Magnetic Resonance Imaging For EMC Engineers

Presented to the Twin Cities Section
Electro Magnetic Compatibility Chapter
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Topics

- Diagnostics
- MR Principles
- MR Example
- MR equipment
- Image Processing
- Reducing Interference

Differential Diagnostics

- Almost every symptom is common to several causes
- Doctors use Differential Diagnosis to sort the possible causes
- Interview - what the patient tells you and does not tell you
- Physical symptoms - pain, heart rate, respiratory rate, blood pressure
- Functional symptoms – motion, speech, sight, hearing
- Internal symptoms - blood, urine, EKG

Next Diagnostic Steps

- In the 1940’s the next step was the use of X-rays or Exploratory Surgery
- In the 2000’s Doctors can use X-rays, Ultrasound, Positron Emission Tomography, or Magnetic Resonance Imaging. Exploratory surgery is seldomly used today.

X-Rays

- X-ray images of bone are far better than images of soft tissue.
- A computer may control some of the equipment functions
- Some X-ray machines are moveable
- X-rays produce fuzzy images
- Under certain conditions X-rays can damage tissue.
- A radiologist interprets the images

Exploratory Surgery

- The diagnosis and / or an X-ray is used to select the site of the surgery
- The operation may not find the cause or the cause may not be treatable
- There is always pain
- The patient may not survive the operation

Ultrasound

- Ultrasound images is mostly used for soft tissue (can be used for bones)
- Images are good
- A computer controls some of the equipment functions
- The equipment is very portable
- A radiologist interprets the images

Positron Emission Tomography

- PET images are usually used for lungs, veins, and other soft tissue
- Images are good
- A computer controls some of the equipment functions
- A radiologist interprets the images

Magnetic Resonance Images

- MR images are used for soft tissue such as the brain, breast, and heart
- 125 micrometer resolution (or better) is possible
- A specialist selects the imaging parameters
- A computer controls the equipment functions
- A specialist interprets the images

MR Principles - 1

- MR was developed after World War II
- The techniques used in radar were employed
- The transmitter is pulsed on.
- Then the transmitter is disconnected from the antenna and the receiver is connected to the antenna
- The echo is detected

MR Principles - 2

- When certain elements are placed in a magnetic field, the nucleus will resonate
- The strength of the magnetic field determines the resonant frequency.
- For example, a hydrogen nucleus resonates at 400 MHz when it is in a 9.4 T field

MR Example - 1

- The antennas are
- Single turn coils
- 1.0 centimeters in diameter (Some antennas are rectangular and are larger)
- Resonant at 400 MHz
- Has a loaded Q of 40

MR Example - 2

- The sample has free water
- The hydrogen resonates at 400 MHz
- Amyloid plaque (studied for Alzheimer's Disease) shifts the hydrogen resonance 0.01 parts per million
- A voxel is 60 x 60 x 120 micrometers
- The voxel is 5 mm from the center of the antenna

MR Example - 3

- The transmitter parameters are
  - Output frequency 400 MHz
  - 2.5 kW peak output power
  - 10 ms burst duration
  - 2000 ms burst repetition period

MR Example - 4

- The hydrogen nuclei emit a 400 MHz signal after being excited
- The voltage at the input of the receiver is about 1 nanovolt RMS
- The measurement is repeated 256 times and averaged to reduce the uncertainty
- The measurements take 512 seconds

MR Equipment

- Shielded chamber
- Main magnet
- Gradient magnets
- RF generator, modulator, and amplifiers
- RF resonators
- Receivers
- Image processing computer

Shielded chamber

- The walls are made of copper because steel walls distort the steady magnetic field
- The chamber has two walls
- Lights are powered with direct current
- Conductors go through bulkhead connectors
- Optic cables go through waveguides

Main Magnet - 1

- The main magnet is a solenoid magnet
- The magnet wire is a superconductor
- Liquid helium is used to cool the wire
- Liquid nitrogen is used as a thermal barrier between the room and the helium
- The walls of the Dewar flask are aluminum

Main Magnet - 2

- The patient is placed in an axial tunnel
- The field inside the tunnel is 9.4 T
- The field is very uniform in space
- The field is very steady in time

Gradient Magnets

- There are 3 gradient magnets (x, y, and z)
- The gradient magnets scan the region of interest
- The magnet wire is copper
- The gradient fields change in direction, time, and space
- A computer controls the gradient amplifiers that drive the gradient magnets

RF Generator, Modulator, and Amplifier

- The RF generator and modulator are controlled by a computer
- In the example, the frequency of the RF generator is 400 MHz. Other frequencies are used when other elements are imaged
- The modulator produces wave shapes that have the desired frequency characteristics
- The amplifiers have high peak power output but low continuous power output

RF Resonators

- The antennas are designed and built for
- Different frequencies for different elements
- Different organs, e.g., brain, breast, heart
- Different Regions of Interest

Receivers

- The receivers are under computer control
- The receivers have a low noise front end
- The signal is down-converted to 20 MHz
- The 20 MHz signal is filtered
- The 20 MHz signal is digitized
- Digital filters are used to extract the desired information

Image Processing

- The processing is under computer control
- Fourier transforms are used to produce the image
- The signals are filtered
- The image is presented via a LCD (CRT images are often distorted by the main magnet)

Reducing Interference - 1

- Coaxial cables that go through connectors mounted on the chamber bulkhead are used for
  - Transmitter output
  - Receiver input
  - Receiver output

Reducing Interference - 2

- Coaxial cables that go through connectors mounted on the equipment walls are used for control signals
- Physiologic monitoring of the heart and respiration will often use fiber optic cables

Reducing Interference - 3

- The computer room and the transmitter room are usually not shielded
- Separation from interfering sources is the usual protection