Proceedings of the 5th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/124/2025.20043

Analysis of the Application of Automation in Smart Industry

Shichen Ruan[1,a,*]

[1]*Beijing Xinfu International Academy, Beijing, 101300, China*
a. dl2806138009@gmail.com
**corresponding author*

Abstract: This paper explores the roles of passive and active devices in intelligent industrial automation. The study proposes a model for converting the volume energy density of passive components to the mass energy density and describes the use of highly miniaturized on-chip passive devices using coplanar waveguide structures. Additionally, the paper discusses the application of low-profile Ku-band active phased array antennas for automation communication systems, which achieve optimum volume, weight, and power consumption. In general, this paper discusses the key role of passive and active devices in advancing intelligent industrial automation through the method of literature review. The research results show that the miniaturization of passive components and the versatility of active devices lay the foundation for the development of more compact, efficient, and powerful automation systems, and promote the continued development of intelligent industries.

Keywords: Automation, smart industry, active device, passive device.

1. Introduction

Nowadays, with the high progress of technology, a new version of industrial form has been introduced -- smart industry. Specifically, the smart industry is usually regarded as a new industrial system of physical equipment, computer networks, and human brain wisdom integrating with each other to construct a trinity [1].

Initially, the first industrial revolution of physical equipment improved production efficiency to a considerable degree relatively, which achieved the combination of physical equipment and the human brain [2]. Regarding the second industrial revolution, when the productivity of physical equipment is further improved so that the integration of the two is more efficient. Consequently, automated production mode is beginning to take shape [3]. Finally, due to the Internet, the popularization of artificial intelligence has triggered the third industrial revolution, which has successfully combined the three to form a production method known as smart industry [4]. This essay will introduce two particular devices that will promote intelligent production in many fields, there are active devices and passive devices. Devices that require energy sources are called active devices, and devices that do not require energy sources are passive devices. Active devices are generally used for signal amplification, conversion, etc., and passive devices are used for signal transmission, or "signal amplification" through directionality [5].

Currently, the experiments of the two types of devices used in smart industrialization are mainly focus on minimizing their size and being allocated more compact. In doing so, the cost and space during the smart industrial process will not be a pressure. An article entitled "Capacitors and Resistors

© 2025 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/124/2025.20043

Attain Enhanced Performance" Manufacturers of passive components persist in providing higher performance goods in more compact package sizes, asserting that miniaturization is the sole constant in the passive component business. This movement spans various industries, including consumer electronics, wearables, automotive, and industrial sectors.[6]. Another area that is developing rapidly and is ready to be used in the smart industry is the use of active and passive components in communicative systems. 5G - Active Antenna Applications illustrates that active antenna can be projected in order to present a high directivity either, allowing the operation in a wider bandwidth.

This article aims to convey that through the application of active and passive components in smart industry, various serious problems that have plagued the industry for many years will be largely alleviated, by reducing the cost and the space in smart industry.

2. Alleviating the size of passive device in automation

As mentioned before, that minimizing the size and volume of passive devices is really necessary when it comes to automation.

2.1. Alleviating the size of passive device in air industries

In one situation, the idea mainly originated from the increasing calls for electrification for transportation (e.g., electric vehicles, hybrids, or electric aircraft). Therefore, the need for systematic guidelines that gauge passive component-specific energy density for weight-optimized converter design has become apparent. However, there is currently a lack of quality data on passive components (which usually make up the majority of the weight of the converter) and the corresponding modeling process. Researchers tend to point out that passive components (capacitors and inductors) usually account for most of the weight of the converter, and thus their mass and energy density need to be systematically evaluated.

