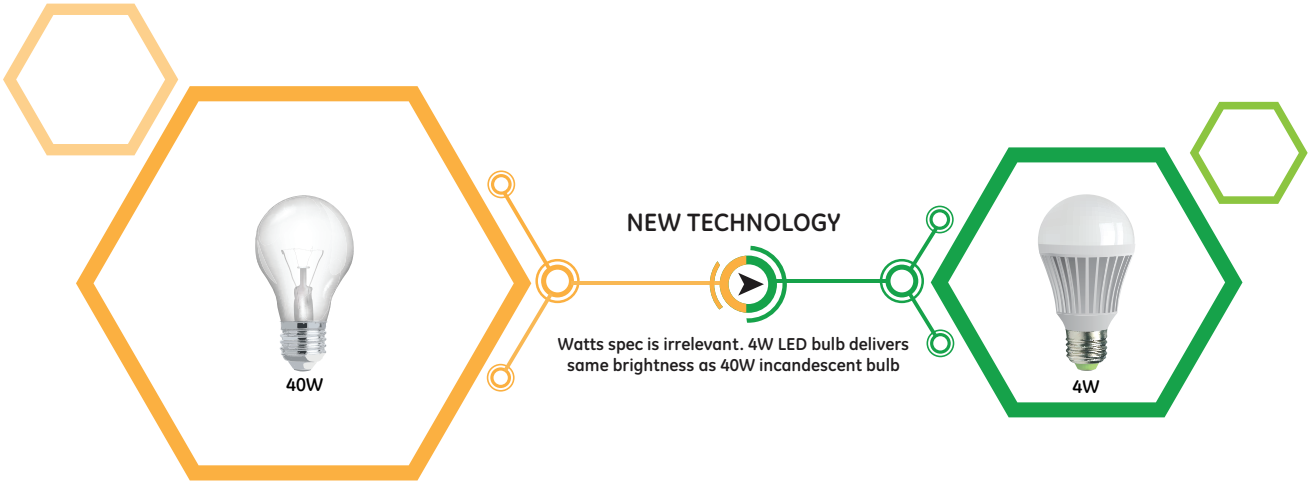
GE Healthcare

SIGNA Pioneer: Ultra High Efficiency Gradient System

Advancing the gradient technology curve



Summary

The SIGNA™ Pioneer 3.0T MRI system introduces novel Ultra High Efficiency (UHE) Gradient technology that represents a shift in the gradient technology curve, generating shorter TR and TE values to deliver exceptional clinical imaging. It redefines what one should expect from a contemporary gradient system.

The UHE Gradient System includes three key attributes. It begins with a high efficiency gradient coil design – one that inherently requires half the amount of current to generate the same gradient field as a conventional design. The next attribute is a high voltage gradient driver operating with very high efficiency. And finally, the system features Intelligent Gradient Control (IGC) that utilizes an advanced control system and sophisticated modeling to optimize the pulse sequence waveforms. By employing, a predictive model of the thermal and frequency dependent characteristics, the Intelligent Gradient Control is able to fully harness the high efficiency of the gradient hardware to deliver superior TR & TE values. The use of both feed-forward and feedback digital controls enable the UHE gradient system to control gradient waveforms with very high accuracy.

With UHE Gradient technology, the SIGNA Pioneer excels in gradient intensive sequences such as FIESTA, EPI, and DTI. In these sequences, the UHE gradient system delivers TR and TE values that can match or even outperform systems with higher gradient specifications. The result is exceptional image quality and clinical performance that redefines the expectations of what a 36/150 gradient system can do.

High Efficiency Gradient Coil Design: The Shift from Current Type to Voltage Type

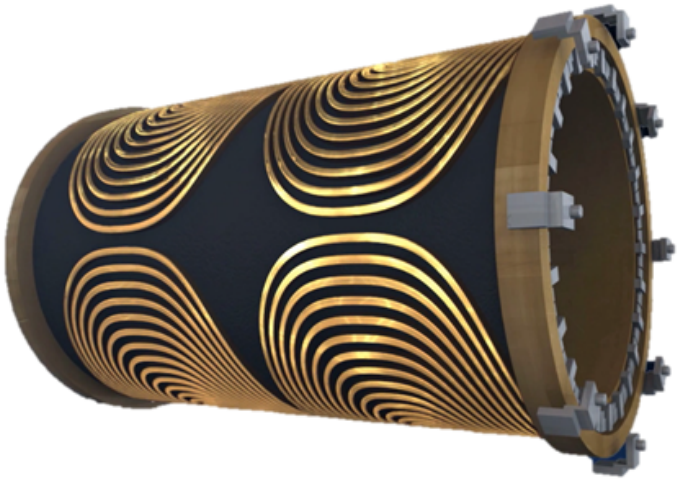
Magnetic flux (Φ is expressed by a relationship between current (I) and self-inductance (L) as shown in the formula below:

$\Phi = L*I$

This formula illustrates there are two ways to generate strong magnetic fields. One method is to increase the amount of current, leaving self-inductance the same. The other is to increase the self-inductance while keeping current level the same. Consequently, there are two types of design: The "current type" refers to manipulation of only the current, and the "voltage type" refers to manipulation of inductance and hence the operating voltage.

