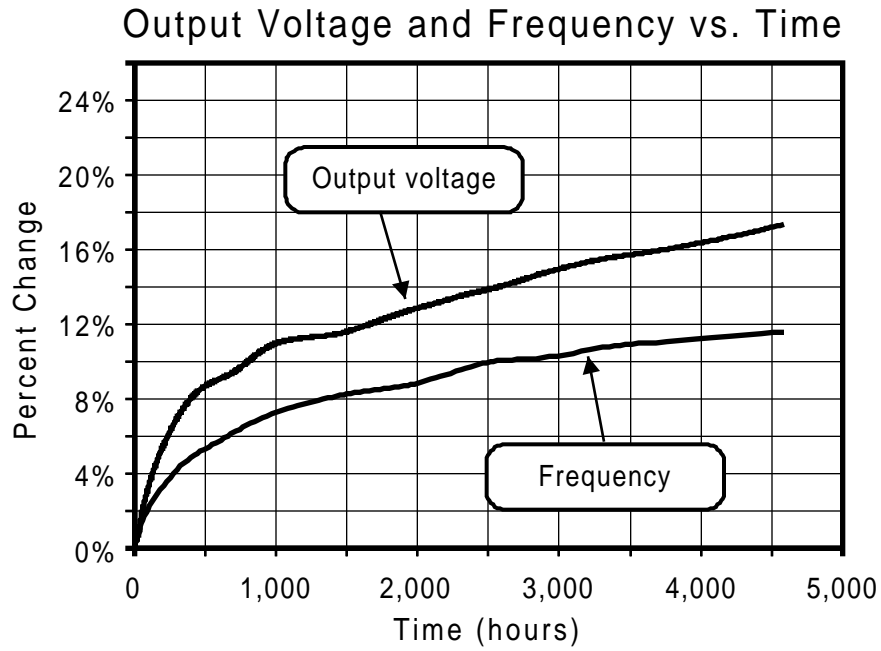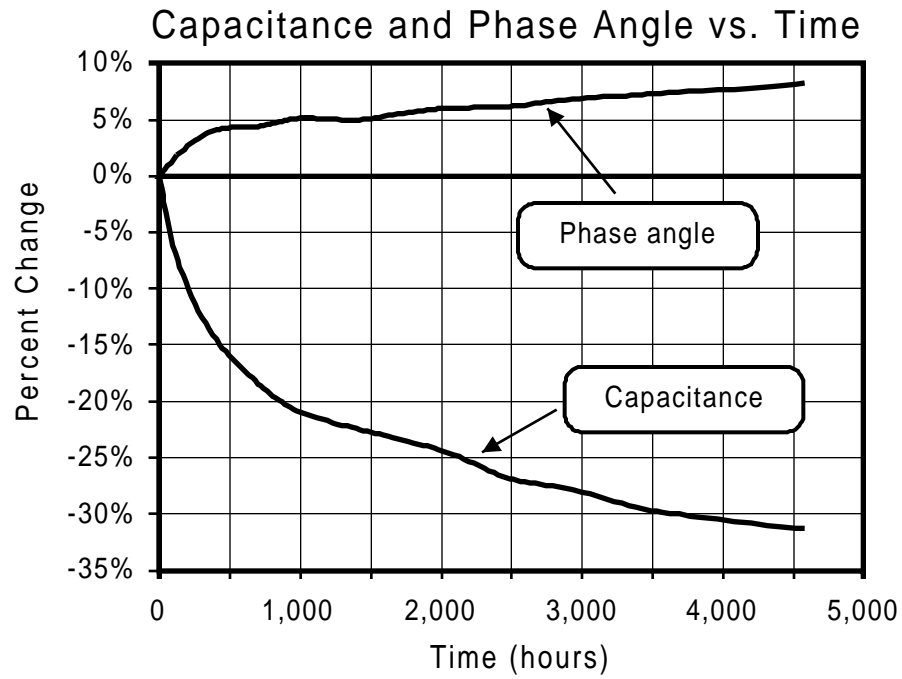
Output Voltage and Frequency vs. Time
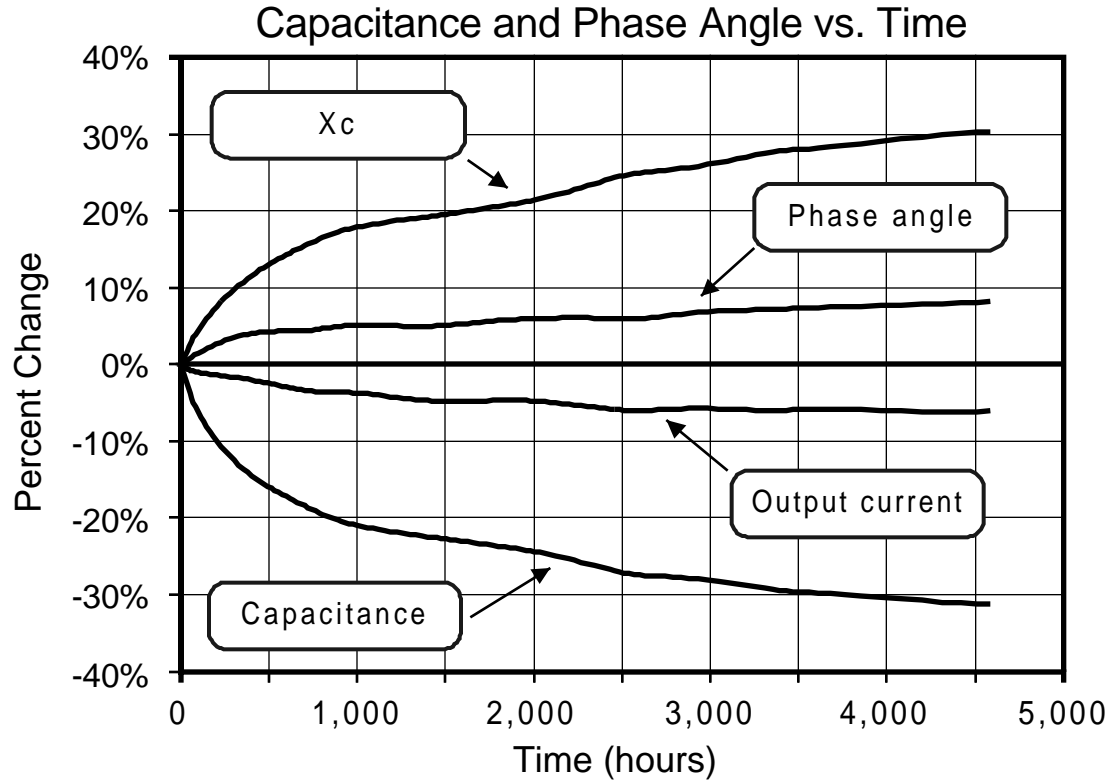

