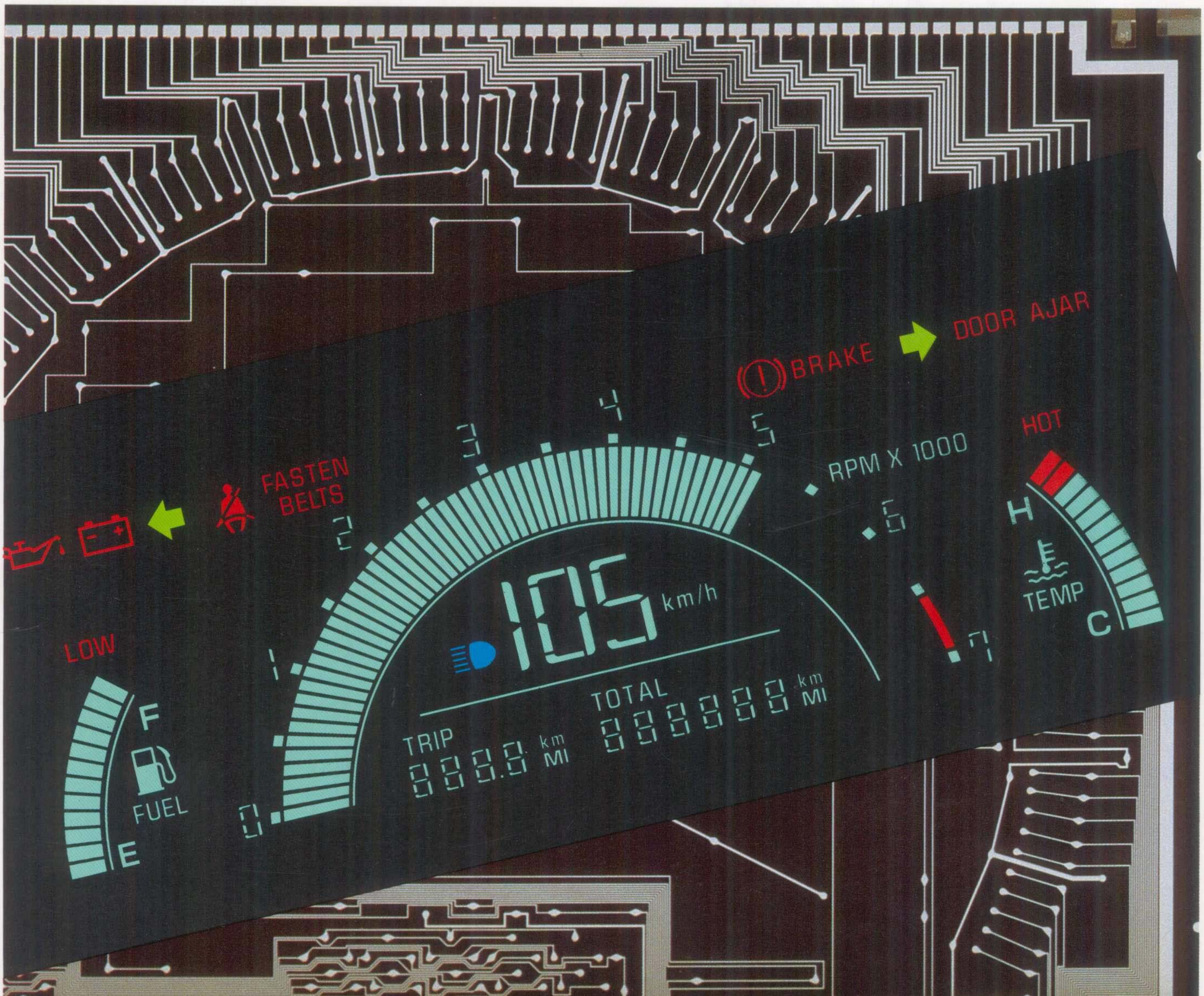
AN-E-1103A

VACUUM FLUORESCENT DISPLAY

APPLICATION NOTE

VACUUM FLUORESCENT DISPLAY CHARACTERISTICS AND OPERATION GUIDE



FUTABA CORPORATION

Contents

1. General Description

The Vacuum Fluorescent Display (VFD) is self emissive and evolved from the CRT. Electrons emitted from the oxide coated cathode collide with the phosphor coated anode to emit light. The VFD is now utilized in various application with features such as multicolor, low voltage drive, and high reliability.

2. Type of VFDs

Numerous types of VFDs exist and can be classified by structure, display system, displayed message and driving method. Various combinations are used in the market place.

- Structure
  - diode
  - triode
  - tetrode
- Display System
  - ordinary (VFD)
  - front luminance (FLVFD)
  - multi-layer (BIPLANAR)
- Message
  - numeric (7-segment)
  - character (alphanumeric, dotmatrix)
  - fixed pattern (mark, sign, symbol)
  - bar graph (level meter)
  - graphic display (full dot)
  - plane luminance (light source)
  - light cell for large screen
- Drive System
  - Static
  - Dynamic

3. Structure and Operation Principle

At present, the VFD triode structure is most widely used. Primarily, a front and base plate constitute a vacuum envelope, in which the filament, cathode, grid and anode are arranged to form electrodes.
Figure 1 shows the perspective view of the disassembled VFD. Figure 2 shows the cross section. Figure 3 shows the basic operating principle of the VFD.