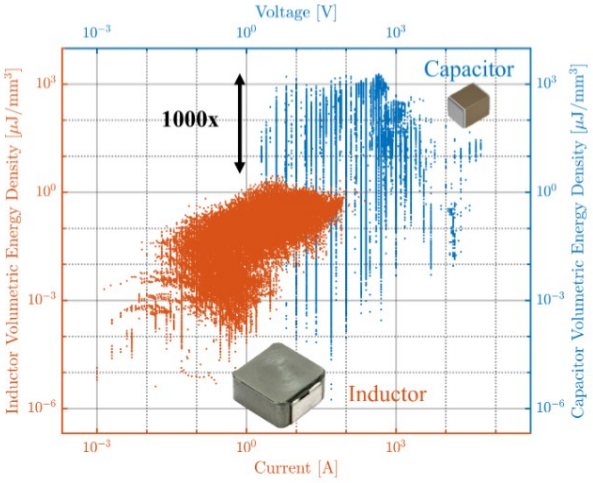

Figure 1: A comprehensive survey on 2 different capacitors

As shown in Figure 1, according to several experiments done, researchers conducted a comprehensive survey of more than 500,000 commercial passive components and found that the peak volume energy density of capacitors can be nearly 1,000 times higher than that of inductors.

This provides theoretical evidence for the design of topologies by using a large number of capacitors as energy transmission components, such as flying capacitor multilevel converters.

In that case, the priority is to alleviate the size of the capacitor. Therefore, an empirical model based on component technology, rated voltage and rated capacitance is proposed to convert the

DOI: 10.54254/2755-2721/124/2025.20043

volume energy density of a component into mass energy density. While calculating the volumetric energy density of a passive component is relatively easy because the component dimensions are usually given in the data book, designing lightweight converters is made more difficult by the lack of quality data.

To this end, scientists propose an empirical model for the conversion from volume energy density to mass energy density of passive elements. The model is based on the type of technology of the component (such as ceramic, aluminum electrolysis, etc.), rated voltage and rated capacitance, and the mass of the component is estimated by an empirically specific gravity model.

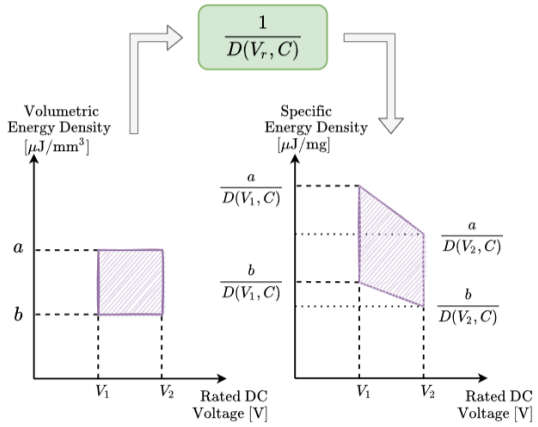

Figure 2: The graph of volumetric energy density relating to the rated DC voltage

This model can help designers better optimize the design of lightweight converters.

After conversion, the mass energy density of the capacitor is more obvious than the volume energy density difference, up to 10,000 times. Aluminum electrolytic capacitors have the highest mass energy density at low pressure, but may be less suitable as flight capacitors in terms of other factors such as ESR, frequency range, RMS current, etc.

As an example, the proposed mass energy density estimation model is applied to the design of a 10-level flying capacitor multilevel converter and the accuracy of the model is verified. The results show that capacitors with different technologies have different advantages under different voltages, and designers need to choose according to specific application conditions.

The experimental results show that the prediction error of the proposed mass energy density estimation model is less than 20%, and the prediction error of the power fitting model is further reduced to less than 10%. This provides a reliable reference for designers to optimize the design of lightweight converters. Consequently, this model not only provides a basis for minimizing the size of passive devices but also offers various methods for scientists to select the optimum solution [7].

2.2. Alleviating the size of passive device in COMS structures

Another situation illustrates the fact that alleviating the size of a passive component is useful in terms of silicon COMS devices.

With the development of silicon CMOS device process technology, the demand for integrated CMOS RFIC is increasing, but traditional wireless communication passive devices cannot be integrated into RFIC due to their large size.

