# Tim Matrix Modes

Arne Reykowski, Ph.D.

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# Tim Matrix Modes

Arne Reykowski, Ph.D.

Siemens AG
Medical Solutions,
Magnetic Resonance Division, Coil Development,
Erlangen, Germany

## 1. Why Matrix Coils?

**Matrix coils are about flexibility, scalability and upgradability:**

Flexibility, because Matrix coils can be combined to larger arrays to satisfy individual needs. For example, Head Matrix and Neck Matrix can be used together as Neuro-Vascular Array. By adding several Body Matrix coils with Spine Matrix and Peripheral Angio Matrix, the Field-of-View can be subsequently extended up to a whole-body range of 205 cm (6'9"). Furthermore, in order to accommodate head-first and feet-first exams, Body Matrix and Peripheral Angio Matrix can be rotated by 180° without loss in SNR (= signal-to-noise ratio – which is a measure of image quality).

Scalability, because Matrix coils are equipped with so called "Mode Matrix" combiners which allow a scalable use of RF channels. Depending on the Field-of-View chosen, the number of RF channels determines the iPAT (integrated Parallel Acquisition Technique) capability of a Tim (Total imaging matrix) system. No matter how many channels a Tim system has, the Mode Matrix will always guarantee maximum image quality in the important center region of the image.

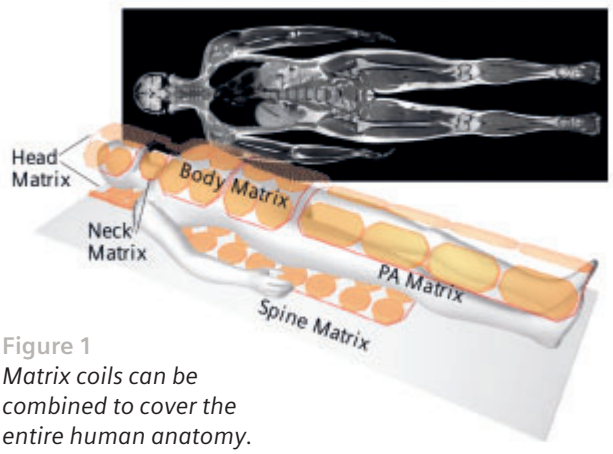



Figure 1
*Matrix coils can be combined to cover the entire human anatomy.*

Upgradability, because a Tim system upgrade towards a higher number of RF channels will not require exchange of any Tim coils. Tim and its Matrix Coils are 100% compatible with all upgrades. Not a single coil needs to be re-purchased in case of an upgrade, e.g. from Tim [32x8] to Tim [76x18] or Tim [76x32]. More importantly, with the different Matrix Modes (CP, Dual, Triple), the Matrix coils can be "scaled" to the Tim levels. The same coils can make full use of the higher number of RF channels with a higher Tim level.

## 2. What is a "Mode Matrix"?

The Mode Matrix is a smart combiner network which ensures RF channel scalability. It is a piece of hardware built into the Matrix Coils. A Mode Matrix has an identical number of input and output signals. Using all available output signals ("Mode signals") is equivalent to using the original input signals. However, when using less than the maximum number of output signals, the Mode Matrix ensures highest image quality, i.e. maximum SNR, at the center of the region-of-interest.

A good analogy to the Mode Matrix is broadcasting: First radio transmissions used single-channel mono broadcast signals. A mono signal contains all necessary information to listen to a broadcast. It can be described as the sum of the signals for left and right audio or simply L+R (left plus right).

With the advent of stereo broadcasting, a transmission format had to be designed which ensured compatibility with existing mono radio receivers. Therefore, stereo broadcast transmissions still transmit the mono L+R signal on a main channel. On a second channel, a differential signal L-R is transmitted. This is identical to transmitting L and R on two individual channels but at the same time ensures full compatibility with mono receivers.

