# The Signal-to-Noise Indicator or How to Navigate the 'Bermuda Triangle'

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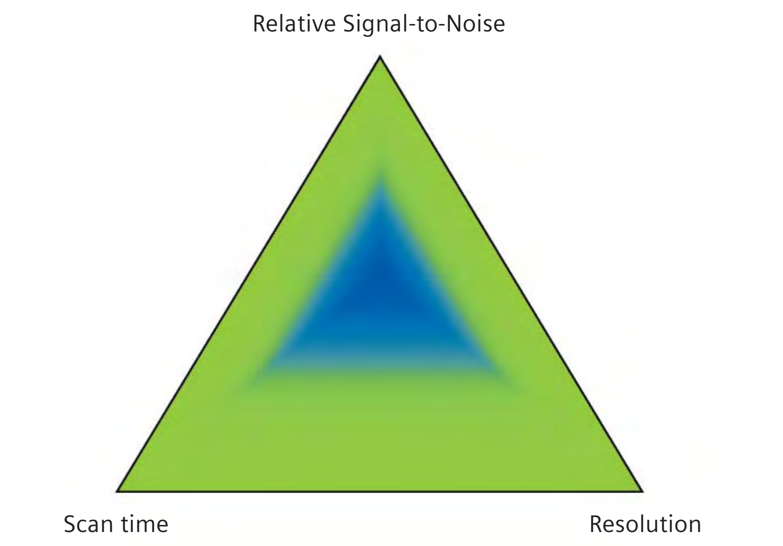


**1** 'Bermuda Triangle' of dependant MR quantities.

We observe quite often that people feel uneasy with the interpretation of the numbers the signal-to-noise (S/N) indicator shows on the *syngo* program-card. "May I change the protocol although the SNR indicator shows a value of 0.3?" "Why does oversampling improve S/N? The larger FOV only covers more air." Such questions and many more will be answered in this article. We will take away the mystery of parameter changes and explain their mutual dependencies (Fig. 1).

## What is signal-to-noise?

The total MR-signal is a mixture of the signal from the pure MR experiment plus thermal noise and other sources of noise. A measure of quality for a medical image is the ratio of the signal-intensity in the object divided by the signal-intensity of the noise (SNR) typically measured in the air outside the body.

## Why is the SNR relative?

The SNR indicator of a saved protocol always shows the value 1.00 or 100%. Changing certain MR parameters changes this indicator value but only relative to the initially stored version of this protocol. After saving the performed parameter changes the SNR indicator switches back to the value of 1.00. Do not use this value for comparisons between different protocols!

## Which parameters influence the SNR indicator?

There are several parameters which alter the signal S. Or, looking at the equation, the signal S is proportional to certain parameters.

$S_{2D} \sim 1/\mathrm{sqrt}\,(BW) * \Delta x * \Delta y * \Delta z * \mathrm{sqrt}\,(AC * N_{pe})$

$S_{3D} \sim 1/\mathrm{sqrt}\,(BW) * \Delta x * \Delta y * \Delta z * \mathrm{sqrt}\,(AC * N_{pe} * N_{3D})$

- BW – bandwidth in Hz/pixel
- $\Delta x$ – inplane resolution in x-direction: $FOV_x / N_{re}$
- $\Delta y$ – inplane resolution in y-direction: $FOV_y / N_{pe}$
- $\Delta z$ – Slice thickness or partition thickness in 3D case: slab-thickness/ $N_{3D}$
- AC – Averages: number of excitations per same encoding step
- $N_{re}$ – Base matrix size in read direction
- $N_{pe}$ – Number of phase encoding steps
- $N_{3D}$ – Number of phase encoding steps in 3D direction or Z-direction

For our problem we are only looking for dependencies with respect to resolution, i.e. voxel size, total number of acquired echoes (number of phase encoding steps), number of averages (number of excitations) and readout-properties such as bandwidth per pixel. Parameters determining contrast like TE, TR, TI and flip angle as well as the sequence type, field strength and coil type do not play any role for the SNR indicator (Fig. 2).

