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By Vibha Rajnag & Mrinal Sarvagya

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MULTIBANDANTENNASDESIGNTECHNIQUESFOR5GNETWORKSPRESENTANDFUTURERESEARCHDIRECTIONS

Multiband Antennas Design Techniques for 5G Networks: Present and Future Research Directions

Vibha Rajnag [α] & Mrinal Sarvagya [σ]

Abstract- With the development of wireless communication system has demanded compact wireless devices that allow more space to integrate the other electronics components. Advancement in technology creates challenges in implementing antenna for multiple RF band with a wide range of frequencies. With the advancement of optimization technique we can improve the antenna design as well as provide us the motivation of analyzing the existing studies in order to categorize and synthesize them in a meaningful manner. The objective of this paper contributes in two ways. First, it provides the research and development trends and novel approaches in design of multiband MIMO, smart reconfigurable and defected ground structure (DGS) antenna techniques for wireless system. Secondly, it highlights unique design issue reported in literature. The proposed paper aim is filling the gap in the literature and providing the researcher a useful reference.

Keywords: multiband MIMO, smart reconfigurable, integrated components, printed slots, fractals.

I. Introduction

The development of wireless communication technology such as computer, cellular technology, Person Area Network for remote regeneration and observing of surroundings information has demanded for antenna suitable to operate with dual or multiband characteristics in wireless communication devices. Broadband Antenna in wireless communication area has demanded the design of antennas that must operate effectively over a wide range of frequencies. Concurrently, Multiband antennas are required for mobile communication technology which operates in different frequency ranges. The design and development of antenna should be in the compact size in order to offer more space to integrate other electronics components for reduction of volume of the wireless communication system. The integration of broadband, Multiband antennas with frequency reconfigurability is based on P-I-N diode, Material, Optical switch, Mechanical movement based. This is the most challenging scenario for deploying the antenna for desired frequency. In addition, Use of defected ground structure, Use of Metamaterial with high quality factor for antenna miniaturization is required [1] [2].

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The new frequency band are require to cover some communication system with improved data rate as they need to operate on a new band multiband MIMO antennas are required. To overcome the global bandwidth shortage in today's wireless cellular networks, the fifth-generation (5G) communication system is expected to utilize millimeter-wave bands [3], which have a large amount of available spectrum. Several measurements have demonstrated the promise of orders of magnitude greater bandwidths combined with further gain via beam forming and spatial multiplexing from multi-element antenna arrays [4]. As a result, designing an optimal antenna for millimeter-wave beam forming could be an important step for realizing 5G wireless cellular networks. Although there are different beam forming techniques [6], so far, the active-phased array [7], [8] is the most popular beam forming technology. Consequently, millimeter-wave phased-array antennas have recently drawn increased attention.

The objective of this paper is to provide an idea of current research and development trends and novel approaches in the design and analysis of MIMO multiband, reconfigurable, defected ground structure and metamaterial antennas for 5G wireless applications. The purpose of this paper is to fill the research gap in the literature and providing the researcher to analyze the existing studies and future challenges.

a) Contributions

The design idea and methodology of various Multiband MIMO technology, reconfigurable and DGS antenna has been described operating at short range communication and multiband antenna covering different frequencies in one wireless device playing an important role to target low profile, small and multiple antennas.

- Overview of the current research trends and novel approaches used in design of multiband, frequency reconfigurable and DGS antennas is provided.
- The key ideas that will help researchers in identifying the research gaps present in the literature are presented.

To disentangle the idea of present and future research trends toward different wireless applications this paper is organized as follows. In section II the research domain and design approach for various wireless communications has been provided. Section III reviews the different literature based on their mechanism. Section IV highlights the conclusion with the future research suggestions to improve the design as well as results of the antenna.

II. Antenna Design Techniques

a) *Multiband MIMO Antenna*

Due to requirement of multiband antenna to cover number of applications for wireless system in less space the multiband MIMO Antenna Technology demand is getting increased for current 4G and future 5G. To design the antenna is not the easy task, but always special modification or shape combination should be implemented or proper optimization is required to get the multiband frequency range. 5G network will highly depend upon MIMO systems as it demands limited space as well as less cost. To meet all these requirement multiband MIMO antennas can be obtained by these methods.

i. *Insertion of Parasitic elements*

Parasitic elements can be used to enable virtual rotation of the antenna. The insertion of parasitic elements in MIMO array antenna will reduce the mutual coupling. The parasitic element is placed at distance λ/64 to the active element to avoid power loss. We have possibility to keep short circuited/open circuited parasitic elements shown in the figure1.

