DEPARTMENT of PHYSICS & ASTRONOMY

UBC PHYSICS 420

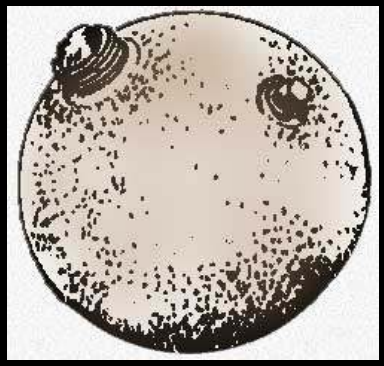
The Application of Physics in Landmine Detection

INTRODUCTION

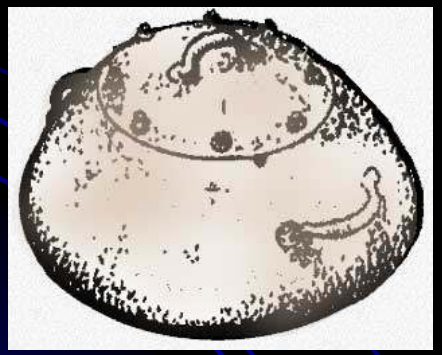
- History of Landmines
  - Types of Landmines
  - Landmine Detectors
- Current Issues on Landmines
  - Landmine Problem
  - New Landmines
  - Landmine Detectors
    - Advantages and Disadvantages
    - Physics of Landmine Detection
- Demonstration
  - Metal Detection
  - Mechanical
  - Electrical

HISTORY OF LANDMINES

• First descriptions of a pressure activated landmine was provided by a German military historian H. Frieherr von Fleming in 1726.



• The first devices designed to explode on 'target-contact' were floating mines first employed by the US Confederate Navy in 1861. Reference was made to these mines during the Battle of Williamsburg in 1862.



• The Americans were actually the first nation to develop and use operational landmines. On May 4th 1862 while scouting a road, a horse rider activated one of these mines becoming the first person killed by a pressure-operated landmine.

• The British Army was interested to use landmines during their African campaigns in the 1880's. During these wars, tripwire and pressure-operated mines were generally manufactured in the field.

HISTORY OF LANDMINES (2)

• By the 20th century the concept of landmine warfare had permeated through most regular armies. This was largely due to answering of the presence of a new piece of technology on the battlefield: the assault tank.

• In WWI landmines were the Germans partial answer to the Americans growing number and effectiveness of tanks in battle.

• Not until WWII (1939-45) were landmines truly developed and put to use, into the present day image that we have of conventional landmines. Landmines in WWII were principally used as anti-tank devices. These mines were large, clumsy and easily-redeveloped by the opposing side.

HISTORY OF LANDMINES (3)

• In answering the question of the redevelopment of ones own landmines, anti-personnel landmines evolved. Smaller and used to injure and kill infantrymen, these were defensive measures to the opposing side disarming and/or redeveloping the landmine.

• More notable dates and locations of landmine use:

  • Korean War (1951-1953): nearly 10 different countries relied on landmines for defence.

  • Vietnam War (1958-1968): landmines were har laid and dropped from the air. Little to no records were kept of landmine placement.

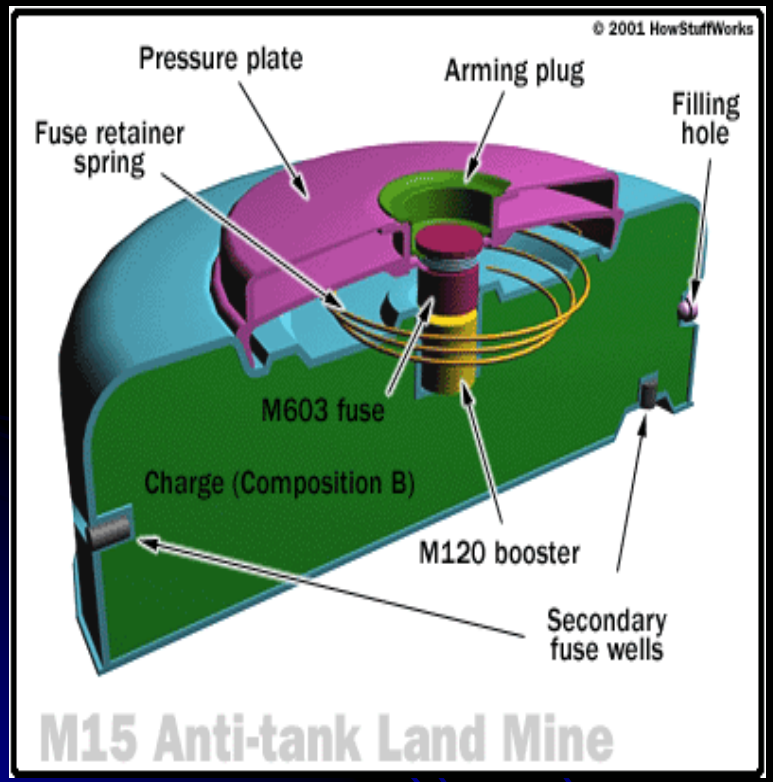
  • Angola (1975-present)

  • Mozambique

  • Cambodia (1978-present)

  • Afghanistan: one of the three most heavily mined countries in the world. Over 30 different types of landmines have been found there.

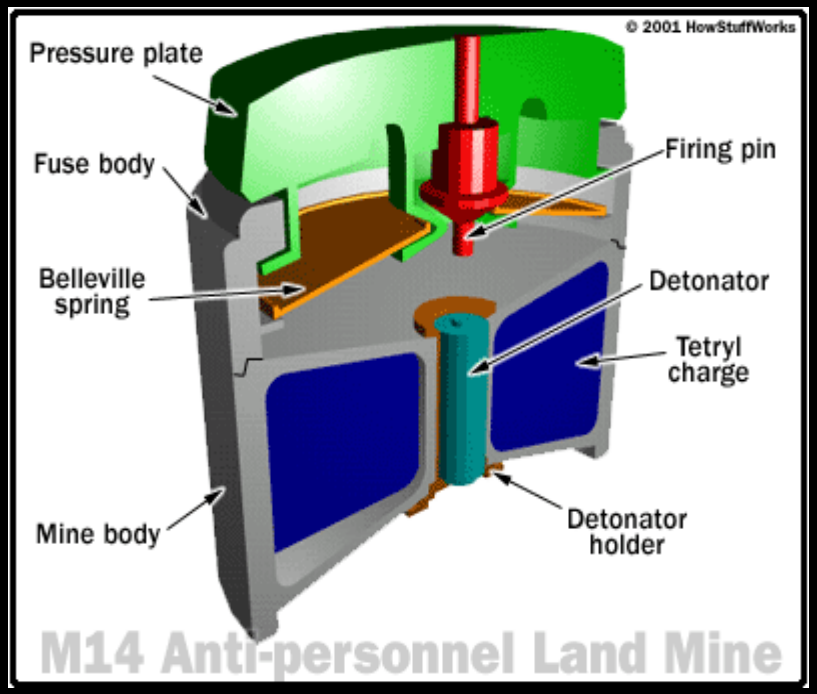
DIFFERENT TYPES AND PURPOSES OF LANDMINES (2)



