Sarcouncil Journal of Engineering and Computer Sciences

ISSN(Online): 2945-3585

Volume- 05| Issue- 04| 2026

Research Article **Received:** 01-03-2026| **Accepted:** 25-03-2026 | **Published:** 11-04-2026

A Unified View of Fleming's Right-Hand Rule

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Abstract: The aim of this paper is to facilitate a better understanding of four electrical phenomena: electromagnetic induction, transformer operation, wireless charging, and the skin effect. Central to this understanding is the principle that magnetic flux density is of primary importance for induction. John Ambrose Fleming established the Fleming's Right-Hand Rule, which dictates the relationship between motion, fields, and current: the thumb represents the direction of motion (Force), the index finger represents the magnetic field (B) from North to South, and the middle finger represents the direction of the induced current (I). This paper proposes that F be used specifically to denote magnetic flux density within this framework.

Keywords: Magnetic flux density, magnetic field and current.

INTRODUCTION

The aim of this paper is to present a unified view of Fleming's Right-Hand Rule which was initially developed by John Ambrose Fleming [Bogach, V. A. 2002].

Fig. 1 illustrates the Right-Hand Rule developed by Fleming, but a little change was added. In this model, the thumb represents the varying Flux density (where F still can be used). With that, it can help explain the following phenomena:

- Electromagnetic induction (a magnet moving over a wire)
- Transformer operation (how energy transfers between coils)
- Wireless charging
- The skin effect (why current migrates to the surface of a conductor)

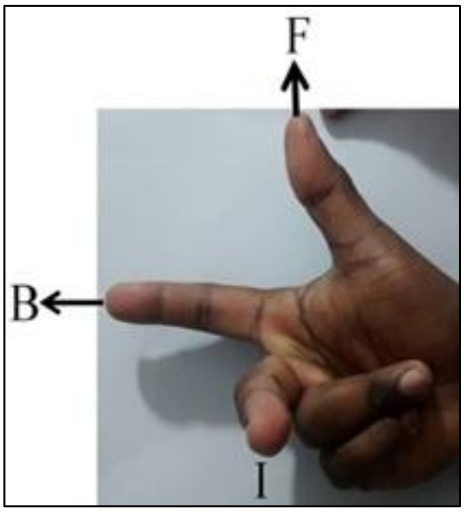

Fig. 1: Fleming's Right Hand Rule

While physics teachers often use "F" for "Force," a more descriptive approach for electrical engineering is to view it as the direction of the varying Flux density (F).

- The Thumb (F): Points in the direction of the varying flux density as perceived by the wire.
- The Index Finger (B): Represents the direction of the magnetic field (North to South).
- The Middle Finger (I): Indicates the direction of the induced current flow.

Fig. 2, magnetic flux lines shown by iron filings sprinkled on a piece of paper under which is a magnet. The flux lines travel from the North to the South pole. Flux density is greatest near the poles, where magnetic strength is highest. The magnetic field strength (B) is inversely proportional to the square of the distance from the pole [Anderson, M. 2025].

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DOI- https://doi.org/10.5281/zenodo.19519314

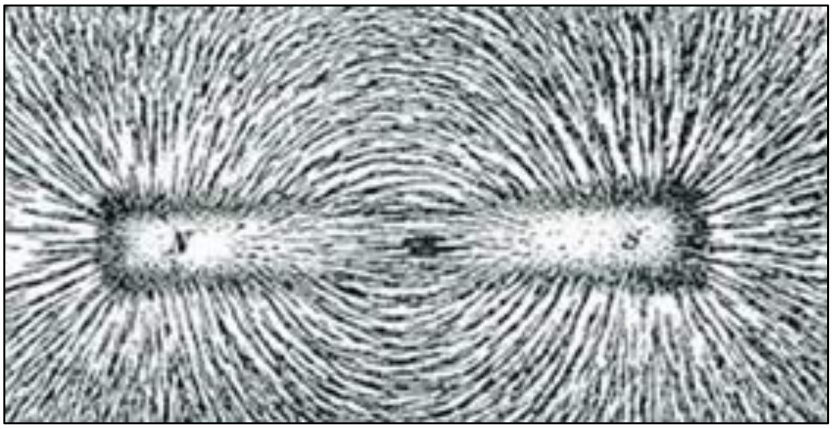

Fig. 2: Magnetic flux lines formed by a magnet

Electromagnetic induction (a magnet moving over a wire)

