Keywords: Power Supplies for Pentium, PowerPC, and Beyond

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APPLICATION NOTE 672

Power Supplies for Pentium, PowerPC, and Beyond

The latest microprocessors to emerge from Intel, Motorola, and others are forcing fundamental changes in the power supplies for desktop and portable computers. Not only do the µPs demand lower and more precise supply voltages, but their main clocks also exhibit start/stop operation that causes ultra-fast load transients. As a result, the relatively simple 5V/12V supply has been transformed into a system with five or more outputs, featuring unprecedented accuracy and 50A/µs load-current slew rates.

These characteristics present a problem: it appears that the classic, centralized power-supply architecture cannot provide the accuracy and transient response needed by coming generations of computer systems. The more effective approach will be a distributed architecture in which local, highly efficient dc-dc converters are located on the motherboard next to the CPU. Expect power-supply manufacturers to respond with smaller, higher-frequency ICs and modules that feature improved dynamic response and better synchronous rectifiers. The PC's offline (silver box) power supply won't disappear; it will remain to generate the main bus for small dc-dc converters on the motherboard.

This article examines the power-supply architectures proposed for next-generation computers, and takes a close look at solutions for the problems currently facing designers of board-level computers.

Voltage Proliferation

The most significant trend associated with CPU power supplies is that of lower and lower supply voltages. The race downward to new voltage levels proceeds in jumps, as each major CPU manufacturer brings successive new fab processes on line. Currently, the lowest voltage mentioned around Maxim is 1.1V—rumored as the V_{CC} required for certain CPUs yet to be released.

It seems likely that core-logic chips, which will probably make use of the fab capacity vacated by CPUs as they graduate to finer-lithography fabs, will follow the CPUs in supply voltage. DRAM voltages, on the other hand, will probably remain at 3.3V for some time to come because of the large investments in 3.3V fabs. Five volts should remain for a long time as well, even if used only to support audio and the existing customer base for PCMCIA cards and other 5V-only peripherals. The result is a list of likely voltages (**Table 1**) that apply to ICs ranging from the present to more than a year away.

Table 1. Current and Projected Operating Voltages

Supply	Imminent	1.5 Years Out	3 Years Out
CPU	2.XV	2.5V or less	1.XV
Core Logic	3.3V	3.3V	2.XV
DRAM	3.3V	3.3V	3.3V
I/O and Analog	5V	5V	5V
PCMCIA, ISA, 12V	12V	12V	?
Bus Termination	none	1.5V	1V
Total Supply Voltages	4	5	5–6

In addition to the standard CPU, I/O, and core-logic supplies, future systems will need a power supply for terminating high-speed data buses such as the 66MHz Gunning Transceiver Logic (GTL) bus (**Figure 1**). Invented by Bill Gunning at Xerox, it consists of 144 or more open-drain transistor drivers, each with a 50Ω resistive pull-up to a low-voltage source (typically 1.5V).

