Introduction

As I was watching the world cup, I noticed sometimes the referee is not able to see the goal due to the referee being far away or the goal might be blocked by the players which might make it hard to the referee to see if the ball actually went through the goal-line or not. The objective of goal-line technology is not to replace the role of the officials, but rather to support them I their decision-making. This lead to me researching different ways we can determine if the ball actually went in or not, I found different goal-line technologies that helps however one of them has piqued my interest which was the GoalRef goal-line technology as it involves physics in it which is why I am making my project about this technology, it also made me realise that physics can be used in different things in the industry.

Magnetic Fields

Before we talk about the history and applications of magnetic fields we should start by learning the fundamentals of magnetic fields. Magnetism is a force generated in matter by the motion of electrons within its atoms. The imaginary lines of magnetic force is describe as 'magnetic fields'. Similar to electric and gravitational fields which we previously covered a magnetic field is a region where a force will act at a distance. In the case of magnetic fields, the field is caused by a permanent magnet or by moving charges like an electric current and the force will act on a magnetic material or a charged particle[1]. Similar to electric and gravitational fields, magnetic fields also has field lines represented with arrows point towards the direction of the force which will always be pointing from north to south, the closer the lines are together the stronger the field is. [2] Magnetic field lines do not have a beginning nor an end, they always form closed loops. The magnetic field is described mathematically as a vector field due to it having a magnitude and a direction (north to south). The field-line has some useful properties, Magnetic field lines never cross because a particle only goes on one path, so there cannot be any point where lines of force point it in two directions at the same time. If magnetic field lines intersect each other, then the magnetic field (magnetic field lines) will have

[1] O'Neill, M. (2016). *OCR A level Physics A Student Book 2*. 2nd ed. Pearson Education Limited.

[2] http://www.bbc.co.uk/bitesize/ks3/science/energy_electricity_forces/magnets_electric_effects/revision/3/

two different directions at that point which is impossible[3]. There are basic ways which we can arrange for charge to be in motion and generate a useful magnetic field. We make a current flow through a wire, for example by connecting it to a battery we should keep this in mind as this will be useful for the goalref technology because it requires generating magnetic fields from current flow through a wire.. As we increase the current (amount of charge in motion) the field increases proportionally. As we move further away from the wire, the field we see drops off proportionally with the distance (Described by Ampere's law. [4]

How do we measure magnetic fields?

Magnetic field is a vector quantity so there will be 2 things that we need to measure to describe, similar to gravitational field lines and electric field lines we also need to calculate its strength and direction. In the SI system the magnetic field is measured in tesla (symbol T, named after Nikola Tesla)[5]. The Tesla is defined in terms of the magnitude of force applied to a moving charge due to field.

History of magnetism

Before talking about applications of magnetic fields lets first talk about the history of magnetism and how it was discovered. The first man to investigate magnetic fields was an Englishman named William Gilbert using scientific methods and in the process discovered that the Earth itself is a weak magnet. Later on in the 18th century a Frenchman called Charles Coulomb, who established the law that we know today as the Coulomb's law stating that the attractive force between two magnetized objects s directly proportional to the product of their individual fields and inversely proportional to the square of the distance between them.[6] Very accurate measurement of small magnetic fields has only been practical since the discovery in 1988 of giant

[3] Quora.com. (2018). Why do magnetic field lines not intersect each other? - Quora. [online] Available at: https://www.quora.com/Why-do-magnetic-field-lines-not-intersect-each-other [Accessed 14 Jul. 2018].
[4] Khan Academy. (2018). What are magnetic fields?. [online] Available at: https://www.khanacademy.org/science/physics/magnetic-forces-and-magnetic-fields/magnetic-field-current-
[5] Khan Academy. (2018). What are magnetic fields?. [online] Available at: https://www.khanacademy.org/science/physics/magnetic-forces-and-magnetic-fields/magnetic-field-current-carrying-wire/a/what-are-magnetic-fields [Accessed 14 Jul. 2018].
[6] Ucl.ac.uk. (2018). *Magnetism*. [online] Available at: http://www.ucl.ac.uk/EarthSci/people/lidunka/GEOL2014/Geophysics9%20-Magnetism/Useful%20papers/Magnetism.htm [Accessed 11 Jul. 2018].

magnetoresistance in specially layered materials. This discovery in fundamental physics was quickly applied to magnetic hard-disk technology used for storing data in computers which increased in data storage capacity in just a few years. In 2007 Albert Fert and Peter Grunberg were awarded the Nobel Prize in Physics for this discovery[7].