If a magnet passes at right angle over a straight wire, a current is induced to flow in the wire according to Fleming's Right-Hand Rule. However, if that same wire is coiled within a small area, the magnetic flux acts upon significantly more electrons simultaneously. By coiling the wire, we effectively "multiply" the inductive effect, allowing the magnet to induce current in many loops at once. As a result, coiling the wire generates a much higher induced electromotive force (EMF) and total current than a single straight wire [Kumar, R. *et al*., 2017].

Imagine you are the wire, as a magnet approaches, you will encounter an increasing density of flux lines. The density of the flux lines reaches a maximum as the magnet's pole is over the wire and tapers off as it moves away. This varying flux density (F) is what induces the current to flow in the wire. This is why even if an incredibly powerful magnet is held stationary over a wire, millions of flux lines will enter the cross section of the wire, but they will remain in a steady state as in Fig. 2; therefore, no current is induced in the wire below it.

Transformer operation (how energy transfers between coils)

In a transformer, the primary and secondary coils are not physically connected. Current is induced from the primary coil to the secondary coil because there is a varying flux density (F) in the primary coil whose magnitude follows the AC current waveform.

The primary coil acts as an electromagnet (which has a B), but with the North and South poles flipping at the frequency of the AC.

This presence of F and B induces current (I) in the secondary coil.

But if DC is injected to the primary coil of the transformer, no current is induced in the secondary coil because the varying flux density remains static as in Fig. 2 (F = 0). Of course, when you first energize a transformer with DC, there will be a change in varying flux density from zero to high which will induce current in the secondary coil for that short moment [Chakravorti, S. *et al*., 2013].

The transformer core, which carries the magnetic field from the primary to the secondary coil, is constructed from laminated iron sheets. Although silver, copper, and gold are superior electrical conductors, iron is the most effective material for magnetic transmission due to its high magnetic permeability. While materials like copper or air have a relative permeability (μr) of approximately 1, iron can exceed 1,000. Additionally, as the second most abundant metal in the Earth's crust, iron is also the most cost-effective magnetic material available [Khadanga, R. K., & Mishra, S. 2024].

Table 1: The relative permeability of various material

Material	Typical Max Relative Permeability (μr)
Vacuum / Air	1
Aluminum	1.00002
Iron (99.8% pure)	5,000
Silicon Steel	10,000
Mu-Metal	100,000
Supermalloy	1,000,000

Wireless charging

If the primary and secondary are separated by air—which has a very low permeability—induction can still occur, as seen in wireless charging. However, to compensate for the lack of an iron core, the frequency of the AC wave must be significantly increased (typically to 87 kHz – 205 kHz) to ensure efficient energy transfer across the air gap [Kumar K, J. *et al*., 2022].

Switched-Mode Power Supplies (SMPS)

The physics of AC power dictates that frequency directly determines the physical size of magnetic components. This is best illustrated by the evolution of power supply technology. When I was working on my Final Year Project (FYP) in 1991, I used a standard linear transformer measuring 6” x 6” x 6” that could only handle 6A. In contrast, for one of my current research projects, I use a Switched-Mode Power Supply (SMPS) measuring only 2” x 10” x 5” that can handle a substantial 63A. If we were still forced to use 1991 technology for a 63A load, the transformer would likely be a massive (6 X 10)3 or 60-inch cube!

How is an SMPS so much smaller? The secret lies in frequency. An SMPS takes the 50 Hz or 60 Hz utility frequency and increases it to approximately 100 kHz before it enters the transformer to step down the voltage (e.g., from 240V or 120V to 5V).

