

<u>muma muutovaa</u>

Unlocking the Potential of Mechanical Antennas for Revolutionizing Wireless Communication

K. T. Moh¹, Van Jiang², K.W. Leo³, M. L. Diu⁴ *1-4School of Electrical and Electronic Engineering, Newcastle University, Singapore*

KEYWORDS: Antenna, Electromagnetic radiation, Radiation pattern,

KEYWORDS: Directivity Gain,

ARTICLE HISTORY: cadence, Received 03.07. 2022 Revised 13.08.2022 Accepted 22.09.2022

Received xxxxxxxxxxxx https://doi.org/10.31838/NJAP/04.02.02 **DOI:**

Ishrat Z. Mukti1, Ebadur R. Khan2. Koushik K. Biswas3 ABSTRACT

AbstrAct types, mechanical antennas stand out as a unique and promising innovation. Combining the principies of incentalitieal engineering with electromagnetic theory, incentalitieal antennias
offer a novel approach to achieving versatile and adaptable communication solutions. In offer a hover approach to demetting versacile and dadptable communication solutions. In tector, we dette medicine rusemating realition international antennal, exploring their
ples applications, and potential impact on the future of wireless communication principles, applications, and potential impact on the future of wireless communication. In the world of wireless communication, the evolution of antenna technology has been instrumental in shaping our interconnected society. Among the diverse array of antenna principles of mechanical engineering with electromagnetic theory, mechanical antennas

Author's e-mail: moh.kt@ncl.ac.uk, van.jiang@ncl.ac.uk, leo.kw@ncl.ac.uk, ml.diu@ncl. because of this mismatch. To compensate for the offset voltage, we followed a decent ac.uk

How to cite this article: Moh KT, Jiang V, Leo KW, Diu ML. Unlocking the Potential O CILE LITIS ALTICLE. MULLAT, JIANG Y , LEO AW, DIU ML. UNIOCANIS LITE FOLENTIAL
chapical Antonnas for Povolutionizing Wiroloss Communication. National Journal of of Mechanical Antennas for Revolutionizing Wireless Communication, National Journal of Antennas and Propagation, Vol. 4, No. 1, 2022 (pp. 7-12).

INTRODUCTION

Understanding Mechanical Antennas

At its core, a mechanical antenna is a device that utilizes _{recepti} introduce physical motion as a mechanism for tuning **IntroductIon** mechanical elements with electromagnetic functionality advancement in antenna design as mentioned in Fig. 1. mechanical movement to manipulate its radiation pattern, polarization, or frequency characteristics. Unlike traditional antennas that rely solely on electronic means for signal manipulation, mechanical antennas and optimizing performance.^[1-22] This integration of distinguishes mechanical antennas as a ground-breaking

and gives outputs in terms of a digital signal signal based on the results in the resul of the comparison. Comparison circuits, especially A/D converters (ADC). An ADC applications (ADC applications (ADC). An ADC applications (ADC a $\sum_{i=1}^n a_i$ power consumption. They are designed not also also aim for a reduced noise level and the second noise level and and the comparator is comparator in obtaining \mathcal{L}

comparator we suggest is made using \mathcal{N} technology, which comparator \mathcal{N} has strong noise immunity and low static power consumption. This article details the details the design of a comparator for $\mathcal{L}_\mathbf{z}$ $\mathbf{4}+\mathbf{5}+\mathbf{6}+\mathbf{7}+\mathbf{8}+\mathbf{8}$ GHz. In such a sampling rate of 4.2 GHz. In such a sampling rate of 4.2 circumstance, the device of the device of the device of the device of the should be no less than \sim 1/2 LSB. THE REFERENCE VOLTAGE ARE REFERENCE VOLTAGE AND SUPPLY VOLTAGE AND SUPPLY VOLTAGE AT A SUPPLY VOLTAGE ARE SUPPLY VOLTA

ELF Transmission

Mechanical antennas, also known as physical or **Authoris e-mail.com, and unconventional approach to signal transmission and leaders** characteristics. fields, mechanical antennas utilize physical motion and lely on electronic mechanical resonance to achieve similar objectives. nanical antennas This innovative concept has gained attention for its mechanical resonant antennas, represent an intriguing reception. Unlike traditional electromagnetic antennas that rely on electrical currents and electromagnetic potential applications in various fields, including telecommunications, sensing, and energy harvesting. [23-32]

