Time-Varying Gradients:

Effects / Volumes / Forces / Harms

Tobias Gilk - September 26, 2022

Rules of the Road

- Everything on the screen is for you (you can copy or take photos).
- If you have questions, ask!
- If you disagree, please speak up.

Outline

Time-Varying Gradient Magnetic Fields

- Intro
- Fields / Distributions / Units
- Why We Have Time-Varying Gradients
- Physical Forces / Bioeffects
- Implant Scenarios
- Q & A

“If you don’t know what you’re exposing a patient (or device) to, you can’t begin to perform an MR risk-assessment.”

— Me

Time-Varying Gradients

Recap & Advance

- When & Where
- Units & Measures
- Plots & Graphs
- Physical Effects
- Physiologic Effects
- Implant Scenarios

Time-Varying Gradients

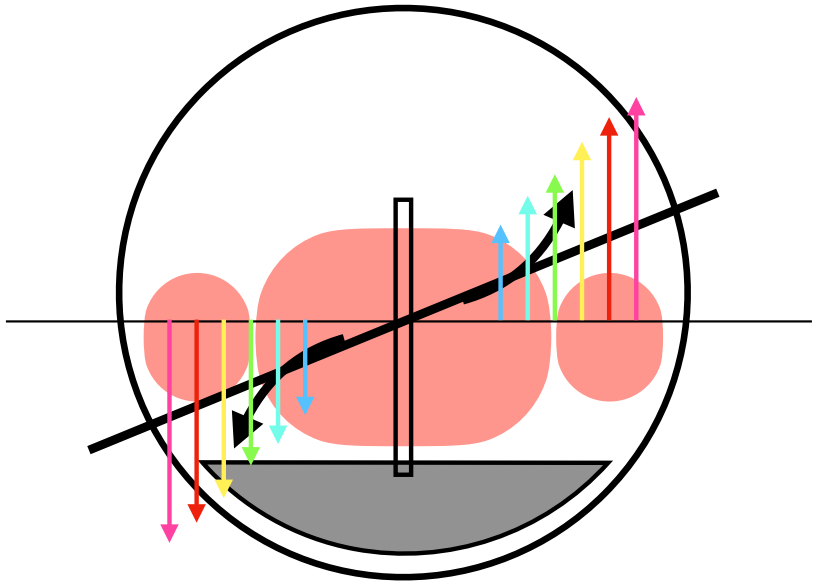
What Are They?

- Rapidly fluctuating magnetic field
- Changing 1,000s or 10s of 1,000s of times per second (in the human auditory range)

Time-Varying Gradients

Why?

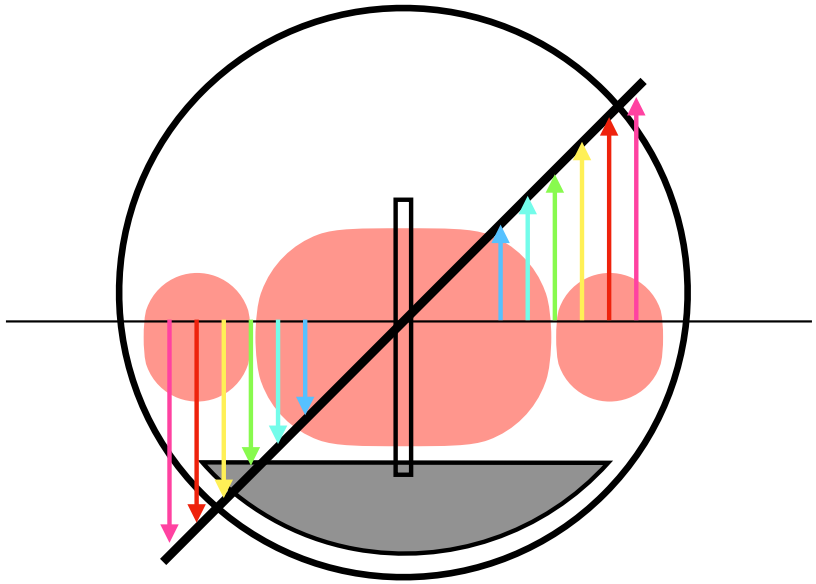
- Because we only want data (signal) from one region (slice) at a time.
- Larmor Frequency



Time-Varying Gradients

When & Where?

