Flexible Feedback, Control, And Protection From A Single Chip

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SUMMARY

Providing two references, two amplifiers, and an output buffer into one chip allows a designer to easily combine voltage and current feedback together to control, regulate, and protect the electrical power going into a load in a variety of ways.

OVERVIEW

Controlling the power/voltage/current from the output of a power supply into a particular load involves sensing the output (voltage and/or current) and using that information as feedback to the primary-side engine of the power supply. To make this happen in an efficient and accurate fashion, there is a need for stable voltage references, gain elements to amplify the difference between the reference(s) and the sensed voltage, and a buffer/driver to take the error amplifier output and apply it as feedback to the main driving stage. Depending the application, the dominant aspect of the output being controlled may be either voltage or current, and protection from output faults (no-load, short circuit, overvoltage) may be required as well. Rather than implement each function with completely separate components, a chip with a combination of capabilities can be utilized to cover the needs of a number of different situations and applications.

POWER SUPPLY

In a typical power supply, the desired output is a constant DC voltage. To implement this, the output voltage is fed to a resistor divider that scales the output voltage so that it can be an input into a differential error amplifier. One input of the error amplifier is this divided-down copy of the output voltage, the other input to the error amplifier is a constant voltage reference. The DC gain of the amplifier is high, and (if implemented and operating correctly in a closed loop fashion) the output of the amplifier therefore is a direct indication of how far the output voltage is from the desired value. In an AC-to-DC power supply, there is a regulatory and safety need for the input and output to be electrically isolated. The main power conversion is occurring on the primary side of the isolation barrier, while the sensing and control is usually done on the (isolated) secondary side. The power conversion electrical isolation is accomplished magnetically through a transformer. Getting the feedback information from the error amplifier to the power stage usually uses optical isolation (optoisolators) because transformer magnetics can only couple AC energy, while the feedback signal is DC. A power supply block diagram below illustrates what is meant.

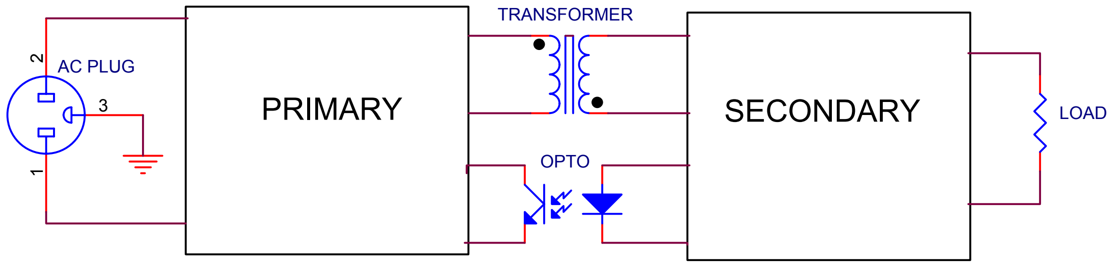

Figure 1. Generic Power Supply

A popular IC for doing voltage feedback is the 431 (one of the original sources is TI, with their TL431). A functional diagram of the 431 is shown below (Figure 2).

