The plasma panel is driven by high voltage, fast switching scan and sustain signals consuming a large amount of power and generating a large amount of heat. It is essential in such conditions to reduce the amount of heat generated and improve efficiency. In addition to high efficiency, PDP power supplies have to have fast transient response, low noise and low EMI.

A plasma display panel requires the following dc power supplies:

- Multi-power for processing chips, audio amplifiers, and other semiconductors devices: 3.3 V, 3.6 V, +15 V, -15 V, 5 V.
- Address electrode power supply (70 V)
- Sustain and scan power supply (200 V).
A PDP power distribution system is shown in Fig 1. It consists of the following elements:

- Main full-wave bridge rectifier
- Main line filter
- Power Factor Correction, PFC
- Multi-power supply for ICs, audio, etc.
- Sustain power supply VSUS
- Protection circuits (no shown)

Power factor correction reduces reactive power and introduces pre-regulation. The sustain power supply provide over 75% of the entire power requirement of the PDP. To ensure high efficiency, low noise and EMI, soft-switching resonant converters are used.
Power factor Correction, PFC

The purpose of PFC is to reduce the reactive load current which is of no real value to the device. Only resistive power consumption is of any value as far as the device is concerned.

A fully resistive load when fed with a sinusoidal voltage is said to have a power factor of one. Power factor is defined as

\[
\text{Mean power} / V_{\text{rms}} \cdot I_{\text{rms}}
\]

If the voltage and current are pure sine waves, the power factor is given as \( k = \cos \theta \), where \( \theta \) is the phase difference between the current and voltage waveforms. Since for a resistive load, current is in phase with the voltage, it follows that \( \theta = 0 \) and \( \cos 0 = 1 \). Hence the power factor \( k = 1 \).

For a purely resistive load, power \( P = V_{\text{rms}} \times I_{\text{rms}} \). However, for a reactive load, the power factor has to be taken into account and power is given as

\[
P = V \times I \cos \theta
\]

Thus, with a power factor (\( \cos \theta \)) of 0.5, only half of the power is useful power and the other half is completely wasted power.

A power factor of one is the highest power factor possible in which all power consumed by the device is useful power. On the other extreme, a purely reactive load, e.g. a pure inductor or a pure capacitor, has a power factor of zero since \( \theta = 90^0 \) and \( \cos 90^0 = 0 \). A power factor less than one
can also be obtained if the voltage and/or current waveforms are not pure sinusoidal, if they containing harmonics, even though the load is resistive. This is the case with all types of rectification including controlled rectification. For this reason, the power rectification and supply circuits look reactive to the mains supply with a power factor of between 0.5 and 0.7.

To rectify this situation, power factor correction, PFC is employed to ensure that as little power as possible is wasted. Furthermore, under European law, mains harmonics are restricted for devices of 75 W and over. A power factor correction is therefore needed to ensure that these harmonics do not exceed the permitted level. A further reason for using PFC is to reduce the amount of imbalance on the three-phase mains power supply caused by low power factors. Such interference becomes noticeable with high power requirements for equipments such as electric motors and PDPs. With PFC, a power factor of 0.9 is possible.

**Power factor correction**
With the simple rectifier circuit illustrated in Fig. 2, the diodes act as switches which conduct for a short period of time depending on the load current even if the load was fully resistive.

The current flows only when a pair of diodes conducts naturally, i.e. when they are forward biased during the period when the instantaneous value of mains voltages on their anodes exceeds the capacitor voltage on the cathode side. The current waveform is therefore a relatively narrow pulse as illustrated in Fig. 2. While the fundamental of the current waveform is in phase with the incoming voltage, its harmonics are not resulting in a low power factor. This may be tolerated where power requirements are low (10s of Watts). However, when power consumption is high, in the region of 100s of Watts, then the losses due to low power factors are high and must be avoided. This is carried out
by a power factor correction, PFC circuitry. Instead of the capacitor receiving a charging current once every half cycle, PFC ensures that the charging current is small but more frequent; 100s of times every half cycle.

