Solving EMI for Low Wattage Universal Input Power Supplies

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***Abstract*-This paper presents methods and results to solve line conducted electromagnetic interference (EMI) for low wattage universal ac line input switching power supplies. The EMI noise reduction is shown for each technique. Techniques include the use of a common mode input coupled inductor, and X ac line capacitor, hot-to-cold ground Y capacitor, schottky rectifiers, and the use of ferrite beads.**

Introduction

A 20 watt multiple output flyback switching power supply is very common in today's consumer products. Two such products are set-top boxes for cable TV, and satellite receivers for TV's. The supply usually is a universal type varying from 85 Vac to 240 Vac with a line frequency variation from 47 Hz to 63 Hz. In a satellite receiver there are usually four output supply voltages: 3.3 Vdc, 5.0 Vdc, 12.0 Vdc and 32 or 38 Vdc. The system uses only a two-wire ac power line cord. The only earth ground connection is through the antenna.

Two power supplies were designed as examples to show how to use two different control ICs and meet the EMI limits. The first design uses a MC33364 with an external power MOSFET operating in a critical conduction mode (CCM), sometimes referred to as borderline conduction mode (BCM). The second design uses a fixed frequency, 100 kHz high voltage SmartMos control IC, NCP1001, operating in discontinuous voltage mode (DCM).

Two important factors effecting cost are (1) time to market and (2) EMI suppression cost. The purpose of this article is to help designers reduce their test time and redesign time if they use the MC33364 or the NCP1001 in the power supply.

FCC

The units were tested to the FCC Class B, Part 15, sub-part J limits. An HP spectrum analyzer with a peak detector and bandwidth of 10 kHz is used to make the measurements. One HP model number is the HP 8562A the other is the HP E7401A EMC Analyzer. A dual Line Impedance Stabilization Network (LISN) is used as shown in Figure 1. This LISN is for the US standards and has a 50 uH series choke on each leg of the ac line. There is a series 0.1 uF capacitor and a 50 ohm resistor going to ground. The capacitor is different for European test and needs to be changed if using IEC test limits. A commercial dual LISN, EMCO model 3810/2, was modified to meet the FCC requirements.

The FCC limits are 48 dBuV (dB micro-volts) from 450 kHz to 30 MHz. For a production design an additional 6 dB of safety margin is added to ensure compliance over component tolerance ranges. A limit of 42 dBuV was used for these reference designs. The Class B specifications are lower than industrial Class A limits and are more difficult to meet for production designs targeted for consumer products.

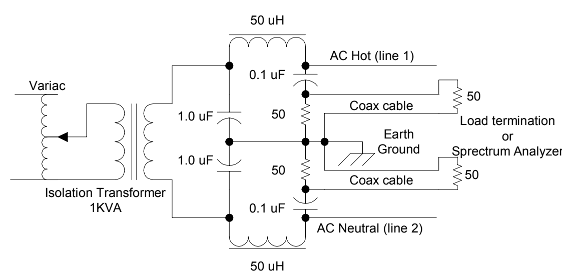


Figure 1. Dual LISN. This is a 50 uH inductor and 0.1 uF capacitor system. Shown are inputs and outputs.

No EMI Filter Components

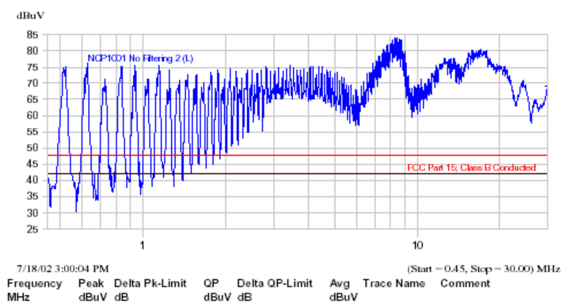
Plot 1 shows the effect with no EMI filtering. This test was performed with the power supply setting on an isolated platform. The FCC limits are shown and the 42 dBuV limit can been seen. This was performed using the NCP1001. Without any EMI filter this would fail and cause interference with ac line connected products such as an AM radio.