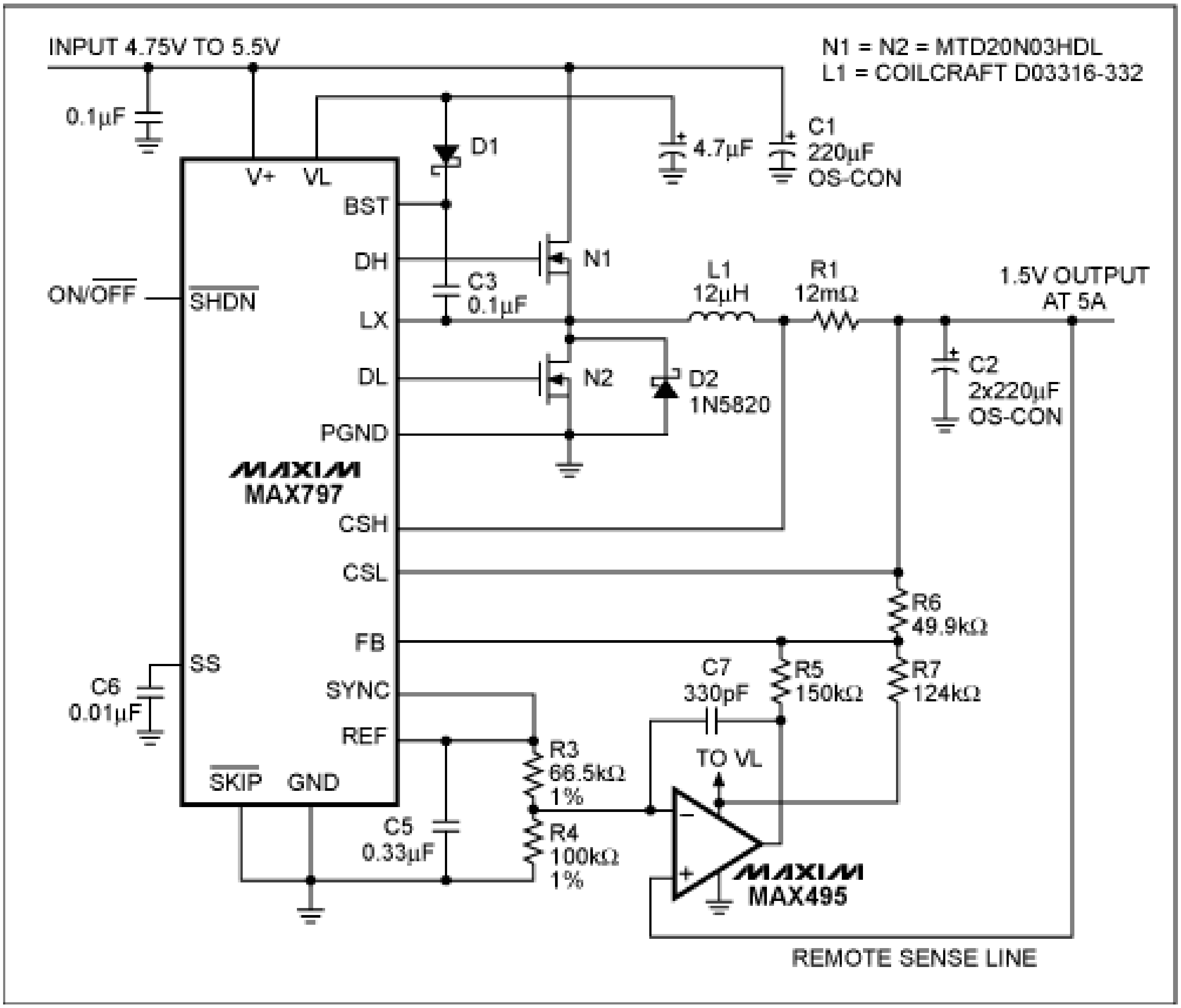


Figure 1. This highly accurate, 1.5V step-down dc-dc converter powers the termination resistors in a Gunning Transceiver Logic (GTL) bus. The converter's architecture-buck topology with synchronous rectifier-is by far the best choice for low-voltage, high-efficiency distributed power systems.

Special CPU Voltages

In addition to the trend toward lower voltages, another factor is proliferating the levels of supply voltage: the tendency for manufacturers to specify special levels for certain models or clock-speed variants of a given CPU. This "voltage du jour" practice, conducted to enhance manufacturing yields at high clock speeds, includes 4V (Cyrix), 3.6V (Power PC), and 3.45V (Intel).

A good example of special supply voltage is the "VR" version of Intel's P54C Pentium, which requires a supply voltage between 3.30V and 3.45V including noise and transients. This spec gives headaches to power-supply designers, who must worry about noise, transient response, and the minute voltage drops in connectors and wiring, as well as fundamental dc accuracy. Their complaints about layout difficulty and extra cost, however, are rightly outweighed by savings in the CPU itself. Paying 20% less for a $500 CPU can finance a lot of power-supply stuff, so don't expect CPU makers to avoid non-standard supply levels-especially for their latest and "hottest" models.

Cross-Regulation Error

Another challenge for power-supply designers is cross-regulation error—the variation at one regulated output caused by load-current variation at another—which is common in classic, low-cost, multi-output offline supplies. This error, produced in "green PCs" governed by load-switching power-management techniques, is actually caused by a power-saving measure—the absence of minimum loads on the regulated outputs.

The standard low-cost power supply for PCs generates multiple output voltages by including extra transformer windings on a flyback or forward off-line supply. A minimum load on the main output is necessary for maintaining regulation on the secondary outputs. But, this technique causes problems in the new computers (Green PCs), which employ load-switching and clock-halting schemes to reduce power consumption. The resulting wild fluctuations of load current at each output can produce severe cross-regulation errors in conventional supplies. Along with fast load transients and tight output-accuracy specs, the cross-regulation problem is one reason why future systems will probably adopt a distributed power-supply architecture.

Another reason is parasitic inductance in the high-current paths. For systems in which the CPU clock starts and stops abruptly, even a few inches of wire contributes enough inductance to cause excessive ringing or sagging (or both) at the V_{CC} pins. For the many cases in which IR drops and unwanted inductance completely rule out a centralized power supply, you must adopt a distributed-power architecture. It usually consists of small, local dc-dc converters or linear regulators on the CPU motherboard, fed with 5V or 12V from the familiar silver-box power supply in the PC.

