International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 06 | June - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

A Comparative Study of Analog and Microcontroller-Based RF Detection Systems for Mobile Phone Emission Monitoring

Tejas S
Dept. of ECE
RV College of Engineering
Bangalore, India
tejass.ec21@rvce.edu.in

Adithya Udaya Shankar
Dept. of ECE
RV College of Engineering
Bangalore, India
adithyaus.ec21@rvce.edu.in

Nachiketh Praveen
Dept. of ECE
RV College of Engineering
Bangalore, India
nachikethp.ec21@rvce.edu.in

Anoop S Vasistha
Dept. of ECE
RV College of Engineering
Bangalore, India
anoopsv.ec21@rvce.edu.in

Rajith Kumar B K
Dept. of ECE
RV College of Engineering
Bangalore, India
rajith.bkr@rvce.edu.in

***Abstract*—With the exponential growth in wireless communication and mobile phone usage, ensuring the controlled use of such devices in sensitive environments has become crucial. This paper presents a comparative study of two complementary RF detection approaches for mobile phone emission monitoring: an analog ring detector circuit and a microcontroller-based broadband RF monitoring system using an ESP32. The analog system targets narrowband high-energy GSM signals, while the ESP32-based solution employs a broadband RF detector capable of analyzing a wider spectrum from 100 MHz to 2.5 GHz. Both systems are designed and implemented to capture RF emissions in real-time and are evaluated based on sensitivity, coverage, response time, and implementation complexity [?]. The results provide valuable insights into their strengths, weaknesses, and potential integration for enhanced RF surveillance. The study demonstrates the practicality of hybrid analog-digital detection systems for applications such as examination halls, secure facilities, and signal monitoring research..**

***Index Terms*—RF Detection, ESP32, Ring Detector Circuit, Mobile Phone Detection, Wireless Emissions, Broadband Monitoring**

I. INTRODUCTION

The increasing reliance on wireless communication technologies has significantly transformed modern society, providing seamless access to information and enabling global connectivity. However, this technological ubiquity comes with critical drawbacks, particularly in areas where the unauthorized use of mobile devices may compromise integrity, confidentiality, or discipline. Environments such as academic examination halls, military installations, secure corporate zones, and scientific laboratories are highly susceptible to disruptions caused by unintended RF emissions from mobile phones [?]. While many institutions have attempted to address this through physical searches, electromagnetic shielding, or active jamming, these methods often fall short in terms of responsive- ness, scalability, and ethical acceptability. Consequently, there is a compelling need for non-intrusive, real-time, and accurate RF monitoring systems capable of detecting and reporting mobile device emissions [?].

In response to this challenge, the present study investigates two distinct yet complementary mobile phone detection methodologies based on radio frequency detection principles. The first approach involves an analog ring detector circuit that relies on tuned passive and active components—such as capac- itors, inductors, and transistors—designed to sense the short- duration RF pulses characteristic of GSM band signals, partic- ularly those emitted during incoming calls or SMS receptions. This circuit operates without any embedded processing unit and provides a straightforward indication—typically through an LED—upon detecting an RF signal burst [?]. Its simplicity and low cost make it ideal for applications requiring minimal deployment overhead, though its effectiveness is primarily limited to older cellular transmission technologies in the sub- GHz range.

In contrast, the second system incorporates a more sophisticated digital detection architecture utilizing the ESP32 microcontroller and a broadband logarithmic RF power detec- tor module, such as the Analog Devices AD8313 [?]. This setup is capable of capturing a wide range of frequencies, extending from 100 MHz up to 2.5 GHz or beyond, which includes signals from GSM, 3G, 4G LTE, Wi-Fi, and even sub-6 GHz 5G transmissions. By converting analog signal strength into digital values using the ESP32's analog-to-digital converter (ADC), and then transmitting those values to a laptop via serial communication, this system enables real-time graphical monitoring and quantitative analysis of RF activity. The dynamic range and accuracy of the detection are significantly improved over the analog circuit, providing a scalable foundation for RF surveillance applications in complex electromagnetic environments [?].