HOT-to-Cold Ground Capacitor

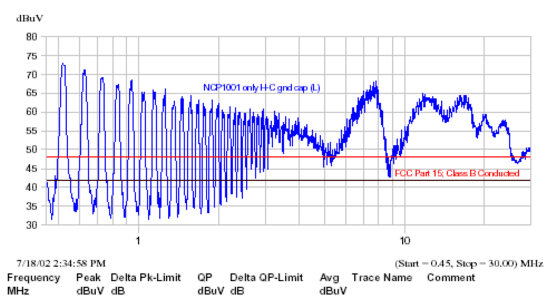
The first component added to the system is often called the 'Hot-to-Cold ground capacitor'. This capacitor provides a high frequency path between the primary and secondary side. The limiting value of this capacitor is dependent on the leakage current allowed by Underwriters Laboratories (UL) at 60 Hz. The UL limit for many products is 0.5 mA, which must be verified per the product safety specifications.

Plot 2 shows the results with a 3300 pF-4 kV ceramic capacitor used in the NCV1001 design. Please note the difference between Plot 1 and Plot 2. The 'hot-to-cold ground capacitor' reduces the higher order frequencies but not the lower frequencies, which is expected. Also note there are discrete frequency peaks caused by the fixed frequency operation.

Photo 1 is the MC33364 and a NTD3N60 design with only the hot-to-cold ground capacitor, 3300 pF 4 kV ceramic. The power supply is loaded to maximum specifications for each output using resistive loads. See Schematic 1 and Schematic 2. The value of this Y type capacitor has not been optimized since the unit was tested using only resistive loads. With no other input filtering, the maximum noise measurement occurred at 550 kHz with 68.83 dBuV, which is located at the low end of the AM radio band.



Plot 1. No EMI Components. Fixed Frequency 100 kHz NCP1001.



PLOT 2. Hot to Cold Y Capacitor. Y Cap is a 3300 pF 4000 kV ceramic capacitor between the IC ground and the output ground.

The MC33364 design was tested using the HP 8562A. A scope camera and Polaroid film was used to record the results. Since the MC33364 is a variable frequency controller, there no separate frequencies as in the NCP1001 design. Also note the frequency scale is linear on this photo while it is logarithmic in the graphic plots.

Common Mode Choke

The common mode choke is a catalog item from Delta, LFZ20H03 [1]. This is a four-section bobbin type with a large space between coils. The choke has minimum inductance specification of 23 mH and maximum resistance of 1.4 ohms permitting it to handle 0.5 Amps of rms current. The choke was measured with the following results. The 1.4 ohms per leg are used as in-rush current limiting on start-up. This eliminates a series input resistor. The choke can easily dissipate 0.5 watts and may even be able to handle 1 watt.

Common Mode Choke Measured Data

Line inductance leg	39.4 mH
Neutral inductance leg	39.4 mH
Resistance per leg	1.3 ohms
Mutual inductance	39.35 mH
Coupling coefficient	0.9975
Capacitance between sections	3.0 pF

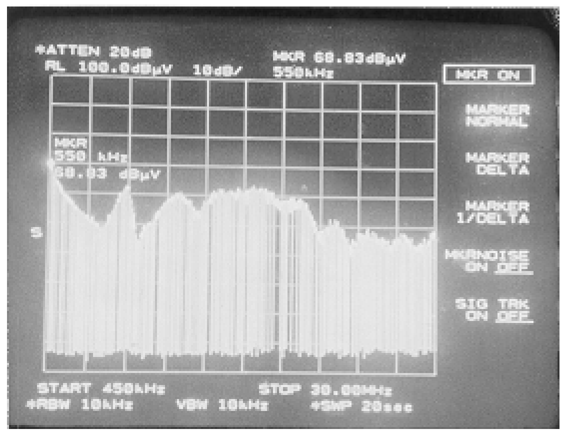
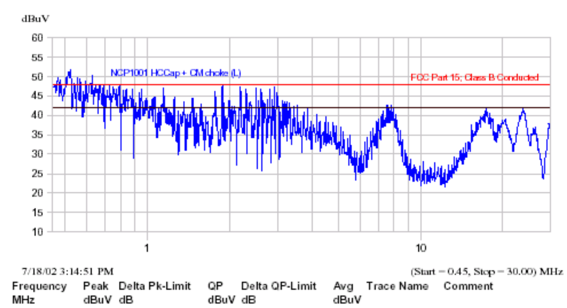