Once you decide on a distributed architecture, the next step is to decide between linear and switch-mode regulators. The issue is usually clear-cut: if you can tolerate the heat and efficiency loss, go with a linear supply; if not, choose a switch-mode supply with a step-down (buck) topology. Future desktop systems will probably distribute a power bus of 5V or 3.3V (or both), and generate the lower CPU voltages with local linear regulators (**Figures 2** and **3**). Portable systems, in which efficiency is always paramount, often distribute their battery voltage to switch-mode converters located on the motherboard.

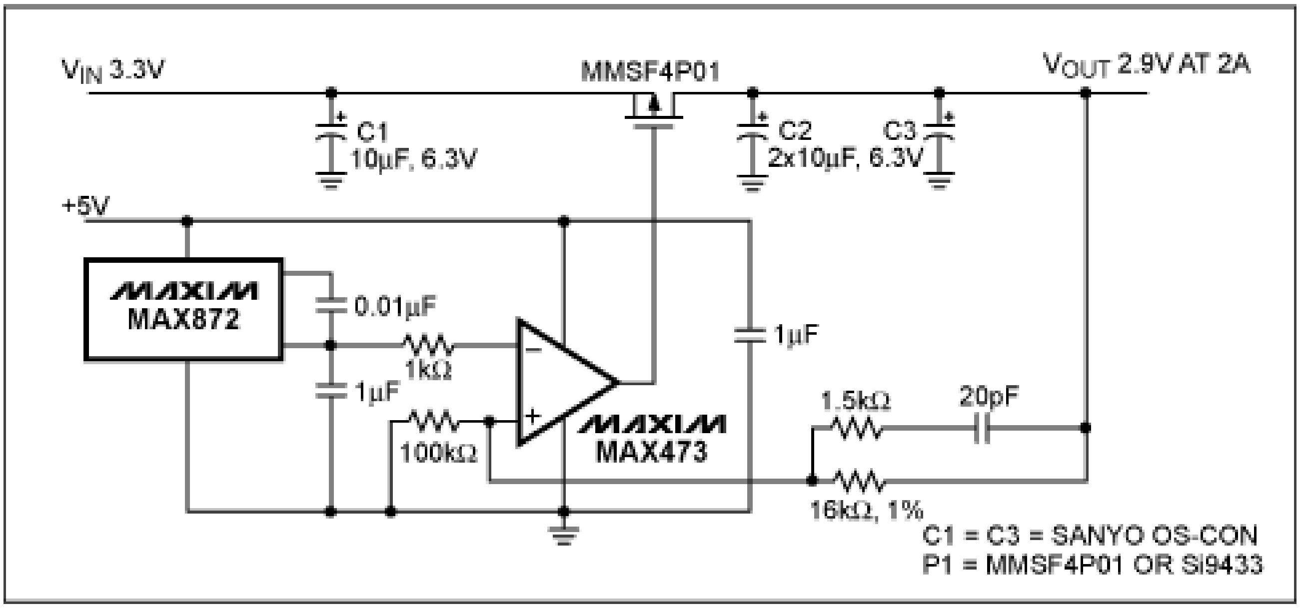


Figure 2. This linear-regulator circuit includes a fast, low-power op amp for excellent dynamic response to fast-load transients caused by the latest dynamic-clock CPUs. The low-threshold, p-channel MOSFET (vs. a bipolar transistor) provides an ultra-low dropout voltage and minimum quiescent current.