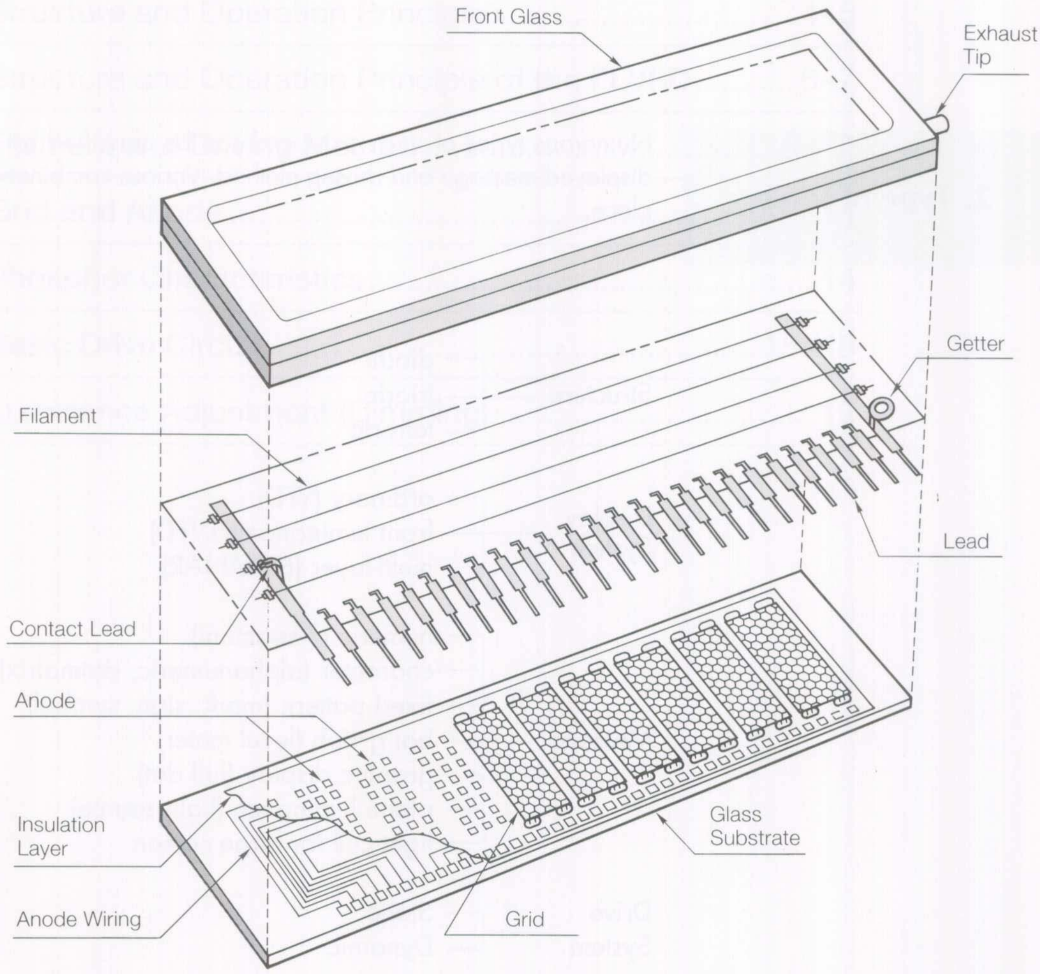


Figure 1. VFD triode structure

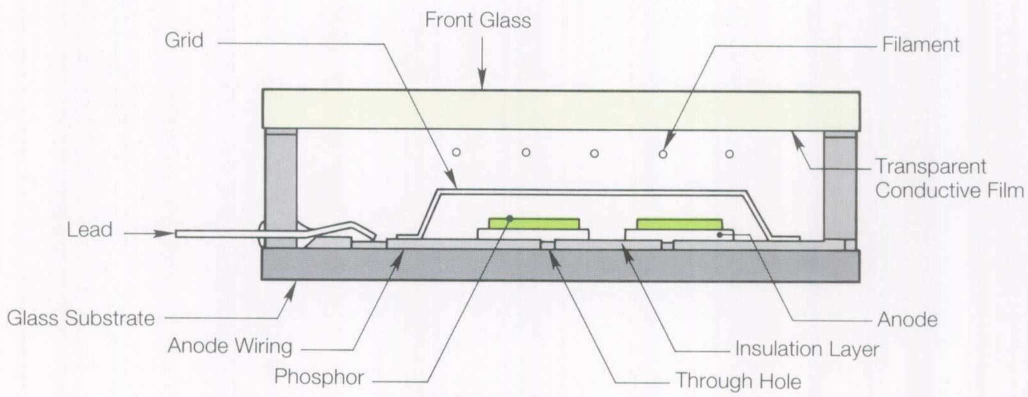


Figure 2. Cross sectional view of VFD

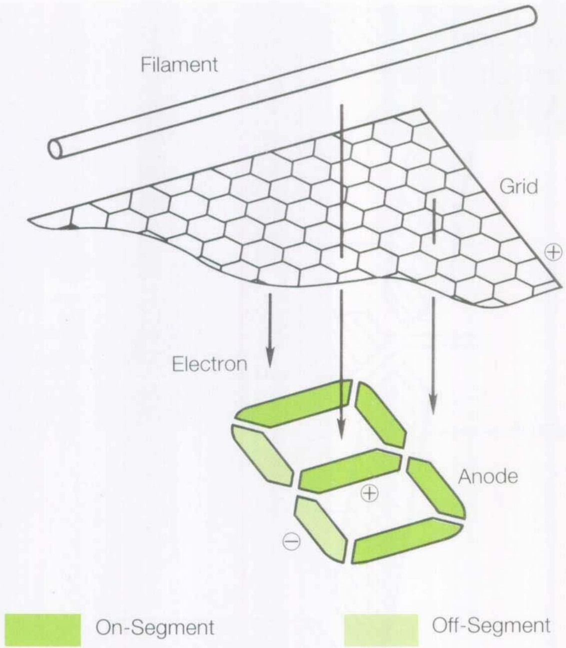


Figure 3. Principle of VFD Operation

The filament, consists of a very thin tungsten wire coated with barium, strontium and calcium oxides. It is held between a filament support and anchor which apply tension to the wire. Application of a specified voltage raises the temperature of the filament cathode to about 600°C which causes thermionic emission.

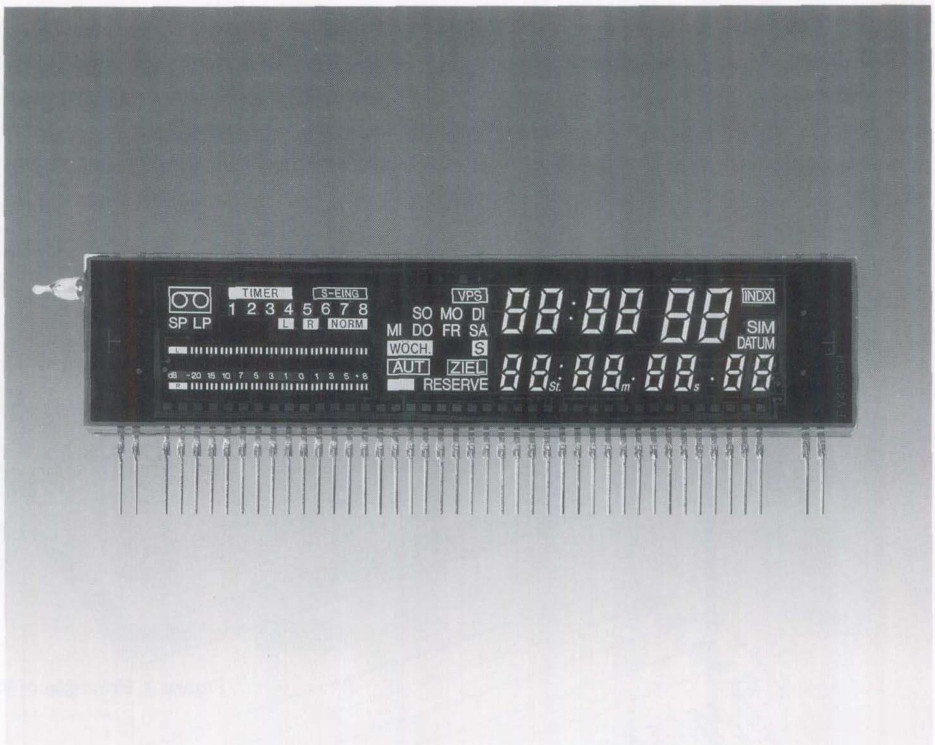
The grid is a thin stainless steel mesh formed by photo etching. When a positive voltage is applied to the grid, electrons emitted from the filament are accelerated and diffused towards the anode. When a negative voltage is applied to the grid, electron flow to the anode is cut off.

The anode consists of a conductor, such as graphite, which is coated with phosphor that is formed into the desired graphic pattern. When a positive voltage is applied to the phosphor coated anode, electrons that are accelerated and diffused by the grid, collide with the anode and excite the phosphor which then emits light. The most widely used phosphor is ZnO: Zn which operates at low voltage and has a green peak wavelength of 505 nanometer. Various colors, ranging from reddish orange to blue, can also be obtained by using different types of phosphor.

In addition to the three fundamental electrodes described above, a transparent conductive layer is formed on the inside of the front glass, as shown in Figure 2. The conductive layer, which protects the display from external electrostatic effects is either set to the filament level or a positive potential.

A getter, as shown in Figure 1, is important in maintaining a high vacuum level by absorbing residual gas after the exhausting process.

4. Structure and Operation Principle of the FLVFD



The sample of FLVFD

The Front Luminous Vacuum Fluorescent Display (FLVFD) is observed from the opposite side of the ordinary VFD. The display pattern is hatched with very thin traces of aluminum which act as conductors. The phosphor which covers the pattern emits light not only in the direction of the filament cathode but also through the phosphor layer towards the baseplate. Figure 4 compares the direction of observation for the ordinary VFD and the FLVFD.