- Anti-Tank (AT) Mines:
  - Larger in physical dimensions and explosive material content
  - Designed to be detonate from the applied pressure that appreciable from a small automobile up to and including tanks
  - Purpose of anti-tank landmines were three-fold:
    - Destroyed and immobilize vehicles and the occupants
      - Catastrophic kill (k-kill), Mobility kill (m-kill)
    - Slowed the progression of an advancing armor group
    - Demoralized the personnel of the armor group

DIFFERENT TYPES AND PURPOSE OF LANDMINES

- Anti-Personnel Mines (AP)
  - Smaller in physical dimensions and explosive material content
  - Designed to be detonated from the applied pressure appreciable to that of the weight of a child up to a grown adult
  - Purpose similar to that of the anti-tank landmine:
    - Slow the movement of an advancing infantry group
    - Kill or purely maim individuals who detonate the mine
    - Demoralize the advancing soldier through death and destruction



HISTORICAL LANDMINE DETECTORS

- Historically, the detection of landmines was quite rudimentary with a focus on military clearance.
    - Here the methods of detection/removal would have been:
        - Manual demining in sensitive areas
        - Ranged bombardment to just destroy the minefield with artillery or explosives
        - Low-tech mechanical clearance

- Military versus Civilian Demining:
    - Military – to clear the route as fast as possible to continue troop movement and reduce casualties.
    - Civilian – to clear the route as effectively as possible to return land to previous condition and NO casualties.

CURRENT NEWS : RECENT EVENTS

- Thursday May 23, 2002
  - Six Canadian soldier escaped unharmed when the armoured vehicle they were riding in struck an explosive device in Afghanistan. The explosion destroyed a wheel on the Bison.

Earlier that month, Canadian soldier traveling in an American Humvee struck a landmine. One Canadian solider was slightly injured and the vehicle was destroyed.

Source: http://www.cbc.ca/news/story/2002/05/23/bison_landmine020523.html

GLOBAL LANDMINE PROBLEM

- There are estimates of around 110 million anti-personnel that litter the ground and another 100 million that have been stockpiled.
- More than 350 different types of anti-personnel landmines exist in present day. The current problem primarily lies with AP mines because they have a much more far spread affect than those of AT mines.
    - The presence of AP mines has the ability to kill and maim the local population.
    - Landmines carry out what they were designed for regardless of whether they are civilian or combatant, landmines do not discriminate.
    - Un-recovered landmines have far reaching affects especially for post-conflict regions: inability to seek clean water, resources and farm crops. To reestablish an infrastructure, to rebuild and expand.

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GLOBAL DISTRIBUTION OF LANDMINES

Source: http://www.icbl.org/lm/2005/maps/res/color/5-ProblM.EnglPost-LM2005.jpg

NEW TYPES OF LANDMINES

- Plastic landmines
  - Advantages and Disadvantages, what might they be from both points of view?
- Anti-Tamper landmines
  - New landmines are designed with mechanisms in place to detonate if they are moved, altered or attempts to defuse them are made. How are these not the perfect landmine?
- Anti-Detection landmines
  - New landmines have also been fitted with electronic devices to detect the presence of magnetic fields and other associated detection fields. If detected they may detonate in order to not be disarmed.

CURRENT LANDMINE DETECTING TECHNIQUES

- Manual Demining:
  - Trained humans prod the ground with specialized tools to detect buried landmines, mark and/or remove them, then safely detonate them.
  - This is long hard work, that demands immense concentration and focus.
  - This method is nearly 100% effective in clearing a minefield.
  - There are several disadvantages, what might they be?

CURRENT LANDMINE DETECTING TECHNIQUES (2)

- Biochemical “Dog” Detection:
  - The most advanced biochemical sensor on the market to this date, is a dogs nose. These dogs are trained to detect to scent of explosive substances, similar to those that detect hidden narcotics.
  - A dogs sense of smell is estimated at nearly 10 000 times greater the sensitivity to that of any man-made substance detecting instrument.

- As good as a dog’s sense of smell is what challenges might arise?

CURRENT LANDMINE DETECTING TECHNIQUES (3)

- Metal Detectors:
  - In 1925, Gerhard Fischar was the first t invent a portable metal detector. Fischar's model was not made commercially available until 1931 and eventually Fischar would be behind the first large-scale production of metal detectors.
  - New metal detectors are much more advanced allowing for customization of the detector for different metals given soil conditions, types of metal you are looking for, amount of metal that may be present, etc.

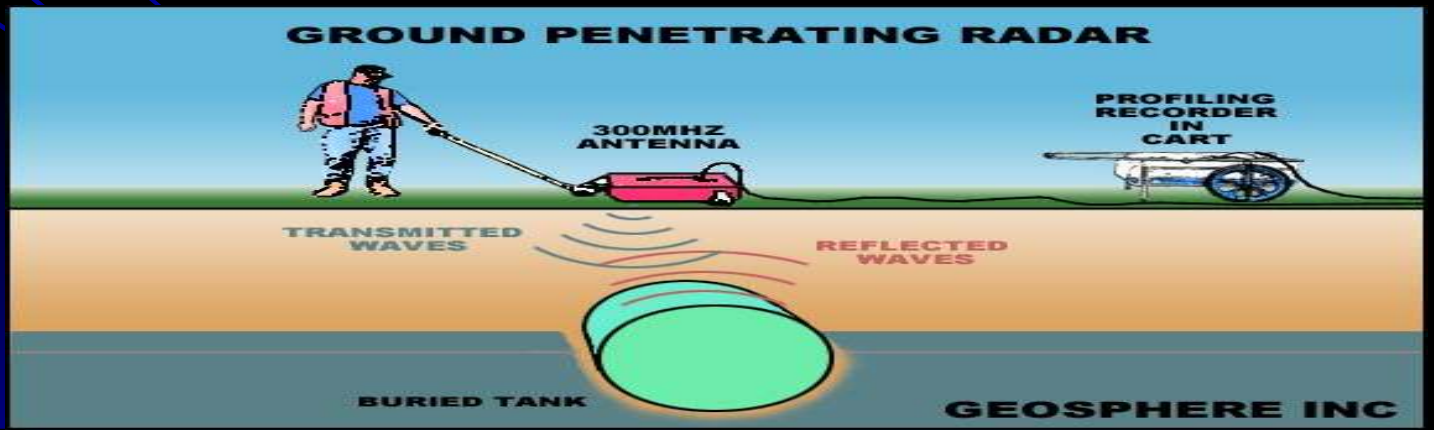
- Given that metal detection has come such a long way, with this form of UXO and landmine detection why might it still be risky?