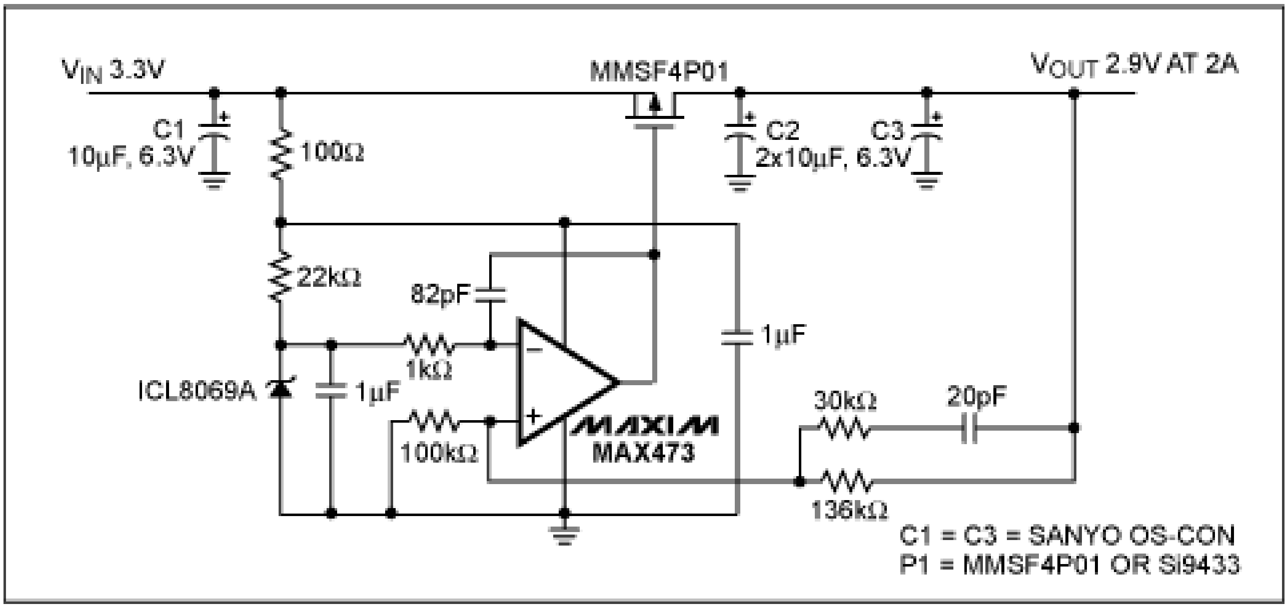


Figure 3. For systems in which 5V is unavailable for the op amp, this stand-alone linear regulator operates entirely from the 3.3V bus, generating 2.9V with only a minor degradation in transient response.

Linear regulators cost $2 to $3, vs. $6 to $7 for a switch-mode type. Faster loop response lets the linear types handle load transients with less output capacitance. And in many cases, the linear regulator's efficiency is acceptably high even for portable applications.

Discounting the losses due to quiescent and base currents, the efficiency of a low-dropout linear regulator equals V_{OUT}/V_{IN}. A 5V-to-3.3V converter, for example, has an efficiency of 66%—which means that a maximum load of 3A will produce 5W of heat dissipation. That amount of power is easily handled with a heatsink, but for multiprocessor LAN servers with four or more CPUs, the required dissipation jumps to 20W. That power level is hard to disperse in a system that is already blazing hot. For 5V-to-3.3V desktop systems, the load-current crossover point at which heatsinking problems outweigh the extra cost of a switch-mode supply is about 5A.

Step-down switching regulators exhibit typical efficiencies of 90% or better, almost independently of V_{IN}. But, compared with linear regulators they are more expensive, require a more careful pc layout, and generate more ripple and EMI. The classic buck topology (**Figure 4**) is by far the best choice; it is simple, has very high efficiency, and has the smallest magnetic components of all the competing topologies (forward, flyback, Cuk, etc.). Buck regulators are also compatible with synchronous rectifiers—a feature of increasing importance as CPU voltages fall, causing the power loss in a forward-biased rectifier to become a larger portion of the output power.

