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EMC AND THE CHOKE FED POWER SUPPLY

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INTRODUCTION

The imminent arrival of more stringent European Electromagnetic Compatability (EMC) regulations has caused consternation among electronic equipment manufacturers. One area of worry is the amount of interference which is coupled into the mains from the equipments power supply system. An area of concern is the use of switched mode power supplies and much effort has been concentrated on reducing interference from them. Another area of concern is the conducted interference from conventional transformer coupled power supplies operating at mains frequencies. It is these sorts of supplies that are the subject of this paper which will discuss both the commonly used diode/capacitor supply and the less used choke fed power supply. The paper will also discuss techniques for reducing the number of components in the choke fed supply.

Historical note

The choke fed supply is an old idea and in fact was the dominant power supply technology in the valve era because the valve and gas tube rectifiers used in those days had limited peak current capabilities. The arrival of solid state rectifiers with high peak current capabilities heralded the increased use of the diode capacitor supply with its attendant reduction in cost.

THE DIODE CAPACITOR SUPPLY

The circuit of the conventional fullwave diode capacitor supply is shown in *Figure 1.*

It consists of a step down centre tapped transformer feeding two diodes. The other ends of the two diodes are connected to a smoothing capacitor which provides the smoothed DC output. The way the circuit works is that the diodes will conduct when the voltage from the transformer is greater than the voltage on the capacitor. Under normal operation this condition will exist for a short period of time at the peaks of the AC waveform (*see Figure* 2) during this time. The capacitor is charged by the current through the diodes and its voltage rises until the capacitor voltage equals the input voltage (assuming a zero voltage drop rectifier). This happens at the peak of the AC waveform in one ideal supply. From then until the next half cycle the capacitor is discharged by the load current and thus falls.

Thus we see that the ideal capacitor diode supply provides the following:

(a) An output voltage approximately equal to the peak voltage output of the transformer.

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b) A ripple voltage which depends on the current drawn from the supply. This is because as the load current increases the smoothing capacitor is discharged more.

c) A current spike at two times the line frequency due to the short charging period of the capacitor. This current is a function of output current and ripple voltage, low ripple at high current implies a large spike.

Implications

The implication of the above is that the diode capacitor is capable of producing a considerable amount of high frequency noise currents both to the mains supply and to system being provided with power.

This high current spike can clearly be coupled into the mains via the transformer, although some of the high frequencies may be reduced by the leakage inductance of the transformer.

The high current spike can also couple into the system being powered because if the system and the capacitor charge a common earth then the high current spikes can generate a noise voltage in the common impedance of the earth. Although this impedance may have a resistance of fractions of an ohm because of the high current of the spike significant interference may be generated (*Figure 3* shows how this occurs). The result, due to the presence of high-frequency components, is an annoying buzz.

Another implication of this type of supply is that all the spikes are synchronised to the mains so that several pieces of equipment on the same mains supply may generate an appreciable amount of interference as their spikes will add coherently.

The current spike also requires that the transformer be over-rated to cope with the peak current demands. Based on figures quoted in Schade [1] one could require a transformer VA rating of 2 to 3 times the desired DC output VA rating.

The size of the current spike

In theory the current spike could be very large, for a 10% ripple factor the diode must conduct for only $^1/_7$th of the cycle, thus the current spike would have to be 7 times the DC current, assuming a square wave charging current. For a 1% ripple factor the charging period is only $^1/_{22}$nd of the cycle with an attendant increase in the peak charging current! In practice the leakage inductance of the transformer and parasitic resistances of the transformer and the diodes cause the conduction angle to be greater than this (see *Figure 4*) and so reducing the peak current. However there is still a large peak.

Practical results

Figures 6 and 7 show the current wave forms in the transformer and capacitor. In the supply shown in *Figure 5* the spikes are clearly visible and notice that the transformer current is a series of alternating polarity, whereas the capacitor current is a series of unipolar pulses.

