Altaire™

High-Field Performance Open MR

The Advantage of VOSI™ Technology

Vertical-Field with Optimized Sub-System Integration (VOSI) Technology

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Preface

The Advantage of VOSI™ (pronounced Vo' sigh) Technology is intended for readers with a working clinical knowledge of MR imaging who desire to know more about the technical aspects of the images acquired from Altaire, Hitachi's high-field performance Open MR. To be sure, quality MR images are the result of conscious choices that affect the many parameters associated with scanning and the design of the imaging system. This document is a supplement intended to highlight specific features, not replace materials that address the complex aspects of magnetic resonance physics.

Image Quality

It is generally accepted that key factors to image quality are the following:

Signal-to-Noise Ratio is used to describe the relative contributions to a detected signal of the true signal and random superimposed signals ("noise") so as to provide the basis of sufficient information to view the image.

Spatial Resolution defines the ability to discriminate small distance between two points in the object that can be distinguished as separate details in the image.

Contrast Resolution defines the ability to discriminate adjacent objects as a function of their gray level differentiation. Compared to conventional radiography, object contrast is more difficult in MR imaging as there are more object parameters affecting the image, and their relative contributions are very dependent on the imaging technique used.

These key image quality factors are also relevant with respect to determining quality of MR images. Various components of the MR system contribute to the optimization of these image quality factors.

VOSI Technology

An MR imaging system is made up of sub-systems that must work in close concert to create a high quality magnetic resonance image. Careful specification and design of not only the magnet, but also the gradient, radio frequency and computer sub-systems is critical to consistently high image quality. Optimization of any one of these sub-systems in isolation will not necessarily yield high image quality.

VOSI (pronounced Vo' sigh) technology is the embodiment of Hitachi's attention to each aspect of the imaging system's specification, design and manufacture.

This discussion illustrates the VOSI approach to optimizing image quality in an open architecture vertical field system in order to provide image quality comparable to conventional high-field imaging systems.

How VOSI Technology Enhances Image Quality

Signal-to-Noise Ratio (SNR):

The useful information in the MR image is based on signal, while noise is both fundamental to the imaging process and machine-induced. Whereas available signal is fundamentally the function of field strength, total noise is under our control. The VOSI approach maximizes signal and minimizes noise by employing the best available radio frequency technology and the conscious choice of the vertical field direction.

Let's look at how VOSI maximizes signal and minimizes noise, thus optimizing SNR.

Available MR Signal

Boltzmann tells us that there is proportionality between static magnetic field strength and net longitudinal magnetization:

$$M_0 \propto \frac{B_0 N_P}{T}$$

Where M_0 is the net longitudinal magnetization, B_0 is the static magnetic field strength, N_P is proton density and T is the tissue temperature.

The net longitudinal magnetization (M_0) is the ultimate signal source representing potential signal. It may be assumed that in imaging, a higher magnitude field strength (B_0) will translate directly into a proportionately higher signal to noise ratio (SNR). This is not the case. Therefore, there must be other factors to consider. We need to look not just at available signal, but at the signal-to-noise ratio as it appears to the receiver.

MR Signal-to-Noise (SNR)

This expression potentially illustrates a relationship between the SNR as presented to the receiver and other important factors (ignoring pulse sequence parameters):

$$SNR \propto C\eta M_0 \sqrt{\left(\frac{\mu_0 Q \omega_0 V_C}{4FkT_C\Delta f}\right)}$$

Where C is a function of coil geometry, η is the coil filling factor, μ_0 is the permeability of free space, Q is the quality factor of the coil, ω_0 is the Larmor frequency, V_c is the volume of the coil, F is the noise figure of the preamplifier, k is the Boltzmann constant, T_c is the coil temperature and Δf is the RF receiver bandwidth.