CURRENT LANDMINE DETECTING TECHNIQUES (4)

- Ground Penetrating Radar Detection:

  - Ground penetrating radar entails focusing radar waves just below the grounds surface and objects below reflect the waves back. Radar waves are electromagnetic radiation in the microwave band (30MHz – 3000MHz) UHF/VHF band. This method requires a transmitter and detector component, one spreading the waves, and the other receiving reflected waves.

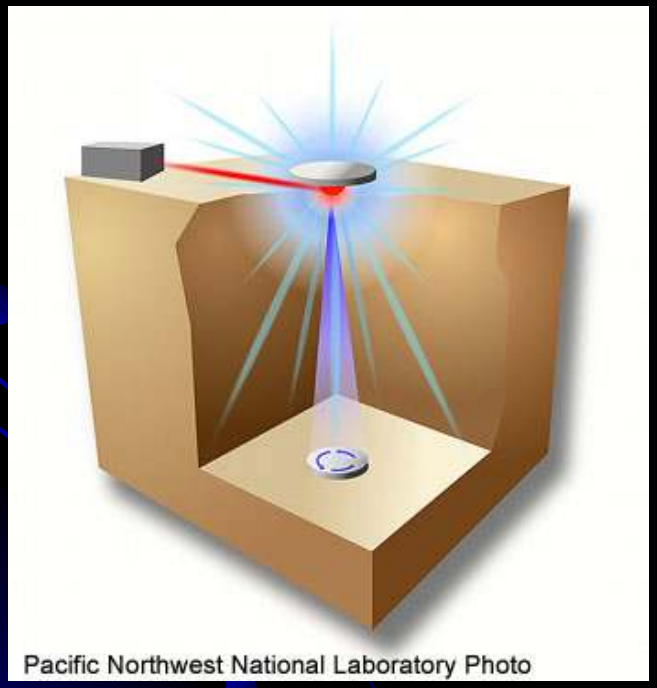
  - This would be an overhead view of what lies below the detector, with that common shapes and dimensions of landmines can be seen. Reflected waves dependent on soil and site conditions.



CURRENT LANDMINE DETECTING TECHNIQUES (5)

- Acoustical Detection:

  - Researchers are using acoustic waves to shake the ground and measure the resulting movement – in order to catch unusual ground vibrations associated with buried landmines.



Pacific Northwest National Laboratory Photo

  - The group is finding much success with the combination of ground penetration radar and acoustical detection.
  - Where ground penetrating radar may fail where does acoustical succeed?

CURRENT LANDMINE DETECTING TECHNIQUES (6)

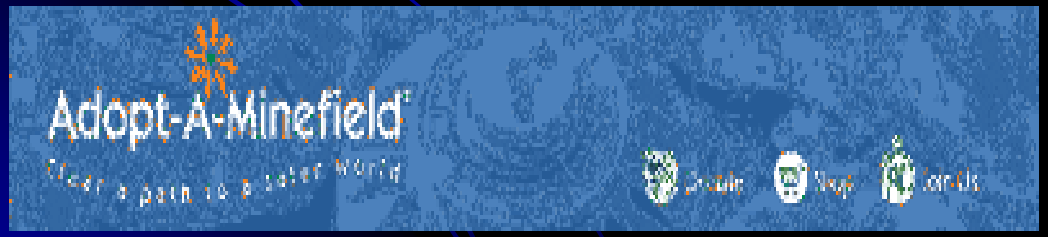
- Thermal Neutron Activation Detection:
  - Detects the presence of nitrogen in an irradiated volume by injecting slow neutrons into the ground and measuring the energy levels of the returned gamma rays.
  - The majority of explosive compounds are nitrogen based therefore since explosive substances have a large percentage by weight of nitrogen (18-38%) compared to soils (0-0.1%) detection of significant amounts will usually indicate the presence of explosives.
  - Where might this form of detection falter?

RECOVERY DEMOLITION VIDEO

- Landmine reality: www.youtube.com – Stop land mines
- Landmine demolition: www.break.com – Hundred Tons of Explosives

INITIATIVES

- Adopt-A-Minefield: http://www.landmines.org/
- International Campaign to Ban Landmines: http://www.icbl.org/
- Veterans for America: http://www.veteransforamerica.org/ModuleID/239
- United Nations Ban on Landmines
- Hundreds of not-for-profit organizations, companies and government agencies devoted to stopping the production, use and effectively the removal of landmines all over the globe.



RESULTS AND GOALS

- Ottawa Treaty on the Ban of Landmines
- Hundreds of countries banned the production and use of landmines.
- Hundreds of thousands of landmines still litter the globe but steps are being taken to remove them, slowly but surely.
- Huge humanitarian efforts are being made to remove UXO and landmines so that war torn regions have a fighting chance at rebuilding for a better future.

INSPIRATION FOR PROJECT

• Essentially the inspiration for this project came from a quote that I try to live by:

" I have an irrepressible desire to live till I can be assured

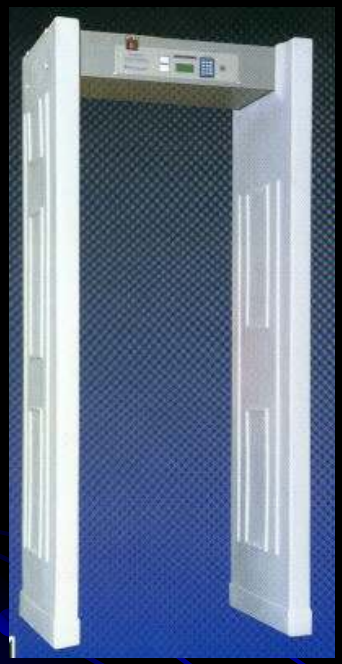
that the World is a little better for my having lived in it."