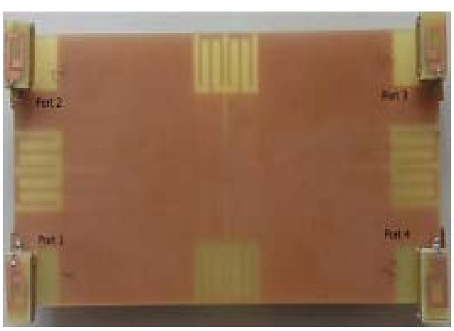
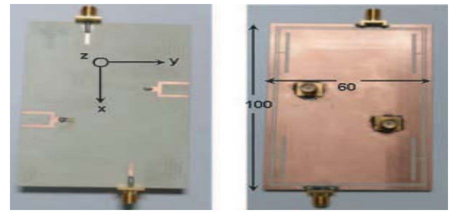


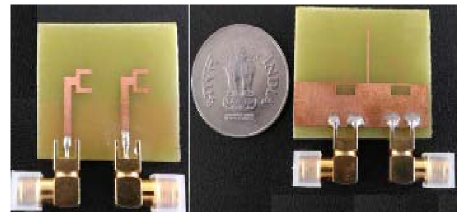
Fig. 1: Multiband MIMO with Insertion of parasitic element [9].

ii. *Use of Slots*

In Multiband MIMO with the use of slot the Slot is a cut in the patch antenna to improve the bandwidth. As the current flow in the circuit the patch can be represent as the LC circuit. As the current flows around the slot, the length of the current path is increased. The two resonant circuits couple together and form a wider bandwidth. The effect of slot is different at different resonance frequency hence multiband frequencies will be obtained [11] shown in Figure 2 respectively.



(a) (b)

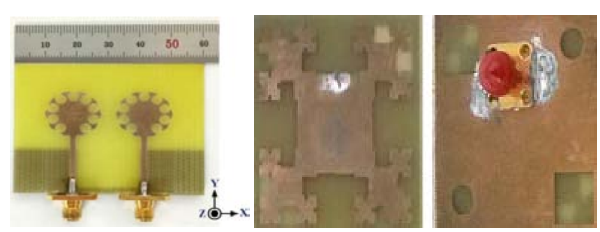


(c) (d)

Fig. 2: Illustration of integrated MIMO antenna design (a) top view (b) bottom view [10] (c) top view (d) bottom view [11].

iii. *Use of Fractal*

Fractal antenna often multiband properties when they radiate and zoom in on a fractal object it will look similar or exactly like the original shape. Such antenna could be used to improve the functionality of modern wireless communication system. Fractal can be used in two ways to enhance antenna design. The first method is in design of miniaturized antenna elements. The second method is to use the self similarity in the geometry to blue print antennas which are multiband or resonant over several frequency bands. Small antennas are of prime importance because of the available space limitation on device and the oncoming deployment and multi input multi output (MIMO) system. However the classical small antenna suffers from insufficient performance. Fractal geometry provides the solution by designing compact and multiband antenna in most efficient and sophisticated way. There are many fractal geometries available like Sierpenski Carpet, Sierpenski Gasket, Koch Fractal Loop, Hilbert Curve and Contor Set. The fractal antenna with Decagon and Koch geometry illustrated in figure 3 (a) and (b).



(a) (b)

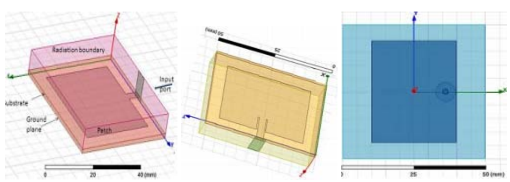
Fig. 3: (a) Decagon fractal MIMO antenna [18] (b) square patch antenna [19].

iv. *Feeding Methods*

Selection of feeding techniques depends upon how much power is transferred by feed line to the radiating patch. Power transferred depends upon the impedance matching. Feeding technique can be classified into two techniques one with contacting and other with non –contacting. In contacting, radiating patch is directly given the feed as by Microstrip line. In non -contacting, power is transferred by electromagnetic coupling between radiating patch and the feed line.