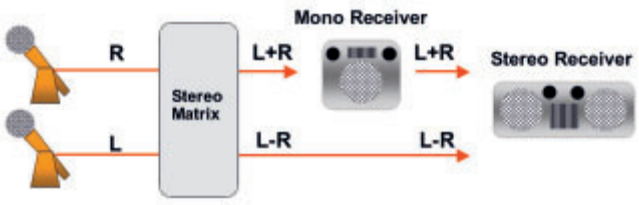



Figure 2 *Stereo broadcast consists of a mono broadcast signal plus a differential signal.*

The Mode Matrix combiner works in a similar fashion. All input signals are combined to a circularly polarized (CP) output signal on the main output channel. This CP Mode signal is the MR signal equivalent to the L+R mono signal in broadcasting applications. The higher-order output signals of the Mode Matrix contain differential information, designed to ensure RF channel scalability.

The sum of the three mode signals P, S and T ( for Primary, Secondary and Tertiary) contains the same information as the original signals R, M and L (for Right, Middle and Left) from the coil elements.

The user selects CP, Dual or Triple Mode in the user interface. Primary, Secondary and Tertiary Modes are intermediate signals, invisible to the user.

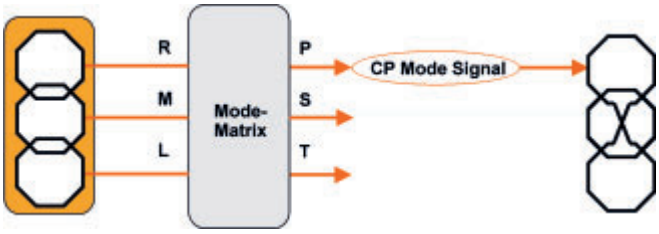



Figure 3 *In analogy to stereo broadcast, the Mode Matrix delivers high SNR, a circular-polarized signal plus additional differential signals for iPAT applications.*

## 3. What is a Ring? What is a Cluster?

Matrix coils allow the reception of high SNR signals from all regions of the human body. They are organized in multiple rings of up to 6 elements which surround the human anatomy and are stacked in head-feet direction (along the z-axis of the magnet).
Typically, a single ring of elements is divided into an anterior and a posterior cluster.

A cluster is a group of typically 3 coil elements with individual preamplifiers which are fed into a Mode Matrix combiner.

The output signals of this Mode Matrix combiner are termed Primary (CP), Secondary and Tertiary Mode Signals.

In CP Mode, only the Primary (also called CP) Mode signal is fed into a receiver channel.

In Dual Mode, the Primary and Secondary Mode signals are fed into two independent receiver channels.

In Triple Mode, the Primary, Secondary and Tertiary Mode signals are fed into three independent receiver channels.

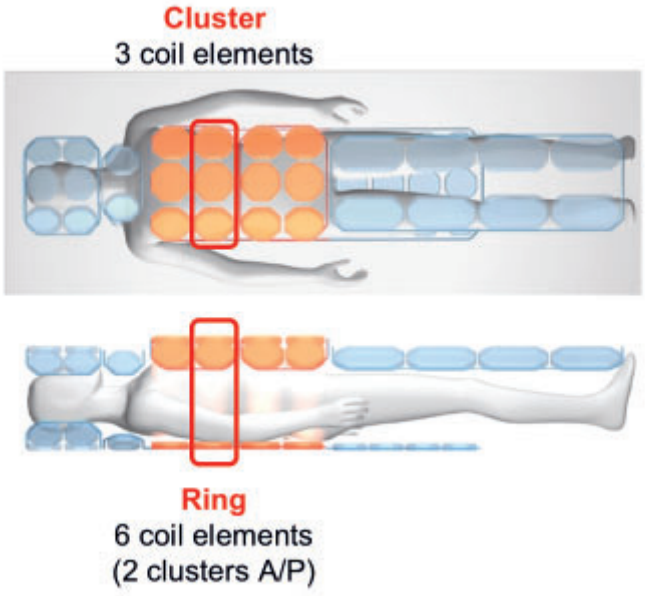



Figure 4 *The individual elements of Matrix coils are organized in rings and clusters. Each cluster is connected to a Mode Matrix combiner.*