To solve this problem, a highly miniaturized on-chip passive device is developed by using a coplanar waveguide with a periodic grounding structure (PAGS).

DOI: 10.54254/2755-2721/124/2025.20043

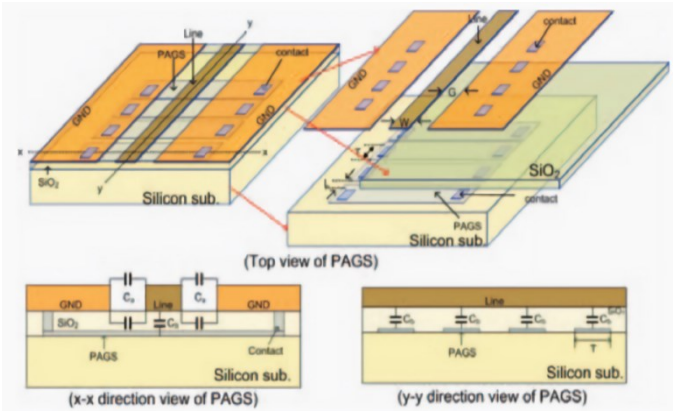

Figure 3: Structure of coplanar waveguide employing PAGS.

The PAGS structure can produce slow-wave characteristics, which shorten the wavelength of coplanar waveguides to 60-65% of that of traditional waveguides. This is due to the PAGS structure adding additional capacitance, which reduces the characteristic impedance and guiding wavelength.

By using the PAGS structure, three highly miniaturized passive devices were developed: multi-stage transformers, 90° hybrid couplers, and ring hybrid couplers. These passive devices maintain good RF performance while being small in size.

A three-stage transformer made with PAGS structure, with a size of only 8.7% of traditional designs. The transformer exhibits good return loss and insertion loss characteristics in the 8-49.5 GHz frequency range.

A 90° hybrid coupler made with a PAGS structure, with a size of only 37% of traditional designs. The coupler exhibits good power and phase distribution characteristics in the 41.75-50 GHz frequency range.

A ring hybrid coupler made with PAGS structure, with a size of only 19.3% of traditional designs. The coupler exhibits good power and phase distribution characteristics in the 37-55 GHz frequency range.

Conclusive speaking, this paper proposes a coplanar waveguide using PAGS structure, and successfully develops a series of highly miniaturized on-chip passive devices that maintain good RF performance while greatly reducing the size, providing a promising solution for integrating CMOS RFIC.

For summarizing, the major application of passive devices in the automation is to alleviate and allocate its size so that more spaces can be allowed [6].

3. The role of active device in communication

Moving on to the application of active devices in automation, researchers are mainly focusing on its impacts on cutting-edge technology relating to communication.

In an essay, A Ku-band low profile active phased array antenna for mobile satellite communication system (SOTM) is introduced.

The antenna has the function of polarization tracking and wide Angle beam tracking, which solves the problems of polarization matching and transmitting and receiving isolation of the SOTM antenna.

The invention relates to an electron adaptive polarization tracking method, which realizes the acquisition of arbitrary linear polarization by adjusting the phase difference. This method can realize the electronic control of beam direction and polarization direction simultaneously. Assume the receiving signal for the antenna is $E0\cos\omega t$ and polarization orientation is θ. So, the signals from ports H and V are EH and EV respectively. EH and EV are depicted as follows:

DOI: 10.54254/2755-2721/124/2025.20043

$$E_H = E_0 \sin\theta \cos\omega t$$
$$E_V = E_0 \cos\theta \cos\omega t$$

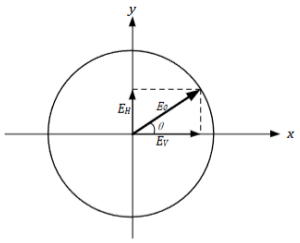

Figure 4: The generation of arbitrary linear polarization

Regarding Active phased array Antenna Design, Using the doubly fed microstrip antenna element, the broadband characteristic is realized by electromagnetic coupling. The triangular array layout can effectively suppress the antenna sidelobe level. The channel structure is used to improve the isolation between the transmitting and receiving antennas.