Factors under our control are the coil geometry, fill factor, the quality factor, the coil volume, preamp noise figure and receiver bandwidth. These factors fall into two broad areas, coils and receiver technology. The following table provides some description of these factors:

Factor	Description
Coils	
C	Coil geometry: A constant demonstrating the impact of coil architecture on SNR. Coils can be of solenoid, saddle, multi-element resonator and other types.
η	Fill factor: Represents the relationship of the receiver coil's size to the size of the imaged object. The closer the receiver coil size is to the imaged object size, the higher the fill factor. Given that this factor apparently has as much impact on signal to noise as net longitudinal magnetization (M_0), careful attention should be paid to it.
Q	Quality factor: Describes coil selectivity. Higher Q coils have a higher selectivity and SNR.
V_c	Coil volume: While it seems that an increased coil volume will increase SNR, in practice the increased electrical resistance of the elements and inherent added noise likely negate a larger coil's advantage.
Receiver	
F	Preamplifier noise figure: The noise figure is related to: $\frac{SNR_{in}}{SNR_{out}}$ for the preamplifier stage.
Δf	Receiver bandwidth: The range of detectable frequencies. This parameter is a function of pulse sequence parameters and is normally set as low as possible without introducing artifacts.

Of the factors listed above, coil geometry, fill factor, preamplifier noise figure and receiver bandwidth are the most significant for this discussion. Let us examine the VOSI technology advantage for each of these factors.

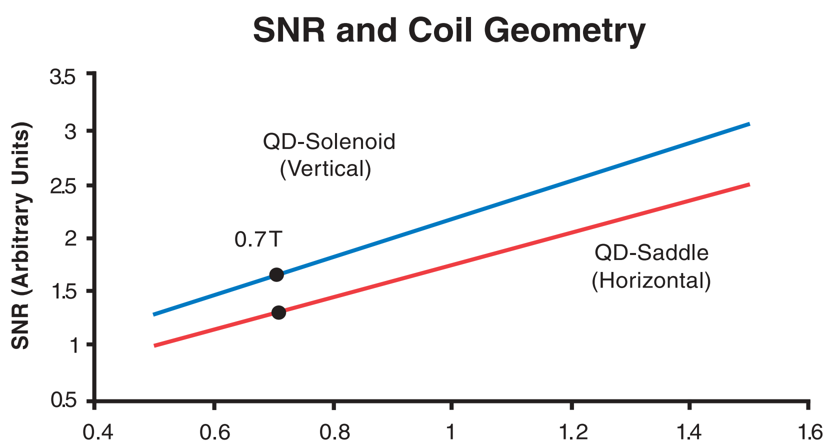
Coil Geometry (C)

As the first step in reception of the vanishingly small MR signal, the coil basic technology is fundamental to signal-to-noise (SNR). The choice of the quadrature (QD) solenoid design for volumetric coils in the Altaire offering ensures optimal signal to noise and uniformity.

A solenoid is simply a loop or loops of conductor. The QD solenoid adds another element arranged in such a way that up to 40% more SNR is realized. With this performance and simplicity comes a higher image sensitivity and SNR than other receiver coil geometries.

The axis of the receiving coil needs to be perpendicular to the direction of the field (B_0) to detect transverse magnetization. For horizontal field systems, solenoid type coils can be employed, but they are used in a *surface* application. Because the long axis of the patient is parallel to B_0, it is often not possible to use such coils in a volume application where the coil completely encloses the anatomical region. Horizontal field systems usually employ saddle type coils that have an inherently lower SNR for volume applications.

The following figure illustrates SNR as a function of field strength and field orientation for the QD-Solenoid and QD-Saddle coils.



Note that for all field strengths, the QD-Solenoid combination coil SNR is 30% higher than that of the QD-Saddle type employed in a horizontal field application.

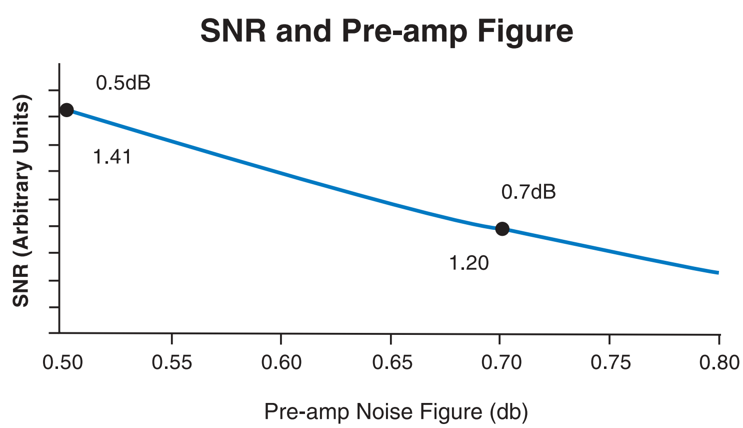
Therefore, the theoretical SNR advantage obtained from much higher field strength is reduced by the vertical field applicability of the much more sensitive QD-Solenoid coil geometry over the QD-Saddle type coil.