## 4. What are CP, Dual and Triple Modes?

**CP, Dual and Triple are the Matrix Modes for a Tim system.**
In CP Mode, only the CP signal (also called Primary signal) from the output of the Mode Matrix combiner is used for data acquisition and image reconstruction. The CP Mode,

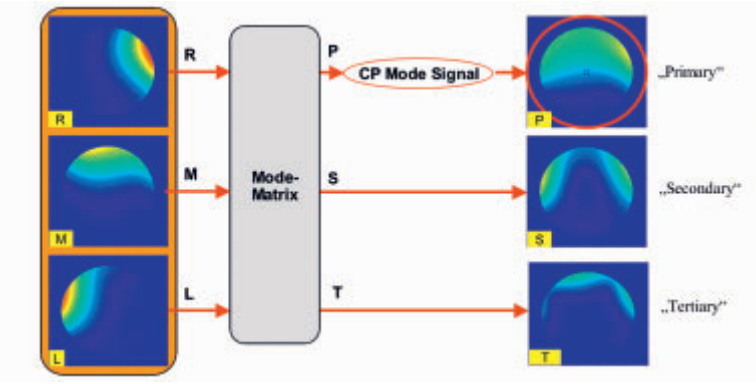



Figure 5 *The Mode Matrix combiner transforms the coil signals R,M,L into mode signals P,S,T. The primary mode signal P is equivalent to a high-SNR CP coil signal.*

with its circular polarization, already offers highest image quality in the center of the region of interest and is therefore used for standard imaging. CP Mode is the mode of operation which uses the smallest number of RF channels. Since the CP Mode generates less data compared to the other modes, shortest recon times can be achieved.

In Dual Mode, the CP signal as well a Secondary signal are used for data acquisition and image reconstruction. This Matrix Mode typically uses twice the number of RF channels as compared to CP Mode operation. Dual Mode improves iPAT with phase-encoding (PE) direction left-right in all regions of the human anatomy. Dual Mode also increases SNR in the image periphery.

Triple Mode is the highest Matrix Mode available. Triple Mode unfolds the full power of the Matrix coils in terms of iPAT capability and (peripheral) SNR. The Triple Mode uses the full number of mode signals available from all selected Matrix coils.

## 5. How do CP, Dual and Triple Modes relate to iPAT performance?

In general, for iPAT with phase-encoding directions anterior-posterior or head-feet, CP Mode is sufficient.

Dual Mode and Triple Mode offer additional benefits for iPAT with left-right phase-encoding direction. With the Head Matrix, the Spine Matrix and the Body Matrix coils, Dual Mode allows for a max. PAT factor of 2 in left-right direction, while Triple Mode allows for a max. PAT factor of 3 in left-right direction. The max. PAT factor for anterior-posterior direction and head-feet direction is fairly independent of the Matrix Mode.

There are also some cases, where PAT with left-right phase-encoding direction can be performed in CP Mode, e.g.:

a) The Peripheral Angio Matrix has individual elements for each leg, therefore permitting iPAT in left-right direction.
b) For the examination of obese patients it is possible to place two Body Matrix coils to the left and right of the patient. This setup allows the use of iPAT in left-right direction even in the CP Mode (and higher-than-normal PAT factors with Dual and Triple Modes).

## 6. Can I use all Matrix Modes (CP, Dual and Triple) with each Tim level?

Yes, all Matrix Modes are compatible with each Tim level. The differentiator between the various Tim levels is the maximum coverage in z-direction possible with different combinations of Tim levels and Matrix Modes.

For example, with Tim [32x8] you can select up to 4 Rings in CP Mode (about 60 cm* in z-direction), 2 Rings or 4 Clusters in Dual Mode (about 30 cm in z-direction), or 1 Ring or 2 Clusters in Triple Mode (about 17 cm in z-direction).

With Tim [76x18] you can select up to 4 Rings in CP Mode and Dual Mode (about 60 cm*), or 3 Rings or 6 Clusters in Triple Mode (about 45 cm* in z-direction).

