Since the beginning of time medical doctors have looked for better ways to diagnose and treat patients who suffer from internal ailments or injury. The ability to examine and treat patients from within in a minimally invasive way and with the least amount of discomfort has been an important part of medical practice starting in the 1800s. Current endoscopy trends are pushing towards adoption of digital imaging techniques leading to great advances in image resolution, tissue identification, and explaining the treatment to the patient and their families. However, these features require multiple digital processors to process and distribute the image data. There arises the design challenge - how to fit all the electronics and associated power regulators in the same form factor as the previously installed endoscopic camera control units (CCUs) to minimize installation and adoption costs.

**History of Endoscopy**
Most historians consider Bozzini’s Lichleiter to be the first resemblance of the endoscope we know today. Invented in the early 1800s, it was rigid with angled mirrors to project the image to the doctor’s eye, but with only a single candle for illumination image quality was poor. Then around the turn of the 20th century, illumination techniques had improved to the point where several inventors created a way to capture endoscopic still images on camera. In the 1950s, Japanese pioneers Mori and Yamadori recorded the world’s first motion picture from an endoscope featuring a live birth. The disadvantage with photography and motion pictures of that time was that the images could not be shared or manipulated in real time. Now modern digital imaging technology supports these functions with better resolution than ever before as we continue along the path laid out by these early pioneers.

**The Move towards Digital Endoscopy**
In the 21st century, CMOS image sensors have reached the image resolution and low power dissipation sought by medical professionals. These image sensors provide high quality images at resolutions up to full HD (1980 x 1080 pixels) and beyond. Some companies are taking a step beyond standard 2D HD images by introducing 3D stereoscopic endoscopes. Power dissipation (and resulting temperature rise) is also an important factor as the CMOS sensor is often situated in the camera head at end of the endoscope in a form factor designed for convenient hand manipulation by the surgical team to position the lens to present the desired view. The image resolution and low power dissipation of modern CMOS sensors are the foundation for the high interest around digital endoscopy.

Digital endoscopy benefits doctors and patients in several ways: 1) A digital image (or video) in real time enables doctors to collaborate with their peers wherever they might be around the globe for more effective treatment and faster recovery; 2) The image can be instantaneously manipulated so different tissue structures can be more easily identified by the surgical staff; 3) The surgery can be easily recorded and annotated for training purposes; 4) 3D endoscopes give surgeons even better visibility and depth perception to better target tissues for treatment; 5) The images are readily stored in the patient’s electronic medical records for review by the patient and family for a more thorough explanation of the diagnosis, treatment and healing process. These five benefits do come with a requirement and enough processing horsepower to handle all the data.

**Increasing Digital Processor Content Decreases PCB Area for Point of Load Regulators**
It should be no surprise that these features: creating, displaying, manipulating, distributing and storing the large amount of data created by these CMOS sensors requires a great amount of digital processing horsepower, most often located in the camera control unit (CCU). The main components of a typical endoscopic system include image processors, one or more FPGAs, memory, A/D converters, video display ports, and an Ethernet controller, which must be integrated to support these features. Subsequently, a majority of these devices require multiple input voltages for operation. The resulting challenge to design engineers is how to support the dramatic increase in the number of power rails in a smaller space.
To facilitate integration of all these digital components and their benefits to patients and doctors alike, the space saving LTM4644, a 14V\textsubscript{IN} quad-output step-down \textsuperscript{\textregistered}\mu\textsuperscript{Module} regulator was introduced by Linear Technology. In a 2.3cm x 1.5cm space (Figure 1) on a dual-sided PCB, the LTM4644 regulates four output voltages each delivering up to 4A of current to meet the power requirements of FPGA and other digital processors in digital endoscopy systems (Figure 2). In contrast, comparable step-down module solution from competing vendors requires as much as four times more PCB area. Moreover, with current sharable outputs, this step-down \mu\textsuperscript{Module} regulator gives engineers the flexibility to configure the regulator as a single (16A), dual (12A, 4A or 8A, 8A), triple (8A, 4A, 4A) or quad (4A each) output. This flexibility allows endoscope system engineers to source and qualify just one simple and compact \mu\textsuperscript{Module} regulator for the variety of voltage and load current requirements of FPGAs, ASICs, microprocessors and other board circuitry.