Conventional gradient coil technology uses a "current type" design whereas the SIGNA Pioneer adopted a "voltage type" design. The Variable Resonance Module (VRMw) gradient coil used in SIGNA Pioneer enhances inductance through increased number of winding wires. When measuring the amount of power required to generate the same magnetic field, VRMw has a higher resistance value because of the increased wire material. However, the total amount of power used across the three axes on VRMw is only 56% of what conventional gradient coils require. This reduced power consumption is because VRMw requires about half of the current.

		Current [%]	Resistance [%]	Loss [%]
VRMw/ conventional gradient coil	X	53%	206%	58%
	Y	53%	204%	57%
	Z	49%	217%	51%



Gradient Driver Design: The Maximum Voltage and The Maximum Efficiency

To generate adequate slew rate on the gradient coil with high inductance, the output voltage of the gradient amplifier was raised. The formula for Voltage is expressed as follows:

$V = L*di/dt + R*i$

Where inductance of gradient coil is *(L)*, resistance is *(R)*, and the current is *(i)*

The SIGNA Pioneer gradient coil operates at 600V above conventional gradient coils to gain the same level of slew rate.

The new Gradient amplifier design on the SIGNA Pioneer provides high voltage to the gradient coil using a topology called H-Bridge, which consists of 4 switches called IGBTs. To operate at such high voltages, the bus voltage of each H-Bridge was increased. Further, the switching frequency of the IGBTs, air cooling filter design, and control system were optimized such that the voltage per H-Bridge could increase. As a result, this gradient amplifier has the highest voltage of any GE MRI system to date.

When the gradient amplifiers on three axes are operational at full capacity, there is a high peak power load on the primary side of the gradient power supply. Therefore, improvements in the cooling capability were implemented on the power supply to support a high duty cycle consistent with 3.0T imaging. The loss due to the switching was minimized using a topology called series resonant control. This topology has the advantage of "zero" switching loss when the IGBTs turn on. The topology also improves the turn off loss at very high loads by sequencing turn off to occur at less than peak current. Additionally, power density was improved over earlier generations by water-cooling the IGBTs. All of these technological improvements contribute to the high efficiency of the gradient driver along with very consistent high duty cycle performance.

This highly efficient gradient driver design also contributes significantly to reduction in siting space for the SIGNA Pioneer to help enable the 3.0T SIGNA Pioneer system to fit within a 1.5T siting space. This gradient power driver has same chassis size as other 1.5T products[2]. However, it achieves 1.75 times more output power to deliver gradient magnetic capability that is expected from a high-end 3.0T product.

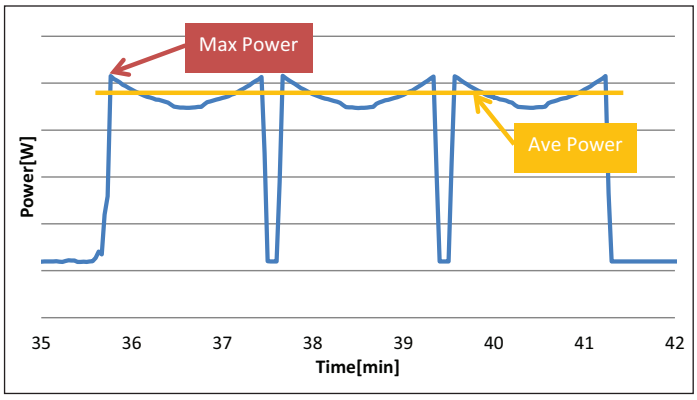
	SIGNA Pioneer/Conventional 1.5T
Output Irms [%]	117%
Output Vrms [%]	150%
Output Power [%]	175%

Intelligent Gradient Control: Fully leveraging the high-efficiency gradient hardware

Intelligent Gradient Control Technology is a combination of sophisticated modeling and advanced control system design.

To deliver a highly accurate amplifier response, the frequency response of the VRMw gradient coil was utilized to implement feed-forward control compensation. In addition, frequency components like eddy current correction, which exceed the maximum frequency MRI requires, were attenuated. This enabled a more accurate and focused reproduction of the frequency components that should be controlled.