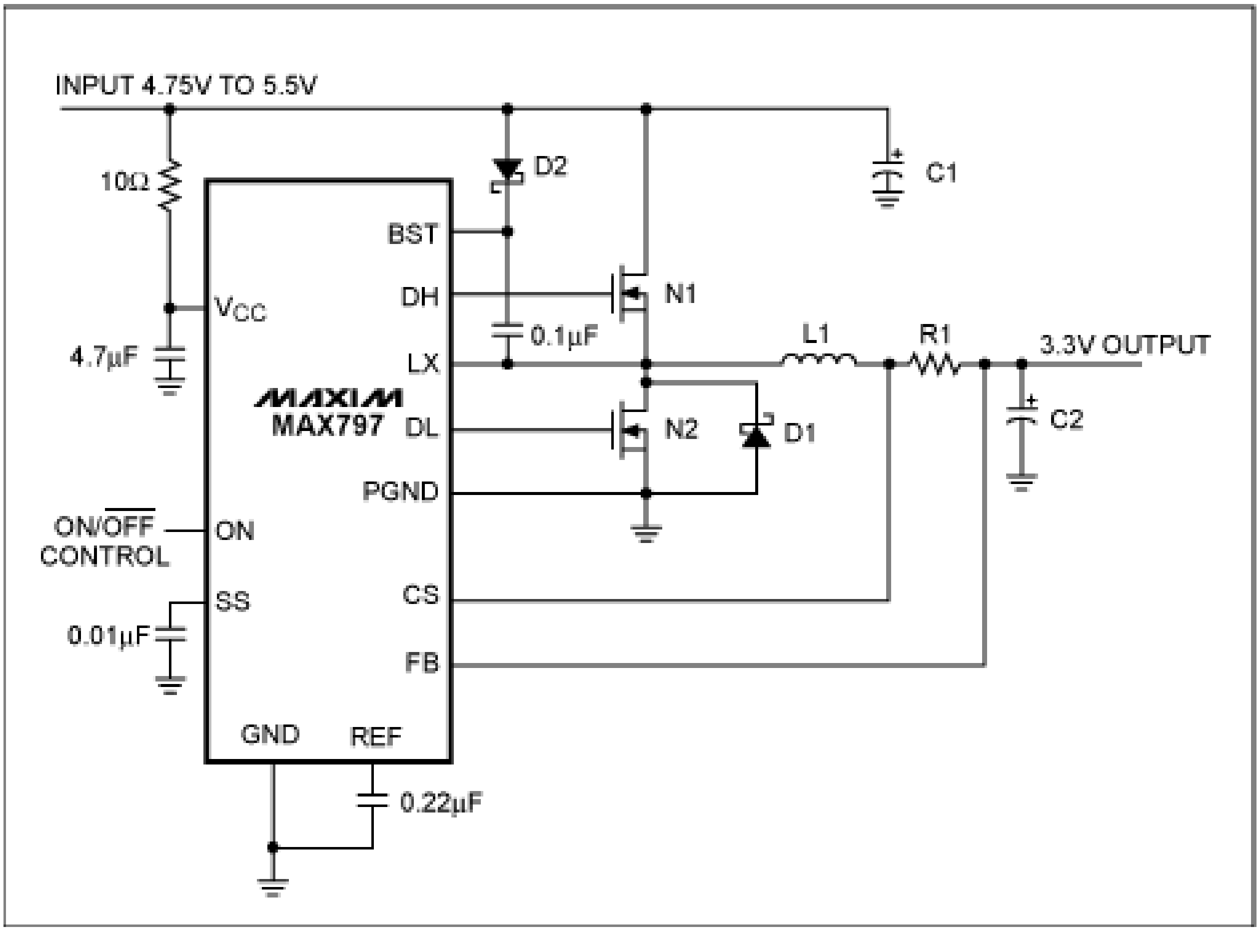


Figure 4. This step-down (buck) switching regulator employs all n-channel MOSFETs to save cost, and operates at 300kHz to minimize the physical size of its inductor.

Low-Voltage, High-Accuracy Supplies

At lower levels of supply voltage, the logic swings decrease and produce a corresponding shrinkage in noise margins. Power supplies for future systems must therefore have very good dc and ac accuracy to avoid noise-margin problems. A 5%, 1.5V supply, for instance, has an output tolerance of just ±75mV. Small voltage drops across the resistance of a connector, power-MOSFET switch, or wiring harness can so degrade accuracy as to render this supply unusable.

The dominant term affecting overall accuracy in a power supply is that of the internal reference-voltage accuracy. Reference accuracy is therefore a key parameter in power-supply ICs for the next generation of low-voltage systems. The question for IC designers is, how much manufacturing cost do you allow for the reference? The issue is not so much silicon area as the cost of laser trimming, testing, and yields.

The reference in today's typical power-supply IC represents 20% to 25% of the IC's manufacturing cost, and has a ±2% output tolerance. The ±2% error band allows the manufacturer to test at room temperature only, and screen for temperature extremes by sample testing only. But at ±0.5%, all the parts must be tested over temperature, and the the laser trimming must be more precise. Costs increase accordingly. Thus, the decision to include a precision, data-acquisition-grade reference in a power-supply IC is not to be made lightly.

Two circuit configurations provide high-accuracy supply voltages, each with a different tradeoff between cost and accuracy (**Figures 5** and **6**). Both reduce the load-regulation error (to 0.1%) by increasing the dc-loop gain with an external integrator amplifier (MAX495). The first circuit achieves low reference error with a screened ("T" grade) version of the MAX767, whose reference tolerance is ±1.2% maximum. This Pentium P54C-VR application circuit is available from Maxim as an evaluation kit. The second circuit achieves still lower error with an external reference (MAX872), whose contribution to output uncertainty is only ±0.38% over temperature.