Figure 13.

Capacitance and Phase Angle vs. Time

Figure 14.

Capacitance and Phase Angle vs. Time

Figure 15.

Relative Brightness vs. Time

Figure 16.

Standard Package

.55 [14,0]   .30 [7,6]
.17 [4,3]

3

.50 [12,7]

2   1

.85 [21,6]

1.25 [31,8]

.025 [0,64]

.15 [3,8]
Min (3X)   .95 [24,1]

1. +Vin
2. Common
3. Vout

P Package

.25 [6,4]   .510 [13,0]

3   1

.600 [15,24]   .550 [13,97]

2

.12 [3,0]

1.01 [25,7]

.025 [0,64]
Square
(3X)   .70 [17,8]

.82 [20,8]

.125 [3,18] Min (3X)

1. +Vin
2. Common
3. Vout

H Package

.600 [15,24]   .35 [8,9]

.29 [7,4]

1   2

.620 [15,75]

4   3

.400 [10,16]

1.10 [27,9]

.87 [22,1]

.025 [0,64]
Square
(4X)

1.20 [30,4]

.14 [3,6] Min (4X)

1. +Vin
2. - Vin
3. Vout
4. Vout

LP Package

.800 [20,32]   .117 [2,97]

1   2

.820 [20,83]   .600 [15,24]

4   3

1.190 [30,23]   .107 [2,72]

.148 [3,76]
(4X)

.025 [0,64]
Square
(4X)

1. Vin(+)
2. Common
3. Vout
4. N/C

.340 [8,64]
Max

L Package

Red   Vin(+)
Black   Vin(-)
Green   Vout
Brown   Vout

6.00 [152,4] (4X)

.95 [24,1]

.85 [21,6]

1.25 [31,8]

E300 Package

.60 [15,2]

1.15 [29,2]

.60 [15,2]

.10 [2,6]
MIN (2X)

3   4

.10 [2,6]
MIN (2X)

1   2

.025 [0,64]
Square (2X)

1.26 [32,0]

.025 [0,64]
Diameter (2X)

.33 [8,4]

.45 [11,4]