- Only during active imaging
- Only in the bore
- But not uniform throughout the bore



Time-Varying Gradients

Modes

Normal Mode

- 80% of Mean Perception Threshold

First Level Controlled Operating Mode*

- 100% of Mean Perception Threshold

Second Level Controlled Operating Mode

- Up To & Including Pain

201.3.208
FIRST LEVEL CONTROLLED OPERATING MODE
mode of operation of the MR EQUIPMENT in which one or more outputs reach a value that can cause physiological stress to PATIENTS which needs to be controlled by MEDICAL SUPERVISION

Time-Varying Gradients

Amplitude - Slope - Slew

Amplitude

- Single Factor (often mT)
- Max change to field

Slope

- Two-Factor (T/m)
- Change to Field *as a function of distance*
- Steeper Slope = Thinner Slices

Slew

- Three-Factor (T/m/s)
- Captures All 3 Dynamic Elements of TVG

Time-Varying Gradients

Rise-Time & Rate of Change

Also…

Rise-Time

- Single-Factor (ms)
- Speed of Acquisition

Rate

- Two-Factor (T/s)
- Uses Max Values For Amplitude & Rise-Time

Time-Varying Gradients

Plots & Graphs

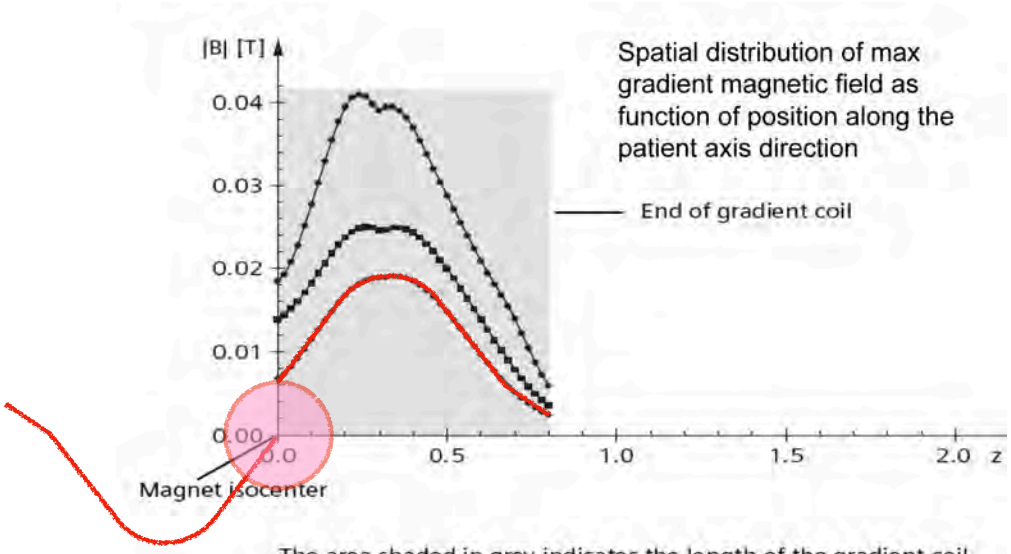
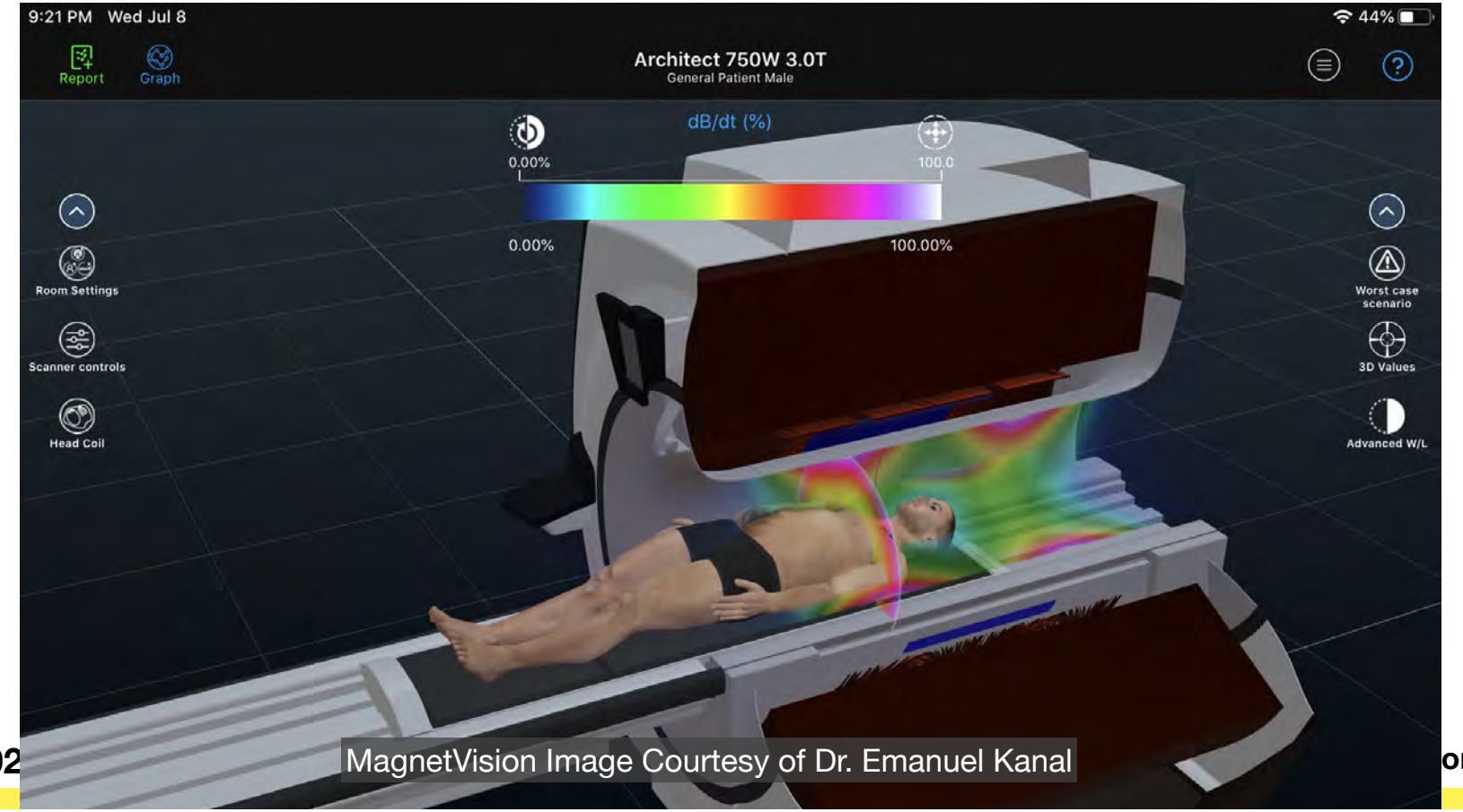


