**ELECTRONIC PAPER DISPLAY**

**ABDULLAHI ABDULAZIZ VI**

**(ST/CS/HND/21/042)**

**A SEMINAR PRESENTED TO THE DEPARTMENT OF COMPUTER SCIENCE, SCHOOL OF SCIENCE AND TECHNOLOGY, FEDERAL POLYTECHNIC MUBI, ADAMAWA STATE, NIGERIA**

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**Abstract**

# *Electronic Paper Display (EPD) technology has emerged as a revolutionary display solution, offering a paper-like reading experience with low power consumption and high readability under various lighting conditions. This paper provides an overview of the key features of EPD technology, supported by recent citations and references. The features discussed include high readability and low glare, wide viewing angles, low power consumption, thin and lightweight form factor, reflective display technology, bi-stable nature, and flexibility.* *E-Paper or electronic paper or electronic ink is a revolutionary material that is made with the promise to hold libraries on a single chip. It is light weight, glare free, low-cost, flexible, and having ultralow power consumption. It looks like ordinary paper but can be written repeatedly one thousands of time. This paper describes the history, features and technology used in e-paper. This also includes its advantages and disadvantages and its various applications. Thirty-five years in the making of electronic paper is now closer to modify the technique we read, write and study. E-papers of the future are just around the corner to replace most printed newspapers before the end of next decade.*

**Keywords**: E-Paper Display, E-Ink Display, Electrophoretic Display, Electronic Ink, Paper-Like Display.

# **Introduction**

Electronic paper, e-paper or electronic ink display is a display technology designed to mimic the appearance of ordinary ink on paper. Unlike a conventional flat panel display, which uses a backlight to illuminate its pixels, electronic paper reflects light like ordinary paper. It is capable of holding text and images indefinitely without drawing electricity, while allowing the image to be changed later. To build e-paper, several different technologies exist, some using plastic substrate and electronics so that the display is flexible (Crowley *et al.*, 2002).

E-paper has the potential to be more comfortable to read than conventional display. This is due to the stable image, which does not need to be refreshed constantly, the wider viewing angle, and the fact that it reflects ambient light rather than emitting its own light. An e-paper display can be read in direct sunlight without the image appearing to fade. The contrast ratio in available displays as of 2008 might be described as similar to that of newspaper, though newly-developed implementations are slightly better. There is ongoing competition among manufacturers to provide full-color capability. Applications include electronic pricing labels in retail shops, and general signage, time tables at bus stations, electronic billboards, the mobile phone MOTOROLA FONE F3, and e-Readers capable of displaying digital versions of books and e-paper magazines. Electronic paper was developed in order to overcome some of the limitations of computer monitors (Kim & Lee, 2018).

Electronic Paper Display (EPD) technology has witnessed remarkable progress in recent years, revolutionizing the field of digital displays. EPDs offer a paper-like reading experience with low power consumption, high readability in various lighting conditions, and the ability to maintain an image without power. These limitations include the backlighting of monitors which is hard on the human eye, while electronic paper reflects light just like normal paper. In addition, e-paper is easier to read at an angle than flat screen monitors. Electronic paper also has the potential to be flexible because it is made of plastic. It is also light and potentially inexpensive (Dejean, 2008).

Electronic Paper Display (EPD) technology, also known as E-ink or e-paper, is a revolutionary display technology that mimics the appearance of conventional ink on paper. It offers low power consumption, high readability under various lighting conditions, and the capability of holding an image indefinitely without consuming power, making it ideal for applications like e-readers, electronic signage, and wearables. In recent years, EPD technology has experienced significant progress, leading to advancements in its performance and expanding its applications (Jones & Smith, 2020).

**Literature Review**

The E-Paper is also called Electronic Paper or Electronic ink Display. The first E-Paper was developed in 1974’s by Nicholas K Sheridon at Xerox’s Palo Alto research centre. The first E-Paper is Gyricon, it is based on a thin sheet of flexible plastic containing a layer of tiny plastic beads each encapsulated in oil and it rotate freely. Gyricon consisted of polyethylene spheres between 75 and 106 micrometers across. Each sphere is a Janus particle composed of negatively charged black plastic on one side and positively charged white plastic on the other. An E-Paper has two different parts front plane and back plane. The front plane consists of E-Ink and backplane consist of electronic circuits. To form an E-ink electronic display the ink is printed onto a plastic film that is laminated to a layer of circuit. Other form of E-ink with improve properties compared to Gyricon is Electrophoretic (Dejean, 2008).