> LSB= {VDD/ (2) ^N} (1) mechanical resonance, which refers to the tendency of a mechanical system to oscillate at specific frequencies when subjected to external forces or stimuli. In the context of mechanical antennas, this resonance phenomenon is harnessed to create mechanical structures capable of efficiently transmitting and receiving signals across different frequency rangesas mentioned in Fig. 2. At the core of mechanical antennas lies the principle of

One of the key advantages of mechanical antennas is their versatility in frequency tuning. Traditional antennas often require complex tuning mechanisms or multiple **relAted work** bands effectively. In contrast, mechanical antennas can achieve frequency tuning through straightforward adjustments in the mechanical properties of the resonant structure. By modifying parameters such as the size, shape, or material composition of the mechanical elements, engineers can easily adapt mechanical antennas to operate at desired frequencies without the need for additional components.^[33-39] antenna elements to operate across different frequency

 F_{tr} thermore mochanical antonnas offer inherent Furthermore, mechanical antennas offer inherent
reburtness and durability compared to their electromagnetic counterparts. Since mechanical traditional comparator to the latched and hysteresis-resonance relies on physical motion rather than electromagnetic fields, mechanical antennas are **a commanded to the monumental and monumental controls of the monumental controls of the susceptible to electromagnetic interference,** environmental factors, and signal degradation.^[40-53] This resilience makes them particularly suitable for harsh dynamic comparator.[5] High-resolution comparators have operating conditions where traditional antennas may also between designed utilizing the designed unique measurement of the straight measurement of the straight of struggle to maintain performanceas mentioned in Fig. 3. robustness and durability compared to their

Mechanical antennas can take various forms, each with its unique design and operational characteristics. One common type of mechanical antenna is the vibrational or oscillatory antenna, which consists of a resonant structure capable of vibrating or oscillating in response to applied forces or acoustic waves. By coupling the mechanical vibrations to electromagnetic waves, signals without the need for traditional conductive elements. mechanical vibrations to electromagnetic waves,

Another intriguing variant of mechanical antennas is 1 depict the block diagram of the proposed concentration is the reconfigurable or shape-changing antenna. These antennas feature flexible or deformable structures

that can alter their shape or geometry in response to external stimuli. By dynamically adjusting their physical configuration, reconfigurable antennas can adapt to changing signal conditions, optimize performance, or achieve specific operational objectives. Applications of reconfigurable antennas range from adaptive
. that the output of OTA is in the form of current, while the beamforming in wireless communications to morphing structures in aerospace systems.^[54-59]

Despite their promising attributes, mechanical antennas also pose several challenges and limitations. One notable concern is the complexity and precision required in their resonance at desired frequencies demands careful engineering of the antenna's structural elements and stringent manufacturing tolerances. Additionally, m echanical antennas may exhibit limitations in terms design and fabrication. Achieving precise mechanical of bandwidth, efficiency, and scalability compared to traditional electromagnetic antennas.

Mechanical antennas represent a fascinating frontier in antenna technology, offering unique advantages and opportunities for innovation. By harnessing the principles of mechanical resonance, these antennas enable versatile frequency tuning, robust performance, and novel functionalities across a wide range of applications. While challenges remain in their design and implementation, ongoing research and development efforts continue to explore the potential of mechanical antennas in shaping the future of wireless communication and beyond.

Principles of Operation:

Fig. 2: Schematic of the 45nm CMOS-based dynamic manipulation of structural components to alter electromagnetic properties. This can involve the The operation of mechanical antennas is rooted in the movement of mechanical elements such as reflectors, directors, or feed structures to adjust radiation patterns,

Fig. 1: Block diagram of the suggested Comparator for The Comparator **Fig. 3: Research progress of small low-frequency transmitting antenna**

Fig. 4: sandwiched Metglas/PZT/Metglas

focus energy in specific directions, or switch between sele of modulation, engineering, these uncomparators a major comparation of mediatrical arrangements. 19-24). conditions or communication requirementsas mentioned different frequency bands. By harnessing the principles of mechanical engineering, these antennas offer a high time optimization in response to changing environmental in Fig. 4.