Along with that while attending a conference a lecturer gave us (engineers) a motto to live by:

" No evil robots"

Engineering should be about helping people live better lives, we should make it such that we reduce risk, increase safety, utility and efficiency. In many cases we are the bridge between people and things, whether it be water, enjoyment, peace of mind or surgery. That is a large bill to fill…

TYPES OF METAL DETECTION

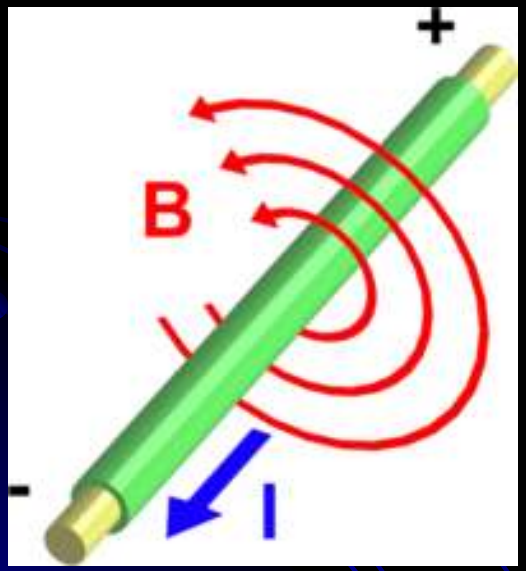


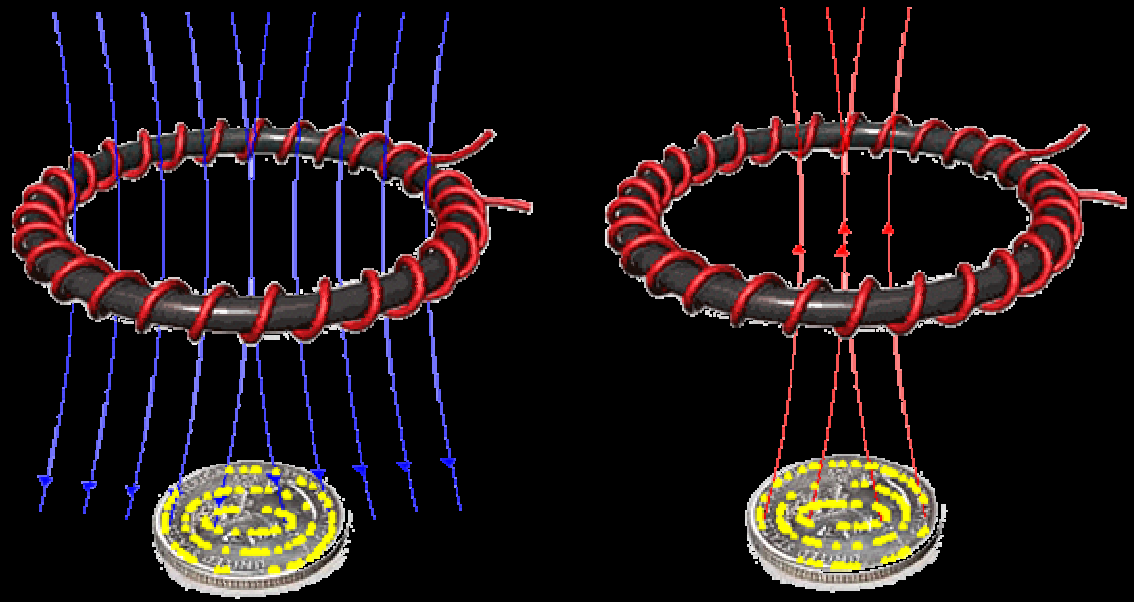
There are three mainstream forms of metal detection:

1. Very Low Frequency (VLF)
2. Pulse Induction (PI)
3. Beat Frequency Oscillation (BFO)

Very Low Frequency Metal Detectors

An alternating current is driven through a transmitter coil (inductor) creating a magnetic field of alternating polarity. This alternating magnetic field induces a magnetic field in **conductive** materials, this induced magnetic field influences the receiver coil inside the transmitter coil and creates a current which can be measured.





http://www.thomasathomas.com/Metal_detectors_work.htm

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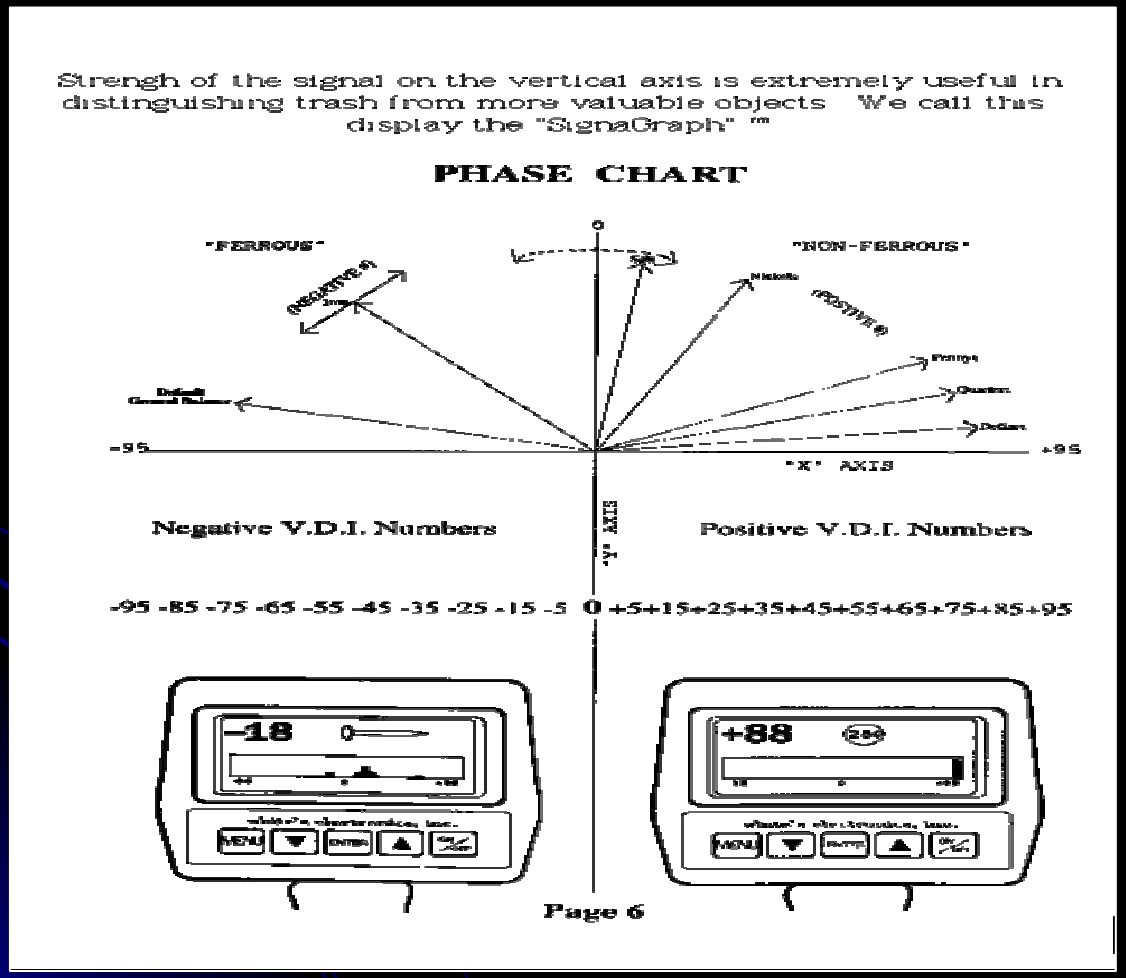
Very Low Frequency Metal Detectors