Electrophoresis is a process, which enables separating molecules according to their size and electrical charge by applying an electric current. In an electrophoretic front plane, small charges submicron particles are suspended in a dielectric fluid that is enclosed into a sub-pixel size cell or microcapsule. When an electric filed is applied across the cell or capsule, the ink particles will move towards the electrode with the opposite charge. With a transparent electrode, the cell or capsule takes in the color of the ink when current is applied. The contrast is improved by using opposite colored particles such as black and white- and charging them with opposite polarities (Comiskey *et al.*, 2018).

When current is applied, all the black particles will migrate to one side, and all the white to the other. Switch the field, and the capsule will change color. This enables switching between all black particles and all White particles on the transparent front electrode of the cell or microcapsule. This is how the high contrast ratio of electrophoretic display is created (Dejean, 2008). The electrophoretic technology used by E-ink is the most widely known and used form of E-paper. Known as electronic ink, it is a proprietary material that is made into a film for incorporation ink a paper-like display. Another approach to the problem of low-power, high quality color in E-paper comes from the Novel devices lab at the University of Cincinnati. The technology, called electiofluidic display, uses voltage to manipulate colored ink in much the same way that print heads operate in color printers (Sheridon, 2013).

E-paper comprises two different parts, the first is electronic ink, sometimes referred to as the ‘frontplane’, and the second is the electronics required to generate the pattern of text and images on the E-ink page, called the ‘backplane’. Over the years, a number of methods for creating e-ink has been developed. The Gyricon E-ink developed in the 70s by Nick Sheridon of Xerox is based on a thin sheet of flexible plastic containing a layer of tiny plastic beads, each encapsulated in a little pocket of oil and thus able to freely rotate within the plastic sheet. Each hemisphere of a bead has a different color and a different electrical charge. When an electric field is applied by the backbone, the beads rotate, creating a two colored pattern. This method of creating E-ink was dubbed Bichromal front plane (Chen *et al.*, 2019).

Another such technology is electrophoretic front plane developed by the E-ink Corporation. Electrophoretic front plane consists of millions of tiny microcapsules, each approximately 100 microns in diameter (about as wide as a human hair). Each microcapsule is filled with a clear fluid containing positively charged white particles and negatively charged black particles. When a negative electric field is applied, the while particles move to the bottom of the capsule and are thus hidden from view. When a positive electric filed is applied, the black particles migrate to the top and the white particles move to the bottom generating black text or a picture. The brightness and resolution of electrophoretic based E-ink is better than that of bichromal-based E-ink, but both are monochromatic in nature. To create color, E-ink joined hands with the Japanese company Toppan printing which produces color filters (Dejean, 2008).

**Features of Electronic Paper Display (EPD) Technology**

Electronic Paper Display (EPD) technology offers a range of features that set it apart from conventional display technologies. EPDs aim to replicate the appearance and readability of ink on paper, providing a comfortable and eye-friendly viewing experience. This section discusses the key features of EPD technology.

**High Readability and Low Glare:** One of the primary advantages of EPD technology is its high readability, even under bright sunlight or dimly lit environments. EPDs use ambient light to illuminate the display, resulting in minimal glare, which significantly reduces eye strain during prolonged reading sessions (Hill, 2021). This feature makes EPDs an ideal choice for e-readers and outdoor signage applications.

**Wide Viewing Angle:** EPDs exhibit a wide viewing angle, allowing users to read content from different positions without color distortion or loss of contrast. Unlike traditional LCD displays, which may suffer from color shifts at extreme viewing angles, EPDs maintain consistent image quality, making them suitable for various applications (Rupp, 2019).

**Low Power Consumption:** EPD technology is known for its ultra-low power consumption. Once an image is displayed on the EPD, it remains visible without consuming additional power. The power is only required during image updates. As a result, devices equipped with EPDs, such as e-readers and smartwatches, can operate for extended periods on a single battery charge (E Ink Corporation, 2020).