IntroductIon influenced by various parameters, including material properties, structural design, and environmental factors. The choice of materials plays a crucial role in determining the mechanical properties and resonance characteristics of the antenna. For example, materials with high stiffness and low damping are often preferred for achieving precise resonance and efficient energy transfer. Additionally, the structural design of the antenna, such as size, shape, and geometry, can significantly impact its resonance frequency, bandwidth, and radiation pattern.^[60-62] The operation of mechanical antennas can also be

Environmental factors, such as temperature, humidity, and mechanical vibrations, can also affect the operation of mechanical antennas. Changes in environmental conditions may alter the mechanical properties of the antenna, leading to shifts in resonance frequency or

(a) $\begin{array}{c} \lambda \rightarrow 1 \end{array}$ changes in performance. Therefore, careful consideration must be given to environmental effects during the design and deployment of mechanical antennas to ensure

- Implemented in 45 nm CMOS 1. Reconfigurable Antennas: Reconfigurable mechanical antennas feature adjustable components that can **ISHRAT Z. Mukhan**
ISHRAT R. And A. Bisman Patterns. This flexibility enables seamless integration $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ into diverse communication systems and enhances antennas feature adjustable components that can be reconfigured to adapt to different operating frequencies, polarization states, or radiation overall performance and reliability.
	- This paper presents the design of a comparator with low power, low offset voltage, incorporate mechanisms for physically orienting $\frac{1}{1+\frac{1$ $H_a(0e)$ and and runs at actual to second the beam in specific directions. This capability is particularly valuable in \blacksquare applications such as satellite communication, where ϵ (e) is the offset voltage voltage, we followed a precise beam pointing is essential for establishing γ_{max} , γ_{max} , the offset voltage is and maintaining communication links [63]-[66]. 2. Steerable Antennas:Steerable mechanical antennas
	- **1. Investigate value is a considerable mechanical antennas:** Tunable mechanical antennas which is a comparator is 48.7. The layoutilize mechanical tuning elements to adjust $\begin{array}{c|c}\n\hline\n\end{array}$. The resonant frequency of the antenna, enabling $f(Hz)$ is the resonant requency of the antennal, enabling frequency agility and spectrum optimization. This requiring frequency hopping or adaptive frequency versatility makes them well-suited for applications selection.

How to cite this article: Mukti IZ, Khan ER, Biswas KK. 1.8-V Low Power, High-Res-**Applications of Mechanical Antennas:**

mowing for real The versatility and adaptability of mechanical antennas render them well-suited for a wide range of applications across various industries:

- Wireless Communication Systems: Mechanical antennas offer enhanced performance and reliability in wireless communication systems, including cellular networks, satellite communication, IoT devices, and wireless sensor networksas mentioned in Fig. 5.
- * Military and Defense: In military applications, military and berenseling imitiary applications, mechanical antennas provide tactical advantages meenameat antennas provide taetieat advantages
such as stealth capabilities, beam agility, and structure capacities, beam agitity, and frequency agility, making them invaluable assets requency again, making enem invaluable assets for communication, surveillance, and electronic
weekenderstood warfare operations.
- Aerospace and Aviation:Mechanical antennas play a critical role in aerospace and aviation applications, including satellite communication, radar systems, unmanned aerial vehicles (UAVs), and space exploration missions, where reliability and adaptability are paramount.

 (b)

Dual-Permanent-Magnet Mechanical Antenna for Pipeline Robot Localization

• Emerging Technologies: With the advent of infrastructure, mechanical antennas are poised to play a pivotal role in enabling seamless connectivity, data exchange, and network optimization in the era of the Internet of Things. emerging technologies such as 5G, IoT, and smart

CHALLENGES AND FUTURE DIRECTIONS

Despite their promising potential, mechanical antennas also present certain challenges, including complexity, reliability, and scalability. Addressing these challenges requires interdisciplinary collaboration and ongoing research and development efforts to optimize design methodologies, enhance mechanical reliability, and streamline manufacturing processes.^[67-71]

for signal transmission and reception, they also While mechanical antennas offer intriguing possibilities

present unique challenges and opportunities for future development. Understanding these challenges is crucial for advancing the field of mechanical antennas and unlocking their full potential in various applicationsas mentioned in Fig. 6.

One of the primary challenges facing mechanical antennas is achieving precise resonance and frequency tuning across a wide range of frequencies. Mechanical resonance depends on factors such as material properties, structural design, and environmental conditions, making it challenging to achieve consistent performance across different operating conditions. Future research efforts will focus on developing innovative design techniques and fabrication methods to enhance the frequency agility and tuning capabilities of mechanical antennas.