Photo 1. EMI noise only hot and cold ground capacitor 3300 pF-4.0 kV, MC33364 design, 120Vac-60 Hz

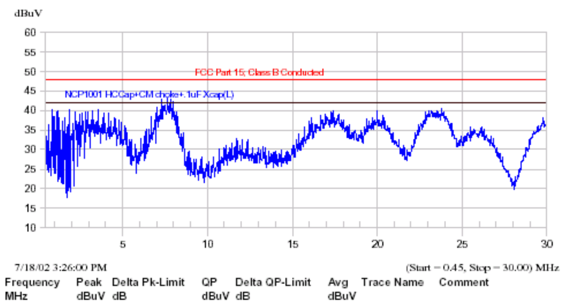


Plot 3. Hot-to-Cold Y Capacitor with Common Mode Choke.

X Capacitor

Next a capacitor is added to the ac line side of the common mode choke. This capacitor is across the ac line and must have an ac rating like 125 Vac or 250 Vac. For a universal input, this must be a 250 Vac rated capacitor. This capacitor is called an 'X Capacitor' and must pass special test for both UL and the IEC. Plot 4 shows the effect of this capacitor when the pc board is on an isolated surface. Plot 4 is with a 0.1 uF capacitor. The graph is made using a linear frequency scale.

Analysis of Plot 4 shows the power supply passes the FCC limits. It should be noted the supply is not mounted to any dead metal like a chassis. The distance between the chassis and the pc board varies between 0.25 inches and 0.5 inches.



Plot 4. Common mode choke with X capacitor.

The MC33364 and NTD3N60 design was tested with the same type of EMI components: common mode choke, 0.1 uF-250 Vac X capacitor, and a 3300 pF-4 kVdc Y capacitor. The results are shown in Photo 2. Both Plot 4 and Photo 2 are with a linear frequency scale. A comparison can be made between the two.

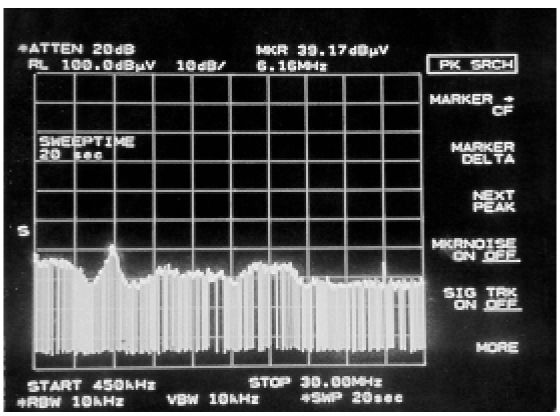


Photo 2. MC33364 with simple EMI filter. Data taken at 120 Vac using a Common Mode Choke, 0.1 uF X capacitor and 3300 pF Y capacitor.

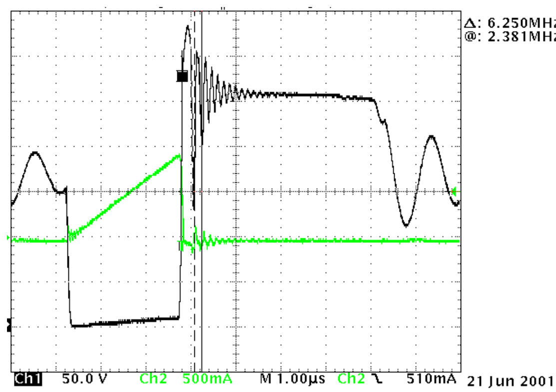
Design Difference

There is little EMI difference between the two switching power supply on an isolated base. The EMI noise using the fixed frequency 100 kHz, NCP1001 was nearly identical to the noise generated by the MC33364 and the NTD3N60.