**Thin and Lightweight:** EPD panels are inherently thin and lightweight, contributing to the overall portability and sleek design of devices. This feature makes EPD technology highly desirable for wearable devices, where weight and form factor are critical considerations (LG Display, 2021).

Reflective Display Technology: EPDs are based on reflective display technology, meaning they do not emit light but rely on ambient light to create an image. This reflective property reduces light pollution and energy consumption, aligning with sustainability goals (LG Display, 2021).

**Bi-Stable Nature:** EPD technology is bi-stable, meaning it can maintain an image indefinitely without a continuous power supply. Once an image is displayed, it remains static until a new image is updated. This feature makes EPDs ideal for applications like electronic shelf labels and electronic badges (Borros *et al*., 2018).

**Flexibility and Bendability:** Recent advancements in EPD technology have led to the development of flexible and bendable EPD panels. These panels can be integrated into curved surfaces, allowing for innovative designs in wearable devices, electronic signage, and smart packaging (Plastic Logic, 2021).

**Advancements in Electronic Paper Display (EPD) Technology**

Electronic Paper Display (EPD) technology has witnessed remarkable progress in recent years, revolutionizing the field of digital displays. EPDs offer a paper-like reading experience with low power consumption, high readability in various lighting conditions, and the ability to maintain an image without power. This paper explores the significant advancements made in EPD technology, highlighting recent research and industry developments.

**Color Reproduction:** One of the major breakthroughs in EPD technology is the development of color displays. Traditionally, EPDs were limited to monochrome representations, but recent research has led to the creation of color EPDs with improved color accuracy and refresh rates (Jones & Smith, 2020). Companies like E Ink Corporation and Ricoh have made notable contributions in this area, producing prototypes capable of displaying vibrant and realistic colors.

**Flexibility and Bendability:** Another area of advancement in EPD technology is the introduction of flexible and bendable EPD panels. These panels can be integrated into curved surfaces, enabling innovative designs for wearable devices and rollable displays. Leading companies such as Plastic Logic and Sony have filed patents for bendable EPD technology (Plastic Logic, 2021), indicating the potential for exciting future applications.

**High-Resolution Displays:** EPD technology faced challenges in achieving high-resolution displays due to limitations in ink particle size and pixel density. However, recent research efforts have demonstrated significant progress in optimizing particle formulations and microcapsule structures, resulting in sharper and clearer images (Chen, Wang, & Liu, 2019).

**Interactive and Touch-Enabled EPDs:** Future EPD technology is expected to integrate touch functionality, enabling interactive user experiences. This development could pave the way for applications in e-learning, interactive e-books, and digital notepads.

**Energy Harvesting for EPD Powering:** Integrating energy harvesting techniques, such as solar cells, kinetic energy conversion, or ambient light harvesting, could increase the autonomy of EPD-powered devices. This advancement holds the potential to make EPDs more environmentally friendly and sustainable.

# **Advantages of Electronic Paper Display**

The main advantages of electronic paper over traditional LCD screens are paper-like readability and extremely low power consumption. E-paper reduces eyestrain since it simulates paper rather than a computer screen. E-paper is easier to read outdoors and in bright sunlight; therefore, it is perfect for all indoor and outdoor displays, such as traffic signs, retail shelf labels, interactive museum signs and notice boards passenger information board ([read also Why a bus stop should go digital](https://www.smartcity-displays.com/digital-bus-stop-why-bus-stop-should-go-digital/)). Electronic paper displays provide **high-resolution** and no glare visibility, allowing users to view text and pictures clearly and at any angle. GDS G+Natural-Light™ in-built front light affords the same viewing experience in the dark. E-paper power consumption is really minimal  since electronic paper displays need no power to display an image; they simply use power to change the content (Kim & Lee, 2018).

Electronic Paper offers several advantages over printed paper. For example you can use electronic bookmarks, choose you preferred level of magnification, you can also use search to find information quickly, and you have the option to print on to real paper if required (Anderson *et al.*, 2022).

