Digitally Controlled High Voltage Power Supplies

Designing Digital Signal Processing Technology
Into Applications Offers Important Advantages

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Today's sophisticated Digital Signal Processors (DSPs) are capable of controlling a high voltage power system with far better results than were previously achieved by analog controllers - and therefore, this new technology is rapidly becoming more popular among high voltage system designers.

With a digital signal processor at the heart of a high voltage system, component count is lowered, system reliability is increased and noise immunity during arcs is enhanced. All of this translates to better performance, as well as a reduction in the time needed to develop an application and bring it to market.

Of course, designing a DSP into an application requires more than simply picking the latest digital controller off the shelf and installing it. Due to the need to match the right power source perfectly to specific system characteristics, DSP-based systems are typically custom-engineered by a supplier who specializes in a particular application as well as specializing in digital power controlled technology.

Some Background About Digital Power Controls

Until recently, digital control loops were not widely used in high voltage power systems, mainly because they were not fast enough and not versatile enough to provide the servo loop bandwidth and accuracy required by the most common applications – including medical and industrial X-Rays, lasers, e-beams, power feed equipment, communications equipment and several other technologies. High voltage applications usually include several multimode power supplies that are interconnected, interlocked and regulated in ways that require several separate circuits in order to monitor, control and operate many different aspects of the system all at the same time.

A typical X-Ray system, for example, includes the cathode and anode source and regulators, as well as the filament source. Some X-Ray systems also include a bias supply, and, the emission current regulator that controls the X-Ray tube current by adjusting the filament current or the bias voltage. Obviously, such systems demand that many processes can operate simultaneously. Therefore, it was difficult in the past for a single microcontroller system to complete every task before the first task needed attention all over again. For this reason, the first digital power supplies were hybrid systems that used microcontrollers to perform “some” of the signal processing and computer interfacing, but the bulk of the critical error amplifiers and pulse-width modulators were still performed by discrete analog components.

Many designers soon realized that this approach had limited use in high voltage systems since it didn't offer any real advantages in cost, size, or time to market. Plus, the limitations of this technology introduced new problems...including noise susceptibility during arcs and new components of radiated noise and other factors that outweighed the small benefits.

For instance, a typical high voltage system of this kind used the microprocessor or microcontroller to perform functions such as front panel controls and display, RS-232 or RS 485 computer interface, along with on/off logic and interlock, as well as some limited signal processing functions such as ramp generation, "digital calibration" or programmable operation, depending upon the specific x-ray tube or type of load used. Indeed, it was the right time for DSPs to take high voltage power to the next step.

DSPs Mean More Speed and More Design Possibilities

In recent years, with the introduction of digital signal processors designed for embedded applications, the idea of digitally controlling a complete system with a single DSP became more commonplace. Largely due to their speed and versatility, today's newest DSPs are gaining popularity among high voltage designers, who are increasingly incorporating the digital technology into next-generation applications.

It's important to point out that the difference between a microcontroller and a DSP is that a DSP can perform mathematical operations sometimes ten times faster than an equivalent microcontroller. In addition, DSPs are designed with most of the necessary servo loop components embedded into the DSP itself, including the A/D and DAC converters, pulse-width modulators, gate drive circuits, digital I/O and communication ports.

These powerful DSPs are capable of replacing all of the control servo loop components of a complex high voltage system including: feedback filtering and limiting; voltage, current and power crossover regulators; pulse width modulators; on/off logic and interlocks; soft start and automatic reset; RS 232/485 interface; and many other critical application components.

Yet, with all that versatility and bandwidth, DSPs still have plenty of power remaining to perform many application-specific tasks such as keeping track of heat units on X-Ray tubes, as well as being able to adjust the logic and set points as the tube ages or when it is first turned on after being off for some time. Today's high performance DSPs are also able to switch to a different mode of operation such as transferring to filament emission control in case of bias fault.

Also Consider These Additional Benefits of DSPs

Another significant advantage that digitally controlled power supplies can deliver to high voltage systems is the all-important concept of "component count, reliability and noise immunity." The core of the system typically involves a very compact, multilayer SMT printed circuit board with only a few components and interconnections since most of the circuits are replaced by a single DSP chip. Additional operational benefits reside in the fact that apart from the A/D converters, once the analog voltages are digitized, all the information is processed digitally (with its inherent advantages of noise immunity).