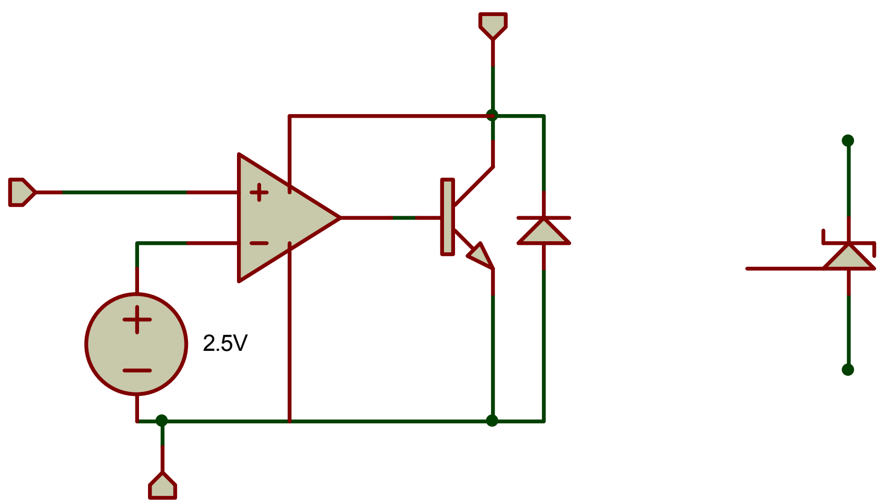

Figure 2. 431 Functional Schematic And Schematic Symbol

It contains a voltage reference and an amplifier wired together into a three-pin (input, output and ground) package. It is a shunt regulator, and uses the amplifier output as its source of power for the internal circuitry. This works well for voltage control, because the internal reference is 2.5 volts and most desired outputs are higher than that, so a resistor divider is all that is needed to connect the power supply output to the amplifier input, and the current controlled output is used to drive the photodiode of the optoisolator. A typical implementation of the 431 is shown in Figure 3 (it includes the voltage divider resistors, optoisolator bias current resistors, and compensation capacitor).

If there is a need for protecting the power supply from overcurrent or short-circuit conditions, the feedback design gets much more complicated. Using another 431 is unattractive, because it is inefficient to have a voltage drop of 2.5 volts in the output current sense resistor. In some flyback power supply applications, there is primary side current sensing being done, which can provide some measure of secondary protection, but it is not overly accurate due to the noise spikes, switching waveforms, and inherent delays inside the PWM chip. There are ways to add offsets to reduce the 2.5 volt sensing threshold, but they add a number of parts, and widen tolerances. And ideally the current sensing needs to be combined with the voltage sensing so an additional optoisolator isn't necessary.

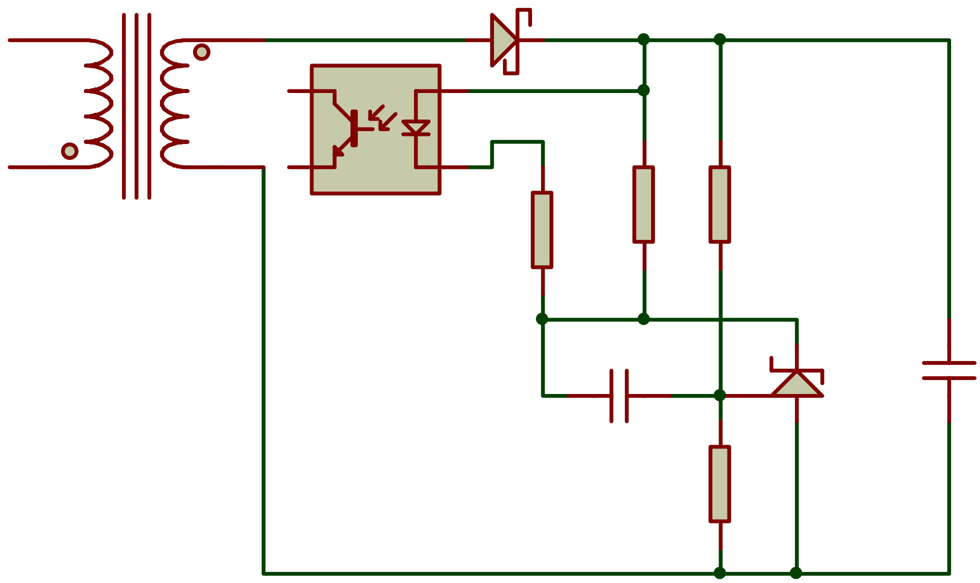

Figure 3. 431 Typical Implementation

A solution that provides efficient and accurate current sensing is a chip like the IPS21 from ASIC Advantage Inc (AAI) (Functional Schematic shown below, Figure 4). It has the voltage control elements described previously, but it also has a second voltage reference at a desirable low value, as well as a second error amplifier, and circuitry that combines the two error amplifier outputs into one drive signal for the optoisolator. With a 0.100 voltage reference in the chip, the current sensing resistor does not have to dissipate a lot of power, which improves the overall power supply efficiency. The IPS21 uses a zener-like shunt regulator to power itself, so a single resistor is all that is needed to provide chip power from any voltage greater than 4 volts. Note that the IPS21 OPTO pin is current source, unlike the 431, which is typically used as a current sink.