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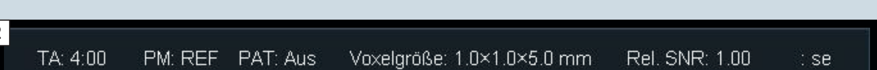


**2** Headline of the parameter card in the *syngo* MR B/C/D-software versions.

## What does the resolution indicator show?

In *syngo* MR A/B/C software versions you get with mouse-over on the resolution field a display of values down to an accuracy of 1/100 mm. In the *syngo* MR D-version you additionally get a display of the measured and the calculated resolution (Fig. 3).
Example:
1.00 x 1.00 x 1.00 mm = $\Delta x * \Delta y * \Delta z$

## What does the scan time indicator show?

The measurement time (TA) depends on the product of TR time, number of averages AC, number of phase encodings, and number of 3D encodings and may be divided by the Turbo factor TF, EPI factor and time saving factors from sampling strategies like iPAT and Halffourier.
$TA_{2D} = [(TR * AC * N_{pe}) / (TF * PAT_{2D})] +$ Prep + Intro
$TA_{3D} = [(TR * AC * N_{pe} * N_{3D}) /$ $(TF \times PAT_{2D} * PAT_{3D})] +$ Prep + Intro

- Prep – preparation pulses at the beginning of a sequence to bring the magnetization into steady state. This takes a few seconds.
- Intro – 3 gradient knockings at the beginning of a protocol to warn the patient; can be switched off for breath-hold series on the sequence card.

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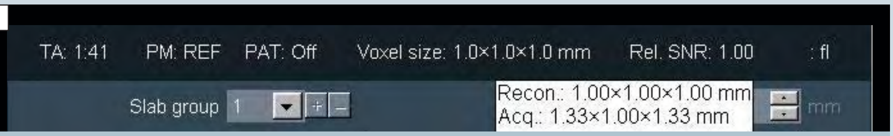


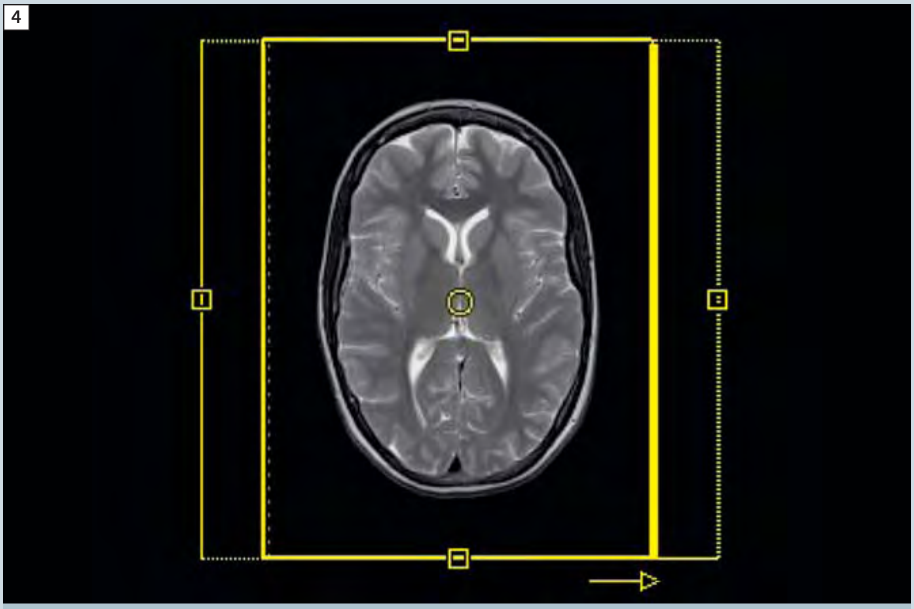

3 Mouse-over on voxel size in the *syngo* MR D-software version.

## What do these values tell me?

Fortunately the MR software does all these calculations for you. When changing parameters of a given protocol which already delivered decent image quality you get an idea of how the scan time, the resolution and the relative SNR change compared to the initial protocol setup. A protocol with a lot of reserve in SNR can still deliver good image quality, even with an SNR indicator on 0.1. But