Still another advantage of a DSP-based system, as alluded to earlier, is the reduction of engineering development time. This is because in just about every instance the same DSP board can be quickly reconfigured for a totally different application. For example, simply by changing a programmable chip, the same DSP technology that controls a multi-power supply medical X-Ray system can also be utilized to control plasma applications or power feed equipment utilizing power factor corrected, current regulated, voltage limited power supplies.

Application Case Study: Digitally Controlled X-Rays

Engineered by Del High Voltage, the DSP-CORE/X-RAY is the first in a future family of DSP based controller sub-assemblies specially designed for high voltage systems. The DSP-CORE/X-RAY contains all the electronics necessary to control a complete X-Ray system including the regulators, interface, overload and interlock circuits, and also the computer interface.

System Description:
(Refer to Figure 1 at end of document)

The DSP-CORE/X-RAY includes the following major blocks:

Cathode Supply logic and regulator

Filament Supply logic and regulator

Bias Supply logic and regulator

Emission Current regulator

Overload and Interlock circuits

Arc Counter

Automatic Reset

Analog remote control interface

Computer interface

Cathode Supply:
The cathode supply of the DSP-CORE/X-RAY is a voltage regulated, current and power limited, high voltage power supply. The voltage reference is the cathode reference input, and the current limit is set to 1.9VDC on the mA feedback input.

The kV and mA feedback signals are digitally filtered. The frequency response of the low pass, digital filter is set to 5kHz, and the servo-loop bandwidth is set to 1kHz. The topology of the driver circuits is a resonating, pulse-width modulated (PWM) configuration, operating at 25kHz. The PWM output has a dynamic resolution of 8 bits, and a 16.67kHz update rate, allowing a settability and regulation of the output voltage better than 0.1% for both line and load changes. The cathode supply logic includes overvoltage, undervoltage, and overcurrent interlocks. The overvoltage is set to 2VDC on the kV feedback, the undervoltage is dynamically set to 5% below the cathode voltage reference, and it has a delayed response of 500mS to allow for turn on delays, and finally the overcurrent interlock is set to 2VDC on the mA feedback input.

During normal turn on, the cathode supply includes a soft start feature that limits the output kV rise-time to 1 second, the mA rise-time to 10 seconds, and output power rise-time also to 10 seconds. If an arc is detected, the logic circuits will turn off the output of the power supply for 1ms to allow for the arc to quench, and then will ramp the kV output with a rise-time of 20mS. If more than 5 arcs in 10 seconds are detected, or more than 20 arcs total are detected, the power supply will turn off and stay off and it will need a reset command to be restarted.

Filament Supply:
The filament supply of the DSP-CORE/X-RAY is a dual mode, current regulated power supply. The filament regulator operates in two different modes: while the high voltage is turned off, the filament operates in “pre-heat mode,” and after the high voltage is turned on the filament automatically switches to “emission current regulation mode.” During pre-heat (or idle) mode, the regulator will set the filament output to 25% of maximum, or about 0.5VDC on the Fil I feedback input. After the high voltage turns on, the regulator switches to emission current regulation mode, and it will increase the filament output in order to match the mA feedback input to the emission current reference, but is limited to 95% of maximum filament current, or about 1.9VDC on the Fil I feedback input.

If at any given time during operation the filament current goes to zero while the regulator is trying to make output, it will be considered an open filament condition, and the power supply will turn off. This “open filament interlock” has a delayed response of 2 seconds to allow for turn-on delays.

The Fil I and mA feedback signals are digitally filtered. The frequency response of the low pass, digital filter is set to 5kHz, and the servo-loop bandwidth is set to 500Hz. The topology of the driver circuits is a resonating, pulse-width modulated (PWM) configuration, operating at 25kHz. The PWM output has a dynamic resolution of 8 bits, and a 16.67kHz update rate, allowing a settability and regulation of the output current better than 0.1% for both line and load changes.

Bias Supply:
The bias supply of the DSP-CORE/X-RAY is a dual mode, voltage and current regulated power supply. The bias regulator operates in two different modes: while the high voltage is turned off, the regulator is in voltage mode and it will try to match the bias reference input to the bias feedback input. After the high voltage turns on, the regulator switches to emission current regulation mode, and it will decrease the pulse width in order to match the mA feedback input to the emission current reference.

The Bias V and mA feedback signals are digitally filtered. The frequency response of the low pass, digital filter is set to 5kHz, and the servo-loop bandwidth is set to 100Hz. The topology of the driver circuits is a pulse-width modulated (PWM) configuration, operating at 25kHz. The PWM output has a dynamic resolution of 8 bits, and a 16.67kHz update rate, allowing a settability and regulation of the output current better than 0.1% for both line and load changes.