Figure 1: Max gradient magnetic field plots

Time-Varying Gradients

Plots & Graphs



MagnetVision Image Courtesy of Dr. Emanuel Kanal

Time-Varying Gradients

Faraday's Law of Induction

Time-Varying Gradients

Faraday's Law of Induction

An electrical conductor exposed to a changing magnetic field will experience an induced electrical voltage.

Time-Varying Gradients

Physical & Physiological Effects

Time-Varying Gradients

Physical Effects

- High-Frequency Vibration
- Induced Voltages

Time-Varying Gradients

High-Frequency Vibration

Time-Varying Gradients

High-Frequency Vibration

- Remember Lenz Effect From Static Field Lecture?
  - Needs *Electrically Conductive Material*
  - Doesn't Have To Be (Ferro)Magnetic

- High-Frequency Vibration Is 'Machine-Gun' Version Of Lenz

Time-Varying Gradients

High-Frequency Vibration

- What Makes TVG-Induced Vibration Stronger?
  - Region of Stronger Gradients
  - Better Electrical Conductor
  - Larger Object

- What Makes Perception Stronger?
  - More Sensitive Nervous Tissues

Time-Varying Gradients

Induced Voltages

Time-Varying Gradients

Induced Voltages

- At TVG Amplitudes & Frequencies, Induced Voltages Are Most Similar to Neuroelectric Signal