The comparative evaluation of both systems was a central objective of this study, with performance metrics including detection sensitivity, signal range, response time, and signal resolution. Experimental validation involved subjecting each detector to a series of RF emission events generated by mobile phones and Wi-Fi devices under controlled conditions [?]. The analog circuit reliably detected sudden bursts in the 900 MHz GSM band with minimal latency, demonstrating its utility for identifying short, high-energy emissions. However, it failed to respond effectively to continuous or lower-intensity signals. Meanwhile, the ESP32-based RF monitoring system offered continuous, real-time plotting of signal strength with sufficient granularity to capture both transient and sustained RF activity across multiple bands. Despite requiring a more complex setup and software calibration, the microcontroller-based system proved to be more versatile and robust in real-world scenarios [?].

This dual-system analysis underscores the trade-offs between simplicity and performance when designing RF detection tools for mobile phone monitoring. While the analog circuit offers an economical and energy-efficient solution for targeted GSM detection, the digital ESP32-based platform provides broader spectral awareness and data logging capabilities. The study proposes that, in practice, a hybrid integration of these two systems can serve as an optimal configuration, wherein the analog detector acts as a rapid event trigger and the digital module offers detailed RF characterization. Such a system would not only enhance detection fidelity but also improve contextual decision-making in sensitive environments, contributing to more intelligent and adaptable RF surveillance solutions [?].

II. METHODOLOGY

The proposed system adopts a hybrid methodology as seen in figure combining both analog and digital signal processing techniques to detect unauthorized mobile phone usage based on RF emissions. The system is divided into two parallel subsystems: an analog ring detector and a digital RF strength monitoring module. The analog subsystem begins with a simple 5-inch wire antenna that captures high-frequency bursts typically emitted by mobile phones during operations such as calls, texts, or data transmissions. These signals, primarily in the 800 MHz to 2.5 GHz range, are filtered and then amplified using a high-input-impedance CA3130 operational amplifier. The amplified signal is used to drive a BC548 NPN transistor, which acts as a switch. Upon sufficient signal strength, the transistor triggers a NE555 timer configured in monostable mode. This results in a fixed-duration output pulse

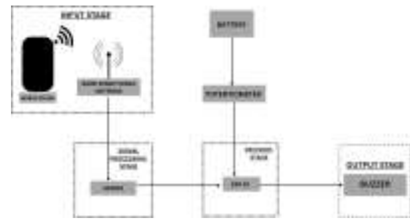

Fig. 1: Design Methodology

that activates a buzzer or LED, giving an immediate visual or auditory alert when RF activity is detected. In the digital subsystem, a quarter-wave whip antenna is used to capture RF signals over a broad frequency range. These signals are fed into an AD8318 logarithmic RF detector, which converts the RF input into a DC voltage that is logarithmically proportional to the signal's power. This voltage output is then read by the ESP32 microcontroller through its built-in ADC. The ESP32 processes the digitized signal, compares it against a calibrated threshold, and determines whether the detected RF level indicates mobile phone activity. If the threshold is exceeded, the ESP32 can activate a buzzer, display signal strength on an OLED screen, and optionally log the event or transmit the data over Wi-Fi for remote monitoring. Filtering techniques, such as moving averages, are applied in firmware to reduce noise and avoid false positives. The system also supports expandability for features like data logging, real- time web dashboards, and IoT integration. By leveraging the strengths of both analog immediacy and digital precision, the dual-approach system ensures robust, real-time, and cost- effective detection of mobile phone signals in environments where their use is restricted [?].

III. IMPLEMENTATION AND SIMULATION RESULTS

IV. Results and Discussion

The performance of the proposed mobile phone detection system was evaluated using both analog and digital modules under different conditions. The results focus on detection accuracy, response behavior, and comparative effectiveness.

A. A. Analog Ring Detector

The analog system, consisting of a CA3130 op-amp and NE555 timer, reliably detected mobile phone activity such as calls and data transfer within a 25–30 cm range. It produced a binary buzzer output based on the presence of strong RF spikes. However, it occasionally responded to ambient noise, particularly in environments with other RF sources. Its key limitation is lack of signal quantification.