Depending on the materials tendency to be more inductive or resistive will determine how the material reacts to the influence of the transmitter coil, this will produce a distinctive phase shift.



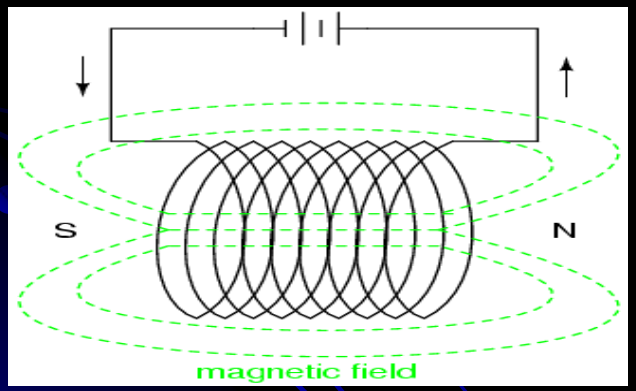
Resistance: to impede the flow of current

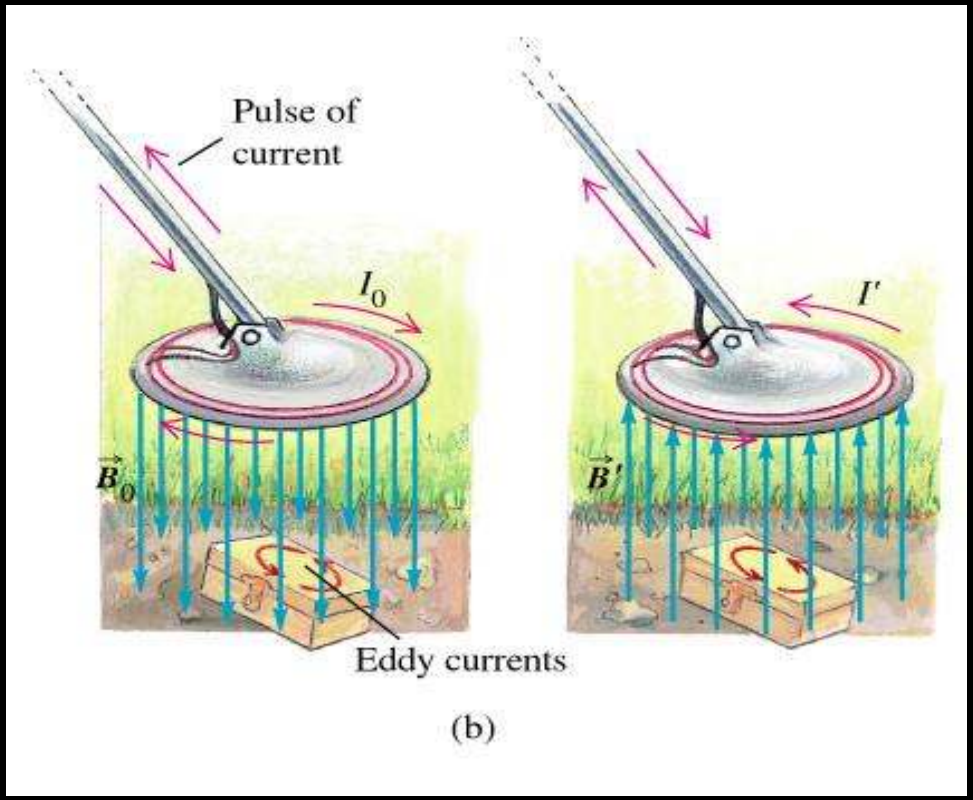
Inductance: to impede changes in the flow of current

http://www.thomasathomas.com/Metal_detectors_work.htm

Pulse Induction Metal Detectors

The detector coil is quickly alternated between a transmitter coil to a receiver coil. A current is driven through the transmitter coil producing a magnetic field which will induce Eddy currents in metallic objects. The detector is switched to a receiver coil and “listens” for decaying magnetic fields produced by the Eddy currents.