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The transformer used in the experiment has significant resistance and leakage inductance and so the current spikes are quite wide. With a better transformer they would be narrower and have a higher peak current.

Figures 8 and 9 show the spectrum of the mains current wave form of the diode capacitor supply of *Figure 5*. *Figure 8* shows the harmonics up to 5kHz and *Figure 9* is a closer look at the first few harmonics. From *Figure 8* one can see that at high harmonic numbers the harmonic level is approximately proportional to $^1/_n$ where n is the harmonic number. However, the first few harmonics (*Figure 9*) are of similar amplitude. As EN60-555-2 [2] requires a rapid drop in amplitude of the first few harmonics this presents one with a problem. For example, the example power supply would exceed EN60-555-2's 5th harmonic rating if it was supplying 15^2 watts with the wave forms shown. One can note that it is the low frequency harmonics which cause the most problem with EN60-555-2 because of its requirement for a rapid drop in harmonic amplitudes for the first few harmonics. The dotted line on *Figure 8* shows the EN60-555-2 specification shifted down so that one can see how the harmonics generated match the shape of the EN60-555-2 curve.

The Choke Fed Supply

The circuit of a full wave choke fed supply is shown in *Figure 10*. It differs from the diode capacitor supply only in the presence of an inductor (choke) series with the diodes and the capacitor.

The waveforms of the ideal circuit are shown in *Figure 11*. The effect of the inductor is to keep the diodes in conduction for longer and to make the current in the capacitor sinusoidal. This results in the current swinging sinusoidal positively and negatively with respect to the average DC current providing the current in the inductor does not drop below zero. The diodes remain in conduction for the whole of their relevant half cycle. This minimises the spikiness of the diode current. Because the amount of variation around the average DC current is a function of both the load presented to the supply and the applied voltage there is a minimum current requirement to ensure that the current in the inductor does not fall to zero. This current is known as I_{crit} and below it the choke fed supply behaves progressively more like a diode capacitor supply. Above I_{crit} the variation about the mean current remains constant and so becomes an increasingly smaller percentage variation relative to the DC current. Thus the choke fed supply provides the following characteristics:

a) Above I_{crit} the ripple is independent of load.

b) The output voltage is the absolute of the peak applied voltage (0.64 Vpeak) above I_{crit} but rises to Vpeak as one reduces the current below I_{crit}.

c) The worst case peak to average current above I_{crit} is 2 to 1 at I_{crit}. It gets progressively less as the load current is increased above I_{crit}.

d) The current in the capacitor is sinusoidal and constant above I_{crit}.

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e) The current in the transformer is a square wave with a sine wave superimposed on top of it.

Figures 12 and 13 show practical results for a choke fed supply using the same components as the capacitor supply of *Figure 5* but with the addition of an inductor of 72mH. Note that the amplitude of the transformers peak to peak current is less than the capacitor diode supply but that it is a square wave. Also notice that the capacitor current is now sinusoidal.

Figures 14 and 15 show the spectrum of the mains current for the choke fed supply when supplying the same power as the diode/capacitor supply. From these results one can see that the high order harmonics are similar to the diode/capacitor supply, although the choke fed supplies harmonics are slightly larger, but that the low order harmonics fall off much faster. This means that for the choke fed supply the medium order harmonics now limit the maximum power output before EN60-555-2 is exceeded. Thus the example choke fed supply could supply 637 watts with the wave-forms shown before exceeding EN60-555-2 on the 19th harmonic. This is a factor of 4.19 over the diode capacitor supply.

Implications

The implications of the above results are that the choke fed supply does indeed produce less interference than the diode capacitor supply. It also makes better use of the transformer. As for current above I_{crit} the ratio of RMS current to DC current approaches unity. This would allow one to use smaller transformers for a given power output. The fact that ripple is a constant above I_{crit} also implies that there would be less intermodulation between the power supply and output signal in power amplifiers.