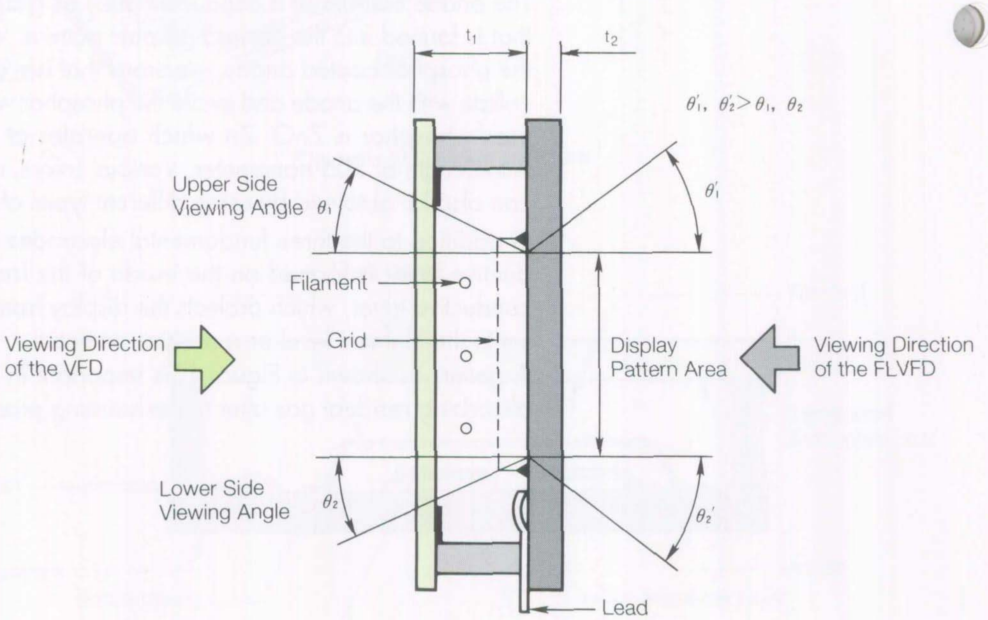


Figure 4. Structure

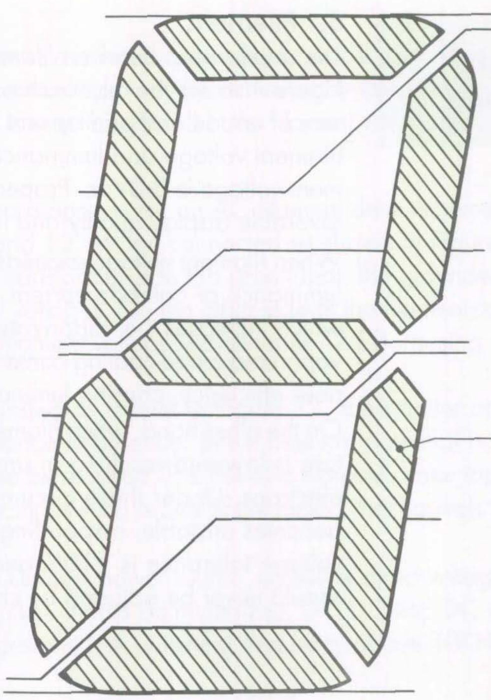


Figure 5. FLVED electrolode pattern

The display pattern of the FLVFD is observed directly through the glass substrate, which facilitates a wide viewing angle of 75° as compared to the ordinary VFD. Consequently, a FLVFD with a wider pattern area can be installed in a package the same size as an ordinary VFD.

When FLVFDs with high transmissivity filters are used, the reflection of ambient light from the aluminum wiring traces often interferes with readability. To solve this problem, an anti-reflection FLVFD was developed by forming a thin film semi-transparent layer between the glass plate and aluminum wiring.

There are considerations involved in using the FLVFD; (1) luminance is lower than the ordinary VFD when the same electrode structure and operating conditions are used, and (2) pattern design freedom is slightly reduced since wiring traces and anode segments are formed on the same plane.

5. Filament and Driving Method

5.1 Filament

The relationship between filament voltage and filament current is shown in Figure 6. Figure 7 shows the relationship of grid and anode currents to the filament voltage. The sum of anode and grid current is known as cathode current. The relationship between filament voltage and luminance is shown in Figure 8. In these figures, the rated filament voltage is 3.0Vac. Proper filament voltage is an important factor in maintaining favorable display quality and long life.

When filament voltage exceeds the specified level their is no recognizable increase in luminance or cathode current. However, a rise in filament temperature does occur, which increases the vaporization rate of the oxide coating on the tungsten wire. The vaporized oxide coating contaminates the phosphor surface which decreases the luminous efficiency, causing luminous degradation and reduced life.

On the other hand, when filament voltage is below specification, the cathode temperature is lowered resulting in unstable emission and an insufficient supply of thermal electrons. Under these circumstances, display quality deteriorates and luminance becomes unstable, responding to fluctuations in filament voltage. The rated filament voltage tolerance is ±10% and should be carefully maintained. Display luminance should never be adjusted by changing filament voltage.

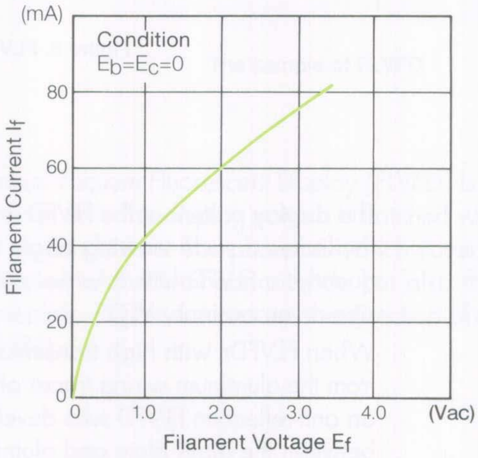


Figure 6. $E_f - I_f$ Characteristics

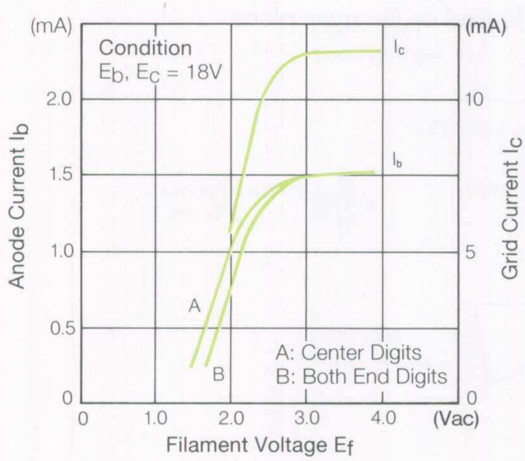


Figure 7. $E_f - I_b$, I_c Characteristics

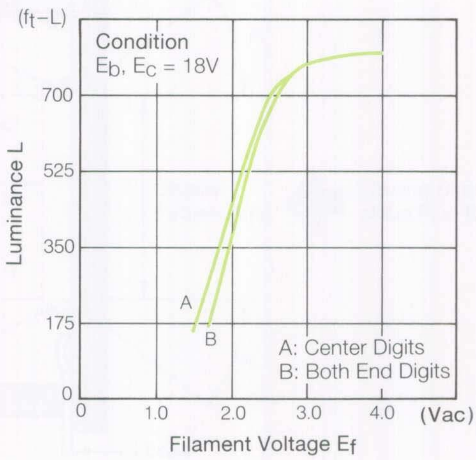


Figure 8. $E_f - L$ Characteristics

5.2 Filament Power Sources

Voltage (Ef) applied to the filament resistively heats the cathode oxide coating to induce the emission of thermal electrons. Application of filament voltage may be achieved by several different methods. To obtain the appropriate filament temperature it is very important that the filament voltage be set at the specified value.

5.2.1 AC Filament Drive

Figures 9 and 11 show the connection diagrams for an AC filament drive scheme. Voltage potentials for each case are shown in Figures 10 and 12. When connected as shown in Figure 9 with one end of the filament/cathode grounded (filament transformer side tap grounded), the grounded side of the cathode is supplied with the true anode and grid voltages. On the other side of the filament/cathode, the anode and grid voltage potential varies with the filament voltage waveform ($\pm\sqrt{2}$ Ef), causing some luminance imbalance to occur.

When the filament center tap is grounded as shown in Figure 11, the smaller amplitude of the filament potential has a lesser effect on luminance imbalance. Since filament potential is smaller with center tap grounding, cut off bias voltage can also be reduced. The use of a filament center tap transformer for biasing is recommended. Filament to grid spacing, which is one of the factors that controls luminance, is uniform in AC filament designs.

When a DC-AC converter is used as a filament power source, excessive direct voltage though the secondary, variable frequencies and waveform spikes should be minimized. DC-DC and DC-AC converters can be a source of audible noise if improperly designed. A switching frequency above 30KHz is also recommended.

5.2.2 DC Filament Drive

The connection diagram for DC filament is shown in Figure 13, and it's voltage potential as related to anode and grid is shown in Figure 14. As seen in Figure 14, the directly heated filament has a voltage gradient from the negative (F−) side to the positive (F+) side. If a typical AC filament designed VFD is connected as shown in Figure 13 the anode and grid voltage potential at the filament positive side will be of a lower potential than at the filament negative side. The result is a luminance gradient directly related to the voltage drop across the filament. Since luminance increases with a decrease in filament to grid spacing, the gradient can easily be corrected by offsetting the filament height. Another contributing factor to luminance imbalance of DC filament displays is a related filament temperature gradient occurring due to cathode current flow. The temperature gradient affects the thermal electron emission rate which then affects the luminance balance. This luminance imbalance is also corrected with adjustment to the filament and grid spacing.

In general, the use of DC filament drive is limited to shorter displays which have correspondingly lower filament voltages.