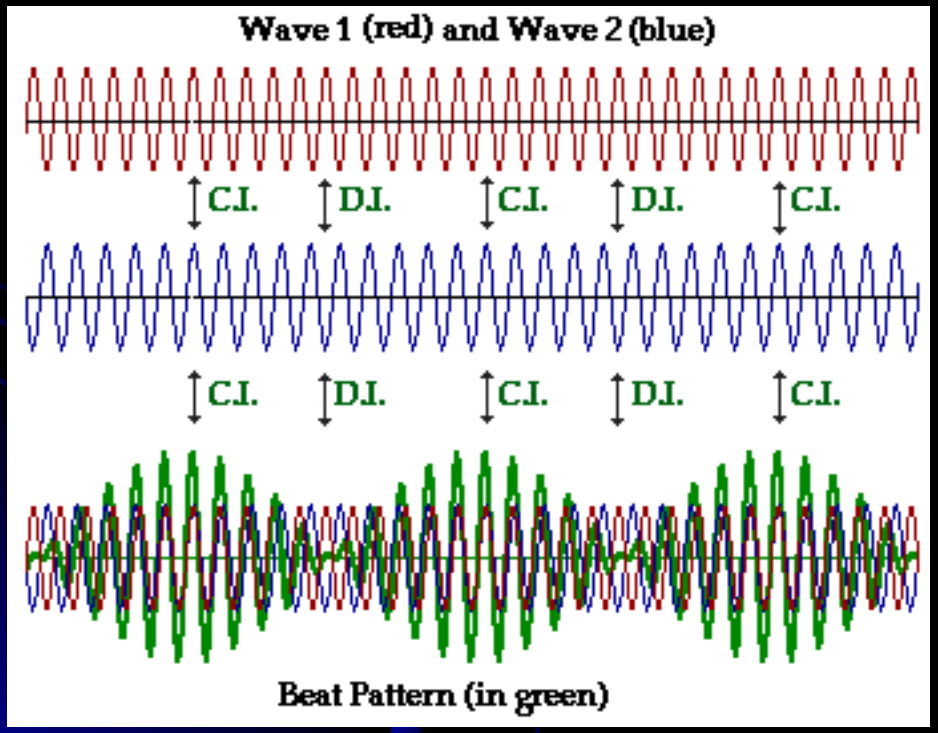
Beat Frequency Oscillation Metal Detectors

An electronic oscillator is driven at a specific frequency as a base for comparison. A second hardware oscillator (i.e. Colpitts, Hartley oscillator) is constructed with a dependent frequency. The hardware oscillator usually incorporates an inductor, as the inductor passes over metallic objects they will affect the inductance of the coil causing the frequency of the hardware oscillator to change. The defined frequency is compared to the varying frequency and the difference is represented as a frequency.

The operation of the beat frequency oscillator is based on the principle of superheterodyning which is essentially the mixing of two frequencies to produce a beat frequency (difference between the two frequencies).

Source: http://www.fas.org/man/dod-101/navy/docs/es310/superhet.htm

The term superheterodyning is used electronics, while the term beat frequency is used in physics.

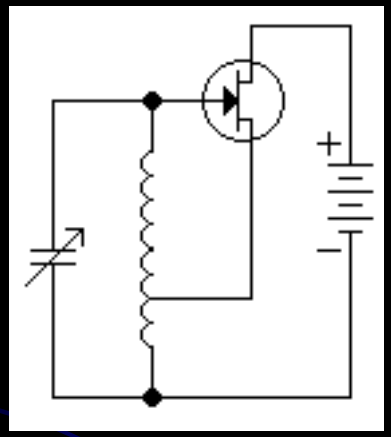


Source: http://www.physicsclassroom.com/Class/sound/U11L3a.html

Beat frequencies in physics are the difference between the frequencies of the interfering waves.

For example, sound waves at 650Hz and 657Hz, the beat frequency will be 7Hz.

For this metal detector the fixed frequency is produced by a ceramic filter. The dependent frequency is produced by an inductor and variable capacitor in parallel, similar to the Hartley oscillator model below.



Hartley Oscillator Model

$$\omega = \frac{1}{\sqrt{LC}}$$

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$$

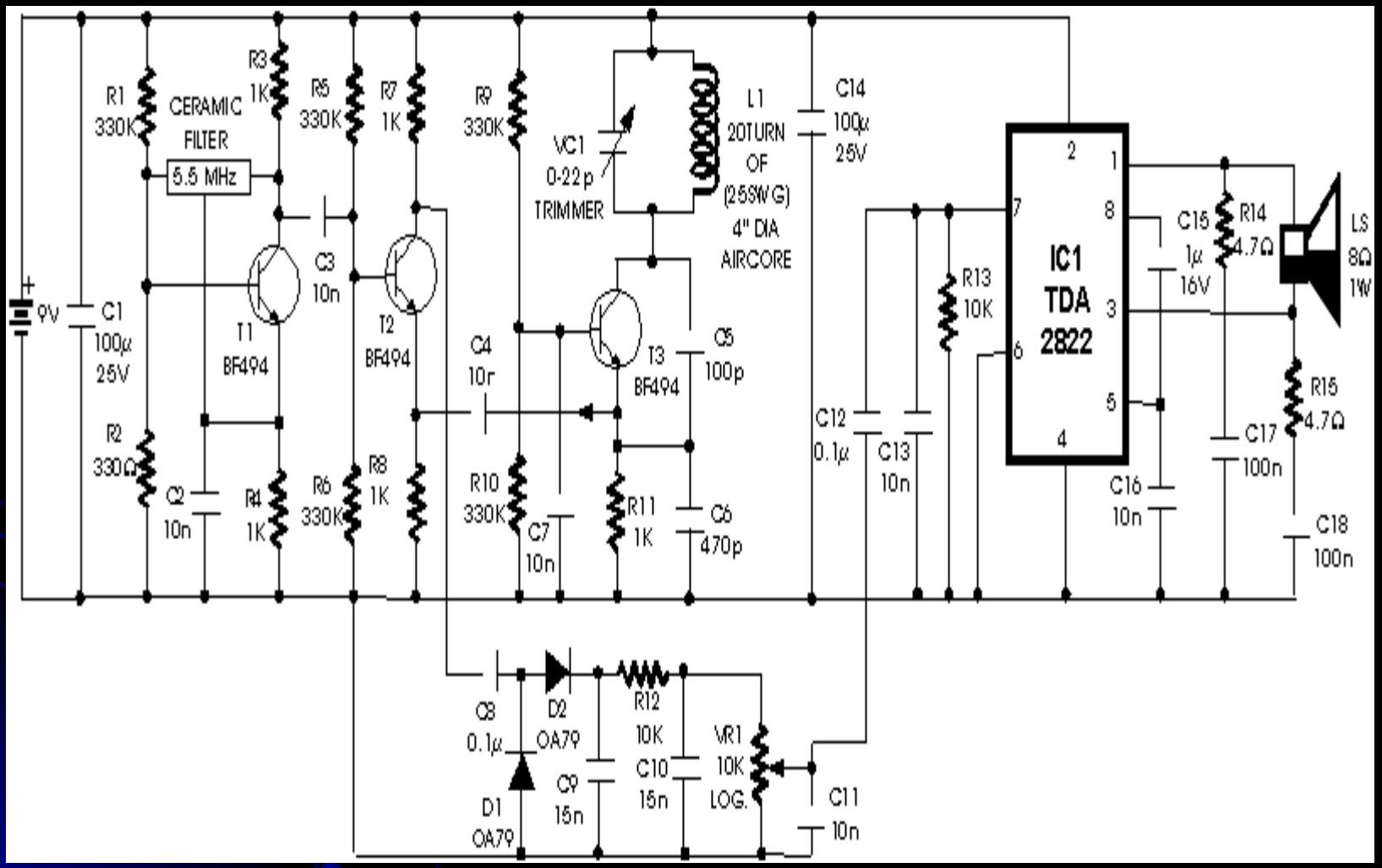
As the search coil passes over a metallic object the inductance (L) of the coil will change producing a different frequency.