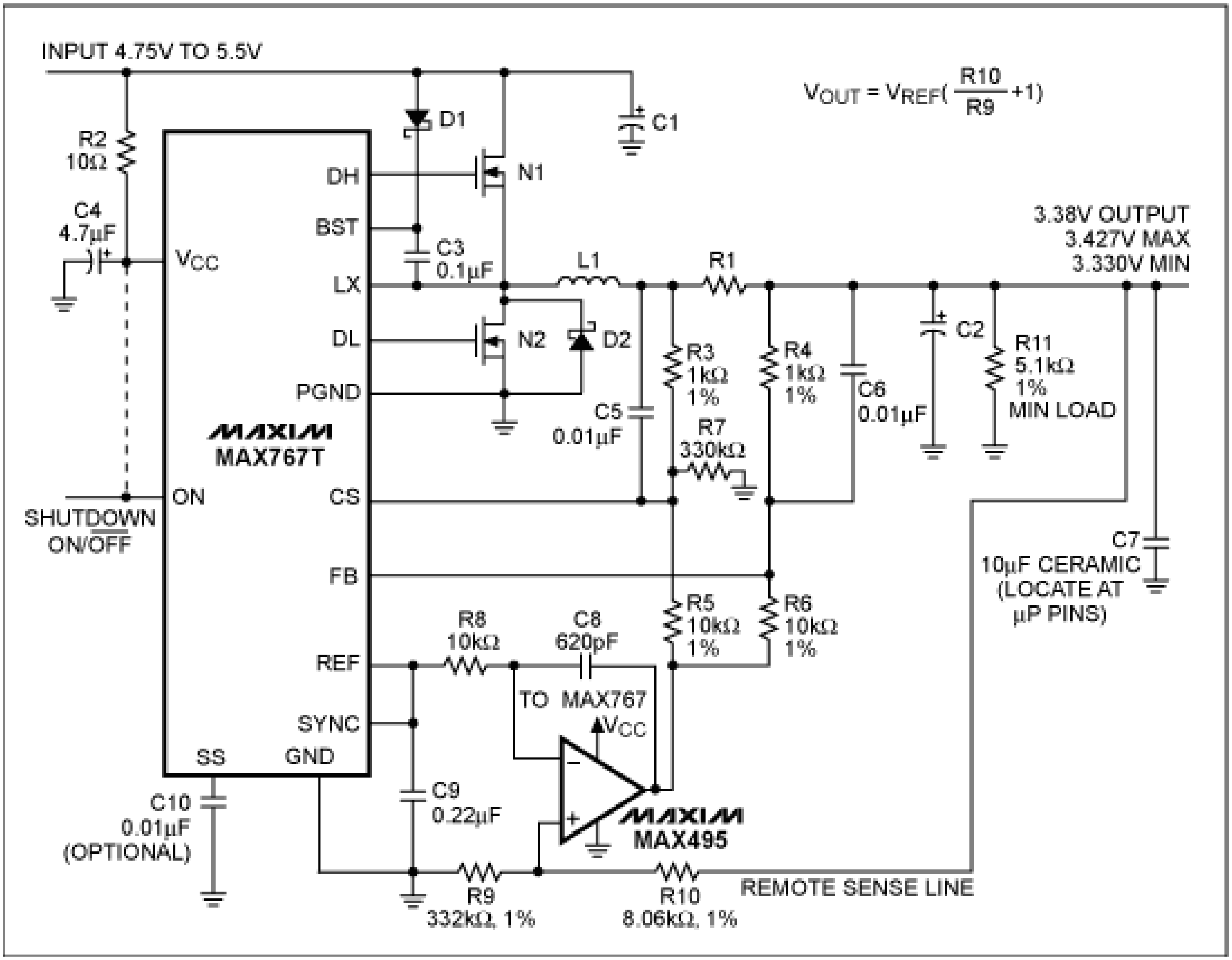


Figure 5. This high-precision, step-down dc-dc converter is intended for Pentium P54C-VR desktop applications with stringent requirements for dc and ac accuracy. An evaluation kit for this Pentium VR application is available to speed designs (see page 2).