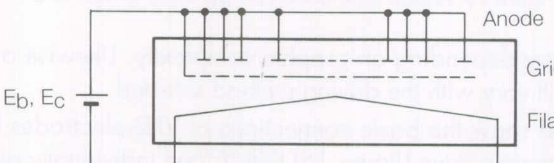


Figure 9. Basic Connection Diagram for Alternating Current as the Filament Voltage (1) (One End of the Filament Grounded)

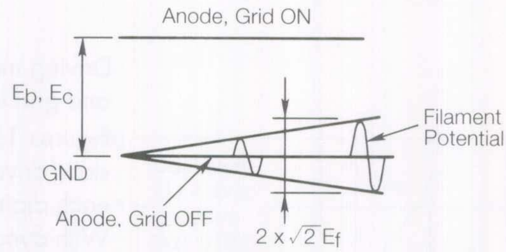


Figure 10. Relation of Electrode Potentials in Case of Figure 9

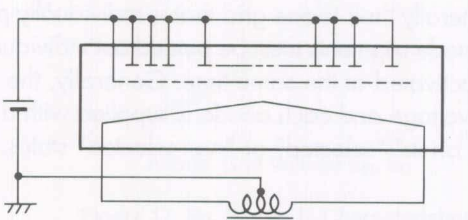


Figure 11. Basic Connection Diagram for Alternating Current as the Filament Voltage (2)
(Center Tab of the Filament Transformer Grounded)

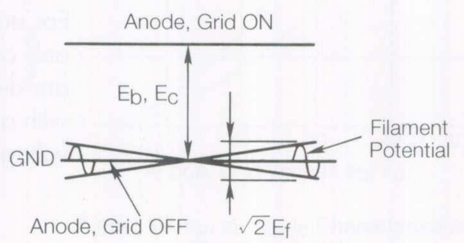


Figure 12. Relation of Electrode Potentials in Case of Figure 11.

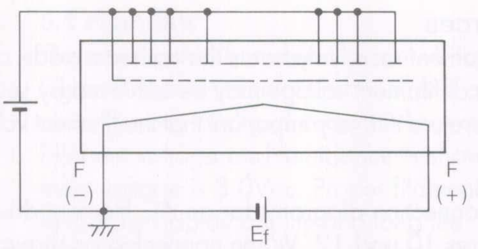


Figure 13. Basic Connection Diagram for Direct Current as Filament Voltage

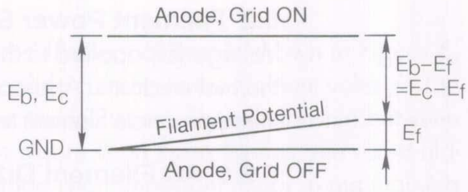


Figure 14. Relation of Electrode Potentials in Case of Figure 13

5.2.3 Pulse DC Filament Drive

In addition to the previously mentioned filament drive methods, there are other types. Pulse DC filament drive is essentially a high voltage square wave applied at a relatively small specific duty cycle. The pulsed waveform is equivalent to the specified RMS value. A simple method used to check if the correct pulsed RMS value is applied to the filament is to do a comparison. Establish another sample of the same display and operate the filament with common DC voltage at the specified value. In a dark room compare the filament temperatures (emission color).

When developing a pulse DC specification considerations must be made so that the filament is not over stressed by to high of voltage. When pulsed DC voltage is used on a display designed for AC filament drive, a slight luminous gradient will occur. To prevent this gradient, it is recommended that the anode and grid not be operated during the filament heating time. Also for pulsed filament drive, careful selection of an operating frequency is required to prevent the generation of noise caused by mechanical resonance and electromechanical interference.

6. Grid and Anode

6.1 Grid and Anode connection

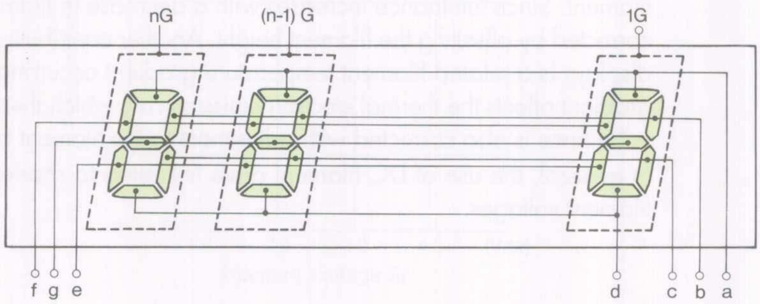


Figure 15. Anode connection for dynamic driven VFD

Driving method vary depending on graphic complexity. Likewise anode connection and grid layout will vary with the driving method selected.

Figures 15 and 16 show the basic connections of VFD electrodes for dynamic and static drive. For dynamic drive (figure 15) their is one individually pinned out grid for each digit. Corresponding anode segments are internally connected and pinned out. With dynamic drive a large number of digits does not significantly increase the number of leads. In order to luminesce a desired segment, it's on time is synchronized with the grid scanning. Attention must also be paid to grid scanning frequency so that flickering does not occur.

For static drive, generally their is one grid that is individually pinned out. Since their is only one grid, all anode segments must be pinned out individually unless two segments are desired to be activated at the same time. Generally, the grid is always supplied with a positive DC voltage and each anode is supplied with a positive or negative DC voltage depending on its' "selected" or "non-selected" status.

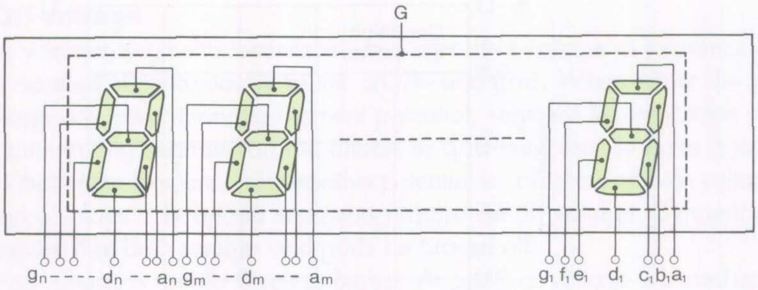


Figure 16. Anode connection for static driven VFD

Although electrode connections vary depending on the driving method, both anode and grid must have a positive voltage simultaneously applied for luminescence to occur. Electrical characteristics are described below.

6.2 Anode and Grid Characteristics

Figures 17 and 18 show the anode and grid currents relationship to anode and grid voltages. Figures 19 and 20 show that luminance varies with anode and grid voltages. In most cases, the anode and grid are operated at the same voltage.

Anode current (ib) is expressed in the following equation:

$ib=(G\cdot e^n)/(1+K)$....(1)

where G: perveance (a constant determined by the distance between electrodes)

e: anode (grid) voltage

n: $\simeq 1.7$

K: current distribution rate (ic/ib)

The relationship of anode and grid voltages to luminance is expressed as the product of the anode power consumption, luminous efficiency (η) and duty cycle (Du).

Luminance (L) is expressed in the following equation:

$$L=\eta\cdot e\cdot G\cdot e^n\cdot Du/(1+K)=A\cdot e^{n+1}\cdot Du........(2)(A=constant)$$

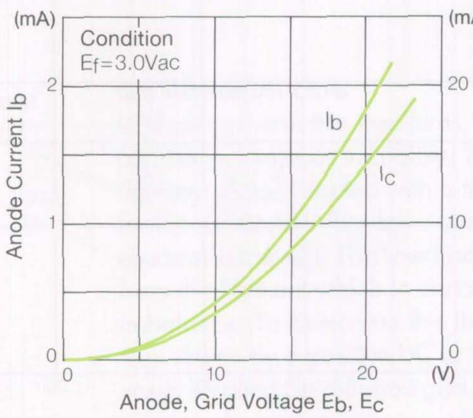


Figure 17. E_b, E_c–I_b, I_c Characteristics (Static Drive)

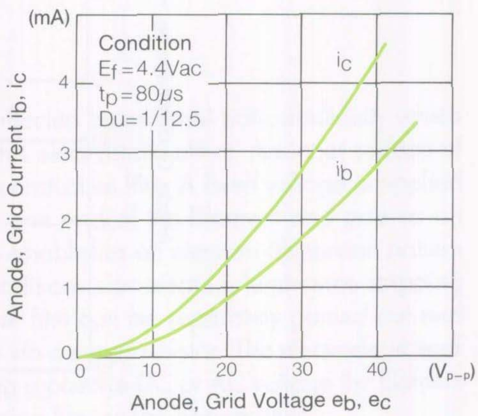


Figure 18. e_b, e_c–i_b, i_c Characteristics (Dynamic Drive)