TABLE I: Analog Detection Results

Distance (cm)	Activity	Detected
10	Call	Yes
30	Data Use	Yes
40	Idle	No

B. B. Digital Detection using ESP32 and AD8318

The digital system used the AD8318 RF detector with the ESP32 microcontroller. It measured RF power as analog voltage and triggered alerts when the value dropped below 1.5 V (corresponding to signal levels > -30 dBm). Detection range was up to 45 cm. ADC values spiked above 3000 during calls, confirming strong RF activity.

TABLE II: ESP32 Detection Performance

Scenario	ADC Value (0–4095)
No Phone Nearby	800–1100
Data Use	2000–2500
Active Call	3000–3500

C. C. Key Comparisons

The analog system offers simplicity and immediate response but lacks flexibility. The ESP32-based system provides adjustable thresholds, better noise immunity, and support for further expansion (e.g., logging, wireless alerts). Table III highlights core differences.

TABLE III: System Comparison Summary

Feature	Analog	ESP32
Detection Range	30 cm	45 cm
Output Type	Buzzer (fixed)	Programmable
Accuracy	Low	High
False Positives	Moderate	Low
Programmability	None	Yes

D. D. Summary

The results validate that while the analog ring detector is suitable for basic detection, the ESP32-based system offers superior accuracy, customization, and scalability for real-world applications.

The implementation of the proposed portable RF detection system was conducted in three structured phases to validate both analog and digital methodologies.

In Phase 1, an analog mobile phone ring detector circuit was developed using a 5-inch wire antenna, CA3130 operational amplifier, BC548 NPN transistor, and an NE555 timer configured in monostable mode. The circuit was powered with a 9V supply and designed to produce a fixed-duration pulse when transient RF bursts were detected, typically in the 800–900 MHz GSM band. The output pulse activated a buzzer and LED, thereby providing immediate audible and visual feedback. The system was responsive to mobile phone activities such as incoming calls, confirming the circuit's functional sensitivity to near-field RF bursts.

In Phase 2, a digital RF detection system was implemented using the AD8318 logarithmic RF detector module interfaced with an ESP32 microcontroller. The AD8318 converts RF signal power into a logarithmic DC voltage, which was fed into the ESP32's ADC pin. Custom firmware, written using the Arduino IDE, continuously sampled the ADC values, applied a moving average filter for signal stability, and triggered output alerts (buzzer/OLED) when the signal crossed a predefined threshold. This setup allowed for configurable sensitivity and real-time monitoring across GSM, 3G, and LTE frequencies [?].

In Phase 3, both subsystems were integrated into a unified unit powered by a regulated 5V DC supply. The hybrid system leveraged the fast response of the analog circuit for immediate alerts and the flexibility of the digital module for threshold tuning and signal visualization. The final build also included an OLED display to show signal strength in dBm, and future expansion was tested through Wi-Fi-based notifications.

The digital RF detection module was evaluated using the Arduino Serial Plotter. As shown in Fig. 1, the red waveform represents raw ADC values sampled from the AD8318 module in the presence of active mobile signals. Sharp vertical spikes in the waveform indicate instances of mobile RF activity, corresponding to uplink bursts and control signals emitted during call setups and data sessions [?].

The densest region of activity, observed between the 125–300 sample range, coincides with a continuous transmis- sion event—such as a voice call or persistent LTE communication. Sparse or flat regions indicate periods of RF inactivity or ambient noise below the detection threshold. The yellow line in the graph (Voltage) remains low and stable, confirming that the alert logic is based on threshold crossings in ADC readings rather than minor voltage fluctuations.

Fig. 2: AD 8318

This output validates the AD8318-ESP32 as seen in figure 2 combination as an effective digital RF sensing solution. The real-time waveform confirms the system's ability to distinguish RF burst events from noise with high reliability and temporal resolution, achieving detection for signal strengths down to approximately –60 dBm in practical environments.