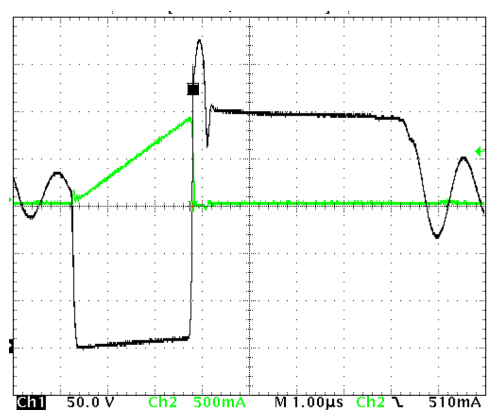
In Photo 2 there is a marker and a peak of noise centered near 6.16 MHz. The peak has an amplitude of 39.17 dBuV. Plot 4 has a similar peak near 7.5 MHz. Both of these units meet the FCC limits, but a reduction or better understanding of the noise source is desired in this 6 to 8 MHz frequency range.

Ferrite Bead

The major noise source causing the peak has been traced to the ringing of the primary at the 'turn-off' time of the power switch. See Waveform 1. This ringing can be can be reduced by the use of a ferrite bead. The ferrite bead is added to the lead connecting the bulk DC filter capacitor to the transformer. The ferrite bead greatly reduces the amplitude of this ringing. The effect is seen in Waveform 2. A simple visual comparison can be made, only a single spike exist after installing the ferrite bead.



Waveform 1. NCP1001 Switch Waveform. The flyback transformer voltage waveform undamped using a diode, resistor, and capacitor snubber.



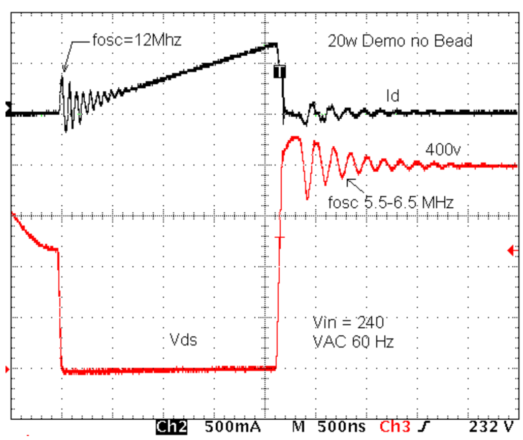
Waveform 2. Flyback Transformer Voltage with Ferrite Bead and a snubber consisting of a diode, resistor and capacitor, NCP1001 design.

The switched waveforms are slightly different for the MC33364 and NTD3N60 operating in the borderline conduction mode (BCM). This unit of the MC33364 has two rings, a 5.5 to 6.5 MHz 'turn-off' ring and a 12 MHz 'turn-on' gate charge ring. These waveforms are shown in Waveform 3 before the ferrite bead and Waveform 4 after the ferrite bead. These measurements were taken with a 240 Vac 60 Hz AC line input.

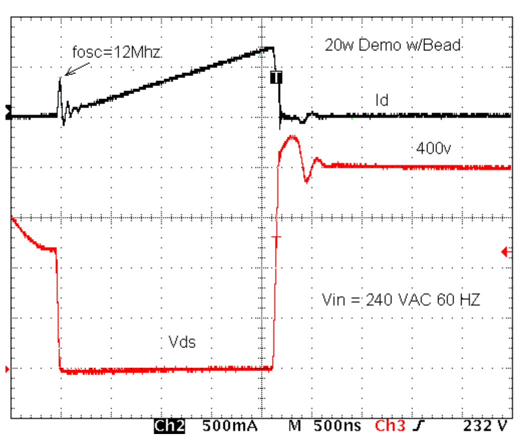
Ferrite Bead Selection

The choice of material is a critical aspect in determining a ferrite bead to attenuate specific frequency regions of the EMI plot. The bead manufacturers catalog should list the properties of the individual materials with applications to a specific bead. Typically graphs of these parameters are presented in the catalogs. This type of information is extremely useful in narrowing down the choice of components.

As an example, the number 43 material from Fair-Rite is specified for suppressing conducted EMI in the 20 MHz to 250 MHz range. The number 73 material is specified for frequencies up to 30 MHz. The impedance, reactance, and resistance characteristics for various bead configurations, ie. bead on a lead, are listed in the specific sections of the catalog. The parametric graphs provide details of a beads' characteristics over a range of frequencies. The designer can use these graphs and choose a component(s) based on any of the given parameters of his frequency of interest. It is always a good idea to choose a few different types of beads and materials in order to maximize the attenuation effects with the circuit.