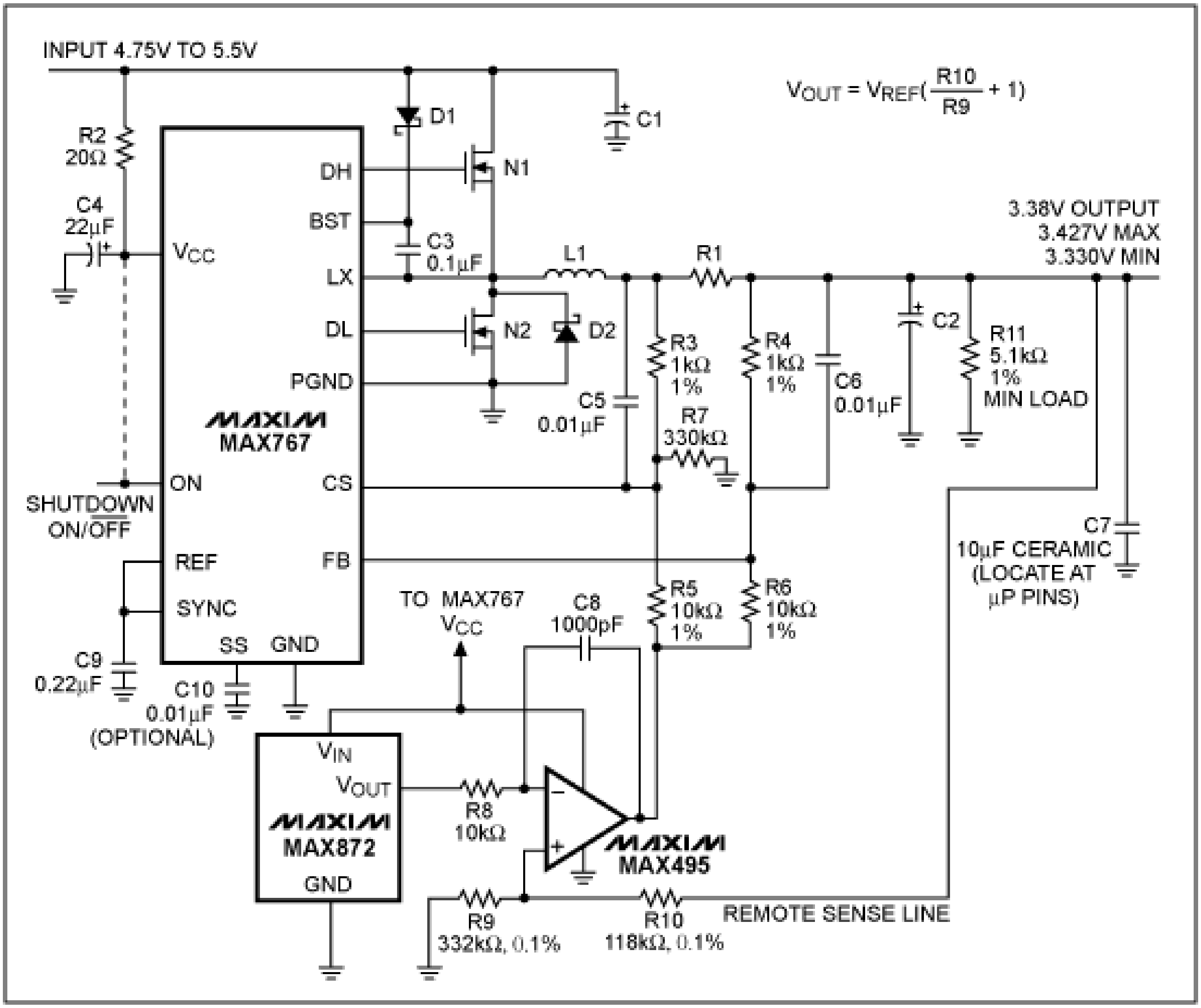
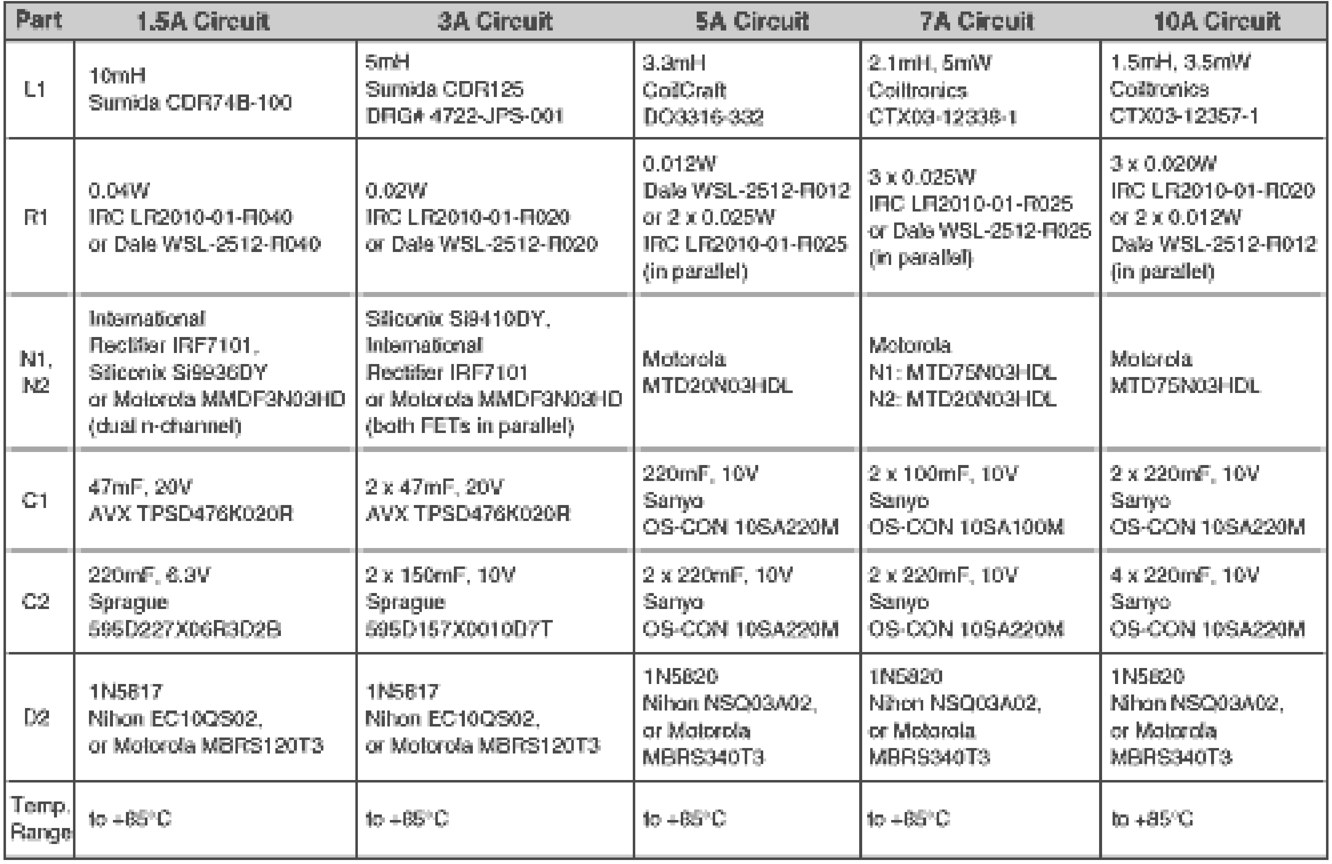