The problem with the choke fed supply is the choke which can be a sizeable inductance. The equation for the minimum inductance for a given current is given by:

$$L_C = \frac{R_L}{950}$$

as $$R_L = \frac{V_{out}}{I_{out}}$$

therefore $$L_C = \frac{V_{out}}{950\, I_{out}}$$

This means that a supply with an output of 50 volts and minimum current of 200 mA requires an inductance of 263 mH. Higher voltages would require higher inductances but higher currents would require lower inductances. The ripple is given by:

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$$\text{ripple factor} = \frac{1.2 \times 10^{-6}}{LC}$$

and can be made small by a suitable capacitor.

The size of the inductor may result in a supply with poorer regulation because of the added series resistance which it introduces. The choke also results in a more expensive supply because of the additional wound component, although the extra cost may be offset by the need to have a less highly rated transformer. The choke has to carry DC and so needs more iron than a transformer to avoid saturation.

A final problem with the choke supply is that the output voltage can rise above its nominal value if:

a) The output current drops below I_{crit}.

b) On turn on the supply can overshoot because of the transient response of the LC filter formed by the choke and the smoothing capacitor.

For these reasons it is worth while having some over voltage protection in the supply.

INTEGRATED MAGNETIC CHOKE SUPPLY

It is possible to combine the choke and transformer into one wound component by making the transformer have a deliberate value of leakage inductance. Note the leakage inductance can be provided either by the provision of coils which cancel out the effect of the AC input or by designing a transformer structure which allows only a fraction of the primary flux to pass through the secondary. The amount of copper and iron used in both cases is likely to be comparable but the former technique fits conventional transformer construction techniques more easily. Note the core of the integrated transformer must be capable of handling both the DC and AC fluxes without saturation and so will have to be larger than the equivalent sized transformer. However, in full wave bridge circuits it may be possible to arrange some cancellation of the DC flux.

This technique results in a power supply topology which looks identical to the common diode capacitor supply, the only difference being that the transformer is different. This offers the potential for integrating the choke fed supply into existing designs, providing space is available in the case work for the larger wound component. The size increase of this component may not be too great overall because the transformer it replaces will probably be over-rated relative to the power demands of the system being powered. The integrated magnetics topology also allows one to keep the same production practices as the old technology in new designs.

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CONCLUSIONS

The choke fed supply offers reduced EMC emissions compared with the diode capacitor supply. It is most useful in systems which require a current which does not vary over a wide range because in these circumstances the size of choke required is reduced.

In an integrated magnetic form it provides a viable alternative to conventional transformers in existing and new designs.

REFERENCES

1 O H Schade. "Analysis of Rectifier Operation", Proc. IRE, vol 31,pp 341-361, July 1943.

2 BSI. BS5406: Part 2: 1988 EN 60 555-2: 1987, British Standard, "Disturbances in supply sytems caused by household appliances and similar electrical equipment, Part 2, Specification of harmonics" [EN title: Part 2: Harmonics].