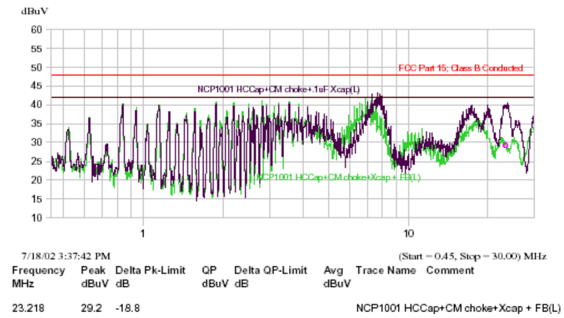


Waveform 3. MC33364 and NTD3N60 without a ferrite bead. Input is 240 Vac-60 Hz with a 20 Watt resistive load.



Waveform 4. MC33364 and NTD3N60 with a ferrite bead. Input is 240 Vac-60 Hz with a 20 Watt resistive load.

Plot 5 shows the effect of the ferrite bead on the NCP1001 design. The darker plot is without the ferrite bead while the lighter gray is with the ferrite bead. The ferrite bead only affects the higher frequencies and has no effect on the lower frequencies like the common mode choke and the X capacitor.



Plot 5. NCP1001 with and without ferrite bead. Dark trace no bead, lighter trace is with a ferrite bead.

Ground Floor

Photo 3 shows the reduction in the noise at 6 MHz. The limit is approximately 38 dBuV, which is at least 4 dB below our design goal. Another spike has risen at 13.45 MHz. This spur is due to an external noise source elsewhere in the area. This is proved with a noise reference floor photo.

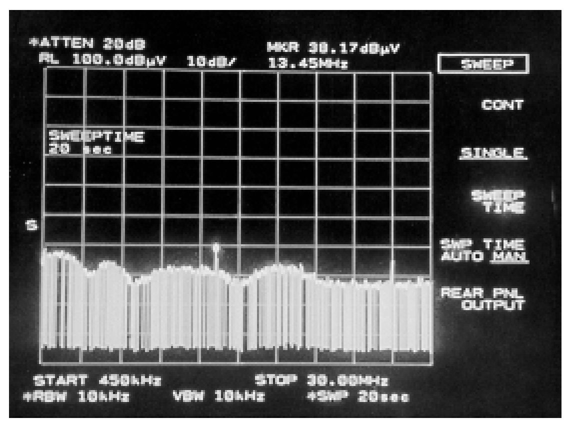


Photo 3. MC33364 Design EMI with ferrite bead added. This met the design goal with very low noise in an ungrounded chassis.

Photo 4 shows the noise floor with no unit attached to the LISN. Note that the noise is flat across the spectrum with the exception of the 13.45 MHz, 37.5 dBuV noise spike. This was performed with an HP 8562 spectrum analyzer.

In order to verify good results the ground floor noise was taken with the HP E7401A EMC Analyzer and the EMCO LISN. The results are given in two plots Plot 6 and Plot 7. Plot 6 is in log frequency scale while Plot 7 is in linear frequency scale.

Metal Chassis

All the above tests were performed on an open-air system isolated system where there is no chassis or ground. When a grounded metal chassis is placed near the power supply or the power supply is placed inside a metal box, chassis, the high frequency EMI conducted noise rises. It is felt this is mainly due to radiated or capacitive coupling of the noise to the metal chassis. This effect is shown in Photo 5.