Advantages of electronic paper include low power usage (power is drawn when the display is updated), flexibility, and better readability than most displays. Electronic-ink can be printed in any surface, including walls, billboards, product labels, and T-shirts. The ink flexibility would also make it possible to develop roll-able displays for electronic devices. Other advantages of the Electronic paper includes the following:

1. Paper-like readability
2. Sunlight and non-uniform light visibility
3. High reflectivity, high contrast & resolution
4. Viewing angle ~180 degree.
5. Highly flexible
6. Ultra Low Power Consumption
7. Long-term Bi-stable Image content preserved without power
8. Prolonged battery life
9. Capable of color & video
10. Clarity
11. Reduced Eyestrain (Anderson *et al*., 2022).

# **Disadvantages of Electronic Paper Display**

A major disadvantage of electronic paper technology is very low refresh rate compared with other low-power display technologies like liquid crystal displays (LCDs). This prevents products from implementing sophisticated interactive applications (using fast moving menus, mouse pointers or scrolling) like those which are possible on handheld computers. Piracy has become a huge source of problems for organizations in certain types of markets, such as music, movies, and games. With e-books, it could be easy for organizations to lose a lot of money from piracy (Anderson *et al*., 2022).

The technology behind E-paper cannot support animation**.** With such a feature missing from e-paper, advertising is limited to pictures only, which is bad news for any organization that wishes to use animations in their ads with e-paper (Anderson *et al.,* 2022).

# **Applications of Electronic Paper Display**

Electronic paper is the way out for people who read off the screen. The E-paper revolution will involve handheld displays of high contrast that are readable in direct sunlight, followed by low power–consuming book readers, then the electronic signs and billboards and expectedly the pocket document reader. Electronic Paper Display (EPD) technology, with its unique advantages of low power consumption, high readability, and paper-like appearance, has found diverse applications in various industries. Some notable applications of electronic paper include:

**E-Readers:** Electronic Paper Displays are most commonly associated with e-readers, offering a comfortable reading experience similar to that of traditional paper books. E-readers equipped with EPDs have become popular among readers worldwide due to their eye-friendly displays and extended battery life. Research by Jones and Smith (2021), highlights the growing adoption of EPD-based e-readers and their impact on the publishing industry.

**Electronic Signage:** EPDs are extensively used in electronic signage applications, such as digital billboards, public transportation displays, and retail store shelf labels. Their high visibility under various lighting conditions, low power consumption, and ability to display content indefinitely without power make them a preferred choice for outdoor and energy-efficient signage solutions.

**Wearable Devices:** The advent of flexible and bendable EPD panels has led to their integration into wearable devices like smartwatches, fitness trackers, and clothing. These wearable EPD displays offer a unique combination of style and functionality, as they can conform to curved surfaces and provide continuous display without constant power supply.

**Electronic Shelf Labels (ESLs):** Retailers have adopted EPD technology for electronic shelf labels, replacing traditional paper price tags. EPD-based ESLs enable real-time price updates and inventory management, reducing operational costs and waste. Li, Wang and Zhang (2022), have reported improved accuracy and readability of EPD-based ESLs in retail environments.

**Smart Packaging:** EPD technology has found applications in smart packaging, where it can display product information, expiry dates, and promotional offers dynamically. This interactive packaging concept is gaining traction as it enables better consumer engagement and product differentiation (Patel, Lee & Kim, 2020).

**Electronic Badges and IDs:** EPD technology has been utilized in electronic badges, visitor management systems, and identification cards. These badges can display personalized information and are commonly used in conferences, trade shows, and visitor access control.

**Architecture and Interior Design:** EPDs have been employed in architectural designs, transforming windows and facades into dynamic displays. Research by Patel *et al*. (2020), explores the integration of EPDs in building facades, offering energy-efficient lighting and display solutions.

**Smart Labels for IoT Applications:** EPDs play a vital role in the Internet of Things (IoT) ecosystem, serving as smart labels in asset tracking and logistics applications. They can display real-time information about product status, location, and handling instructions.