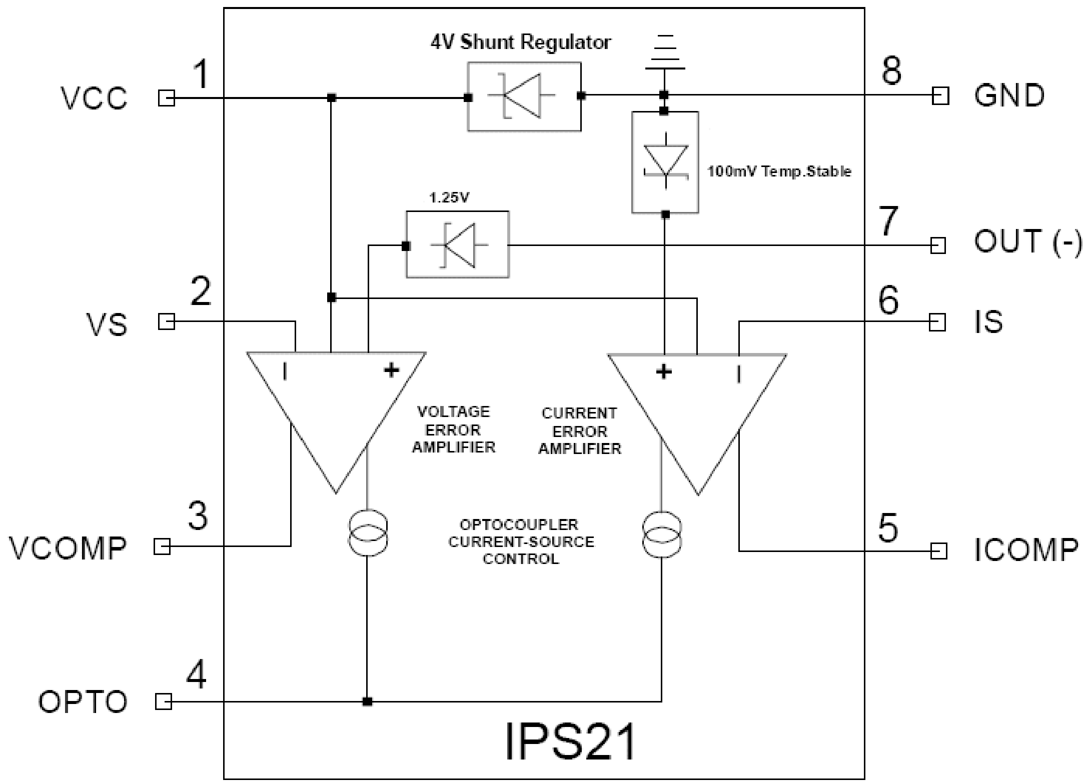

Figure 4. IPS21 Functional Schematic

To show how the IPS21 is used in a typical power supply application, an example secondary side schematic is shown below (Figure 5).