## Max. PAT Factors with Tim

| | Tim [32x8] | Tim [76x18] | Tim [76x32] |
|---|---|---|---|
| head - feet | 4 Head + Neck + Spine + Body<br>2 PA | | |
| ant - post | 3 $Head_{T\ 1\,ring}$<br>2 others | 3 $Head_T$<br>2 Neck, Body+Spine, PA+Spine | |
| left - right | 3 $H.S.B_{T\ 1\,ring}$<br>2 $N_{\square}$, PA | 3 $Head_T$, $Spine_T$, $Body_T$<br>2 $Neck_{\square}$, PA | |
| max. | 9 (3x3 $iPAT^2$) $_{1\,ring}$ | 12 (4x3 with $iPAT^2$) | |

Table 1 *Possible iPAT factors for different Tim configurations and phase encoding directions. For example, with phase-encoding left-right, Tim [32x8] allows iPAT factors of 3 with Head-, Spine- or Body Matrix and iPAT factors of 2 with Neck- or PA Matrix.*

| | Tim [32x8] | Tim [76x18] | Tim [76x32] |
|---|---|---|---|
| CP Mode | $FOV_z \geq 50$ cm (4 rings) | | |
| Dual Mode | $FOV_z \geq 50$ cm (4 clusters)<br>$FOV_z = 30$ cm (2 rings) | | |
| Triple Mode | $FOV_z = 30$ cm (2 clusters)<br>$FOV_z = 15$ cm (1 ring) | $FOV_z \geq 50$ cm (4 clusters)<br>$FOV_z \leq 50$ cm (3 rings) | $FOV_z \geq 50$ cm (4 rings)<br>+ 8 spare channels |

Table 2 *Possible FoV in z-direction for different Tim configurations and Matrix Modes. For example, Tim [32x8] allows a $FoV_Z \geq 50$ cm in Dual Mode if 4 clusters in z-direction are selected (e.g. spine imaging) or a $FoV_Z = 30$ cm if 2 complete rings in z-direction are selected (e.g. abdominal imaging with Body Matrix and Spine Matrix).*

And finally, with Tim [76x32] you can select up to 4 Rings in all 3 Modes (about 60 cm*).

## 7. What is Auto Mode?

Auto Mode is the smart operational mode. Depending on the Tim configuration, Field-of-View and iPAT factor, the Auto Mode selects the optimum Matrix Mode (CP, Dual or Triple) to get the job done.

The Auto Mode function, together with Auto Coil Detect and remote patient table positioning, are designed to minimize user-system interactions in order to maximize the focus of attention onto the exam itself.

In the current implementation of Auto Mode, Triple Mode is chosen most of the times when iPAT is selected and CP Mode is chosen if iPAT is deselected.

When selecting Auto Mode, the Auto Mode switch indicates which Matrix Mode will be used.

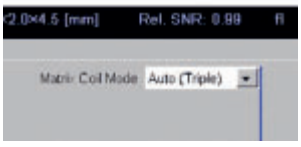



Figure 6 *When selecting Matrix Coil Mode "Auto", the user interface indicates the Matrix Mode chosen by the system (in this example Triple Mode).*

## 8. Is a Tim system limited to Matrix coils?

Not at all!

All MAGNETOM systems, including our new Tim systems, offer a host of coils for dedicated applications, like Wrist, Knee, Shoulder etc.

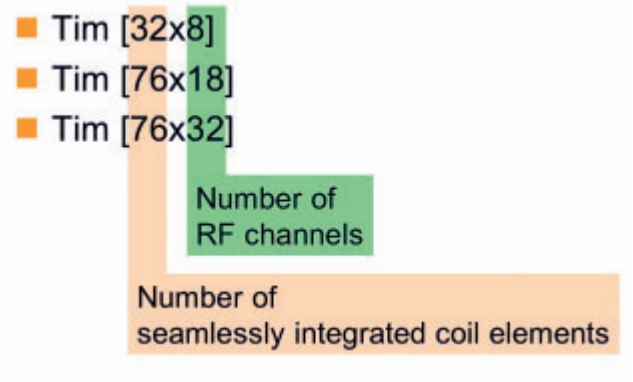
The MAGNETOM Avanto has two coil plugs that are compatible with coils from MAGNETOM Symphony and MAGNETOM Sonata. Most Symphony/Sonata coils can be connected to the system.