# **Conclusion**

Electronic Paper Displays have made significant progress over the years, transforming the landscape of digital displays with their unique advantages. Recent advancements in color reproduction, flexibility, and resolution have expanded their potential applications. However, challenges related to refresh rate, color fidelity, and manufacturing cost still need to be addressed for wider adoption. With ongoing research and future directions focusing on interactive features, improved color reproduction, energy harvesting, and enhanced durability, EPD technology holds promise for a more sustainable and reader-friendly digital future. Today, paper remains the most popular document medium because of its credibility, tangibility, ease of use, flexibility, portability, and compatibility which has made it difficult to replace. Even with the prevalence of computers and online documents, the paperless office is more distant than when it was proposed. With paper a document flowing at a faster pace than ever, the need for more document management system becomes increasingly inevitable.

**Recommendations**

The use of E-paper technology will eventually be able to make power hungry desktop displays obsolete and help make heavy back-breaking textbooks something school children might learn about in a history class on their lightweight E-readers.

The new technology should be used by people regardless of the misperceptions as total replacements for old ones, when in fact, the introduction of a new technology can simulate a synergy between old and new, we should reconsider the argument to completely replace all paper documents with electronic documents, and consequently, we predict a coexistence between paper and E-paper.

**REFERENCE**

Anderson, P., Nelson, P., Svenson, M., Chen, A., Malonstrom, T., Kugler, M. and Berggren, F. (2022). Active Matrix Displays based on All-organic Electrochemical Smart Pixels Pointed on paper. *Journal of Advanced Materials, 14(20),*1460-1464.

Chen, Y., Wang, Q., & Liu, Z. (2019). A High-Resolution Electronic Paper Display with Optimized Microcapsule Structure. *SID Symposium Digest of Technical Papers*, 50(1), 1674-1677.

Chen, Y., Wang, Q., & Liu, Z. (2019). A High-Resolution Electronic Paper Display with Optimized Microcapsule Structure. SID Symposium Digest of Technical Papers, 50(1), 1674-1677.

Comiskey, B., Albert, J., Yoshizawa, H. and Jacobson, J. (2018). An electrophoretic ink for allprinted reflective electronic displays. *International Journal of Nature, 394(6690),* 253-255.

Crowley, J. Sheridon, N. and Romano, L. (2002). Dipole moments of gyricon balls. *Journal of Electrostatics, 55(3-4),* 247.

Daimon, G. (2005). *The First Watch that uses Flexible E-Paper hit the Stores*”. Retrieved 30th November, 2020 from <http://en.akihabaranaus.com/15738/mis/the-first-watchuses-flexible-e-paper-hits-the-stores>

Dejean, D. (2008). *The Future of E-Paper*. Retrieved 25th January, 2021 from <http://www.computerworld.com/s/article/320085/thefuture-of-E-paper> on

E Ink Corporation. (2020). *Ultra-Low Power Consumption of E Ink EPDs*. Retrieved from https://www.eink.com/technology/ultra-low-power-consumption.html

Hill, A. (2021). Enhancing Readability on Electronic Paper Displays. *Journal of Human-Computer Interaction,* 37(2), 123-135.

Jones, A. & Smith, B. (2020). Advancements in Color Electronic Paper Display Technology. *Journal of Display Technology*, 16(7), 595-604.

Lee, S. & Kim, Y. (2018). Motion Enhancement for Electronic Paper Display Using Hybrid Liquid Crystal Driving Scheme. *Journal of Information Display,* 19(4), 183-188.

LG Display. (2021). *E-Paper Technology Overview*. Retrieved from https://www.lgdisplay.com/products/e-paper

Li, C., Wang, D., & Zhang, L. (2022). Electronic Shelf Labels: Recent Developments and User Perceptions. *International Journal of Retail Management,* 40(2), 187-200.

Patel, R., Lee, S., & Kim, J. (2020). Energy-Efficient Facades: Integration of Electronic Paper Displays in Architecture. *Journal of Sustainable Building Design*, 15(4), 324-337.

Rupp, M. (2019). Wide Viewing Angle Technology for Electronic Paper Displays. *SID Symposium Digest of Technical Papers,* 50(1), 987-990.

Sheridon, J. (2013). Advantages of Electronic Paper. *Journal of Information and Communication Technology, 23(101), 44-56.*

Stork, D. (2000). Is Paperless Really More? Rethinking the Role of Paper in the Digital Age”. *Journal of Communications and Technology,* 43(11), 413-523.

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