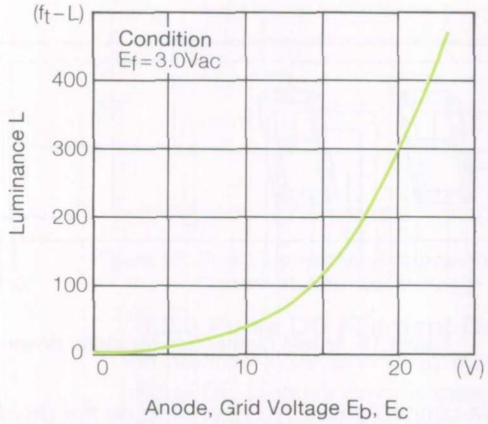


Figure 19. E_b, E_c-L Characteristics (Static Drive)

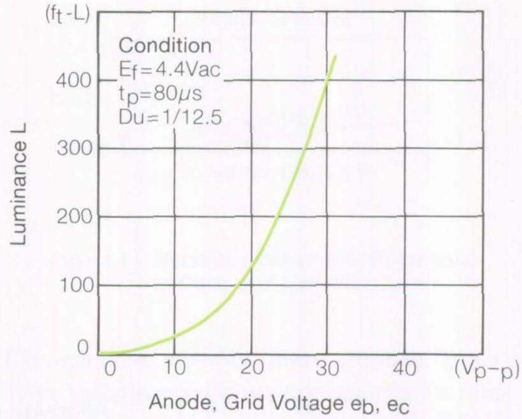


Figure 20. e_b, e_c-L Characteristics (Dynamic Drive)

Within being about 1.7, luminance varies approximately to the 2.7th exponential power approximately with anode and grid voltage. Luminance is equivalent to power, therefore it is necessary to carefully operate VFDs within their specified ratings so that failures are prevented. Failures include grid overloading which may cause thermal deformation, and in extreme cases, short circuits to other electrodes or an excessive rise of anode temperature.

6.3 Setting Anode and Grid Voltage

Applied anode and grid voltages are one of the factors which determines luminance. Luminance levels are determined based upon ambient brightness conditions, hue and transmittance of filters being used and other conditions inherent to the operating environment.

For static and dynamic drive, the desired luminance may be achievable by adjusting the anode and grid voltages. However adjustments must be within the specified range. For dynamic drive, luminance can also be varied by duty cycle. Figure 21 shows an example of luminance and it's relation to duty cycle and anode and grid voltage. When luminance is increased above it's nominal level care must be taken not to exceed the filament cathode emission capacity.

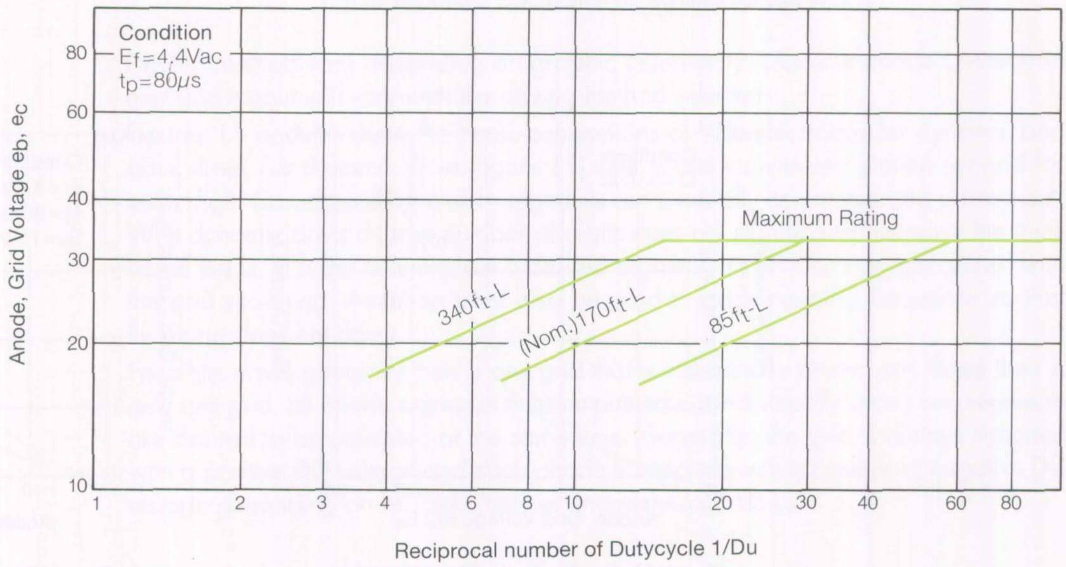


Figure 21. Operating Range Characteristics of Dynamic Drive VFD

6.4 Cut Off Voltage

As previously stated, segments luminesce when a positive voltage as referenced to the filament is applied simultaneously to the anode and grid. When either the grid or anode voltage are lower than the filament potential, segment luminescence ceases. To turn a luminescing segment off the anode or grid must usually have a negative potential to that of the filament. This negative potential is called cut off bias voltage. For static driven displays only anode segments require cut off voltage. Dynamic driven displays require that both anodes and grids be biased off.

Anode cut off voltage is usually 0 volt or higher. Anode bias voltage is based upon the phosphor threshold sensitivity which is the voltage at which luminescence occurs. For the grid to effectively shut off an energized segment it's negative bias voltage must be greater than the anode's. This is due to the initial speed of thermal electrons emitted from the filament, the filament voltage rating and the filament potential. Actively switched display and printed circuit board wiring traces create noise on adjacent traces due to capacitive coupling. Cut off voltage is increased to offset this phenomenon. As shown in Figures 9 through 12, the required negative cut off voltage will be larger when the filament transformer winding is grounded at one end as compared to a center tap grounded transformer. Figure 22 shows an example of grid cut-off voltage.

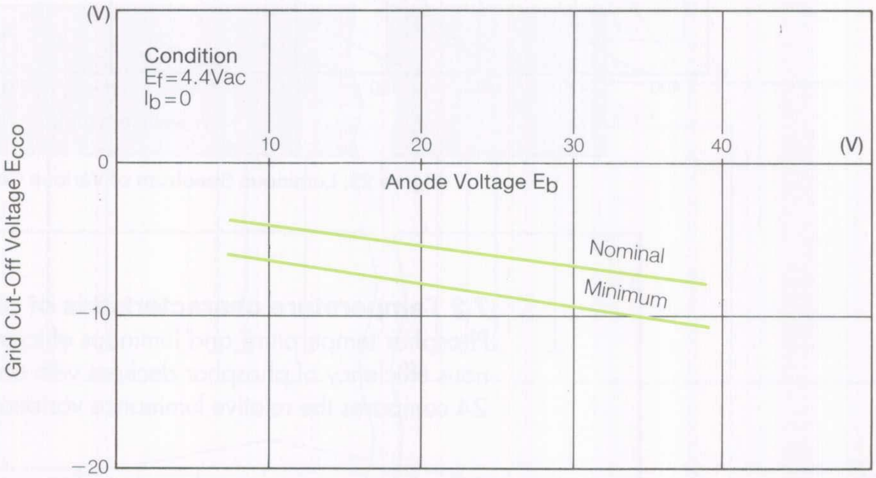


Figure 22. E_b–E_{cco} Characteristics (One End of the Filament Grounded)

6.5 Diffusion Grid

Without preventative measures, VFDs are affected by external static electricity which can cause luminous instability. To prevent this electrostatic effect, the inner surface of the front glass is coated with a transparent conductive film. A fixed voltage is applied to the conductive film by a connection to one end of the filament and acts as an electrostatic shield. This fixed potential also establishes an electron dispersion pattern from the filament which in certain drive conditions can create a luminance stripping imbalance. To overcome this the conductive film can be separately pinned out and then driven by a positive DC or AC voltage via a series resistor. The electrode in such cases is called the diffusion grid. By applying a positive DC or AC voltage the filament electron dispersion pattern is altered correcting luminance appearance.

7. Phosphor Characteristics

7.1 Phosphor Spectra

Figure 23 shows the emission spectra of seven types of phosphor currently available for VFDs. Colors range from blue, with a shorter wavelength, to reddish orange, with a longer wavelength. Green, which is the most commonly used, provides the highest luminance at low voltage.