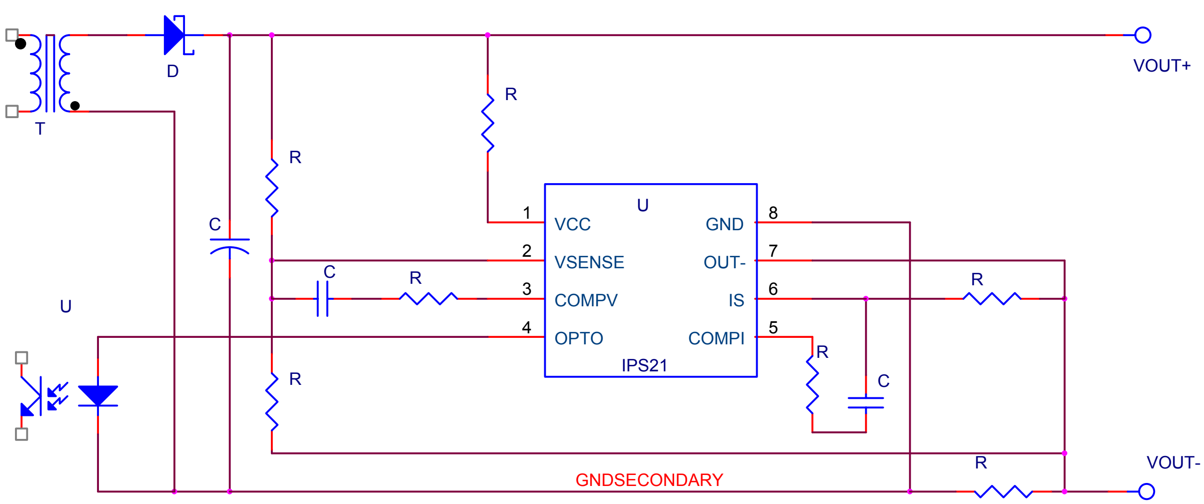

Figure 5. Power Supply Secondary Using IPS21

LED DRIVER APPLICATION

LEDs operate best when driven by a constant current. At a fixed current, their voltage drop has an initial tolerance, as well as variation with temperature. When more than one LED needs to be driven, it is typical to put them into a series string and then drive the string at a fixed current. It is straightforward to implement current feedback to a power supply to provide this drive. There is a need for output protection in case one of the LEDs fails in an open circuit condition to prevent the output voltage from growing to excessively large values. The IPS21 can readily and accurately implement these two functions, allowing the current amplifier to 'be in charge' of the feedback during normal operation and using the voltage channel to implement open-LED/overvoltage protection. An example of this is shown below.

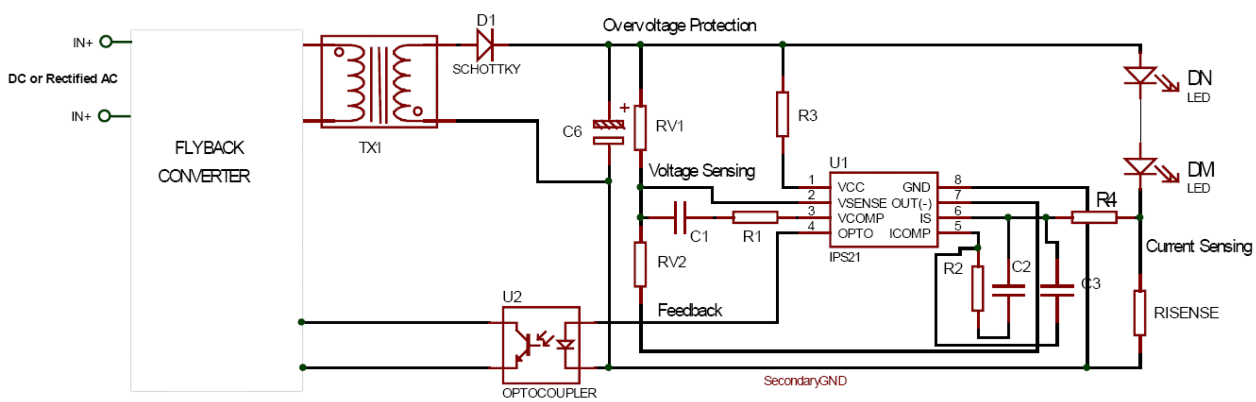

Figure 6. IPS21 LED Driver Schematic

BATTERY CHARGER

Charging a secondary battery is many times done in a constant current manner. The desired charging profile (the desired charging current versus battery voltage) varies with battery size, chemistry, and application. The same idea as shown above as an LED Driver can be used as a battery charger. The charging current is set by the current sensing resistor and the shutoff voltage (the voltage at which the charging current should go to almost zero) is set by the resistor divider. The basic circuit has two states: it is either providing constant current or is shutdown. This is shown in Figure 7 below. More complex schemes can be implemented using additional resistor dividers off the output feeding into the current sensing (to slowly bring down the charging current as the battery voltage increases), or thermistors to limit charging if the battery or ambient temperature is above a certain value.