Coil Fill Factor (η)

The selection of a coil closely conforming to the imaged anatomy is as important as longitudinal magnetization (M_0), according to the expression previously presented. Hitachi has chosen to provide a wide range of anatomically specific coils for optimal performance rather than relying on general-purpose coils. Anatomically specific and flexible type coils optimize fill factor while providing a linearly increasing impact on SNR.

Receiver Pre-amplifier Noise Figure (F)

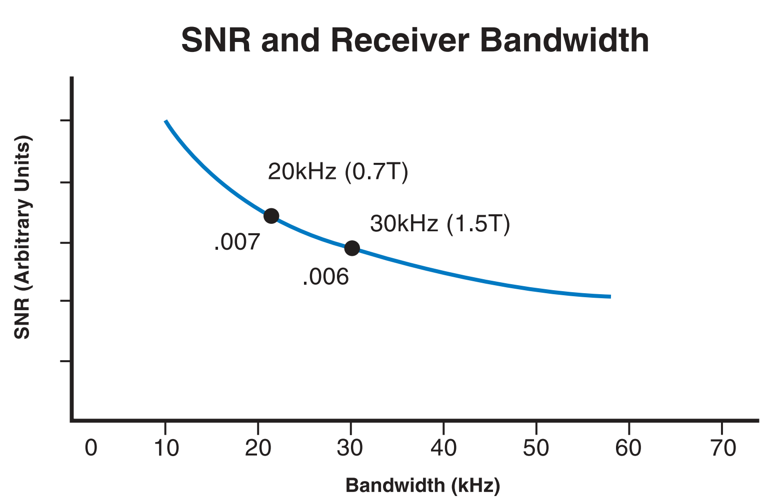
As the first stage of signal reception after the receiver coil, the preamplifier needs to apply significant gain without adding noise. Altaire's pre-amplifiers' 0.5 dB noise figure indicates Hitachi's attention to this critical stage in the signal reception process. Some manufacturers select lower cost RF sub-system components, while Hitachi's VOSI driven design approach resulted in a higher performance device at a premium price point.



Receiver Bandwidth (Δf)

Minimal bandwidth results in higher signal-to-noise ratio as illustrated below. The figure shows an example bandwidth selection of 20kHz for a pulse sequence at 0.7T. This same sequence will be performed at a 30kHz or higher bandwidth on a 1.5T system to avoid susceptibility artifacts. Note the higher SNR associated with Altaire's lower receiver bandwidth.

Altaire's VOSI inspired highly uniform main magnetic field and precision gradient control plus careful receiver design enables automatic or user variable minimal bandwidths, without compromising image quality.



SUMMARY

In summary, the Altaire vertical field permanent magnet technology provides signal-to-noise (SNR) comparable to high-field strength systems by optimizing each sub-system's performance. If we restate Altaire's VOSI technology advantages in terms of a horizontal field imager, we can depict Altaire's virtual horizontal field strength in terms of SNR in the following manner:

Vertical-field and Solenoid RF coil technology advantage	1.30
Receiver Bandwidth advantage	1.20
Pre-amplifier Noise Figure advantage	1.20
Coil Fill-Factor advantage	>1.00
Total Altaire Signal-to-Noise Advantage Compared to Horizontal Field Magnets	>1.90

Therefore, the Altaire effective SNR performance in terms of horizontal field strength is:

$$(1.9)\ (0.7\text{Tesla}) = 1.3\ \text{Tesla}$$

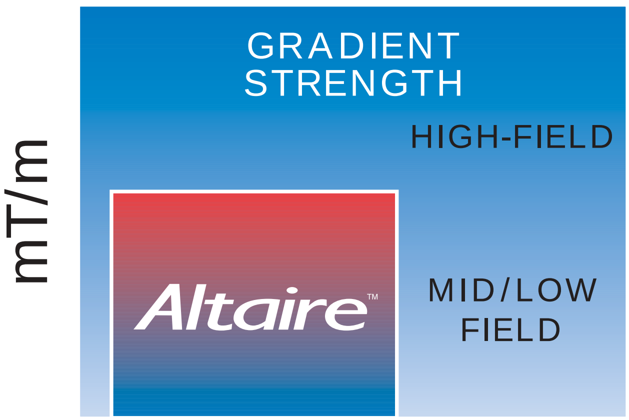
Spatial Resolution:

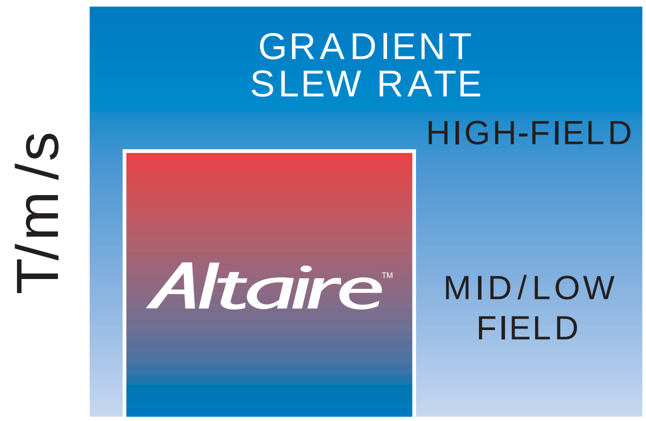
The ability to discriminate between the smallest structures represents the imaging system's spatial resolution. All aspects of the imager contribute to high spatial resolution, but the prime factor is the gradient sub-system.

Gradient Sub-system

In order to provide users with maximum image quality and clinical flexibility, VOSI dictated a high performance gradient sub-system. Altaire's 22mT/m gradient strength and 55 T/m/s slew rate is comparable with conventional high-field imaging systems.

Additionally, Altaire's high performance gradient sub-system delivers advanced MR applications typically observed in high-field MR systems. Very short inter-echo spacing for FSE and EPI as well as short TE for MRA are supported by the slew rate in conjunction with the gradient's high strength for high resolution and maximum flexibility.





In summary, high slew rate gradients deliver high ***spatial resolution*** and ***advanced imaging applications.***

Contrast Resolution:

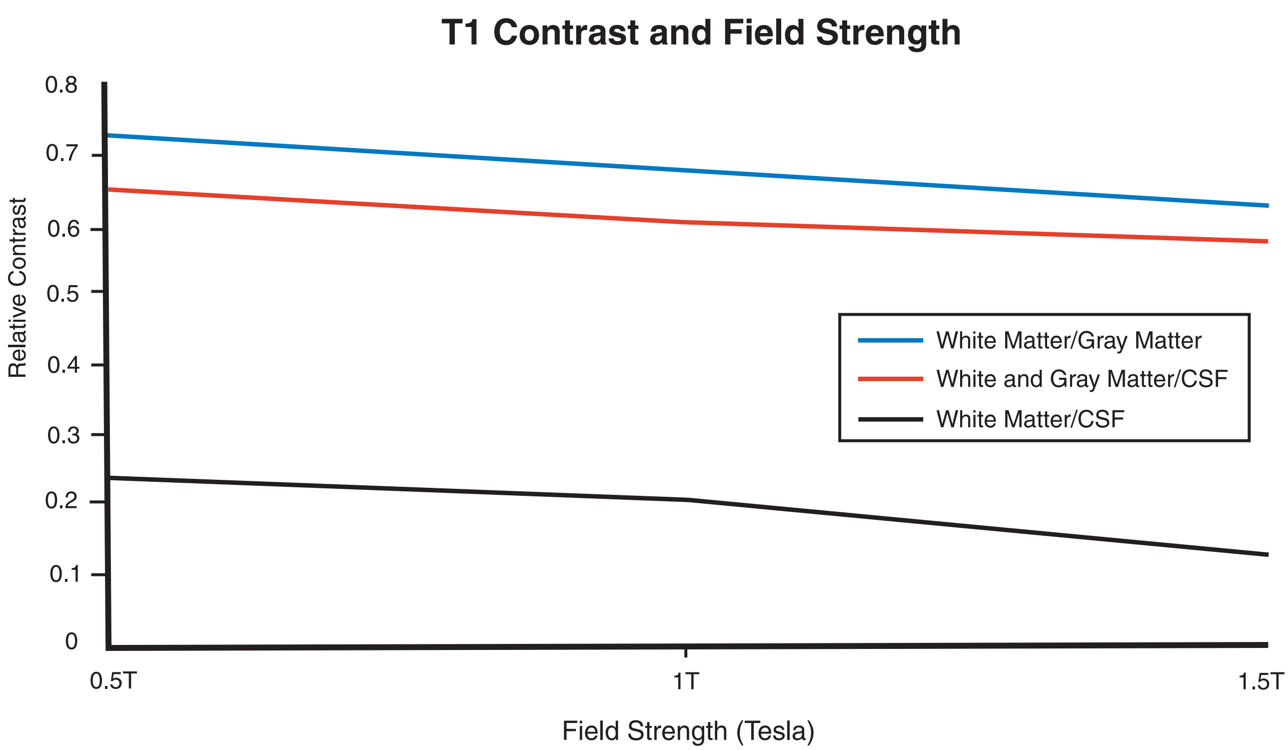
The ability to discriminate between different tissue types, even in a low signal environment, is a key determinant of an imaging system's clinical usefulness.