To visualize this, consider the movement of a single electron. In AC, an electron moves from left to right, then right to left, repeating this cycle. Assuming this electron has 10 magnetic flux lines. At 50 Hz or 60 Hz, the electron reaches zero speed at the moment it changes direction and maximum speed at the center of its oscillation. Because the magnetic flux lines collapse more slowly than the speed of the electron’s movement, the rate of change of the magnetic flux density (F) from the moment of changing direction (zero speed) to the center happens relatively slowly, so F is relatively low, therefore the I generated in the secondary coil is relatively low.

But at 100 kHz, the rate of reaching from 10 flux lines (at the changing direction moment) to the maximum number of field lines (at the center of its movement) occurs at a much faster rate. So, F is much larger therefore I generated in the secondary coil is much higher. You can visualize it this way: instead of moving a magnet at right angle to a wire 50 or 60 times a second, you move it at 100,000 times per second, obviously you will get more current generated in the secondary coil.

Since a much higher I is generated in the secondary at 100 kHz the quantity of iron or magnetic material for the transmission of flux is much less. This high rate of induction allows a transformer with a much smaller cross-sectional core area to transfer the same amount of power from the primary to the secondary winding [Das, A. *et al*., 2024].

The Skin Effect and Eddy Current

While higher frequencies allow for smaller components, they introduce the challenge of eddy currents. Even at 50 or 60 Hz, unwanted circular currents are generated within the conductor itself. You can visualize this by using your right hand shaped as in the Fleming’s Right-Hand Rule and move it along the length of your left arm. The two ends of your arm represent the two changing direction moments of an electron within a wire.

As you move your thumb (representing the varying flux density, F) “up and down” the arm, you can see how current is generated from the center of the wire toward the outside. Assume an electron has 10 flux lines. At the electrons changing direction moments it has only 10 flux lines.

And the middle of your arm is where maximum speed is reached. Since the flux lines collapse slower than the speed of the electron, there will be maximum flux density at the middle of your arm. Since there is a varying flux density from the end of the arm to the middle, there is a F.

Electrons are magnets which have a North and South pole, so there is B. Therefore, a current is induced from the center of the wire to the circumference.

Because electrons within the wire are magnets that can be oriented in any direction (0o to 360o) within the wire, the current generated by the back-and-forth movement of the electrons effectively “crowd” the current from the generator toward the circumference.

This pushes the current from the generator also to the circumference. Engineers optimally want current from the generator to reach the load, but because AC is used, this unwanted current generation within the wire pushes the current from the generator to the circumference or “skin” of the conductor and this is called skin effect [Mohanty, I. *et al*., 2018].

This phenomenon does not occur in Direct Current (DC). Even when the highest DC currents on Earth flows through the wire (assume it does not burn), there will be millions of static magnetic flux lines, but the electrons do not move back and forth therefore there is no varying flux density (F) and therefore no I or eddy current is generated within the wire. Consequently, in High Voltage Direct Current (HVDC) lines, the current flows uniformly through the entire cross-section of the conductor.

In contrast, for HVAC transmission, Fig. 3 depicts an ACSR (Aluminum Conductor Steel Reinforced) cable, consisting of seven strands of steel surrounded by four layers of aluminum. This is because engineers know that no current flows at the center of the wire. But not all is lost, because in ACSR cables, the central steel strands provide greater tensile strength, allowing overhead towers to be spaced further apart, therefore many less expensive towers need to be erected thereby significantly reducing cost [Seetharamu, S. *et al.*, 2012].

Fig. 3: The conductor consists of seven strands of steel surrounded by four layers of aluminum

Aluminum has two major drawbacks: a low melting point of 660°C (compared to 1,085°C for copper) and lower ductility, which makes it more prone to fatigue and breaking. However, aluminum remains the preferred material for power transmission due to its cost-effectiveness—as the most abundant metal in the Earth's crust—and its weight, which is approximately 30% that of copper. If copper is taken as the standard weight for legacy cables, these aluminum alternatives are 70% lighter (100% - 30% = 70%).