3 R W Landee, D C Davis, A P Albrecht, "Electronic Designers' Handbook", McGraw-Hill, Published 1957.

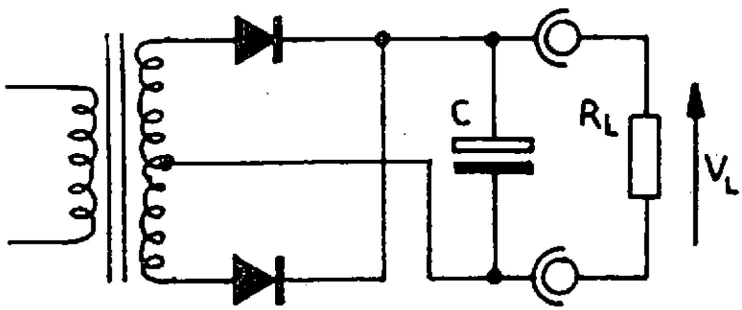

Figure 1: The Diode Capacitor Supply

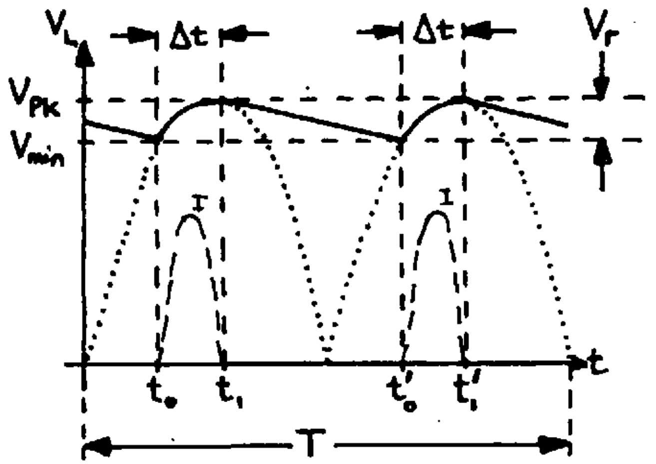

Figure 2: Diode Capacitor Supply Wave-forms

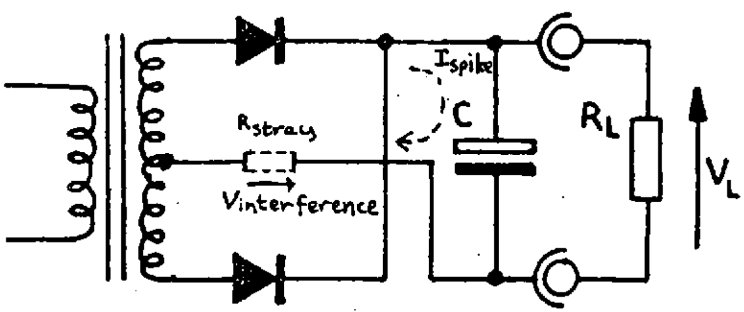

Figure 3: Ground Interference Generation

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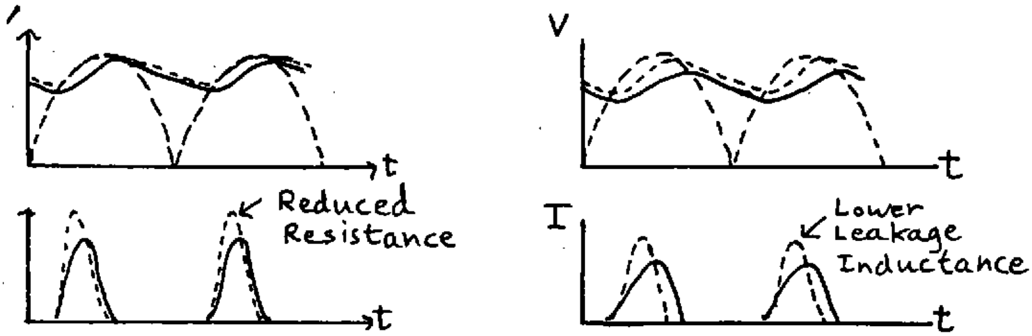