Magnetic field associated with an electric current

When an electric current flows in a straight conductor we can determine the direction of the magnetic field. The field of a single coil carrying current-carrying wire into a single coil, we obtain a magnetic field pattern, this will be relevant later as the goal-line technology involves a ball having a coil within it that would react to the magnetic field. On one side of the coil, the magnetic field lines are in a clockwise direction, whereas on the other side they are anticlockwise. The vector addition of the fields around each wire leads to an increase in the strength of the magnetic field within the coil.[8] Since magnetic field is a vector, we also need to know the direction, for conventional current flowing through a straight wire this can be found by the right-hand-grip-rule. To use this rule imagine gripping your right hand around the wire with your thumb pointing in the direction of the current. The fingers show the direction of the magnetic field which wraps around the wire.[9]

Electromagnetic Induction

Just as a current can create a magnetic field, a magnetic field can also produce a current this is what we call electromagnetic induction. It works when a changing magnetic fields produces a potential difference across a conductor, such as a wire. The way it is done is by moving a conductor back and forth through a magnetic field a potential difference is produced.

. Faraday's law of electromagnetic induction states that the faster the relative motion between a wire and a magnetic field, or the faster the flux within a loop is changed due to a changing magnetic field, the greater the induced E.M.F.

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[7] Khan Academy. (2018). What are magnetic fields?. [online] Available at: https://www.khanacademy.org/science/physics/magnetic-forces-and-magnetic-fields/magnetic-field-current-carrying-wire/a/what-are-magnetic-fields [Accessed 14 Jul. 2018].

[8] O'Neill, M. (2016). *OCR A level Physics A Student Book 2*. 2nd ed. Pearson Education Limited.

[9] O'Neill, M. (2016). *OCR A level Physics A Student Book 2*. 2nd ed. Pearson Education Limited.

Goalref Technology

Before talking about the goal-line technology they made, we should talk about who they are and why they made this technology. Goalref is an association football goal-line technology system developed German research institute Fraunhofer in association with Select Sport[10].One of the reason why we needed a goal-line technology is because all of Frank Lampard's controversial goal against Germany in the crucial match of the 2010 FIFA World Cup which made England fans furious due to the referee disallowing the goal although the ball clearly went through the goal-line. The referee decides in the heat of the moment, sometimes from metres away from the goal and sometimes players blocks the view of sight of the referee which makes it hard for the referee to determine if the ball went in or not, hence why a lot of organisations started developing goal-line technology that would make it easier for the referee to decide if a team scores a goal or not. One of these being GoalRef's technology which will be the one I will be focusing on as it involves magnetic fields which has piqued my interest.

GoalRef technology set up

There will be wires all around the goal, wires will be placed under the goal-line and around the goalposts. Magnetic fields are generated when we pass a current through those wires which will produce a magnetic field covering the entire goalmouth. The balls will have three flexible copper coils.[11]we should keep in mind the copper are good conductors and this will be relevant later as these copper will be needed for electromagnetic induction to happen. Low

[10] En.wikipedia.org. (2018). *GoalRef*. [online] Available at: https://en.wikipedia.org/wiki/GoalRef [Accessed 11 Jul. 2018].
[11] Medium. (2018). *A comparison of 4 goal-line technologies in football*. [online] Available at: https://medium.com/the-digital-sports-blog/technology-in-sport-834b017e20d5 [Accessed 11 Jul. 2018].

frequency magnetic fields do not interact very strongly with the human body so the magnetic fields will not be affected by the players and the players won't get hurt by the magnetic field. The magnetic field produced around the goalpost is different compared to the magnetic fields generated by the copper coils within the ball, this is important because it would be easier to detect a disturbance if the ball goes through the goal-line. The referee will also have a watch that would notify them if the ball crosses the goal line, they receive notification from an antenna that will transmit radio signals which would lead to the referee's watch to vibrate and a message will be displayed on their watches. There will be antennae around the goalpost that will detect the change in magnetic field if a change in magnetic field happens.

How does the antennae detect if the ball has fully crossed the goal line?

This is going back to things we talked about before. When a conductor passes through a magnetic field, a current is induced in the conductor this phenomenon is known as electromagnetic induction. The conductor we are talking about is the copper coil within the ball because as we know copper is a good conductor. The current that was induced in the copper coils within the ball can be detected by the device making the magnetic field because the electronics attached to the coils in the goalposts looks for disturbance on the magnetic field created in the goal area and the disturbance comes from the current within copper coils in the ball.