### Table 1: Changing the number of phase encoding steps and averages affects scan time TA, pixel size and relative SNR.

| FOV (mm) | Matrix $N_{pe} \times N_{re}$ | AC | TA a.u. | Pixel size (mm²) | Rel. SNR a.u. | Explanation |
|---|---|---|---|---|---|---|
| 512 | 256 x 256 | 2 | 1 | 2 x 2 | **4.00** | 4 times the pixel size |
| 256 | 128 x 128 | 2 | 0.5 | 2 x 2 | **2.83** = $(4 / \sqrt{2}) = 2 * \sqrt{2}$ | 4 times the pixel size and 2 times less $N_{pe}$ |
| 256 | 128 x 256 | 2 | 0.5 | 2 x 1 | **1.41** = $(2 / \sqrt{2}) = \sqrt{2}$ | twice the pixel size, but 2 times less $N_{pe}$ |
| 256 | 256 x 256 | 4 | 2 | 1 x 1 | **1.41** = $\sqrt{2}$ | twice the number of ACs |
| **256** | **256 x 256** | **2** | **1** | **1 x 1** | 1.00 | **start protocol (reference)** |
| 256 | 256 x 256 | 1 | 0.5 | 1 x 1 | **0.71** = $(1 / \sqrt{2})$ | half the number of ACs |
| 256 | 256 x 512 | 2 | 1 | 1 x 0.5 | **0.5** | half the pixel size |
| 256 | 512 x 512 | 2 | 2 | 0.5 x 0.5 | **0.35** = $(0.25 * \sqrt{2})$ | quarter pixel size, but 2 times more $N_{pe}$ |
| 128 | 256 x 256 | 2 | 1 | 0.5 x 0.5 | **0.25** | quarter pixel size |



4 33% phase oversampling applied on a 75% phase FOV.

**Table 2: How MR parameters affect TA, resolution and SNR.**

| Parameter | | Measurement time TA | Resolution | SNR |
|---|---|---|---|---|
| Matrix | ↑ | ↑ | ↑ | ↓ |
| Fields-of-view (FOV) | ↑ | – | ↓ | ↑ |
| Slice thickness | ↑ | – | ↓ | ↑ |
| Bandwidth per pixel | ↑ | (↓)* | – | ↓ |
| Averages AC | ↑ | ↑ | – | ↑ |
| Phase oversampling | ↑ | ↑ | – | ↑ |
| Rectangular FOV | ↓ | ↓ | – | ↓ |
| iPAT factor | ↑ | ↓ | – | ↓ |
| Partial Fourier factor | ↑ | ↓ | – | ↓ |

* only if TR can be shortened

when you already pushed resolution and scan time to a level where the images start to get noisy, a further change with a resulting SNR of 0.9 could result in an unacceptable quality. As said, the SNR indicator shows a relative quantity. It depends on the starting conditions.
You will always have to sacrifice one or two items when optimizing the third one.
Better resolution in less scan time with higher SNR is impossible unless you change the measurement conditions like field strength or type of RF coil.

Table 1 gives an example:

- Bandwidth and slice thickness are assumed constant
- No iPAT and quadratic FOV
- Pixel size x slice thickness = Voxel size

Obviously the factor square root of two ($\sqrt{2}$) plays an important role when diminishing or enlarging certain MR parameters by a factor of two. Only alterations of the slice thickness change the SNR indicator linearly. All other parameters go with the square root of the change factor up or down.

## Why does phase oversampling improve the S/N?

Oversampling in phase direction acquires more encoding steps and thus increases SNR. Each independently-sampled phase encoding step adds a portion to the total SNR. Each echo contains information about the whole image; there are no echoes which collect data in the air.
Figure 4 shows a special case with 75% phase FOV combined with 33% phase oversampling (PhOS). Compared to 100% phase FOV with no PhOS you have the same SNR, scan time and resolution. The same is true for a setup with 100% PhOS and half the number of ACs or instead iPAT = 2.