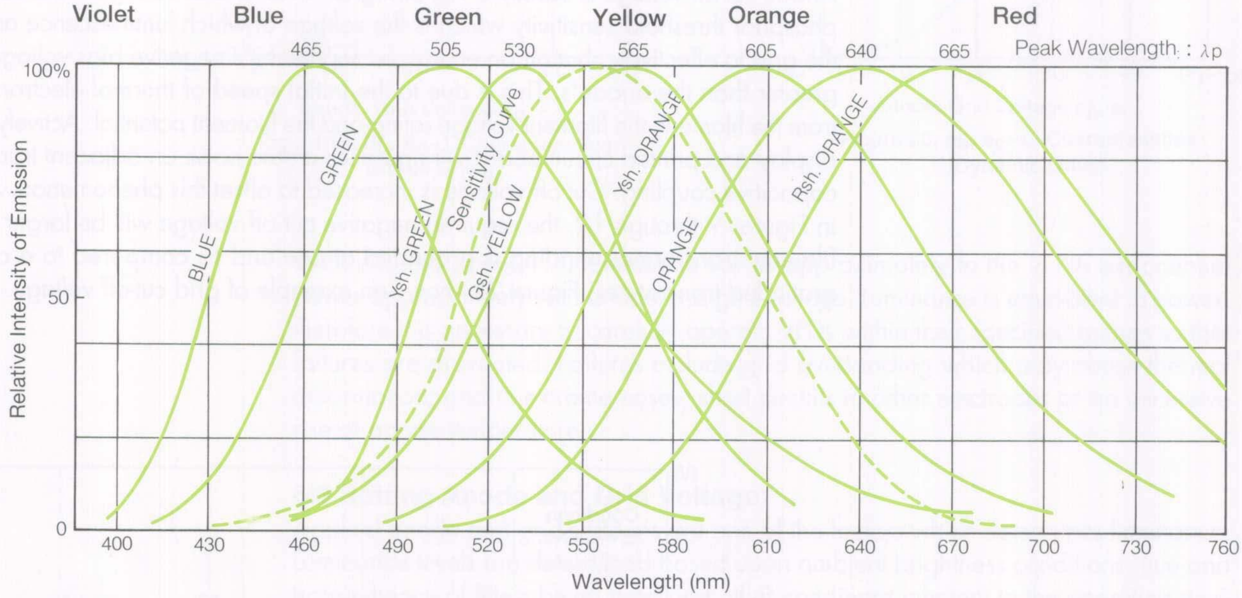


Figure 23. Luminous Spectrum of Various Color Phosphors

7.2 Temperature characteristics of phosphor

Phosphor temperature and luminous efficiency are inversely proportional. The luminous efficiency of phosphor declines with an increase of ambient temperature. Figure 24 compares the relative luminance variation of the seven phosphors.

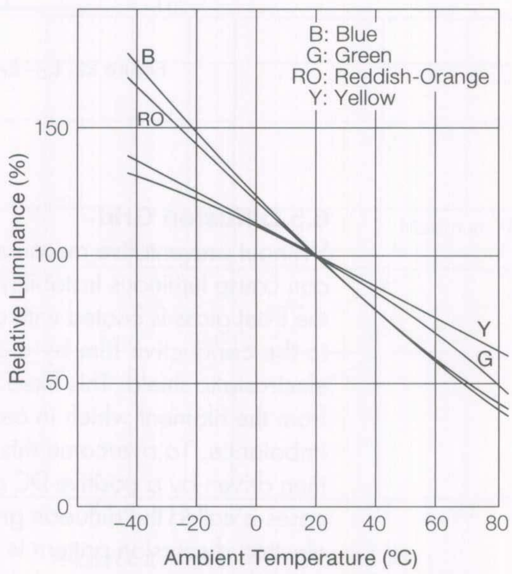


Figure 24. Temperature Characteristics of Various Phosphors

8. Basic Drive Circuit

8.1 Static Drive

The basic circuit for static drive is shown in Figure 25 in which the filament is grounded via the center tap. The number of terminal leads is large because all anode segments must be individually addressed. The static drive system is suitable for automotive applications which require low voltage operation and high luminance or in applications that are sensitive to radio frequency noise that is generated from dynamic drive systems.

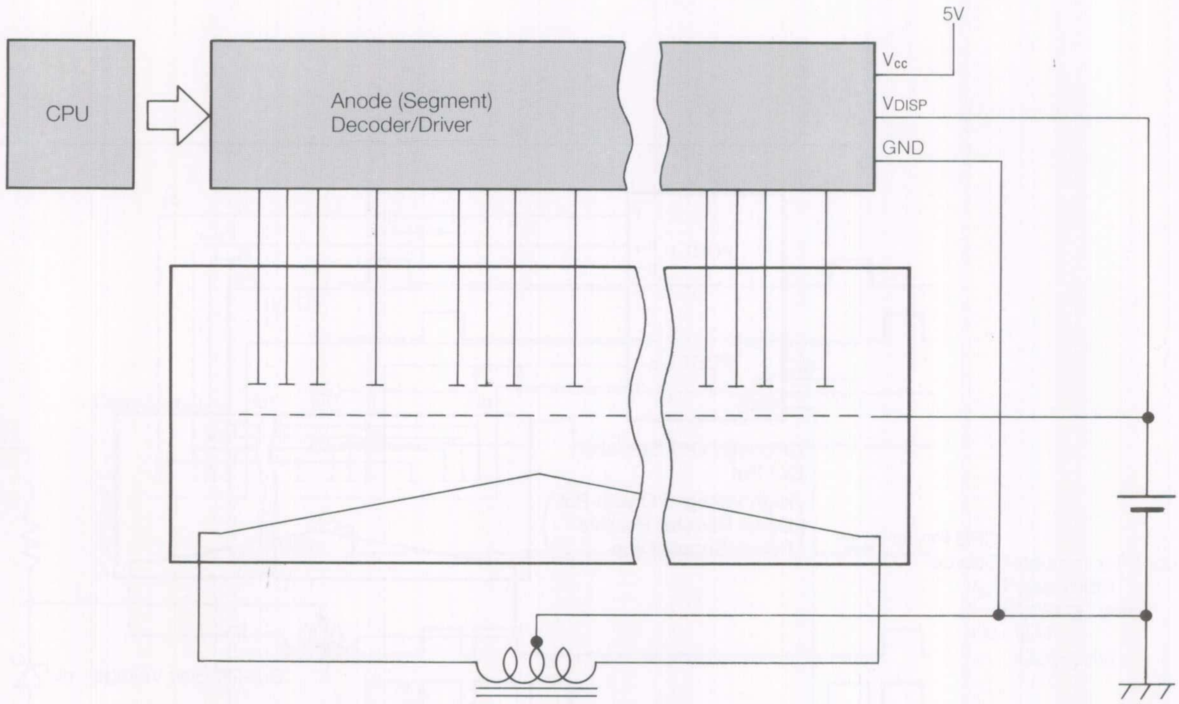


Figure 25. Basic Circuit of Static Drive VFD

8. 2 Dynamic Drive

Figure 26 shows the basic circuitry and related waveform potentials for a dynamic drive system. Figure 27 shows a sample timing chart for the grids (digits) and anodes (segments). The individually pinned out grids, and their corresponding digits, are repeatedly and sequentially driven per the wave forms in figure 27. Anodes that are to be luminesced are driven synchronously with their corresponding grid/digit. Figure 27 gives an example of which segments to drive for the characters "4, 3, 2, 1" under grids 1, 2, 3 and 4 (1G, 2G, 3G and 4 G) .

For the filament circuit as shown in figure 26 a typical method to create a cut off bias voltage is to use a zener diode connected to the center tap of the filament transformer. As can be seen in Figures 9 through 12, when connecting to one side of the filament cathode instead, the zener diode voltages must be increased.

A pull down resistor, is inserted between the grid output and negative bias line. When the grid driver output is not activated, the resistor effectively pulls the grid to the negative bias level. A 10k ohm resistor value is usually acceptable. A higher resistance value may not overcome capacitive coupling inherently found in the system, resulting in partial luminescence of an off segment. A lower resistance value results in wasted power dissipated across the resistor when the grid is energized.