Since the search coil has a rigid air-core the inductance is a function of geometry and number of turns, while independent of current.

$$L = \frac{\mu_0 \mu_r N^2 A}{l}$$

$$L = \frac{r^2 N^2}{9r + 10l}$$

Just a quick look at the metal detector schematic



Source: Unknown

Mechanics

Drive System:

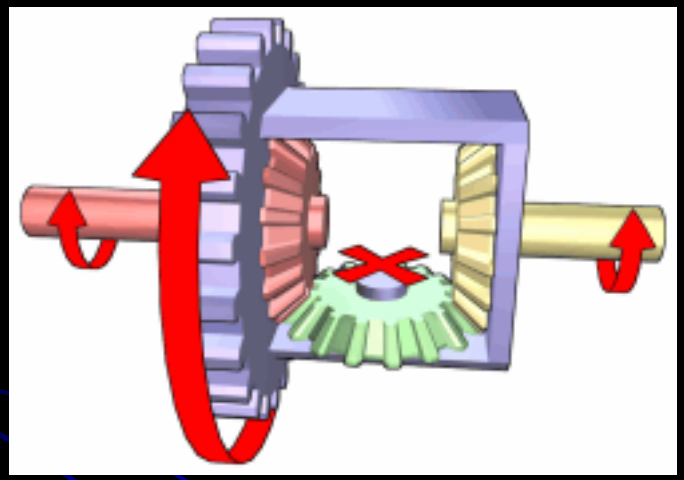
• Worm and Worm Gear: This combination of gears is very common for gear reductions and capable of produce a large amount of torque. The rotation of the worm when coupled with the worm gear will produce rotational motion perpendicular to the worm itself.

The gear ratio for worm/worm gear combinations are for every revolution of the worm the worm gear is rotated by one tooth, which is a small fraction of the entire circumference. For example a 35-tooth worm gear will have a 35:1 gear reduction.

Mechanics

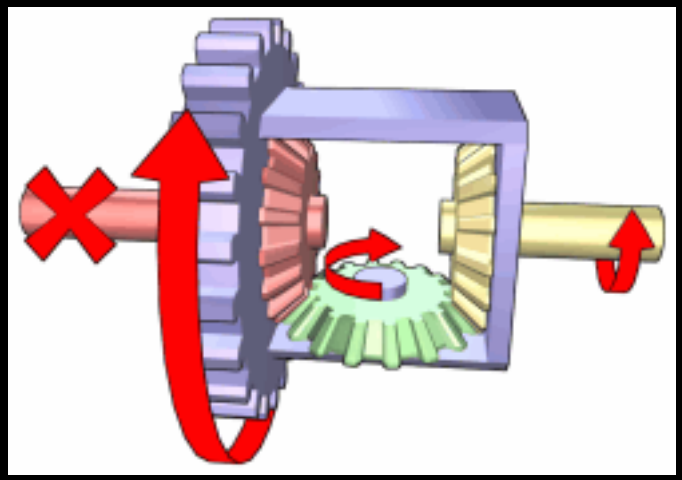
Drive System:

• Differential: A mechanical device utilizing a unique assembly of gears to allow attached shafts to turn at different rates depending on resistance.



Open Differential

If equal resistance is applied to the shafts they will rotate at the same rate.



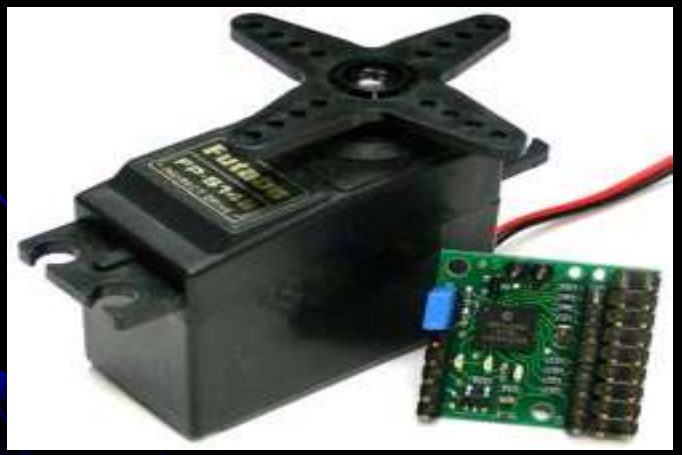
Locked Differential

If unequal resistance is applied to the shafts then the shaft with less resistance will rotate at a faster rate.

Mechanics

RC Servos: steering + detector

- A high torque servo was used to provide the necessary steering for the robot. The servo in combination with steering linkages and shaft arms provides the steering necessary.
- The servo rotates a certain arc length in the x and y direction while the steering knuckle moves primarily in the x-direction in effect steering the wheels.



Mechanics

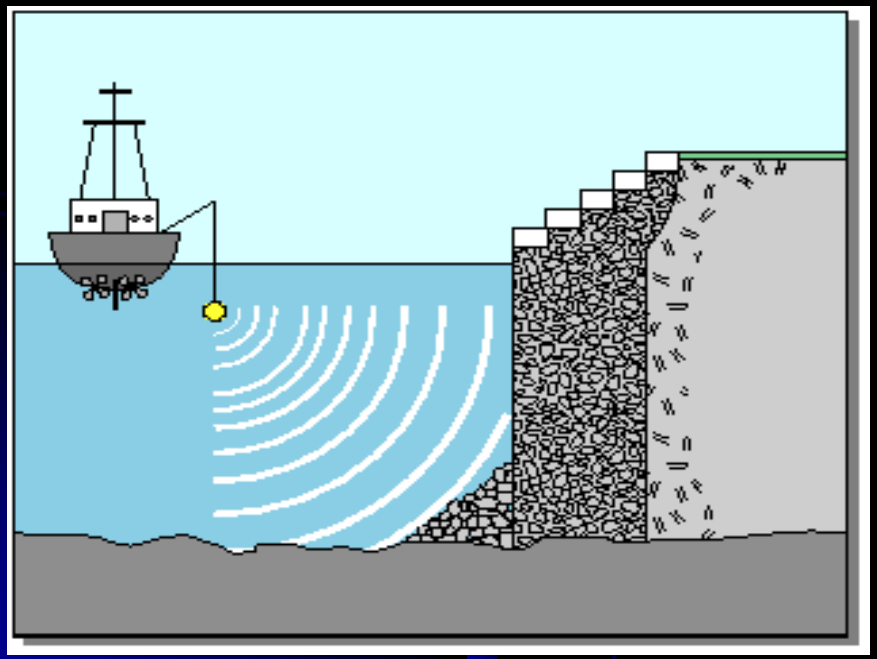
Drive System: Steering in a robotic system can be accomplished in few different ways: skid steering, rack and pinion steering and differential gear steering.