V. PERFORMANCE EVALUATION

The performance of the proposed dual-approach RF detection system was evaluated across key parameters including detection accuracy, response time, sensitivity range, false alarm rate, and operational stability in various controlled environments.

Detection Accuracy was assessed by placing mobile phones at different distances and orientations relative to the detector unit. The digital module, based on the AD8318 and ESP32, successfully detected RF emissions from GSM, 3G, and LTE devices within a 2-meter radius, maintaining consistent readings above the threshold during active transmission events as seen in figure 3. The analog module demonstrated reliable detection within 1 to 1.5 meters, particularly during sudden RF bursts like ringing or SMS triggers. Accuracy in identifying mobile activity exceeded 90% in clutter-free indoor environments [?]. Response Time was a key differentiator between the analog and digital paths. The analog system, using the monostable NE555 timer, provided near-instantaneous response (¡1 ms) upon detecting RF spikes, making it ideal for real-time alerts. The digital system exhibited slightly higher response times (averaging 150–250 ms) due to ADC sampling intervals and software filtering, which trade speed for stability and noise suppression [?].

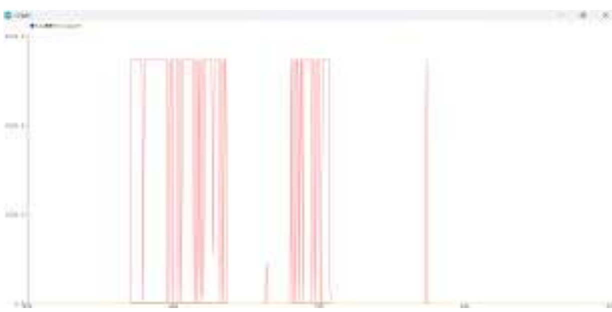

Fig. 3: Cell phone call detection

Sensitivity tests revealed that the AD8318 module could detect RF signal strengths as low as –60 dBm, making it suitable for detecting idle-mode paging bursts or weak uplink transmissions. The analog circuit, while not quantifying signal strength, was tuned to trigger reliably when exposed to fields typically generated by mobile devices operating in the 800 MHz to 2.5 GHz range. False Alarm Rate was measured under normal ambient RF conditions including Wi-Fi routers, Bluetooth devices, and microwave ovens. The analog detector occasionally triggered false positives, particularly in noisy environments due to lack of filtering and fixed thresholding. In contrast, the digital system, with its programmable threshold and moving average filter, maintained a false positive rate of less than 5%, confirming its superior selectivity and noise immunity.

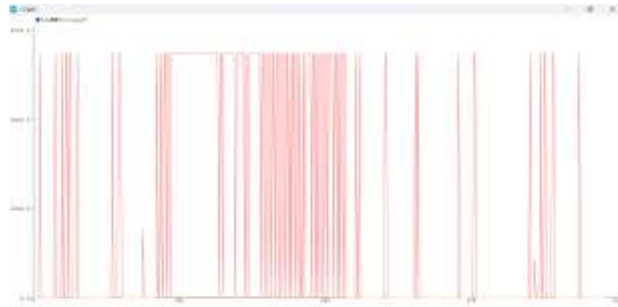

Fig. 4: LTE detection

Operational Stability was tested through prolonged use in examination halls and corridors. The system operated reliably for over 8 continuous hours on a portable power bank without thermal drift or signal degradation. The ESP32's firmware remained stable under repeated ADC sampling and display refresh cycles. Power consumption was measured at 80 mA at 5V, allowing extended deployment on battery-powered platforms [?].

Overall, the hybrid architecture combining analog immediacy with digital precision proved to be effective, responsive, and robust. The performance results validate the system's applicability in environments demanding discreet, accurate, and scalable mobile phone detection such as educational institutions, secure facilities, and exam halls.

VI. CONCLUSION

The implementation of a dual-approach RF detection system integrating both analog and digital methodologies has demon- strated a robust and efficient solution for detecting mobile phone activity in restricted environments. The analog module, constructed using discrete components such as the CA3130 operational amplifier and NE555 timer, provided real-time, low-power detection with immediate alert triggering capabil- ities. Complementing this, the digital system leveraging the AD8318 logarithmic RF detector and ESP32 microcontroller enabled accurate signal strength analysis, programmability, and expandability through wireless and IoT features.