VOSI technology choices assure Altaire's high sensitivity to small differences in tissue contrast under the most demanding scanning parameters.

Prime factors in this sensitivity are Altaire's main magnetic field, its RF technology and sophisticated pulse sequence control.

T1 Contrast

Longitudinal relaxation, governed by tissues' T1 time constant, is field strength dependent. Longer T1 time constants are characteristics of higher field strengths for most tissues. Because of this field strength dependence, the effective relative T1 contrast between many tissues is actually greater at lower field strengths as shown below for brain tissue:



The T1 contrast advantages inherent to 0.7T are further augmented by the powerful capabilities available with Altaire's advanced MR imaging platform.

T2 Contrast

T2 is essentially independent of field strength and the ability to discriminate among different levels of T2 contribution to contrast is often a function of available SNR.

Altaire's sensitive, low-noise receiver electronics support effective T2 imaging. Further, the availability of operator selectable variable bandwidth and imaging parameter flexibility result in optimum signal to noise even with heavily T2-weighted images.

RF Fat Saturation

The resonant frequency difference between fat and water is a function of field strength. The VOSI driven choice of operating at a nominal main magnetic field strength of 0.7T places fat and water far enough apart for effective RF fat saturation. However, it is the highly uniform nature of Altaire's main magnetic and RF excitation fields that enables practical application of RF fat saturation over a large imaging volume.

At ±1.5 ppm @ 35 cm DSV (peak to peak, 15 plane method), Altaire's basic magnetic field uniformity leads the Open MR imaging market. In addition, Altaire provides per-patient first and second order shimming to offset the patient's effect on the main field uniformity.

The main field therefore provides an effective foundation for the highly uniform RF saturation pulse from Altaire's unique flat Quadrature Multi-Element Resonator transmitter.

This VOSI inspired magnet-RF subsystem interaction ensures that the tuned RF saturation pulse reduces the signal from fat throughout the large imaging volume.

FatSep™

Sophisticated pulse sequence and RF control technology also enable a spin-phase dependent fat-water separation technique to be applied to Altaire in addition to the conventional frequency-based approach.

Hitachi's exclusive FatSep pulse sequence provides users with phase sensitive Spin Echo and Gradient Echo, including steady state, sequences featuring ultimate parameter flexibility and high image quality. Effective contrast delineation between fat and water is possible with this technique, supplementing the RF fat saturation sequence.

MTC

Magnetization transfer contrast can provide additional lesion-normal tissue contrast.

The advanced solid-state quadrature power amplifier and Altaire's advanced pulse shaping electronics enable user selectable MTC pulse shape, strength, and frequency offset for maximum flexibility.

Users can selectively apply MTC pulses to Spin Echo and Gradient Echo sequences in addition to 3DTOF sequences for background suppression.

Susceptibility

Susceptibility is the physical basis of the distortion caused in an image by air-tissue interfaces and metallic objects. These distorting effects are proportional to field strength and can compromise contrast resolution in an image, especially when combined with low receiver bandwidths.

Altaire's 0.7T field strength reduces susceptibility effects, compared to higher field strength systems, and its VOSI driven RF technology enable selection of optimal receiver bandwidths for SNR while avoiding distortion artifacts.

In conclusion,

Altaire™ offers an Open MR system that delivers

Image Quality comparable to high-field

Scan Times comparable to high-field

Clinical Capabilities comparable to high-field

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