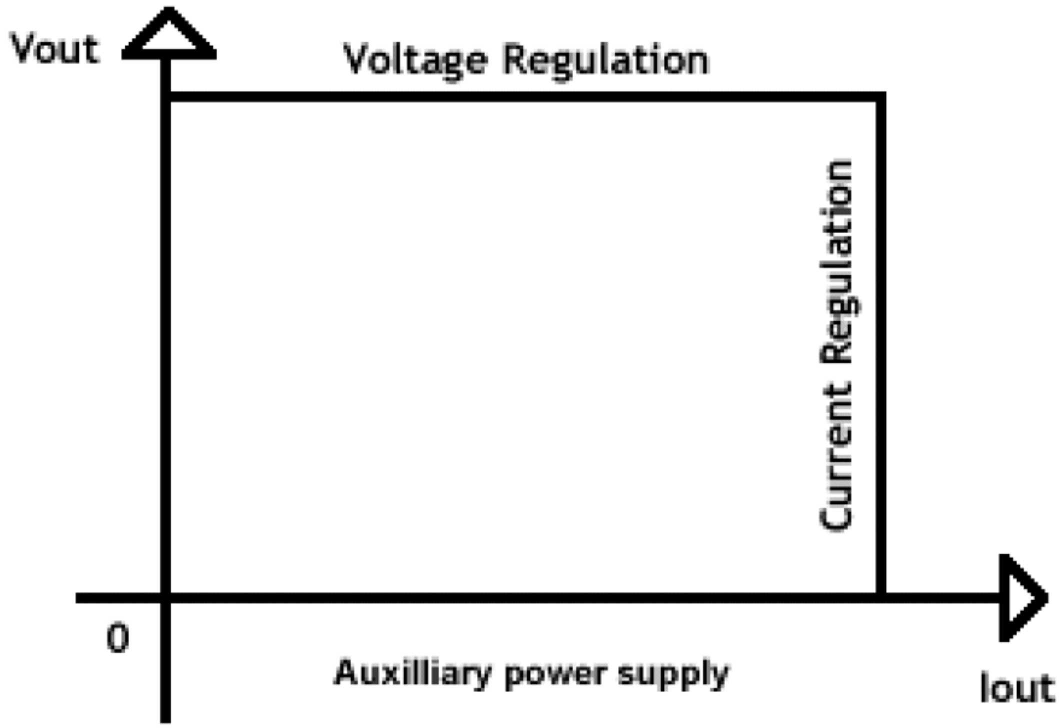

Figure 7. Output V-I Curve

RESISTOR-LESS SENSING

Sometimes there are applications where providing a low-value current sensing resistor is a cost or packaging problem. AAI has a feedback control chip that can provide a solution to this dilemma by allowing the use of a PCB copper trace (available for essentially free in most power supplies and other applications) as a current sense resistor. The IPS20 is functionally identical to the IPS21, except that the 100 millivolt constant voltage reference is replaced by a nominal 50 millivolt reference that increases with temperature (referred to as PTAT [Proportional To Absolute Temperature]). Resistor manufacturers expend considerable engineering effort to provide components that don't vary with temperature. Plain metals like copper, which is used to make the traces on PCBs, have a resistance that increases with temperature, but this variation is predictable. To get accurate sensing over a range of temperatures, it is necessary to compensate for this resistance variation. The IPS20 implements this variation as an internal function, allowing to the designer to focus on other aspects of the application. A typical value quoted for the temperature coefficient of resistance of copper at room temperature is 0.00393 per degree C (this value varies with whether the copper is pure annealed, cold worked, trace impurity levels, temperature, etc.). For a 50 millivolt nominal reference, the 'ideal' slope of a plot of the reference voltage with temperature would be 50 millivolts x 0.00393 = 0.1965 millivolts per degree C. AAI's datasheet nominal value of this slope is 0.16 millivolts per degree C, with measured values a bit higher (around 0.18 mV/degC).