- They Do Also Produce Heat, But No Record of Gradient Heat-Caused Injuries

Time-Varying Gradients

Physiological Effects

- Peripheral Nerve Stimulation (PNS)
- Direct Neuromuscular Stimulation
- Heating

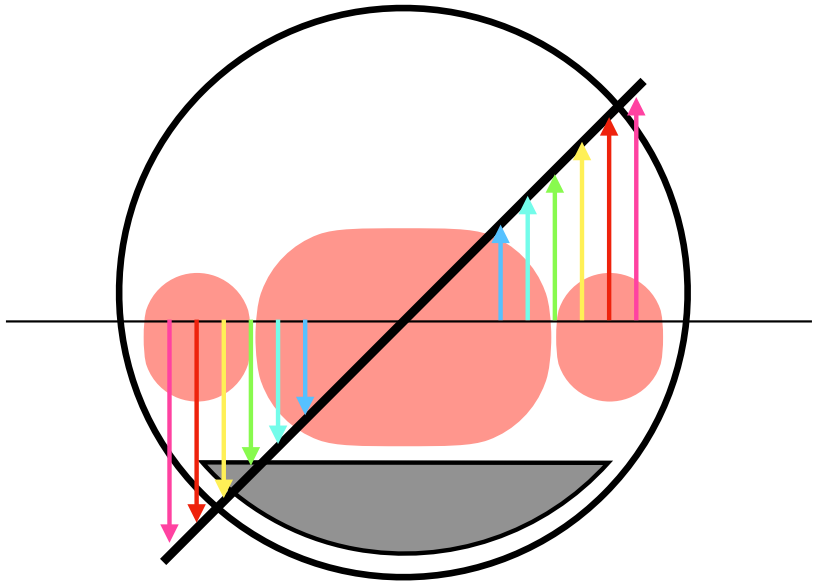
Time-Varying Gradients

Peripheral Nerve Stimulation (PNS)

Time-Varying Gradients

Peripheral Nerve Stimulation (PNS)

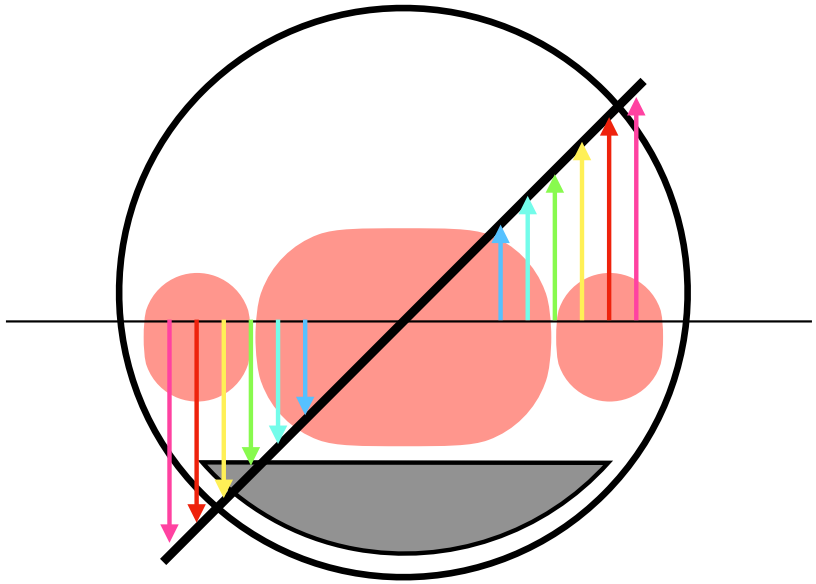
- Why Is It ‘Peripheral’?



Time-Varying Gradients

Peripheral Nerve Stimulation (PNS)