As the frequency increases to 100 kHz, the varying flux density (F) increases tremendously. This generates significantly more eddy current, forcing the current from the generator even further toward the extreme surface of the wire.

Aviation and High-Frequency Design

In aviation, generator rotors spin at 400 Hz rather than the standard 50 Hz or 60 Hz used in terrestrial grids. This higher frequency allows generators and motors to be significantly smaller and lighter—a critical design factor for aircraft where every kilogram counts.

However, because the skin effect becomes more pronounced as frequency increases, the effective conductive area of the wire decreases at 400 Hz. To mitigate this, engineers must use multiple smaller, parallel wires (stranded conductors) to provide sufficient surface area for the current. While a single, thick solid wire would suffice for 50/60 Hz, it would be highly inefficient at 400 Hz due to the current being pushed toward the surface [Karanayil, B. *et al.*, 2016].

Similarly, in high-frequency Switched-Mode Power Supplies (SMPS) operating in the kHz range, "Litz wire" is often utilized for the primary and secondary windings. Litz wire consists of many thin, individually insulated strands twisted or woven together. This configuration maximizes the available surface area and ensures that current is distributed evenly among the strands, thereby minimizing the resistive losses caused by the skin effect [Pandey, A. *et al.*, 2024].

REFERENCES

1. Bogach, V. A. "On Polarity of the Electromotive Force Induced by the Geomagnetic Field and on Necessity to Revise J." Fleming's Rule. (2002).
2. Anderson, M. "Physics and Modern Life: A Panoramic Overview of the Fundamental Science and Its Human Impact." (2025).
3. Kumar, R., Sachan, D., Yadav, S. S., Sihara, A. K., & Misra, P. K. "Design of active inductor at 2.4 GHz frequency using 180 nm

Publisher: SARC Publisher

CMOS technology." 2017 4th IEEE Uttar Pradesh Section International Conference on Electrical, Computer and Electronics (UPCON). IEEE, (2017).

4. Chakravorti, S., Dey, D., & Chatterjee, B. "Recent trends in the condition monitoring of transformers." Power Systems (2013).
5. Khadanga, R. K., & Mishra, S. "A Novel Design Approach to Optimize Core-Loss of Power Transformer." 2024 10th International Conference on Electrical Energy Systems (ICEES). IEEE, (2024).
6. Kumar K, J., Kumar, S., & VS, N. "Standards for electric vehicle charging stations in India: A review." Energy Storage 4.1 (2022): e261.
7. Das, A., Mondal, D., & Adhikary, S. "Chapter-20 Design, Analysis and Optimization of Switched-Mode Power Supplies for Efficient Power Conversion." Computational Techniques in Modern Engineering Research (2024): 171.
8. Mohanty, I., Nagendran, R., Thanikai Arasu, A. V., Baskaran, R., & Mani, A. "Correlation of defect depth with diffusion time of eddy currents for the defects in conducting materials using transient eddy current NDE." Measurement Science and Technology 29.10 (2018): 105601.
9. Seetharamu, S., Kumar, R. K., Sampathkumaran, P., & Shivakumar, K. N. "Review of technological advances in high temperature overhead line composite conductors." Journal of Aerospace Sciences and Technologies (2012): 63-72.
10. Karanayil, B., Ciobotaru, M., & Agelidis, V. G. "Power flow management of isolated multiport converter for more electric aircraft." IEEE Transactions on Power Electronics 32.7 (2016): 5850-5861.
11. Pandey, A., Kumar, J., & Samanta, S. "Precise modeling approach of litz-wire based planar rectangular spiral coils with ferrite core and lateral misalignment for wpt applications." IECON 2024-50th Annual Conference of the IEEE Industrial Electronics Society. IEEE, (2024).

Source of support: Nil; **Conflict of interest:** Nil.

Cite this article as:

Karunakaran, P., Osman, M. S. & Ling, T. “A Unified View of Fleming’s Right-Hand Rule” *Sarcouncil Journal of Engineering and Computer Sciences* 5.4 (2026): pp 27-31.

Publisher: SARC Publisher