Figure 1: Four Output, 4A Step-Down \mu\textsuperscript{Module} Regulator PCB Solution Area

The entire LTM4644 solution requires 3.5cm\textsuperscript{2} on a dual-sided PCB (one capacitor & four resistors on backside)

![Figure 1: Four Output, 4A Step-Down \mu\textsuperscript{Module} Regulator PCB Solution Area](image)

Figure 2: The LTM4644 Supports Up to Four Separate FPGA Power Rails
The LTM4644 µModule regulator supports up to four unique output voltage rails from a 4V to 14V (or 2.375 to 14V with an external bias) input, delivering up to 4A per output to support the power needs of FPGAs, other digital processors, memory and supporting analog circuitry. Only six external ceramic capacitors (1206 case size) and four resistors (0603 or smaller case size) are required for a complete solution.

To save space and design time, the LTM4644 quad output regulator includes the DC/DC controllers, power switches, inductors and compensation in a 9 x 15 x 5.01mm BGA package. A 4V to 14V input supply (or 2.375V to 14V when an external bias supply is applied) powers each regulator channel delivering a regulated output voltage adjustable between 0.6 to 5.5V with ±1.5% accuracy over line, load, and temperature. Separate input power pins allow engineers to power the four channels from different supply rails if desired for power budgeting regardless of whether the outputs current share or not. Taking another step to reduce solution area and cost, the four switchers within the LTM4644 operate 90 degrees out of phase at a common frequency cutting the input capacitance in half for equivalent input ripple performance. As a result, only six external ceramic capacitors (1206 case size), four feedback resistors (0603 case size or smaller) are required for a four output configuration when operating from the same input supply (Figure 2). The LTM4644’s small BGA package combined with the very low external component requirement result in the smallest four output 4A DC/DC step-down solution available today.

Well Controlled Power-Up Sequencing
The LTM4644 has the features necessary to power loads that require specific power-up and power-down sequences. Each output has its own enable (RUN) logic pin, track (TRACK/SS) pin and power good (PGOOD) logic flag. The track pin allows engineers to control the output voltage slew rate during power-up and power-down by applying an analog input. The power good pin indicates when the output voltage is within ±10% of its target regulation point. Because some voltage rails are powered before others possibly resulting in back-feed or when voltage is retained prior to start-up, some of the load’s power rails may be pre-biased at the instant the voltage regulator is enabled. Pre-biased outputs can pose a problem for some synchronous switching regulators whose control loops will immediately discharge the load to ground during start-up even though the FPGA requires a monotonically rising power source for proper operation. Beyond having the necessary control and indicator pins, LTM4644 provides a monotonically rising voltage even in the face of a pre-biased load (Figure 3).

The LTM4644 provides a smooth monotonically rising output voltage to 5V nominal even when the load is pre-biased (2.5V) for proper operation of FPGAs.
**Another Even Smaller Solution for Any Missing Power Rails**

To help engineers deal with last minute design changes, the LTM4624 is a single output version of the LTM4644 available in a tiny 6.25 x 6.25 x 5.01mm BGA package, the same height as the LTM4644. Requiring only two external capacitors and one feedback resistor, the entire LTM4624 solution fits incredibly within one square centimeter on a single-sided PCB (Figure 4). The LTM4624 supports the same operating input, output voltage, and power-up sequencing features described in the previous Well Controlled Power-Up Sequencing section.

![Figure 4: LTM4624: 14V IN, 4A Step-Down µModule Regulator Solution’s Recommended PCB Layout](image)

Only two external ceramic capacitors (1206 case size) and one resistor (0603 case size or smaller) are required alongside the LTM4624, forming a single 4A step-down regulator solution that fits within 1cm$^2$ on a single-sided PCB or 0.5cm$^2$ on a dual-sided PCB. The size advantage makes the LTM4624 a great choice to address last minute design changes or missed power rail requirements.

**Conclusion**

The growing shift towards digital endoscopy promises tremendous benefits for patients and their doctors. CMOS image sensors create digital images and videos inside the body with the image resolution at sufficiently low operating temperatures suitable for handling by surgical teams to capture the desired field of view. These images and videos are easily stored, enhanced and shared for a more effective, faster and lower cost treatment to the benefit of the patient, family and medical team. Accomplishing these three tasks requires a collection of digital processors, memory, A/D converters, video display ports, and an Ethernet controller, which take up an increasing portion of the PCB area. As a result the point-of-load regulators must support an increasing number of voltage rails in a smaller space to maintain the endoscopic system’s form factor. The LTM4644 and LTM4624 step-down µModule regulators present a simple, compact solution designed to meet the challenge.