On top of that. Integration is enhanced with integrated multi-function chips including Lange couplers, low noise amplifiers or power amplifiers, 6-phase shifters and power mergers.

This design can reduce the size, weight and power consumption, and has many advantages over traditional antennas. Similarly, active devices can also be more effective by minimizing their size.

At the end of the article, the author processed an experiment to justify his conclusion. The test results show that the antenna can achieve ±60° wide Angle beam scanning and has excellent performance in polarization tracking and wide-Angle beam tracking.

There is sufficient isolation between the sending and receiving antennas to ensure that the performance of the receiving antennas does not deteriorate.

In summary, this paper presents a new type of Ku-band low-profile active phased array antenna, which has the functions of polarization tracking and wide-angle beam tracking, solves the key technical problems of SOTM antenna, realizes the optimization of volume, weight and power consumption through integrated design, and has a good application prospect [8].

The pivotal product generated from the third industrial revolution is the 5G, which is a new generation of broadband mobile communication technology with the characteristics of high speed, low delay and large connection. 5G communication facilities are the network infrastructure to realize the interconnection of man and machine [9].

To demonstrate the application of active devices in 5G automation, another essay illustrates the information about a kind of system that consists of three parts: active controller, active switch integrated circuit and active antenna. The active antenna consists of a configurable electromagnetic radiation element and an active switch integrated circuit. By switching between different capacitors, inductors and antenna components, the active antenna can provide more than 4 different radiation modes

There is an experiment used in this article. Live demonstration based on 802.11ac Wi-Fi. The demonstration took place in a 3,200-square-foot, two-story test house. The active directional antenna system is applied to the client device and compared with the traditional passive antenna. The results show that in the case of non-line-of-sight transmission and weak signal, the active directional antenna system can bring a throughput improvement of 16-41%

DOI: 10.54254/2755-2721/124/2025.20043

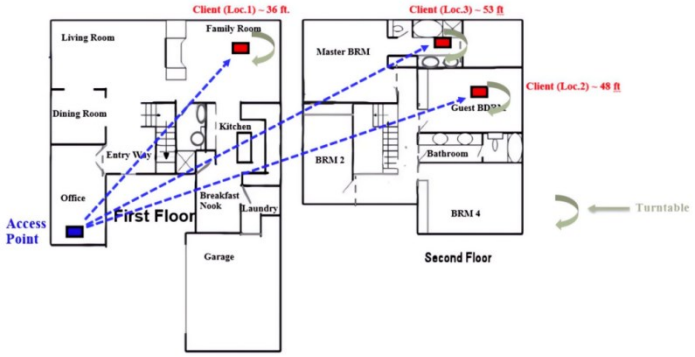

Figure 5: 3200 ft 2/ ~ 300 m 2 Wi-Fi test house floor plan.

Another application is that the system can be applied to low-power wireless technologies such as the Internet of Things (IoT) to reduce the possibility of link failure by improving the strength of the received signal. The system can also be applied to 5G millimeter wave systems to optimize transmission and reception by adjusting antenna beams and spatial patterns.

To sum up this essay, the active directional antenna system can adaptively adjust the antenna radiation mode to obtain the best wireless signal. The system can significantly improve Wi-Fi throughput in high multipath, non-line-of-sight environments and in weak signal situations. The mode and polarization diversity of the system can result in a coverage gain of 2-3 dB, enabling higher modulation coding schemes [10].