- Skid Steering: Also referred to as differential steering, that which armoured tanks use. One tire or track moves in one direction at a certain speed while the other moves at the same or different speed and direction.
- Rack and Pinion / Differential Gear Steering: They are inter-related in that to use rack and pinion one must use a differential gear. This allows the driving wheels to rotate at different rates providing a nice smooth turn.
- Where might one form of steering be better than the other?

Electronics

Navigation:

• Ultrasonic Sensor: A transmitter and receiver sensor that creates a pulse of sound (ping) and then listens for a reflection of the sound signal (echo). The time the reflection takes to return will output a voltage value which can in turn be converted to a distance.



Ultrasonic sensors are superior to infrared sensors because the reflection signal is not dependent on the surface reflectivity and to a lesser extent surface geometry.

Electronics

• Pulse Width Modulation: This the process of running a voltage for a certain amount of time (duty cycle) over a specific amount of time (period) to produce a desired average voltage.

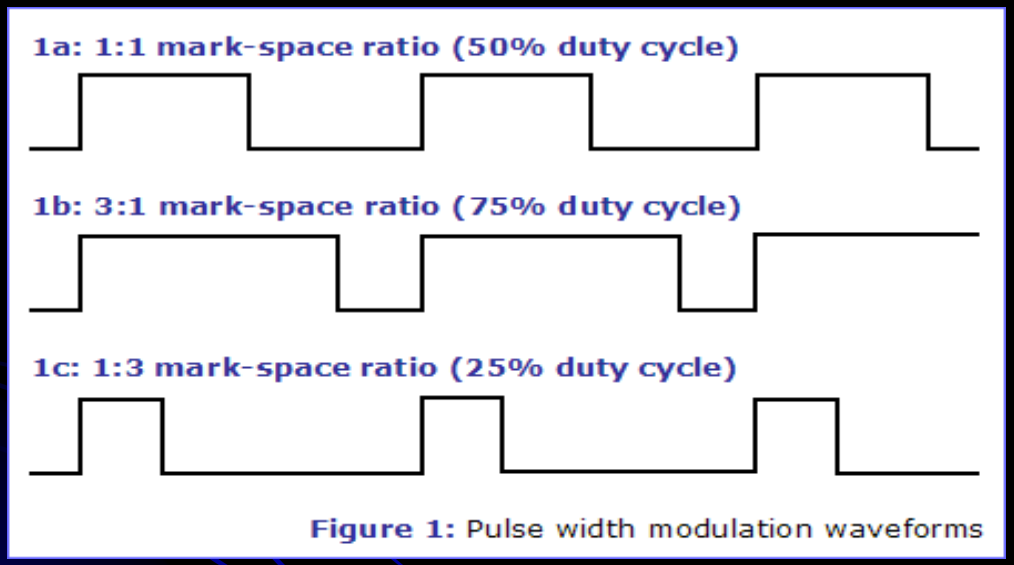


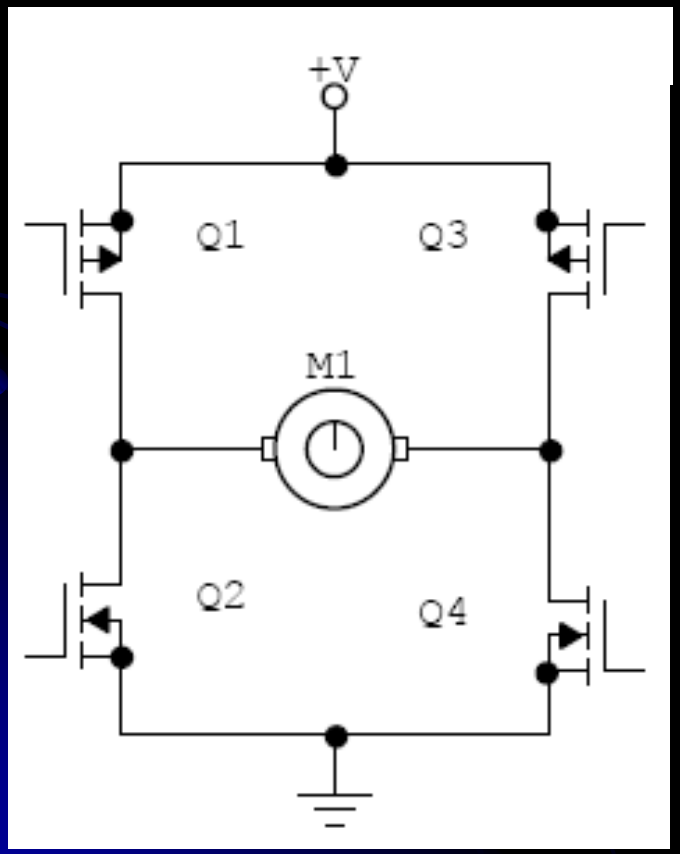
Figure 1: Pulse width modulation waveforms

This procedure allows for a pseudo-analog voltage to be produced. With voltage-controlled transistors this can be utilized to control current flow.

For example: 5.0V run at 50% duty cycle will average out to 2.5V. Similarly, 5.0V run at 75% duty cycle will average out to 3.75V. When applied to motors this will correspond to different speeds.

Electronics

H-Bridge: This circuit is used to run motors in two different directions. The combination of gates allow for current to flow in different directions which results in the motor running in different directions.



- BJT, FETs and MOSFETs are all electronic switches.
- When a current or voltage is applied to the base or gate, current is allowed to flow from the collector-emitter, source-drain.