Refer to Fig. 3. When Switch S is closed, I flows through inductor L in a linear manner storing energy in the inductor. When S is open, current is abruptly cut and back e.m.f. across the inductor provides a forward bias to diode D, inductor L and capacitor C form a resonant circuit and charging current $I_C$ flows to charge capacitor C. Energy stored in the inductor is now transferred to the capacitor. When the capacitor is fully charged and $I_C$ is zero, diode D is reverse biased. At this moment, S is closed and current begins to flow through L and so on. The average current
taken from the mains now follows the shape of the voltage as shown in Fig. 3 resulting in a power factor as high as 0.85 or even 0.9. The switching waveform for S is the pulse modulated waveform shown with a frequency of 40-100 kHz. Note that the mark-to-space ratio of the PMW changes with the sine wave input. The off period increases gradually as the input goes up to peak and decreases as it goes down to zero while the ON period remains the same throughout.

The main element of a PFC circuit is shown in Fig. 4. A power MOSFET, Q1 is used as the switching element. Q1 is driven by bipolar transistor Q2. The PWM pulses are produced by the PFC control oscillator. The duty cycle is determined by the shape and amplitude of the mains sine wave
as well as the output voltage and current levels. In this respect, PFC acts as a voltage pre-regulator.

Fig. 5

Fig. 5 shows the main elements of a practical PFC circuit used by Panasonic employing two balanced MOSFETs for improved power factor correction. Sine wave, current and DC output sensors are used to ensure that the current waveform follows closely as closely as possible the mains voltage.
Soft-switching resonant DC-DC converters

The power supply of a PDP TV employs three types of DC-to-DC converters:

- Linear regulated converter
- Switched Mode Power Supply, SMPS
- Soft-switching resonant converter

The type linear regulators and switched-mode power supplies (SMPSs) used here is normally the flyback DC-DC converter. SMPSs suffer from a number of limitations: high electromagnetic interference (EMI), high stress levels on the switching devices and limited switching speeds to less than 100 kHz. These limitations are mainly a result of the switching taking place at a high current and/or voltage levels. Hence these converters came to be known as hard-switching converters. When switching at high frequencies, these converters are associated with high power dissipation and high EM interference caused by high frequency harmonic components associated with their quasi-square switching current and/or voltage waveforms.

To overcome the limitations of the traditional SMPS, a third generation power converters known as soft-switching (resonant) converters were introduced in the late eighties.

Like switched-mode power supplies, soft-switching power units are DC-DC converters. DC from a rectifier is first converter to AC through a switching element. This AC is fed into the primary of a transformer with a number of
secondary windings for multi-outputs. The secondary outputs are then rectified in the normal way to produce the various DC voltage levels. The new element that resonant converters bring is switching takes place when the voltage across the switching element is zero, known as zero voltage switching (ZVS) or when the current through the switching element is zero, known as zero current switching (ZCS). ZVS and ZCS are produced by using resonant circuits; hence these converters are also known as resonant or quasi-resonant converters. The result is low switching power dissipation and reduced component stress. These in turn result in increased power efficiency, reduced size and weight, faster responses and reduced EMI problems. The reduction in losses due to zero voltage or zero current switching makes it possible to utilise much higher switching frequencies in 100s kHz or even few MHz. And since the size and weight of the magnetic components (inductors and transformers) and capacitors are inversely proportional to the switching frequency, the higher the latter, the smaller the size and weight of the power supply improving its power density. A further advantage of soft-switching resonant converters is, because of their switching frequencies, they can utilise transformer and switching elements’ leakage inductance and capacitance respectively as part of the resonant circuit.

**Principle of operation of resonant converters**
When a resonant circuit is fed with a +10 V step voltage, it oscillates resulting in what is known as ringing. The capacitor charges up to 10 V, at which point current ceases and the capacitor begins to discharge causing current to flow in the opposite direction transferring energy from the capacitor to the inductor. The current continues to flow in that direction until the capacitor is fully charged to -10 V at which point, current ceases and swings back in the opposite direction and so on as illustrated in Fig. 6. As can be seen, the resonant waveform has zero current when the voltage is at a peak and zero voltage when it crosses the 0V line. Resonant converters use this fact to ensure that switching takes place at one of these points.