Figure 6. Otherwise similar to the step-down converter of Figure 5, this circuit adds a data-acquisition-grade voltage reference to further improve dc accuracy.

Both circuits have low output ripple and excellent dynamic response. Step changes from zero to full load produce output excursions of less than 40mV. In particular, each circuit supports the VR (voltage regulator) version of Intel's P54C Pentium CPU, whose supply voltage (including noise and transients) must remain between 3.30V and 3.45V. **Table 2** lists the components recommended for different levels of output current in these two circuits.

Note: To prevent over-voltage at the CPU when the remote-sense line connects at the far side of a connector (which could be disconnected during supply operation), connect 10kΩ from the sense line to the connector's near (power-supply) side.

Table 2. Component Recommendations for Figures 5 and 6



Part	1.5A Circuit	3A Circuit	5A Circuit	7A Circuit	10A Circuit
L1	10mH Sumida CDR74B-100	5mH Sumida CDR125 DRG# 4722-JPS-001	3.3mH CoilCraft DO3316-332	2.1mH, 5mW Coiltronics CTX03-12338-1	1.5mH, 3.5mW Coiltronics CTX03-12357-1
R1	0.04W IRC LR2010-01-R040 or Dale WSL-2512-R040	0.02W IRC LR2010-01-R020 or Dale WSL-2512-R020	0.012W Dale WSL-2512-R012 or 2 x 0.025W IRC LR2010-01-R025 (in parallel)	3 x 0.025W IRC LR2010-01-R025 or Dale WSL-2512-R025 (in parallel)	3 x 0.020W IRC LR2010-01-R020 or 2 x 0.012W Dale WSL-2512-R012 (in parallel)
N1, N2	International Rectifier IRF7101, Siliconix Si9936DY or Motorola MMDF3N03HD (dual n-channel)	Siliconix Si9410DY, International Rectifier IRF7101 or Motorola MMDF3N03HD (both FETs in parallel)	Motorola MTD20N03HDL	Motorola N1: MTD75N03HDL N2: MTD20N03HDL	Motorola MTD75N03HDL
C1	47mF, 20V AVX TPSD476K020R	2 x 47mF, 20V AVX TPSD476K020R	220mF, 10V Sanyo OS-CON 10SA220M	2 x 100mF, 10V Sanyo OS-CON 10SA100M	2 x 220mF, 10V Sanyo OS-CON 10SA220M
C2	220mF, 6.3V Sprague 595D227X06R3D2B	2 x 150mF, 10V Sprague 595D157X0010D7T	2 x 220mF, 10V Sanyo OS-CON 10SA220M	2 x 220mF, 10V Sanyo OS-CON 10SA220M	4 x 220mF, 10V Sanyo OS-CON 10SA220M
D2	1N5817 Nihon EC10QS02, or Motorola MBRS120T3	1N5817 Nihon EC10QS02, or Motorola MBRS120T3	1N5820 Nihon NSQ03A02, or Motorola MBRS340T3	1N5820 Nihon NSQ03A02, or Motorola MBRS340T3	1N5820 Nihon NSQ03A02, or Motorola MBRS340T3
Temp. Range	to +85°C	to +85°C	to +85°C	to +85°C	to +85°C

Application Note 672: http://www.maxim-ic.com/an672

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