## Why does the SNR not increase with more reference lines in GRAPPA mode?

Because the number of reference lines are not included in the formula. The

**Table 3: Parameters for SNR discovery protocols.**

| | SE 2D | TSE 2D | GRE 3D | GRE 2D |
|---|---|---|---|---|
| Sequence name | tse | tse | gre | gre |
| Dimension | 2D | 2D | 3D | 2D |
| FOV read | 256 | 256 | 256 | 256 |
| FOV phase | 100% | 100% | 100% | 100% |
| Base resolution | 256 | 256 | 256 | 256 |
| Phase resolution | 100% | 100% | 100% | 100% |
| Slice thickness | 5 mm | 5 mm | 1 mm | 5 mm |
| TR | 467 ms | 3050 ms | 5.5 ms | 235 ms |
| TE | 12 ms | 107 ms | 2.35 ms | 5 ms |
| AC | 2 | 2 | 2 | 2 |
| iPAT | none | none | none | none |
| Bandwidth | 130 | 130 | 390 | 260 |
| Slice/Slices per slab | 5 | 10 | 64 | 5 |
| Flipangle | 90 | 180 | 25 | 70 |
| Turbo factor | 1 | 9 | n.a. | n.a. |
| Introduction | deselect | deselect | deselect | deselect |
| Coil | 8/12/16- | channel | head | coil |
| TA | 4:00 min | 3:00 min | 3:00 min | 2:00 min |
| Resolution | 1.0 x 1.0 x 5.0 | 1.0 x 1.0 x 5.0 | 1.0 x 1.0 x 1.0 | 1.0 x 1.0 x 5.0 |
| Rel. SNR | 1.00 | 1.00 | 1.00 | 1.00 |

same is true for interpolation. But the SNR actually benefits in most sequences from the additionally sampled number of reference lines using the 'integrated' mode.

## Why does allowed partial Fourier not change scan time in a TSE sequence?

Partial Fourier in a TSE sequence only shortens the echo train length. This gives you the opportunity to shorten TR and gain some scan time if appropriate for the contrast.

## Is there a rule of thumb for changes in the SNR indicator?

A red arrow in Table 2 indicates for both directions a drawback compared to our positive expectations of shorter scan times, better resolution and SNR. There is always at least one red arrow accompanying a black arrow.

## How can I get a feeling for the amount of change in the SNR indicator?

Generate a protocol with the parameters shown in Table 3, save it and than play around with the MR parameters and discover their influence on SNR, TA and resolution. The TRs were chosen that way to get round scan times, which will have slight deviations when changing the number of averages AC. These few seconds are due to the preparation phase at

## Table 4: Influence of the voxel size on total volume and SNR.

| SVS voxel size (mm³) | approx. UI values (mm³) | Volume (cm³) | Rel. SNR a.u. |
|---|---|---|---|
| 20 x 20 x 20 | 20 x 20 x 20 | 8 | 1.00 |
| 18.1 x 18.1 x 18.1 | 18 x 18 x 18 | 6 | 0.75 |
| 15.9 x 15.9 x 15.9 | 16 x 16 x 16 | 4 | 0.5 |
| 12.6 x 12.6 x 12.6 | 13 x 13 x 13 | 2 | 0.25 |
| 10 x 10 x 10 | 10 x 10 x 10 | 1 | 0.125 |
| 7.9 x 7.9 x 7.9 | 8 x 8 x 8 | 0.5 | 0.063 |
| 6.3 x 6.3 x 6.3 | 6 x 6 x 6 | 0.25 | 0.031 |
| 5 x 5 x 5 | 5 x 5 x 5 | 0.125 | 0.016 |

the very beginning of a protocol which is played out only once.

## Is there anything different with spectroscopy protocols?

In single voxel spectroscopy (SVS) you have to be aware of the fact that a slight decrease in the side length of a single voxel will result in a large change to the measured volume, i.e. dramatic decrease in SNR, which can rarely be compensated by an increase of averages (Table 4). CSI protocols can deliver much smaller voxels than SVS due to higher number of encoding steps in two or three dimensions. But this has to be paid for by longer scan times and a more global shim situation.

**→ Visit www.siemens.com/magnetom-world** to download training files in .edx format. Training files are available for software versions *syngo* MR D11D, *syngo* MR B15 and *syngo* MR B17.

References

*Recommended literature for the curious reader in the order of increasing physical depth:*

1 "Magnets, Spins and Resonances"; Siemens 2003.
2 "Magnets, Flow and Artifacts"; Siemens 2004.
3 "The Physics of Clinical MR Taught Through Images": Runge, Nitz, Schmeets; Thieme 2008.
4 "Questions & Answers in MRI": Elster, Burdette; Mosby 2001.
5 "MRI the Basics": Hashemi, Bradley, Lisanti; LWW 2010.
6 "MRI from Picture to Proton": McRobbie, Moore, Graves, Prince; Cambridge 2007.

*Especially recommended for the German speaking community:*

7 „Praxiskurs MRT": Nitz, Runge; Thieme 2011.
8 „MRT-Guide für MTRA/RT": Nitz; Thieme 2012.

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