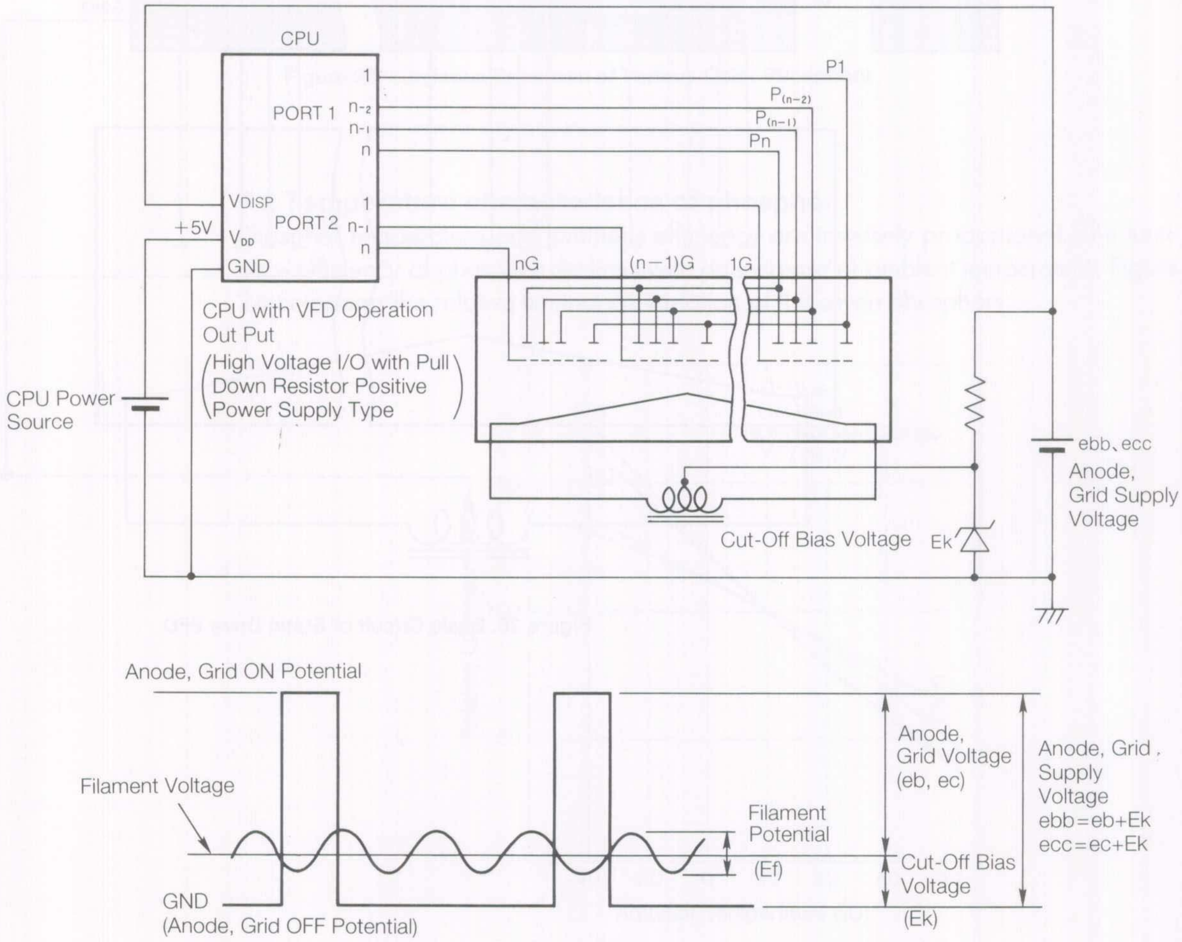


Figure 26. Basic Circuit and Relation of Electrode Potential of Dynamic Drive VFD

Microprocessors and VFD drivers in general, now contain active semiconductor and/or resistor Pull down systems built in. Figure 26 illustrates this type of system. Blanking time is required between grid on times to also prevent unwanted partial luminance of an off segment. The bottom of the grid wave form tends to be rounded, particularly when it transitions from on to off. Interdigit blanking time ensures that cross talking does not occur. A blanking time of 20μs is typically used.

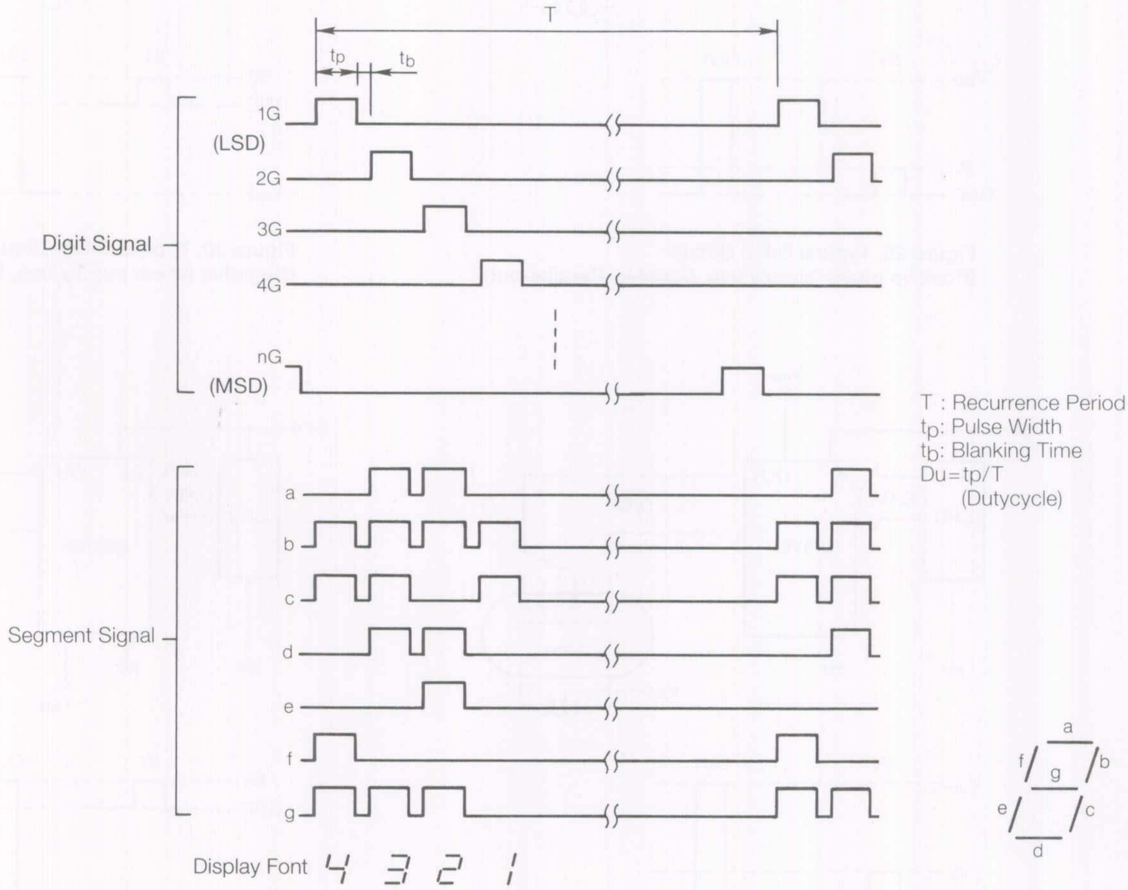


Figure 27. Timing Chart of Grid (Digit) and Anode (Segment) Signals

8.3 Drivers

For dynamic or static drive systems, the originating signals of the data interface lines are usually TTL or CMOS. A driver is necessary to convert the data signals to the useable logic and voltage levels required for the anode and grid lines. Some microprocessors are capable of directly driving VFDs, eliminating the need for a separate driver.

As shown in Figures 28 through 31, the drive configuration is typically serial in to parallel out or parallel in to parallel out. The power supply can be either a positive or a negative power system.