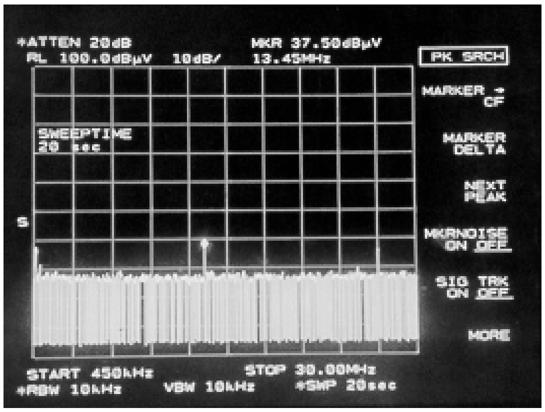
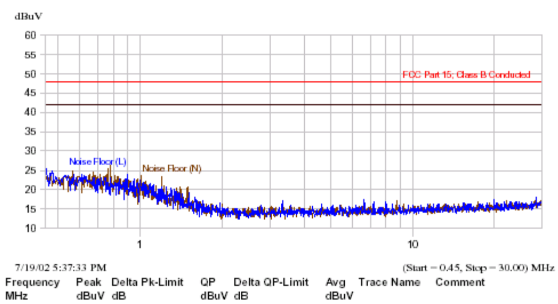
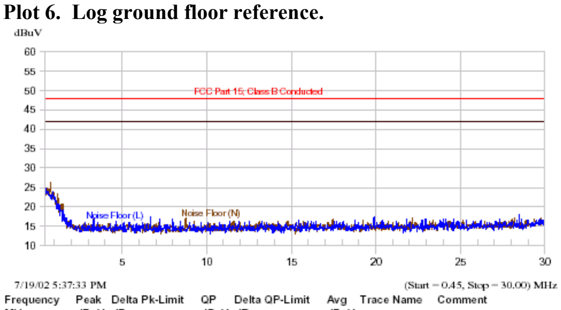


Photo 4. Noise Floor with 13.45 MHz signal. Both LISN inputs have 50 ohm terminations.



Plot 6. Log ground floor reference.



Plot 7. Linear frequency scale ground floor reference.

The line-conducted noise now exceeds the FCC limit and the production design limit of 42 dBuV. The peak occurs at 18.18 MHz having a amplitude of 49.33 dBuV. This noise is caused by the reverse recovery current in the ultra-fast recovery rectifier, MUR120, used to obtain the 3.3 volt supply. An ultra-fast rectifier was used in order to have the proper output voltage, (volts per turn). When the ultra-fast rectifier was replaced by a high voltage schottky, MBR1100, 1 Amp 100 V, the noise was reduced and the voltages were within specifications. The reverse recovery current is shown in Waveform 5.

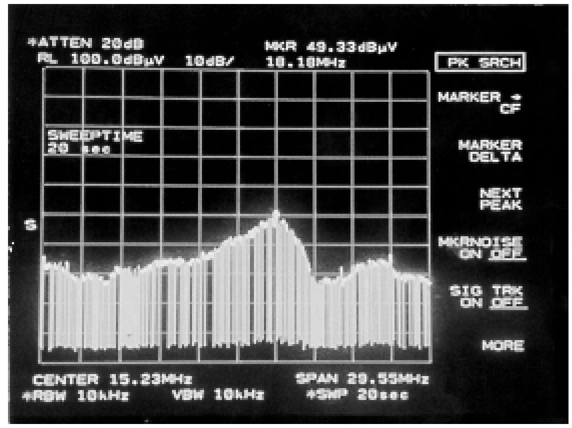
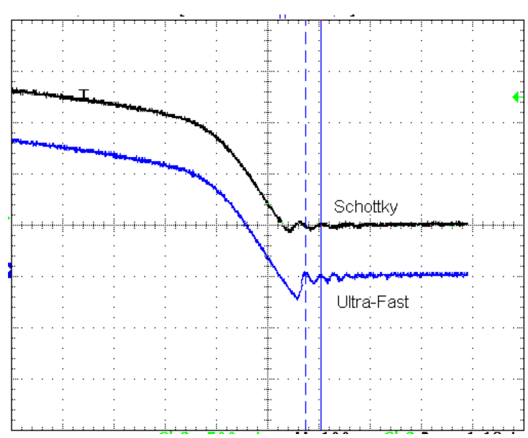


Photo 5. Power supply placed near a grounded metal chassis. MC33364 design.

Schottky Rectifier

The reverse recover time of a fast recover rectifier can have a major effect on the amount of noise in a system. The waveform shown shows that there is reverse recovery voltage and current in a critical conduction mode converter. This does not appear to show up on the NCP1001 fixed frequency design. The reason for this though is due to the bulk recovery time, which exist inside the pn junction of the diode.

The same effect will occur when any fixed frequency system operates at the or near the critical conduction mode. This would occur at low line high load.