* *This is the FoV of the coil rings/clusters for RF signal reception. The max. FoV of MAGNETOM Avanto is 50 cm.*
*4 rings/clusters with an "RF field" of 60 cm allow the flexible positioning of the coils with regard to the max. 50 cm FoV.*
*3 rings/clusters are just sufficient for covering the max. 50 cm FoV, but care has to be taken that the 3 rings/clusters exactly cover the FoV.*

## 9. What is the meaning of Tim [32x8], [76x18] and [76x32] ?

Every Tim system is characterized by two numbers: The total number of coil elements which can be seamlessly connected to the system and the maximum number of true independent RF receiver channels available on the system.

### Three Tim Levels




A necessary and unique component of a Tim system is the full RF channel switching matrix which allows free control over which of the up to 76 coil elements or mode signals are fed into the receiver chain with up to 32 receivers.

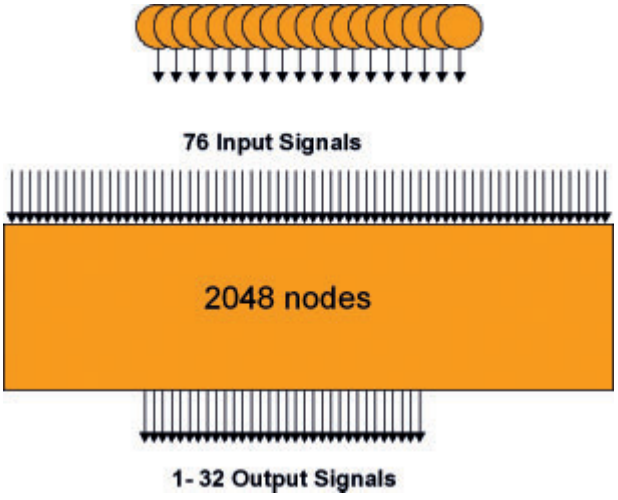



Figure 7 *Each Tim system contains a powerful and unique piece of hardware which allows free selection of up to 32 out of 76 Matrix coil elements.*

This concept is completely workflow-driven: During an exam, there is no need for manual patient repositioning and/or exchange of local coils. Everything can be done right from the user console. Auto Mode, Auto Coil Detect and remote patient table positioning minimize user-system interaction in order to maximize the focus of the attention onto the exam itself.

## 10. Which Tim configuration is the right one?

First, keep in mind that, whatever your initial choice, there is a clear and simple upgrade strategy from Tim [32x8] all the way up to Tim [76x32]. So, if today you are hesitant about going for the most advanced Tim [76x32] and for example instead decide to buy a Tim [32x8], you will not get penalized later when you change your mind and upgrade to Tim [76x18] or [76x32]. The exact same set of coils is available to all three Tim system configurations and there are no built-in obstacles that will make such a later upgrade difficult or highly expensive. The only hardware that is needed for this RF channel upgrade are the additional receivers. This is the major economical benefit from Tim's scalability!

**Tim [32x8]:** Tim performance for the high-end professional clinical routine. Whole-body examinations can be performed with up to 32 CP coil elements (i.e. using all Tim coils in CP Mode). Tim [32x8] allows true whole-body and local MRI in highest quality. It allows Parallel Imaging for the whole clinical routine. Note that Tim [32x8] already offers a performance level far beyond anything that is currently available elsewhere on the market. And this is not only due to a clear and simple upgrade path to higher Tim performance but also and especially due to the Parallel Imaging performance already in place with 8 channels.