APPLICATION COMMENTS AND SUGGESTIONS

To help prevent unexpected or unwanted results, a few implementation hints about implementing feedback circuits, current sensing, and PCB traces are offered below:

- Many primary side PWMs have low feedback current requirements. This is done to keep down the startup and operating power in the chip. The 431 has a minimum operating current that is required to meet the datasheet specifications. It may be necessary to bias the 431 with some additional current that is going through a resistor in parallel with the optoisolators' photodiode in order to get the gain and voltages expected and desired. There are also newer versions of the 431 that have lower bias current requirements.

- For the same reasons as mentioned above, the current through the optoisolator may be less than what the manufacturer requires to meet the current transfer ratio (CTR) specified. Be aware that the CTR and bandwidth of most optoisolators drops with reduced operating current.

- As an example illustrating what might be encountered concerning the above two comments: The AAI Flyback PWM chips (IPS1x family) have an OPTO pin that electrically looks like a 5 volt source with a 50k resistor to the pin. This means that the maximum current needed to pull this pin to ground is 5v/50k = 100 microamps. An industry standard optoisolator like the 817C says it has a current transfer ratio (CTR) of 200-400%. If you use a 431 for feedback, this says you might expect to operate the 431 at a maximum of 100uA/2 = 50 microamps input. The tricky part is that the 431s tolerance specifications are done at 10 milliamps, and the 817Cs are done at 5 milliamps. So, you might want to add a resistor in parallel to the opto to get more current into the 431. And to really understand what to expect in the 817C, some lab bench measurements are in order. Here is data from one 817C at room temperature:

Diode current (mA)	CTR (%)
1	191
0.5	121
0.2	53
0.1	25
0.05	11
0.02	4

  The good news is that the drop in CTR acts to increase the needed photodiode current. The bad news is that the bandwidth of the opto drops as the current drops, making predictions about loop response more difficult.

- The transformer interwinding capacitance can allow high frequency switching currents to interfere with the opto performance. A typical solution is to add a "Y cap" from primary ground to secondary ground near the opto. This cap can get involved in regulatory compliance in a couple of ways: it affects conducted EMI measured at the power plug, has to be low enough capacitance to not allow excessive ground currents, and has to pass the needed hi-pot testing. AAI has had some success with using shield windings in the transformer to reduce the need for this cap. If you want to see an example of this, contact AAI Marketing for a copy of a transformer build specification that contains a shield winding.

- A typical PCB can use 1 ounce copper ("1 ounce per square foot", a unit of measure based on copper's original use before electricity as a roofing/sheathing/building material). This translates to 0.0014 inches thickness (35 micrometers). A HASL (Hot Air Solder Leveling) coating is around 300 microinches of solder. This means that the vertical thickness of the PCB tracks is about 0.0017 inches, with about 82% of it copper. Tin has a volume resistivity of 11.5 microohms-cm, about 6.7 times higher than copper, lead is 22 microohm-cm, about 13 times that of copper. This means that the resistance of a trace is very much dominated by the copper, in spite of a protective tin-lead coating. [The temperature coefficient of resistance for tin is given as 0.0042 per degree C, and for lead it is 0.0040, so their resistance variation with temperature is similar to copper.]. Also be aware that PCBs with plated through holes use an additive copper process for the holes. So, with those boards, the original board copper gets plated-up to a thicker value (an added 0.001 inches) as part of the process. SMOBC (Solder Mask Over Bare Copper) processing can eliminate the HASL thickness, but the plated through hole addition can only be eliminated if you use a single sided board or specifically request non-plated holes.