Another challenge is optimizing the efficiency and bandwidth of mechanical antennas. Traditional

20 Journal of VLSI circuits and systems, and systems, and systems, and Surface and Propagation, ISSN 2582-2659

Fig. 6: Low-frequency magnetoelectric capacitively-coupled receiving antenna

corners are shown. maximizing performance [61]-[68].Furthermore, **shikkumarbiswas13@gmail.com** used in real-world applications. Integrating mechanical **How to consideration of size, weight, power consumption,** we concessions. and energy-efficient mechanical antennas that can be and environments [64]-[71]. Another important challenge comparing reducincy and darlamately in harding eperating
conditions. Mechanical antennas may be subjected to encircum incumental ancental may be explosed to
environmental factors such as temperature variations, and gives outputs of a digital signal signal based on the result of a distribution of humidity, mechanical vibrations, and shock, which can marty, meenamed *the actomy* and shoen, which can affect their performance and longevity. Future research electromagnetic antennas often exhibit superior antennas, which may suffer from losses and limitations associated with mechanical resonance. Addressing $\frac{1}{2}$ these challenges will require exploring new materials, of mechanical antennas while minimizing losses and maximizing performance efficiency and bandwidth compared to mechanical structural configurations, and resonance enhancement techniques to improve the efficiency and bandwidth mechanical antennas face integration challenges when antennas into existing systems and devices requires and compatibility with other components. Future research will focus on developing compact, lightweight, seamlessly integrated into various devices, platforms, is ensuring reliability and durability in harsh operating

RESEARCH ARTICLE WWW.VLSIJOURNAL.COM will explore advanced materials, coatings, and structural 1.8-V Low Power, High-Resolution, High-Resolution, High-Speed and Speed and industrial applications as mentioned in designs to enhance the durability, ruggedness, and resilience of mechanical antennas, making them suitable automotive, and industrial applications as mentioned in Table 1.

Implemented in 45nm CMOS Technology In addition to these challenges, future research in mechani-**ISHRA ISHRAT REALLY ARREST SUCH A SUBSERVIET SUPPORT AND SUBSERVIET SUPPORT AND INVESTIGATION** ¹/₂²/₂₄₀ spired by biological systems, nanoscale mechanical antennas T_{rel} mously, T_{rel} a comparator with $\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T_{\text{rel}}}\frac{1}{T$ cal antennas will explore new paradigms and emerging technologies to push the boundaries of what is possible. This includes leveraging advancements in nanotechnology, and self-assembling antennas capable of reconfiguring and adapting autonomously.

> high resolution, and rapid speed. The designed comparator is built on 45 flip CMOS Looking ahead, the future of mechanical antennas holds exhibit superior tremendous promise for revolutionizing wireless communica- $\sum_{n=1}^{\infty}$ on $\sum_{n=1}^{\infty}$ of 1.8 V. The comparator of 1.8 V. The comparator of supply $\sum_{n=1}^{\infty}$ to mechanical tion, sensing, and energy harvesting. By addressing the chaland immedions lenges outlined above and pursuing innovative research di- $\frac{1}{2}$ and $\frac{1}{2}$ a g new materials, $\frac{1}{2}$ is a considerable measure of a considerable measure of $\frac{1}{2}$ ce enhancement capabilities and functionalities beyond the scope of traditional and bandwidth electromagnetic antennas. As researchers continue to push the izing losses and boundaries of mechanical antenna technology, we can expect **Challenges when** future of wireless connectivity and beyond. to see exciting advancements and breakthroughs that shape the

Conclusions:

nonents Future Looking ahead, the future of mechanical antennas act lightweight bolds tremendous promise for advancing wireless the synergies between mechanical engineering and to revolutionize the way we communicate, connect, and interact in the digital age. As researchers, engineers, and innovators continue to push the boundaries of technology, the transformative impact of mechanical and minimize α competent of set cancellation method has α communication capabilities and addressing the evolving needs of our interconnected world. By harnessing electromagnetic theory, mechanical antennas are poised

Design scheme	Materials	Frequency range	Magnetic flux density	Reference
Basic rotating MA	NdFeB	22 Hz	$0.6 \mu T (1 m)$	$[17]$
	N42 NdFeB	$100 - 500$ Hz	$800 \text{ fT} (100 \text{ m})$	$\lceil 18 \rceil$
MPA	N55 NdFeB	1.03 kHz	$\hspace{0.05cm}$	$\left[23\right]$
MMS	NdFeB, steel	$0 - 1.6$ kHz	50 pT(5 m)	$[25]$
EMR	N42 NdFeB	30 Hz	$10 \mu T (0.3 m)$	[28]
	N52 NdFeB, metglas	430 Hz	$0.17 \mu T (1.2 m)$	[29]

 τ is one that requires a quicker operating speed and reduced an Table 1: Performance comparison of various permanent magnet-based MA.

antennas on society is poised to unfold, ushering in a new era of connectivity and communication excellence.