**Tim [76x18]:** With its 76 seamlessly integrated coil elements and 18 independent RF receiver channels, it is the technology of choice for superior quality MRI, from clinical routine up to demanding research. Anatomically optimized for unlimited iPAT in large Field-of-Views, in all three dimensions.

**Tim [76x32]:** The top-of-the-line performance level, for all clinical areas including the most demanding research. This level is prepared for all new applications like MR-guided intervention where you might need further receiver channels for catheters or further antennas/coils.

## 11. Is there a need to buy new coils for upgrades within the Tim Technology (e.g. Tim [32x8] to Tim [76x32])?

No! This is one of the big advantages of Tim. Tim and its Matrix Coils are 100% compatible with all upgrades. Not a single coil needs to be re-purchased in the event of an upgrade, e.g. from Tim [32x8] to Tim [76x18] or Tim [76x32]. More importantly, with the different Matrix Modes (CP, Dual, Triple), the Matrix coils can be "scaled" to the Tim levels. The same coil can make full use of the higher number of RF channels with a higher Tim level.

With a competitive system, you need to purchase new dedicated multi-channel coils to make full use of an RF receiver channel upgrade. Of course, the old coils would still be compatible – but what's the use of an RF channel upgrade when there are no coils to utilize the additional channels?

## 12. How does Tim help to handle the additional complexity?

**You do not need to select coils on a Tim system – simply select the exam.**
Auto Coil Detection will automatically determine the relative positions of all available coils (Matrix or other) in the Field-of-View. These relative coil positions are then

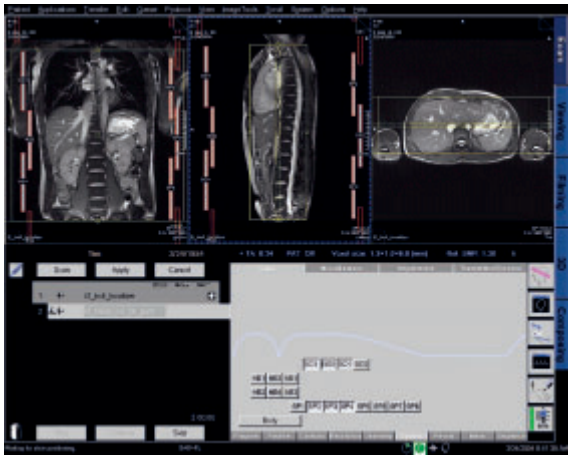


Figure 7 *The relative positions of the various Matrix coil clusters are visualized in the scout view as well as on the coil card in the user interface. In addition, Matrix clusters can be selected via mouse click from the scout view as well as through the coil buttons.*

shown as graphic superposition on the initial body scout views, where they can easily be selected with a mouse click.

With the Mode switch set to "Auto", the system will decide for you which Mode (CP, Dual or Triple) will be used during the exam. Non-iPAT exams are usually run in CP Mode, while iPAT exams may be run in CP, Dual, or Triple, depending on the phase-encoding direction and acceleration factor.

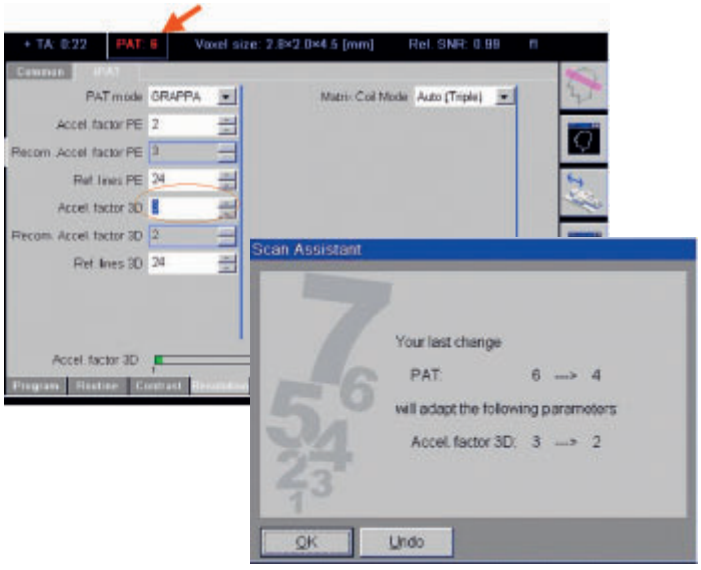



Figure 8 *The Scan Assistant will guide you through the entire setup procedure and will make recommendations where necessary.*