1.   Vin(-)
2.   Vin(+)
3.   Vout
4.   Vout

FB Package

1.   Vin(-)
2.   Vin(+)
3.   Vout
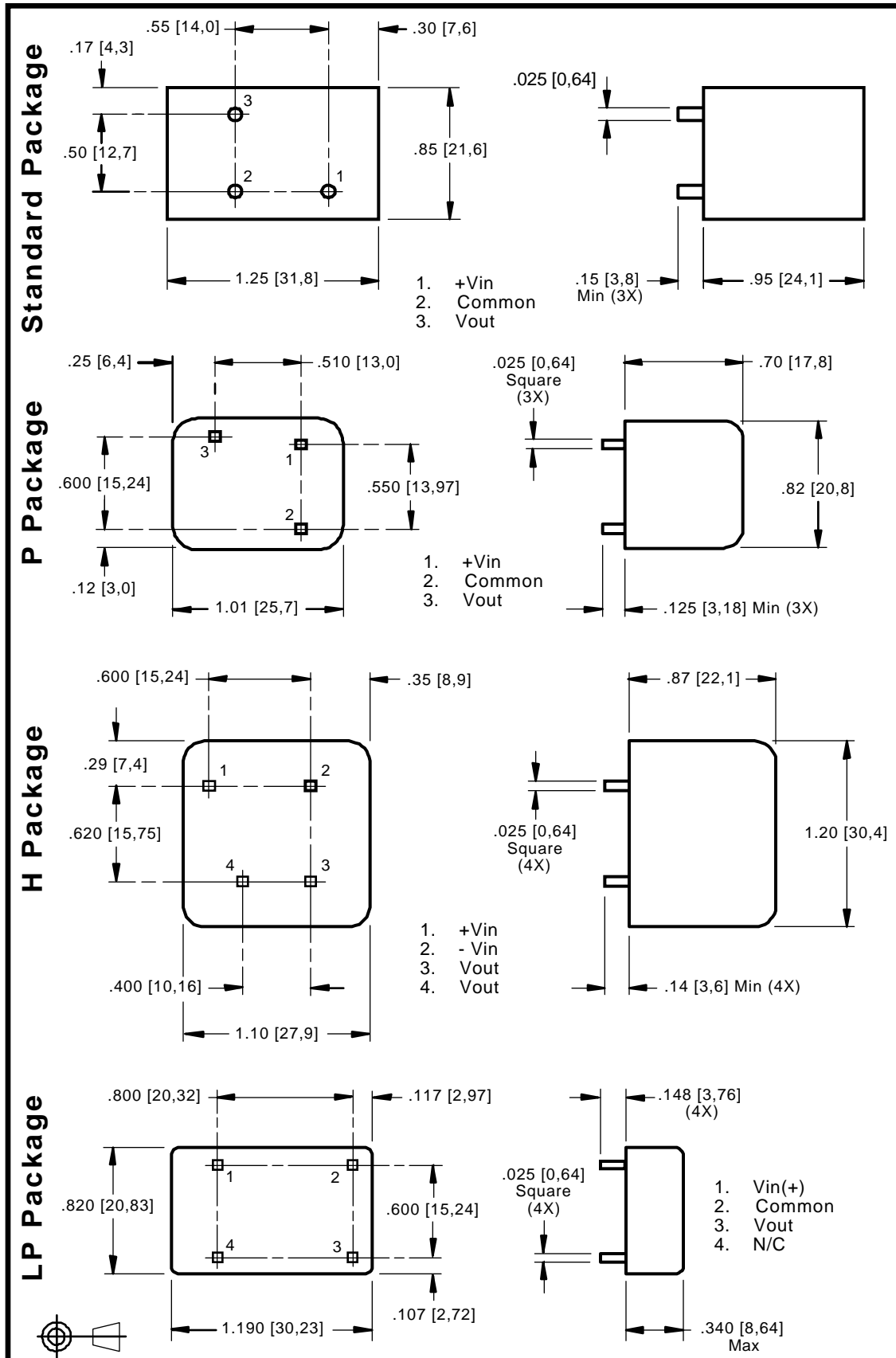4.   Vout

1.63 [41,4]

1.19 [30,2]

.25 [6,4] (4X)

1.13 [28,7]

.60 [15,2]

The LPS Series Overview (Standard and P Package Inverters)						
Parameter	**Symbol**	**Units**	**Code D**	**Code 1**	**Code 2**	**Code 3**
Input Power per unit load	Pin	watts	*0.200	*0.300	*0.400	*0.500
Minimum Input Voltage	Vin(min)	%	-40	-40	-40	-40
Maximum Input Voltage	Vin(max)	%	25	25	25	25
Minimum Operating Temperature	T(min)	°C	-25	-25	-25	-25
Maximum Operating Temperature	T(max)	°C	85	85	85	85
Nominal Output Voltage	Vout	Vrms	60	80	100	120
Nominal Operating Frequency	Fout	Hertz	400	400	400	400
Maximum Number of Unit Loads	Lmax	-	17	10	7	5
Output Voltage tolerance	-	%	±10	±10	±10	±10
Operating Frequency tolerance	-	%	±10	±10	±10	±10
Output Current per Unit Load	Iout	marms	3.1	4.1	5.1	6.2

*   Input power may increase by 10% on low input voltage and/or single unit load inverters.