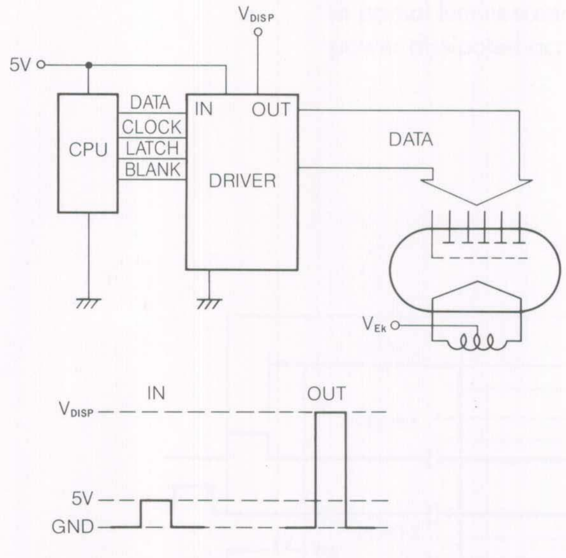


Figure 28. Typical Drive Circuit (Positive power supply use, Serial-in-Parallel-out)

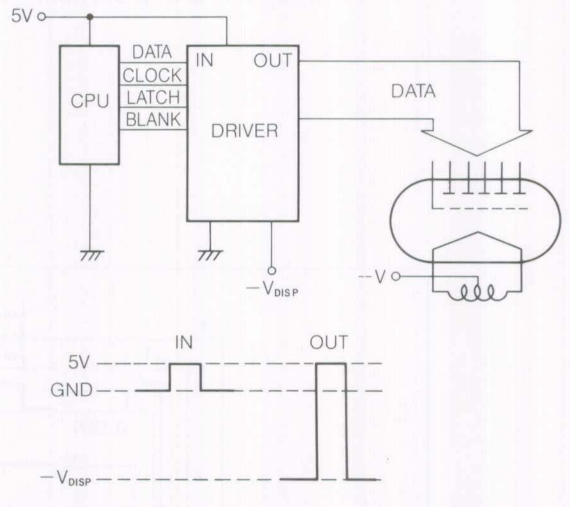


Figure 30. Typical Drive Circuit (Nagative power supply use, Serial-in-Parallel-out)

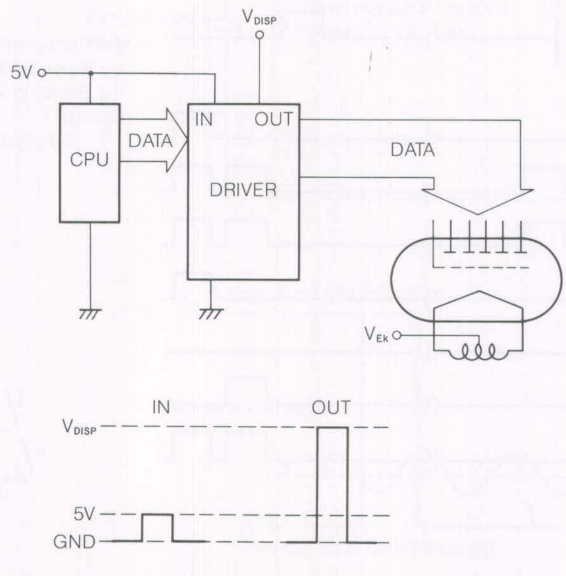


Figure 29. Typical Drive Circuit (Positive power supply use, Parallel-in-Parallel-out)

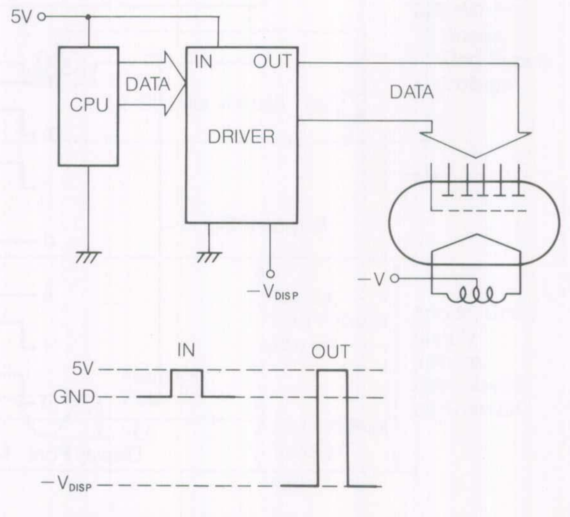


Figure 31. Typical Drive Circuit (Nagative power supply use, Parallel-in-Parallel-out)

9. Luminance Adjustment (dimming)

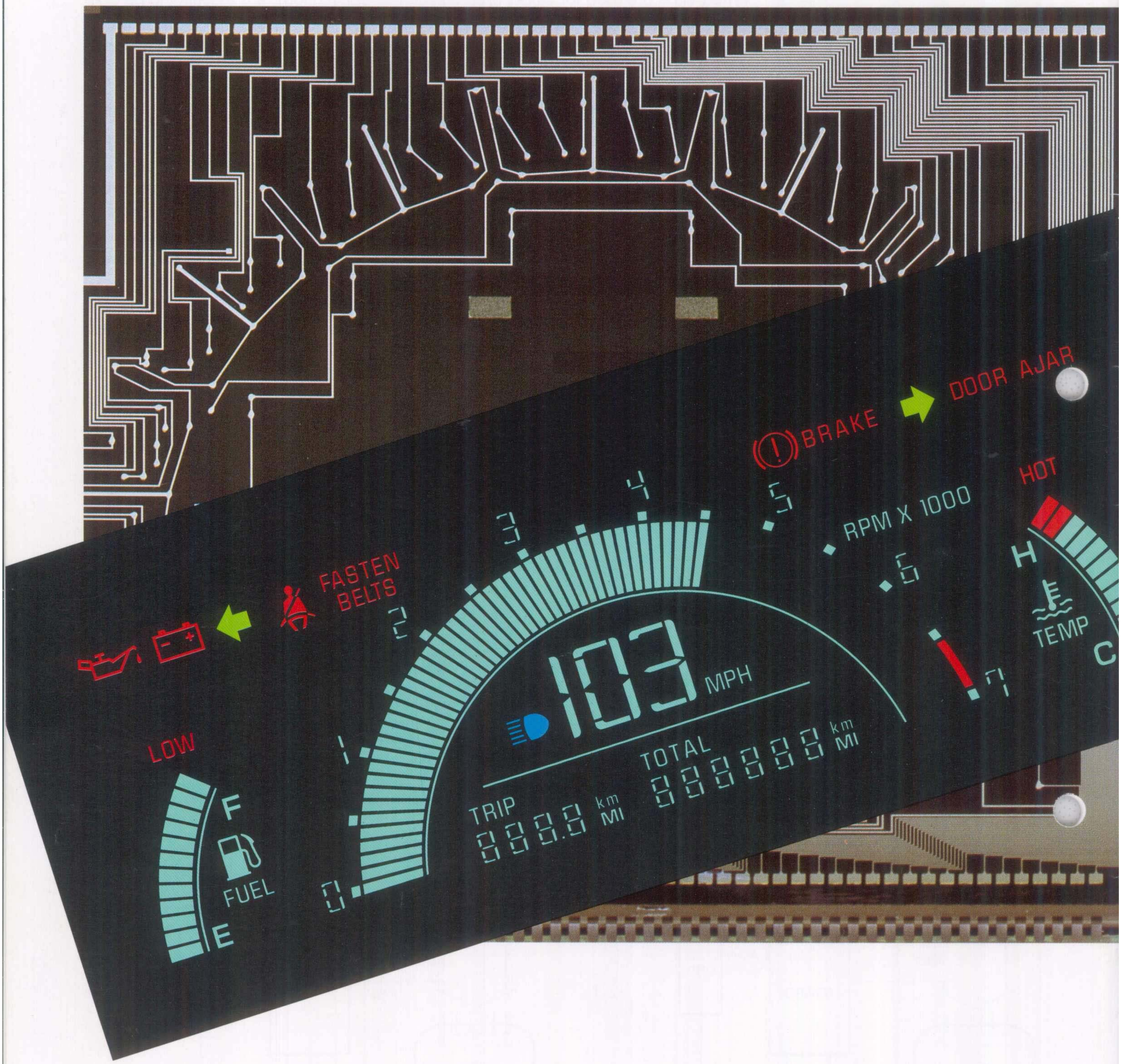
When VFDs are used for clocks or in automotive applications, it is essential to be able to adjust luminance according to ambient brightness. There are two methods to adjust luminance, (1) reduce the anode and grid voltages or (2) change the duty cycle applied to the anodes and grids.

9.1 Dimming by Reducing Voltages

This method is comparatively simple and causes no problems if the anode and grid voltage power supply reduction is within the minimum specified value. If voltage dimming is used below the specified value, display appearance is likely to deteriorate from the weakened acceleration and diffusion of electrons. Another method to decrease anode and grid voltage is to increase the bias voltage, which changes the filament cathode potential to the anode and grid. Care however should be taken with this method as bias voltage may become to high causing segments not to luminesce. The amount that luminance can be lowered by voltage is limited. In applications were luminance is required to be much lower, pulse width controlled dimming is recommended.

9.2 Dimming by Pulse

As explained in section 6.2 luminance varies in proportion to duty cycle provided that other conditions are constant. This method is recommended because luminance can be adjusted to any level without deteriorating display appearance. When a static driven display is dimmed by duty cycle, grid bias voltage is required to completely turn the segments off during the designated non luminescent time period .



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