Once an MRI scan is started, the system generates exactly the same waveform as the programmed protocol. There is a need to model the gradient waveform, which the device is going to produce, to ensure it is acceptable for the hardware.



This prediction model is called the "Gradient Thermal Model." The model automatically corrects the pulse sequence to fit within the acceptable range of hardware based on the prediction of heat and power. This model takes into account every component with high power stresses including gradient power supply, gradient amplifier, and gradient coil. This highly accurate gradient thermal model in turn, enables optimization of the pulse sequence to minimize TR and TE values by leveraging the high efficiency and thermal capacity of the gradient hardware.

MRI requires a different amount of power even during a single scan due to the slice and phase encoding. The thermal models are typically designed to use the maximum power generated during a single scan in order to protect the hardware. This is due to the fact that the waveform fidelity suffers if the bus voltage drops due to high peak load. Since the gradient coil's resistance value has a frequency dependance, FFT was carried out on the waveform to calculate the power as a function of frequency.

In order to correct for the deficiencies in traditional thermal models, SIGNA Pioneer adopted a new calculation method called "Quasi AC Model." This method enables response to the changes in resistance caused by the frequency. With this model, both maximum and average power calculations are taken into account. Therefore, the hardware can be safely and efficiently leveraged by looking at the average power for the heat limit of parts and the maximum power for the supply capability respectively.

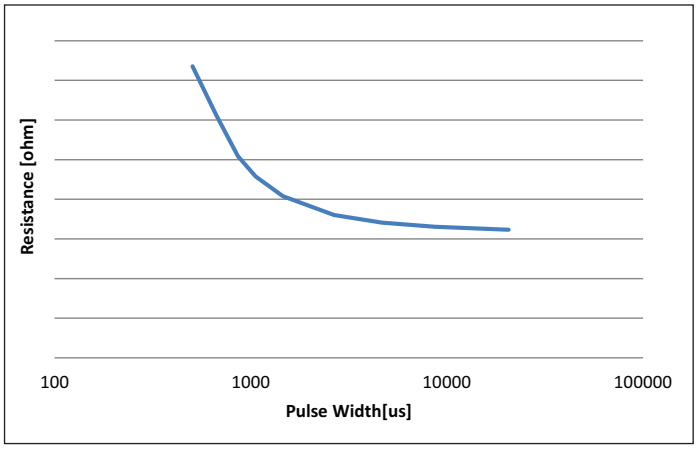
UHE Gradient System: Shorter TR and TE values, Superior Performance

The benefits of UHE Gradient technology is demonstrated through clinical performance. The UHE Gradient System, delivers shorter TR and TE values as shown in the table below for some key sequences:

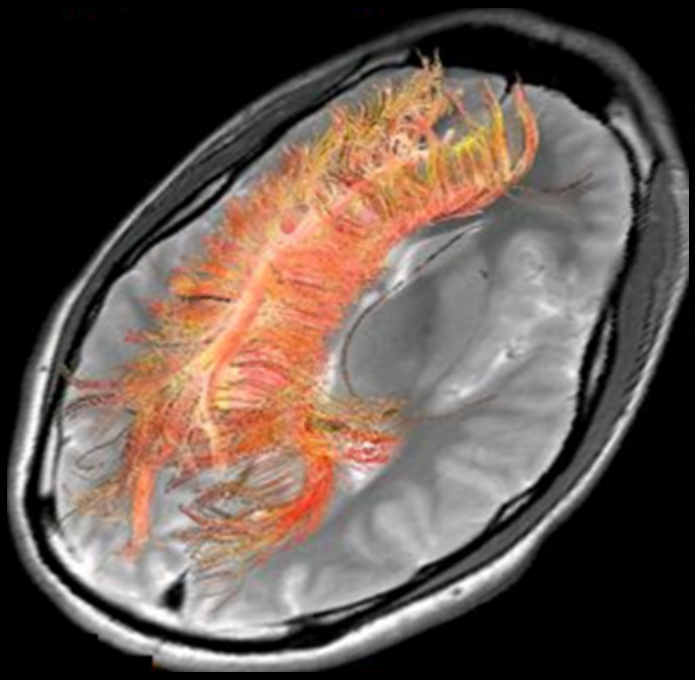
Sequence	TR/TE , other scan parameters
3D Fiesta	2.09/0.488
2D FSE	6/2.1
EPI	6/1.7
EPI (esp)	0.56, 99cm FOV
DTI (B-value)	10000

TR/TE values specified in ms for 256x256 matrix

FIESTA, EPI, and DTI are known to be highly gradient intensive applications. The need to deliver the shortest TR and TE values to generate superior clinical images is greatest with these sequences. It is notable that the TR and TE values delivered by the SIGNA Pioneer in the aforementioned cases match or even outperform MRI systems with higher gradient specifications[3].