Tailoring A Solution For Specific Designs

A digitally controlled X-Ray application as described above is just one of many possibilities for DSPs. Future versions of the DSP-CORE technology discussed in the previous case study will include controllers for: e-beam and laser systems, capacitor chargers, power feed equipment, power factor corrected high voltage power supplies, and several other applications.

By working closely with a DSP supplier who is an expert in the specific high voltage power requirements of a given application, designers can incorporate custom-tailored digital signal processing technology into their designs to provide many important performance benefits.

About the Author

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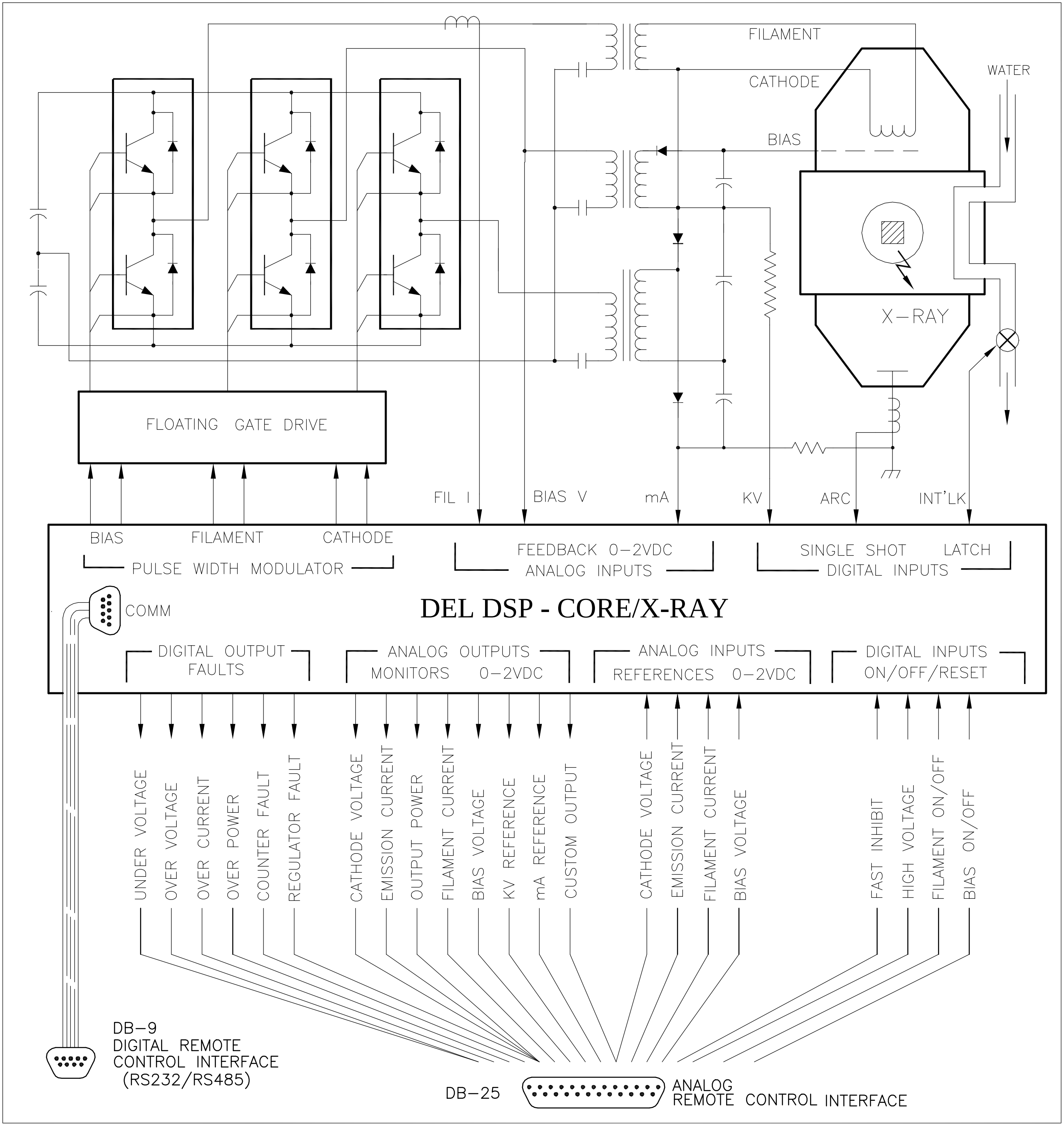

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