4. Discussion

However, Prior research in this field has significant limitations. Experiments have been short-term and overly complex, making it hard to isolate key mechanisms. Sample sizes have been small, undermining statistical power and generalizability. Most studies have been preliminary, lacking thorough validation and replication. Addressing these methodological shortcomings is essential for advancing knowledge and developing more effective strategies for smart industry automation. Rigorous, long-term experiments with larger, more representative samples are needed to test proposed theories and models in a robust manner. Only then can the field make meaningful progress in understanding this important phenomenon.

5. Conclusion

This paper examines the role of active and passive devices in advancing automation in the smart industry.

The research first discusses the need to minimize the size and volume of passive devices, such as capacitors and inductors, to enable more compact and cost-effective automation systems. An empirical model is proposed to convert the volumetric energy density of passive components into mass energy density, allowing designers to better optimize the design of lightweight converters. This model has been applied to the design of a 10-level flying capacitor multilevel converter, demonstrating its reliability. Additionally, the development of highly miniaturized on-chip passive devices using coplanar waveguide structures with periodic grounding is presented as a promising solution for integrating passive components into CMOS RFICs.

The paper then explores the application of active devices, particularly in communication systems for automation. A Ku-band low-profile active phased array antenna is introduced, which can achieve

DOI: 10.54254/2755-2721/124/2025.20043

polarization tracking and wide-angle beam tracking, solving key technical challenges for satellite-on-the-move (SOTM) antennas. The integrated design of this antenna reduces size, weight, and power consumption. Furthermore, the use of active directional antenna systems in 5G automation is discussed, demonstrating their ability to adaptively adjust antenna radiation modes to improve wireless signal strength and throughput, especially in non-line-of-sight and weak signal environments.

Finally, although this paper mentioned that there are still some limitations on the application of active and passive components, I think these limitations can be made up. From my perspective, I will make more efforts to reduce the size of passive and active components in the future. More precise studies and larger sample sizes of experiments allow them to be used on a wide scale in smart industries.

References

[1] *Aleksic, S. (2019). A Survey on Optical Technologies for IoT, Smart Industry, and Smart Infrastructures. Journal of Sensor and Actuator Networks, 8(3), 47. https://doi.org/10.3390/jsan8030047*

[2] *Julian Hoppit, "The Nation, the State, and the First Industrial Revolution, " Journal of British Studies (April 2011) 50#2 pp. 307–31*

[3] *Atkeson, Andrew and Patrick J. Kehoe. "Modeling the Transition to a New Economy: Lessons from Two Technological Revolutions, " American Economic Review, March 2007, Vol. 97 Issue 1, pp 64–88 in EBSCO*

[4] *The Fourth Industrial Revolution: what it means and how to respond. World Economic Forum. [2018-03-20].*

[5] *The difference between the active and passive components _ the difference between passive and active components-CSDN blog. (property-and hit large reserves). https://blog.csdn.net/pxy198831/article/details/90047831*

[6] *A Development of Highly Miniaturized On-Chip Passive Components Employing Periodically Arrayed Ground Structure for Application to Radio Frequency Integrated Circuit (RFIC). (n.d.).*

[7] *Zou, J., Brooks, N. C., Coday, S., Ellis, N. M., & Pilawa-Podgurski, R. C. (2022). On the Size and Weight of Passive Components: Scaling Trends for High-Density Power Converter Designs. https://doi.org/10.1109/compel53829.2022.9829957*

[8] *Xue, X., Shi, H., Jiang, T., Han, Y., & Zhi, G. (2022). Design of a Low-Profile Polarization.Tracking Active Phased Array Antenna for Satcom On the Move. 2022 IEEE 6th Information Technology and Mechatronics Engineering Conference (ITOEC). https://doi.org/10.1109/itoec53115.2022.9734657*

[9] *Ministry of Education. The 14th batch of recommended Chinese translations of foreign words [OL] (2023-03-18). Chinese Language and Character Network*

[10] *multi-RAT multi-connectivity active steering antenna technology for IoT, Wi-Fi, LTE, and 5G (2020). In IEEE RWS 2020.*