Figure 4: Effect of Leakage Inductance and Series Resistance

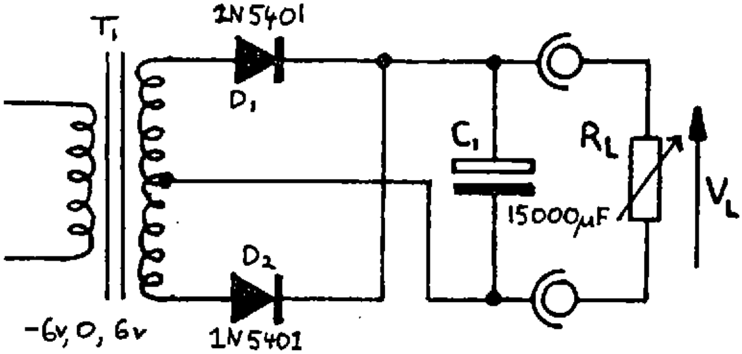

Figure 5: Test Power Supply

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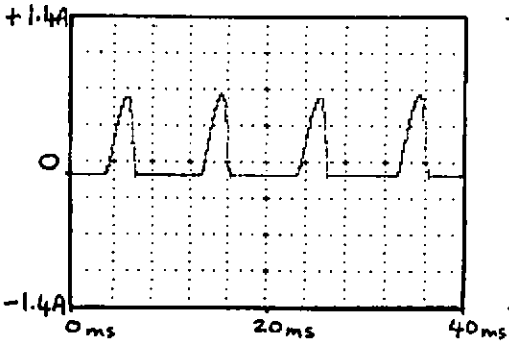

Figure 6: Capacitor Current

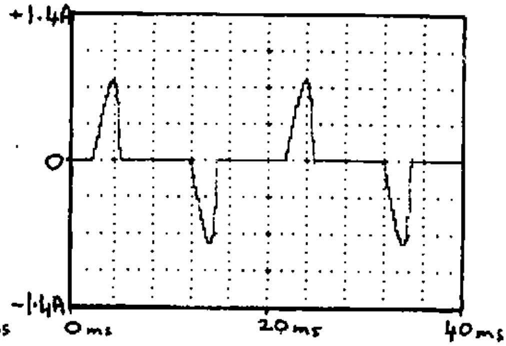

Figure 7: Transformer Current

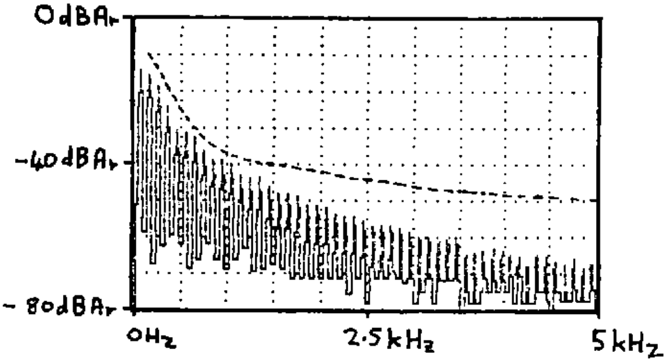

Figure 8: Wideband Current Spectrum

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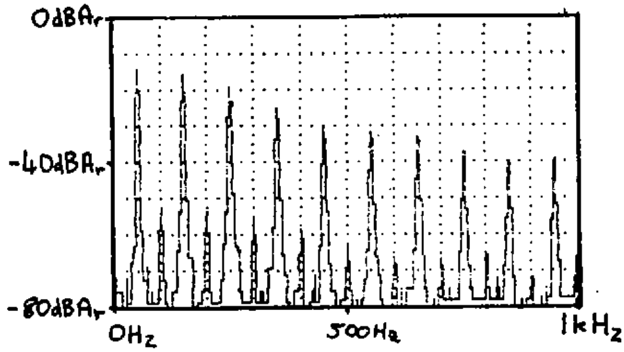