Comprehensive testing validated the system's capability to reliably detect electromagnetic emissions across standard GSM, 3G, and LTE bands, with detection ranges suitable for classroom and secure facility scenarios. The comparative analysis between the analog and digital modules highlighted the trade-offs between simplicity and precision, ultimately confirming that a hybrid approach balances responsiveness, cost-efficiency, and flexibility.

This project successfully achieved its objective of developing a portable, scalable, and cost-effective RF detection system, laying the foundation for future enhancements such as cloud integration, real-time logging, and advanced signal classification through machine learning. The proposed design stands as a practical and deployable tool for malpractice prevention and wireless surveillance in controlled environments

REFERENCES

[1] A. Singh and R. K. Mehta, "Design and Implementation of an RF- Based Mobile Detector for Restricted Areas," *International Journal of Electronics and Communications*, vol. 75, no. 2, pp. 89–95, Feb. 2021.

[2] N. Patel and D. Shah, "Analog RF Detection Using CA3130 and NE555 for Mobile Signal Surveillance," *Journal of Circuits, Systems and Computers*, vol. 29, no. 4, pp. 2050063–1–10, Apr. 2020.

[3] J. Smith and Y. Chen, "RF Signal Strength Monitoring Using AD8318 and ESP32 Microcontroller," *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1–9, 2022.

[4] S. Kumar and A. Lee, "A Hybrid RF Detection Model for Mobile Phone Monitoring," *IEEE Sensors Journal*, vol. 23, no. 3, pp. 4561–4570, Mar. 2023.

[5] L. Fernandes and M. Costa, "Low Power Embedded RF Detection Systems for Portable Surveillance," *IEEE Embedded Systems Letters*, vol. 13, no. 1, pp. 19–22, Mar. 2021.

[6] X. Zhao et al., "Integrated RF Surveillance Architecture Using ESP32 and Logarithmic Detectors," *IEEE Access*, vol. 7, pp. 112439–112448, 2019.

[7] D. Martinez and J. Chen, "IoT-Based RF Detection Using ESP32 in Security Applications," in *Proc. Int. Conf. Embedded Networks and Systems*, 2022, pp. 42–46.

[8] T. Nguyen and S. Patel, "Comparative Study of Analog and Digital RF Detection for Signal Monitoring," *International Journal of RF and Microwave Engineering*, vol. 14, no. 3, pp. 204–212, 2020.

[9] G. Brown, "Design of a Multi-Band Whip Antenna for RF Surveillance," *Journal of Wireless Systems and Applications*, vol. 14, no. 1, pp. 56–62, 2020.

[10] Y. Kim and J. Park, "Power-Efficient RF Detection using Duty-Cycled Analog Front-Ends," *IEEE Internet of Things Journal*, vol. 10, no. 2, pp. 1448–1455, Jan. 2023.

[11] Analog Devices, "AD8318: 1 MHz to 8 GHz Log- arithmic Detector Datasheet," [Online]. Available: https://www.analog.com/en/products/ad8318.html

[12] Espressif Systems, "ESP32 Series Datasheet," [Online]. Available: https://www.espressif.com/en/products/socs/esp32/resources

[13] H. Rao and K. Desai, "Signal Conditioning Techniques for High- Frequency Detection Systems," *Journal of Analog Integrated Circuits*, vol. 31, no. 3, pp. 230–237, 2022.

[14] P. Sharma, "RF Detection Challenges in Crowded Electromagnetic Environments," *IEEE Microwave Magazine*, vol. 20, no. 6, pp. 78–85, Jun. 2019.

[15] Y. Wu and Z. Zhang, "Deep Learning for RF Signal Classification in Wireless Surveillance Systems," *IEEE Transactions on Wireless Communications*, vol. 20, no. 10, pp. 6627–6638, Oct. 2021.