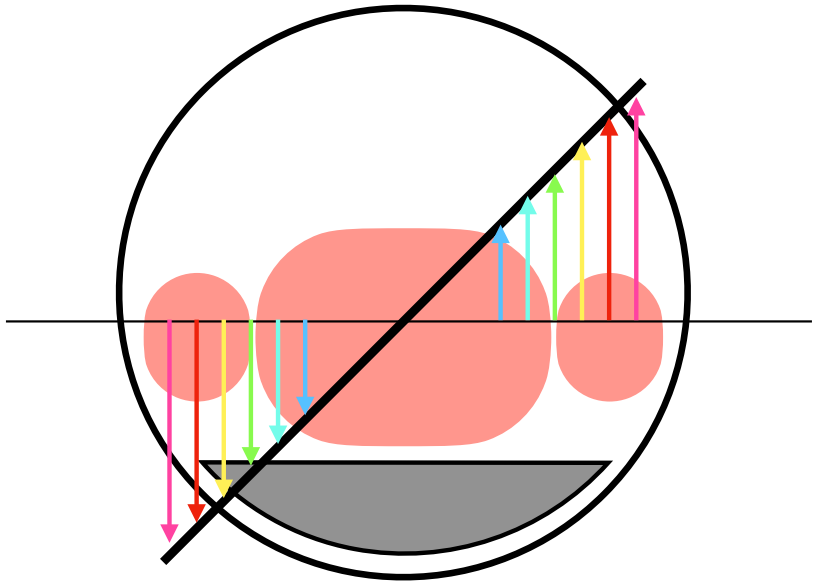
- What Does It Feel Like?
  - Tingling
  - ‘Creepy Crawlies’
  - Buzzing / Shocking
  - Metalic Taste
  - Magnetophosphenes



Time-Varying Gradients

Peripheral Nerve Stimulation (PNS)

- Can Increase All The Way To…
  - Muscle Twitching
  - Pain



Time-Varying Gradients

Direct Neuromuscular Stimulation

"So if gradients can stimulate peripheral nerves, couldn't they also stimulate nerves controlling organs, or even the central nervous system?"

Yes, if MR systems allowed them to go that high. But they don't.

Time-Varying Gradients

Direct Neuromuscular Stimulation

- Different nervous tissues have different tolerances for being activated by time-varying gradient magnetic fields.

Clinical MRI Systems
Can Only Go This Far

  - Sensory Organs
  - Muscles
  - Organ Systems (e.g. Heart, Diaphragm, Lungs, GI)
  - Central Nervous System (e.g. Spine & Brain)

Time-Varying Gradients

Heating

Time-Varying Gradients

Heating

- Can Add Modestly To Heating
- No Documented Patient Injury From Gradient-Induced Heating
- In Some Devices (Large, Flat) There May Be Gradient Limitations

Time-Varying Gradients

The Problem With Leads

- Voxels Of Deposition
- Magnetism & Electricity: Conjoined Twins
- Insulation & ‘Who Is In The Driver’s Seat?’

Time-Varying Gradients

Voxels Of Deposition

- MR System Controls Are Based On Exposure To Human Beings
- What Happens When There's Something Other Than Human Tissues w/in Volume of Deposition?

Time-Varying Gradients

The Conjoined Twin Conundrum

- Enters As Magnetism
- Encounters Good Electrical Conductor
- Switches To Electricity

Time-Varying Gradients

Insulation & ‘Who Is In The Driver’s Seat?’

- Magnetism Passes Through Electrical Insulation
- Enters Lead (Designed To Be Electrically Conductive)
- Electricity In Driver’s Seat
- Can’t Exit Through Insulation

Time-Varying Gradients

Insulation & ‘Who Is In The Driver’s Seat?’

- Capped Leads May Exacerbate Problem
  - Only Half As Many Ways Out

Time-Varying Gradients

The Problem With Leaded Devices

- False Feedback
- Unintended Stimulation

Time-Varying Gradients

False Feedback

- Devices That Monitor Neuroelectric Signal
  - May Perceive Gradient-Induced Voltages As From Patient
  - May Trigger Inappropriate Delivery of Therapy

Time-Varying Gradients

Unintended Stimulation

- Gradient Energies Delivered To Organ
  - May Deliver Unintended Stimulation

Time-Varying Gradients

How We Manage TVG Risks

- Positionally
- ScanWise

Time-Varying Gradients

How We Manage TVG Risks

- Positionally
  - If The Object Of Concern Is Receiving No Incident Gradient Energy (Consider Electrical Pathways), What Risk Is There

- We Can’t Control Spatial Distribution Of TVG Energies

Time-Varying Gradients

How We Manage TVG Risks

- ScanWise
  - Allows For Control Of Level Of Gradient Output
  - Not Positionally Aware

Q&A

Thank You

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