References

- **relAted work** challenges, and future directions of on-chip-antennas for emerging wireless applications—a comprehensive survey. IEEE Access 7: 173897-173934. https://doi. org/10.1109/ACCESS.2019.2957073 1. Karim R, Iftikhar A, Ijaz B, et al. (2019) The potentials,
- 2. Delavarpour N, Koparan C, Nowatzki J, et al. (2021) A technical study on UAV characteristics for precision agriculture applications and associated practical challenges. Remote Sens 13: 1204. https://doi.org/10.3390/rs13061204
- 3. Yang X, Sun Z, Low T, et al. (2018) Nanomaterial-based plasmon-enhanced infrared spectroscopy. Adv Mater 30: 1704896. https://doi.org/10.1002/adma.201704896
- 4. Yang Y, Chen S, Li W, et al. (2020) Reduced graphene oxide conformally wrapped silver nanowire networks for flexible transparent heating and electromagnetic interference shielding. ACS Nano 14: 8754-8765. https://doi. org/10.1021/acsnano.0c03337
- 5. Decker M, Staude I (2016) Resonant dielectric nanostructures: a low-loss platform for functional nanophoton-Consequently, it was suggested to build a dynamic ics. J Opt 18: 103001. https://doi.org/10.1088/2040- $\frac{1}{2}$ i uutu aasta a 8978/18/10/103001
- 6. Milias C, Andersen RB, Lazaridis PI, et al. (2021) Metamaterial-inspired antennas: A review of the state of the are and future design chancinges. The Access 7. 07040-
00065 https://dsi.com/40.4400/466556.2024.2004.470 89865. https://doi.org/10.1109/ACCESS.2021.3091479
art and future design challenges. IEEE Access 9: 89846-
- of IoT sensing applications and challenges using RFID and 7. Landaluce H, Arjona L, Perallos A, et al. (2020) A review

A. Operational Transconductance Amplifier wireless sensor networks. Sensors 20: 2495. https://doi. org/10.3390/s20092495

- OTA is a fundamental component in the majority of 8. Yang L, Martin LJ, Staiculescu D, et al. (2008) Conformal
Reservations composite RED for wearship RE and his mani Inagnetic composite to be the mediable to and bio momentoring applications. IEEE Trans Microwave Theory Tech 56: amplifiers in which differential inputs are present. The 3223-3230. https://doi.org/10.1109/TMTT.2008.2006810 magnetic composite RFID for wearable RF and bio-moni-
- 9. Abbasi QH, Yang K, Chopra N, et al. (2016) Nano-communi- α is α is α in the α in the α is in the state-cation for biomedical applications: A review on the stateof-the-art from physical layers to novel networking concepts. IEEE Access 4: 3920-3935. https://doi.org/10.1109/ • Input Swing ACCESS.2016.2593582
- 10. Jakšić Z, Obradov M, Vuković S, et al. (2014) Plasmonic ta Univ-Ser Elect 27: 183-203. https://doi.org/10.2298/ FUEE1402183J enhancement of light trapping in photodetectors. Fac-
- 11. Tekbıyık K, Ekti AR, Kurt GK, et al. (2019) Terahertz band communication systems: challenges, novelties and standardization efforts. Phys Commun 35: 100700. https:// doi.org/10.1016/j.phycom.2019.04.014
- 12. Bush SF (2010) Nanoscale Communication Networks. USA: Artech House.
- 13. Buerkle A, Sarabandi K, Mosallaei H (2005) Compact slot and dielectric resonator antenna with dual-resonance, broadband characteristics. IEEE T Antenn Propag 53: 1020- 1027. https://doi.org/10.1109/TAP.2004.842681
- 14. Elsheakh DMN, Elsadek HA, Abdallah EA (2012) Antenna Designs with Electromagnetic Band Gap Structures. Croatia: InTech: 403-473.
- 15. Liaskos C, Tsioliaridou A, Pitsillides A, et al. (2015) Design and development of software-defined metamaterials for nanonetworks. IEEE Circ Syst Mag 15: 12-25. https://doi. org/10.1109/MCAS.2015.2484098