## 13. Why do uncombined Matrix images look different?

Advanced users who select "save uncombined images" in the user interface will notice that in Dual Mode and Triple Mode the uncombined images from Matrix coils differ from conventional coil images.

Only the uncombined CP Mode signal from a Matrix coil resembles a traditional coil image. Higher order mode signals only contain information from the periphery of the region-of-interest since the CP Mode signals already contain the full SNR at the center region of the images.

In analogy with stereo broadcasting, where L+R and L-R signals are used, a higher order Matrix mode signal is equivalent to the L-R signal in broadcast applications. In the same way the L-R signal would never be received and processed alone, higher-order mode signals are only received and processed in conjunction with lower-order mode signals.

The user selects CP, Dual or Triple mode in the user interface. Primary, secondary and tertiary modes are intermadiate signals invisible to the user.

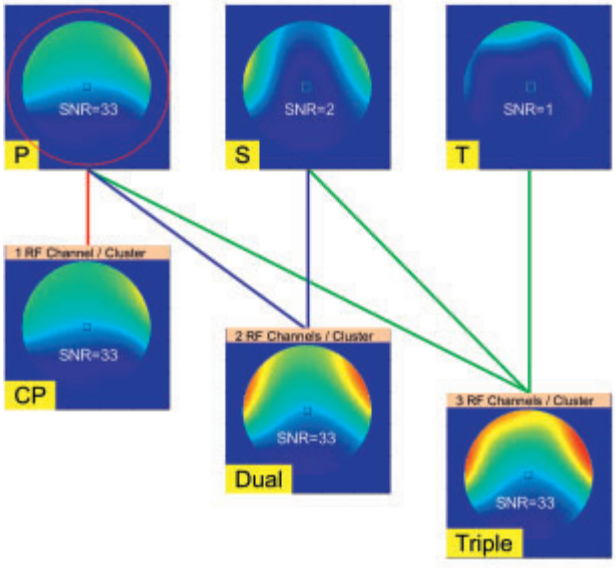



Figure 9 *The uncombined secondary and tertiary Mode signals S and T contain only differential information needed for iPAT, therefore these signals do not resemble conventional coil maps. Nevertheless, the combined array image from all mode signals P, S, T is identical to the array combination of the original coil signals R, M, L.*

The information in this document contains general descriptions of the technical options available, which do not always have to be present in individual cases. The required features should therefore be specified in each individual case at the time of closing the contract.

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**Contact**

**In the USA**
Siemens Medical Solutions USA, Inc.
51 Valley Stream Parkway
Malvern, PA 19355
Telephone: +1 888-826-9702
Telephone: +1 610-448-4500
Telefax: +1 610-448-2254

**In Japan**
Siemens-Asahi
Medical Technologies Ltd.
Takanawa Park Tower 14F
20-14, Higashi-Gotanda 3-chome
Shinagawa-ku
Tokyo 141-8644
Telephone: +81 3 5423 8411

**In Asia**
Siemens Medical Solutions
Asia Pacific Headquarters
The Siemens Center
60 MacPherson Road
Singapore 348615
Telephone: +65 6490-6000
Telefax: +65 6490-6001

**In Germany**
Siemens AG, Medical Solutions
Magnetic Resonance
Henkestr. 127, D-91052 Erlangen
Germany
Telephone: +49 9131 84-0

**Siemens AG**
Wittelsbacherplatz 2
D-80333 Muenchen
Germany

**Headquarters**
Siemens AG, Medical Solutions
Henkestr. 127, D-91052 Erlangen
Germany
Telephone: +49 9131 84-0
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