- During output short-circuit conditions, any IPS 20/21 chip connected to the output will not be operating (obviously). This means no chip connected to the output in this way can provide current limiting or protection. There is a work around for this problem with flyback designs, by running the IPS2x chip off its own extra diode-capacitor connected to the transformer secondary in an anti-phase way compared to the output. The voltage generated this way isn't regulated (it tracks the input voltage), but it will be there whenever there is any switching action on the primary side. An example schematic of this idea is shown below. Essentially, when the transformer is in its energy-dumping, dot-positive state, the output is getting power/energy. During its energy-storage, dot-negative state, the chip VCC and its capacitor are getting power.

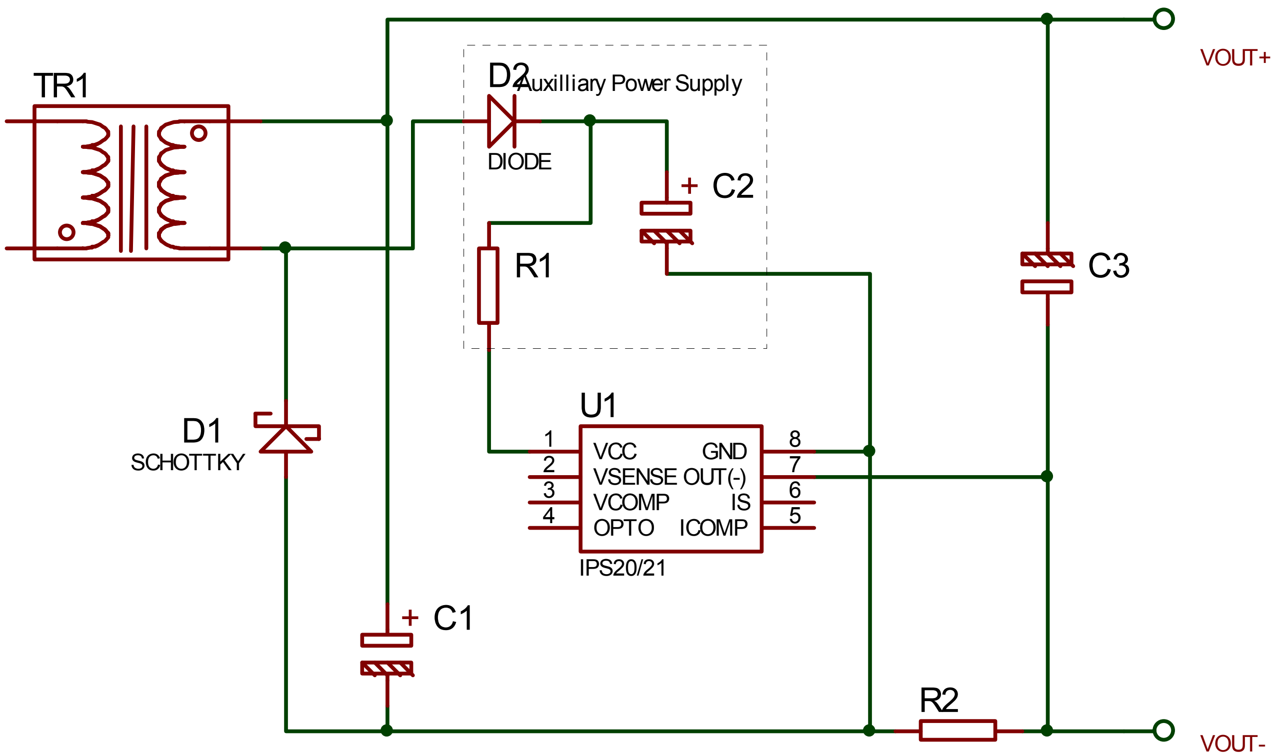

Figure 8. Control Chip With Power Separate From The Output

REFERENCES

1. Application notes and IPS20 and IPS21 datasheets from www.in-plug.com
2. Reference Data For Radio Engineers, Resistivities Of Metals And Alloys