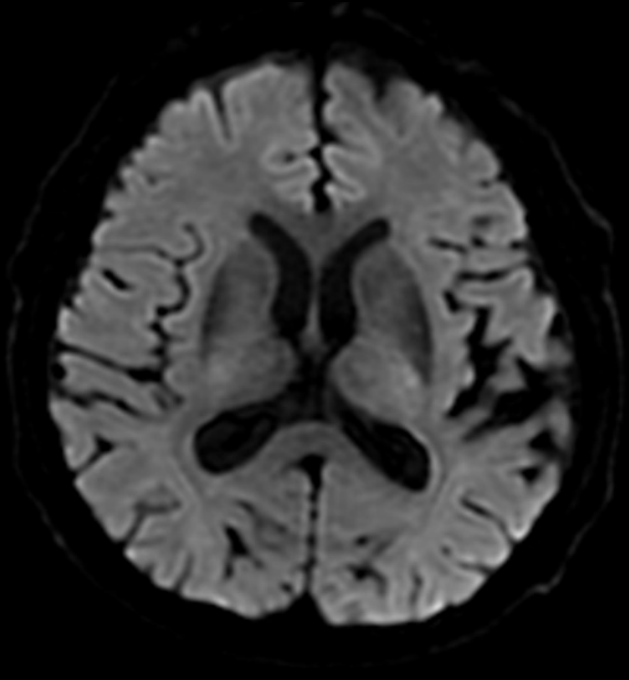
Clinical images demonstrating the effectiveness of the UHE Gradient System are shown below.



DTI

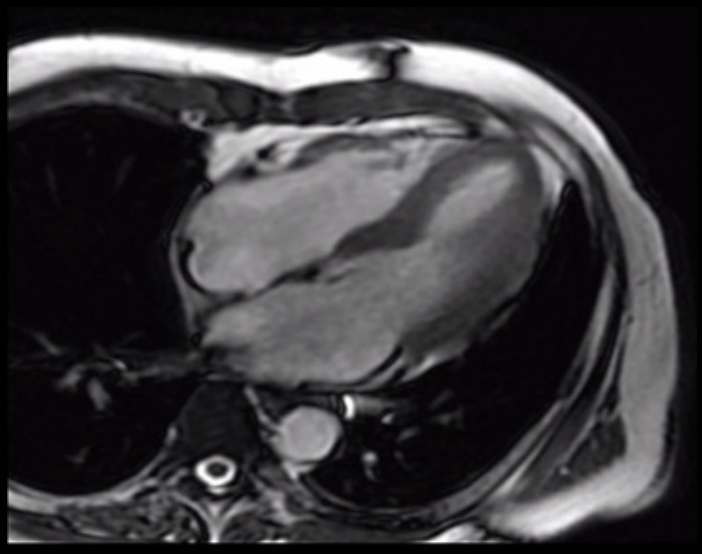
128 x 128, 4 mm, FOV 24cm

25 directions



DWI

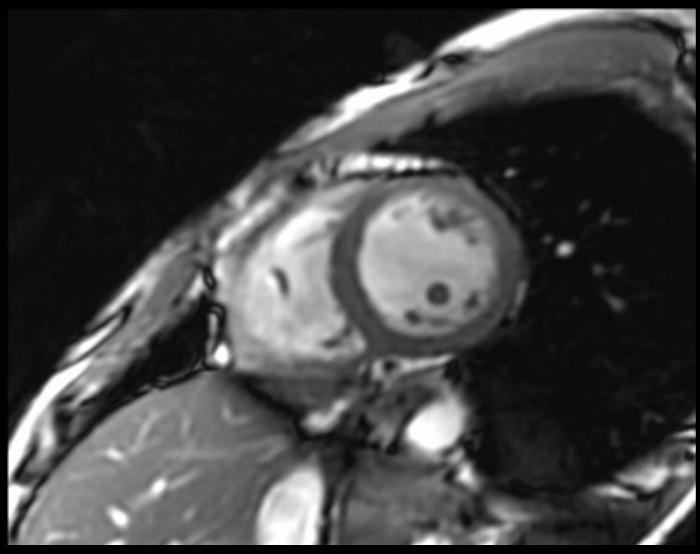
128 x 128, 4mm, b 1000



FIESTA

172x200, 7mm

0:08, TR 3.5ms



FIESTA

176x200, 8mm

0:10, TR 3.6ms

Conclusion

UHE Gradient Technology enables the SIGNA Pioneer 3.0T MRI system to deliver superior performance and exceptional image quality through novel technology that resets the gradient technology curve.

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[1,2,3] Comparison data on file

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imagination at work