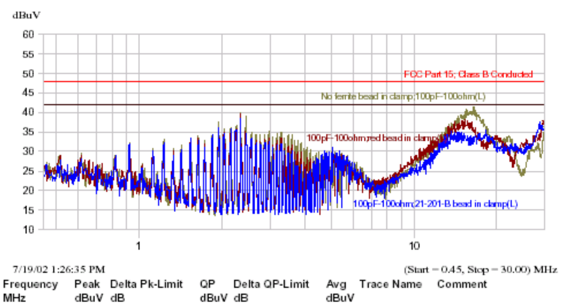


Waveform 5. Reverse recovery current. The ring frequency is approximately 33.33 MHz.

The last photo, Photo 6, shows the effect of the change to a softer diode. The grounded metal chassis is within a half inch of the printed circuit board. The loads are also grounded. This has a maximum peak of 42.67 dBuV at 17.34 MHz which is exceeds our limit by 0.67 dB uV. It is felt this design would meet product variations and pass all FCC limits. It is also felt that this would pass the CISPR 22 (AV) limits. Additional testing needs to be made in a completed product.

Power Switch Snubber

The last EMI reduction tried is a snubber on the power switch. A small 100 pF –1kV ceramic capacitor and a 100 ohm resistor is placed across the NCP1001. It was desired to lower the high frequency EMI noise. The main source of this noise is the turn-off speed of the device. The effects are shown is Plot 8.



Plot 8. RC Snubber with ferrite on NCP1001.