Fig. 6
Steady state analysis of a basic ZCS resonant converter (Fig. 7 and 8)

Fig. 7 Zero current switching (ZCS) resonant converter
In the steady state, load current $I_{L2}$ is constant. The cycle starts when MOSFET Q1 is turned ON by a control pulse while D1 is also ON. With capacitor C1 short circuited by D1, $I_{L1}$ flows through inductor L1 and diode D1. $I_{L1}$ increases in a linear fashion and energy is stored in the inductor. When $I_{L1} = I_{L2}$, diode current drops to zero and the diode turns OFF naturally (zero current switching). With D1 open circuit, L1 and C1 form a resonant circuit. $I_{L1}$ increases to a peak in a sinusoidal manner and energy is transferred to the capacitor as $I_{C1}$ charges capacitor C1. Once $I_{L1}$ reaches its peak (at which point the voltage across C1 is equal to the input voltage $V_{IN}$), it begins to drop and when $I_{L1} = I_{L2}$, C1 is fully charged and $I_{C1}$ drops to zero. When $I_{L1}$ drops further below $I_{L2}$, $I_{C1}$ is reversed and the capacitor begins to discharge transferring energy to inductor L2. When $I_{L1}$ drops to zero, MOSFET Q1 switches OFF naturally (ZCS) keeping $I_{L1}$ at zero. The capacitor continues to discharge and when its voltage falls to zero and $I_{C1} = I_{L2}$, diode D1 switches ON naturally (ZCS) to short circuit C1 and break the resonant circuit. This state continues until Q1 is switched on by a control pulse to commence the next cycle and so on. As can be seen, the period Q1 remains ON is fixed by the resonant frequency of L1 and C1 while the time it is OFF is determined by the control pulse which is varied as necessary to regulate the voltage. This type of resonant converter is known as 'fixed on-time, varied off-time'. The ON period of the power MOSFET switch is the resonant period.
of L1/C1, known as the tank. For heavy loads, the resonant off-time is made shorter.

**Zero Voltage switching, ZVS**

A resonant converter which uses zero voltage switching (ZVS) is illustrated in Fig. 9 with L2/C2 forming a low-pass filter. In the steady state condition, load current $I_0$ is equal to the current through L2. Starting with the MOSFET on, its current $I_T$ and $I_{L1}$ are equal to $I_{L2}$ and Diode D₂ is reverse biased. The voltage across the MOSFET is zero. When the transistor is turned off by a control pulse to its gate, current is diverted into C₁. Capacitor C₁ charges up until, when fully charged, diode D₂ becomes forward biased and conducts and C₁ and L₁ begin to oscillate going up to a peak after which, the voltage across C₁ attempts to reverse and diode D₁ starts conducting. During this time, the MOSFET is
triggered to conduct, but remains off while D₁ is on. As soon as D₁ turns off when \( I_{L1} \) drops to zero and begins to reverse, the transistor turns on (zero voltage switching) and remains on until it is turned off by a pulse and so on. The MOSFET turns off naturally and is turned on by a pulse, i.e. 'fixed off-time, varied on-time'.

Fig. 10 Resonant converter circuit diagram

A circuit diagram for a resonant converter used to supply the sustain voltage for a 42 inch plasma panel as shown in Fig. 10. Two pairs of back-to-back Power MOSFETs Q₁₂/Q₁₅ and Q₁₃/Q₁₄ are used as the switching transistors driven by Q₁₀ and Q₁₁. They are fed with 400V DC from a flyback converter. Two anti-phase PWM control pulses arrive from the control panel to Q₂ and Q₃ to control the switching of each pair. The output for the sustain and the scan electrodes of the plasma panel are provided full-wave rectifiers connected to the secondary of the output transformer. Feedback to the control panel is obtained via Q₆ and Q₇. Although power
MOSFET have been used almost universally, current-driven Insulated Gate Bipolar Transistors, IGBT (Fig. 11) may also be used.

Fig. 11 IGBT symbol