Figure 9: Low Frequency Harmonics

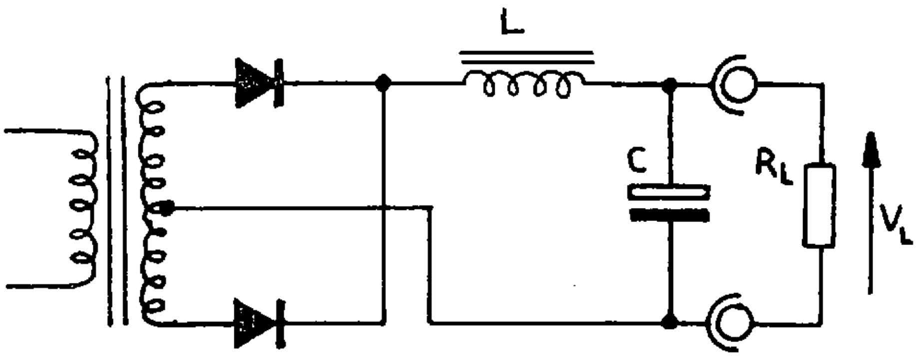

Figure 10: The Choke Fed Supply

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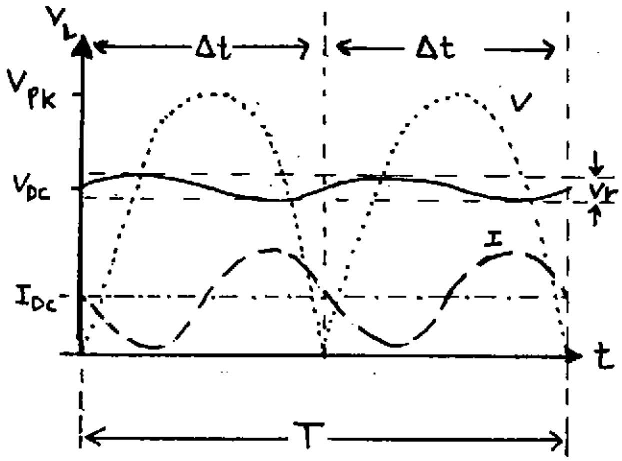

Figure 11: Choke Fed Supply Wave-forms

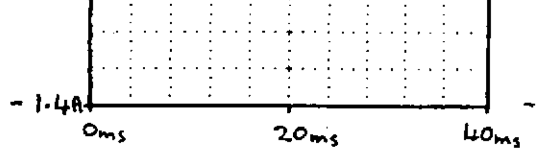

Figure 12: Capacitor Current

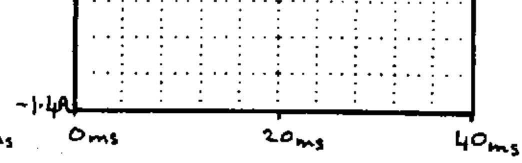

Figure 13: Transformer Current

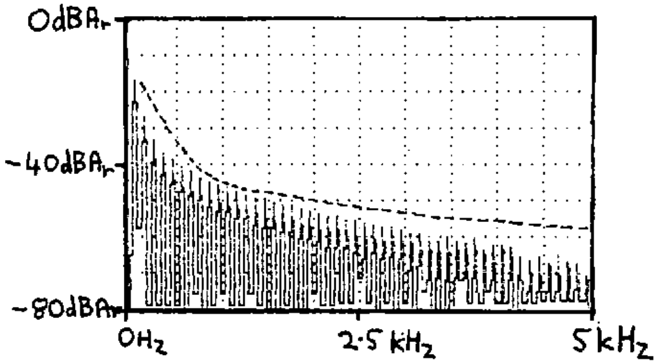

Figure 14: Wideband Current Spectrum

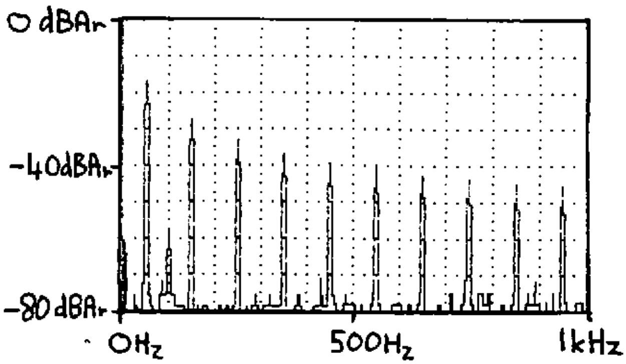

Figure 15: Low Frequency Harmonics

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