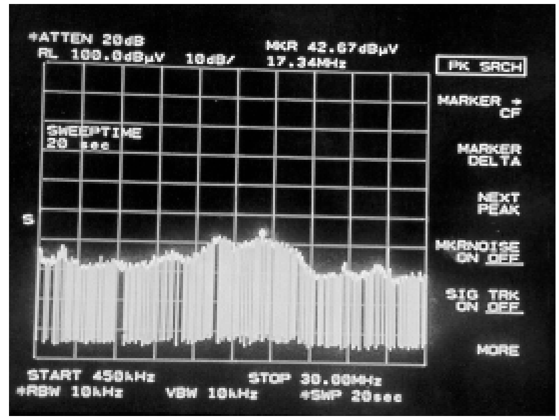
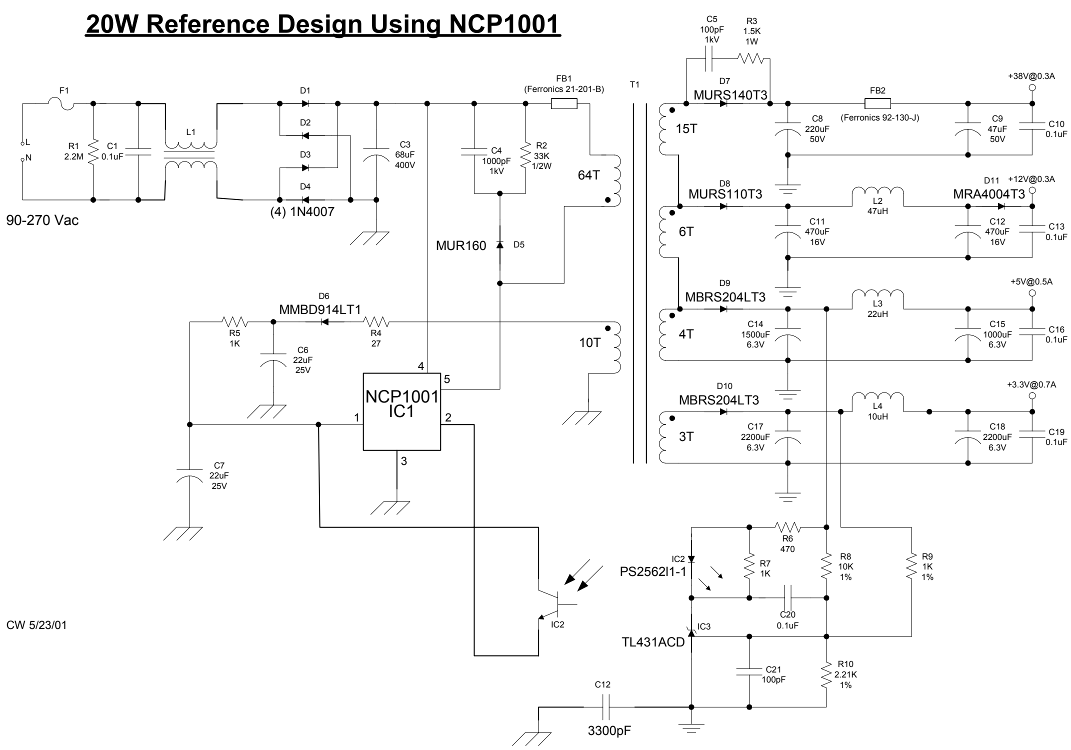
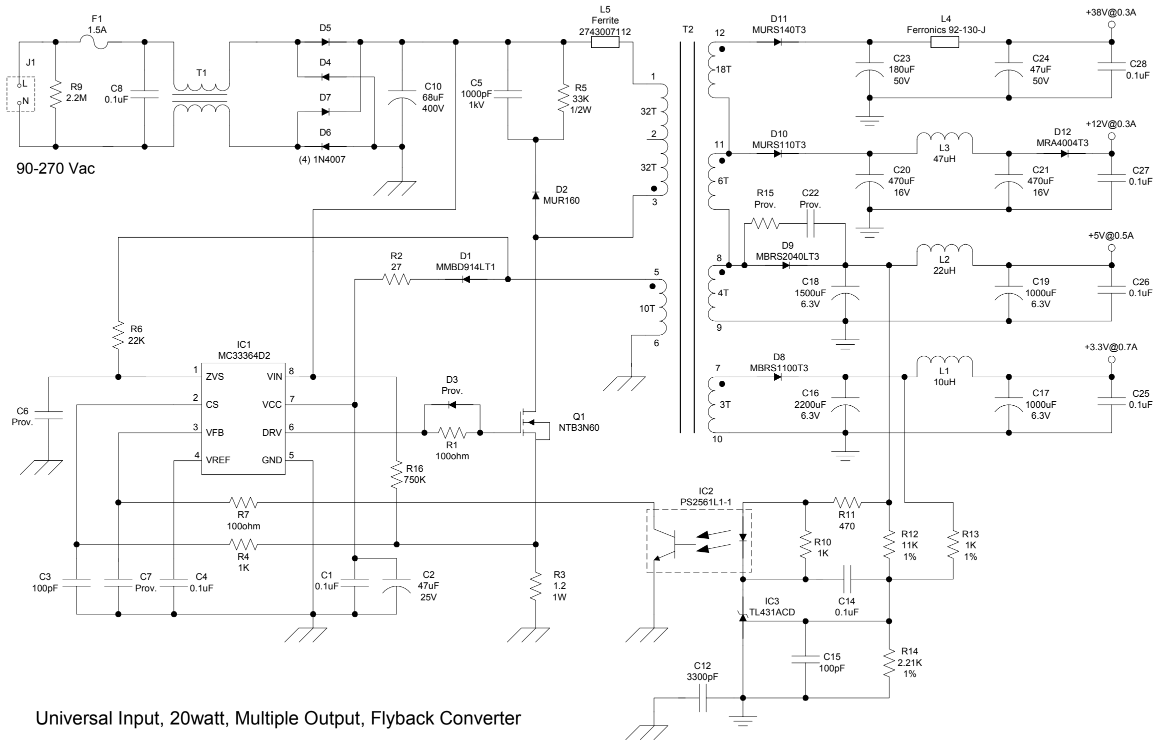


Photo 6. MC33364 line conducted noise using the MC33364 in a metal chassis and a Schottky rectifier for the 3.3 V output.



Schematic 1. NCP1001 Fixed Frequency. Multiple output power supplies for Set-Top Boxes. This unit should meet or exceed the FCC Part B sub part J limits for line conducted noise.

MC33364D2 Reference Design



Schematic 2. MC33364 and a NTD3N60 in a critical conduction mode operation. This is an universal input, 85Vac – 270 Vac, multiple output power supply for set top boxes. This design should pass the FCC part B sub part J, line conducted noise specification.

References

1. **www.fair-rite.com**
2. **www.components.tdk.com**
3. **www.coilcraft.com**