Contacting Feed

- Microstrip Line Feed- A microstrip feed uses a transmission line to connect the radiating patch to receive or transmit circuitry. A microstrip line feed is generally used in two configurations namely Directly fed (a) and Inset feed (b) as shown in the Figure 4.
- Coaxial Probe Feed- In coaxial feed there are two conductors, inner conductor is connected to the patch and the outer is attached to the ground.. A coaxial feed antenna is illustrated in Figure 4 (c).

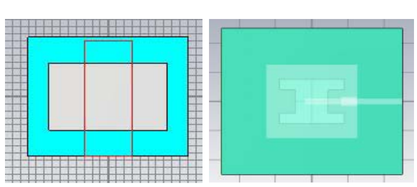


(a) (b) (c)

Fig. 4: Microstrip Direct feed (a) Inset Feed (b) Coaxial Feed [20].

Non-Contacting Feed

- Aperture Coupling Feed - The feed line is coupled to the patch through a slot in the ground plane. An aperture feed antenna is illustrated in Figure 5 (a).
- Proximity Coupling Feed-. The feed line is in between the two substrates and the radiating patch is on top of the upper substrate, it eliminates spurious feed radiation and provides very high bandwidth A proximity coupled feed antenna is illustrated in Figure 5(b).



(a) (b)

Fig. 5: Aperture Coupling feed [21] (a) Proximity coupling feed (b) [22].

b) *Smart Reconfigurable*

Smart Reconfigurable technique improves the previous approaches by modifying dynamically its frequency and radiation pattern properties in a controlled and reversible manner so that its behavior can be changed by reconfiguration and it allow to operate on multiple frequency bands. Polarization reconfigurability or hybrid antenna received much attention as it can fulfill demand for low profile antennas for different services in just single terminal. The techniques that can be used for reconfigurability in antennas are many such as by using active switches based on micro electro mechanical systems (MEMS) [23], PIN diodes [24]-[25], varactor diode ,using photoconductive switch ,doing some change in structure and alteration in material . A reconfigurable antenna can be classified into varies category based on switching network used given below in Figure 6:

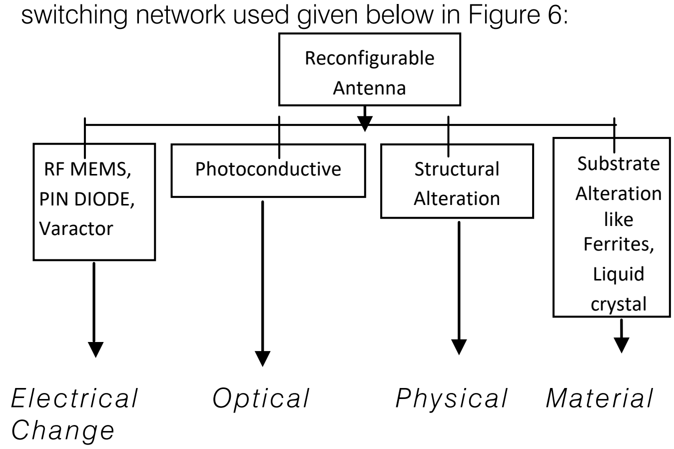
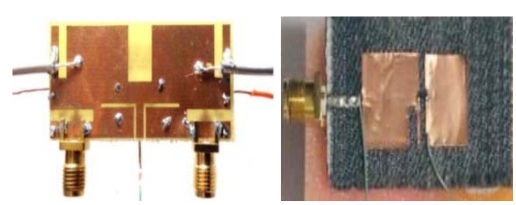


Fig. 6: Reconfigurable antenna various techniques.

i. *Electrically Reconfigurable Antennas*

RF MEMS are new revolution in microelectronics. RF MEMS, PIN diode and varactor diode work in the form of open and closed switch in the antenna structure and redistribute the surface current path.



(a) (b)

Fig. 7: (a) Antenna with MEMS switches [26] (b) reconfigurable antenna using PIN diode [27].

Saber Soltani et al [26] an antenna design with fabricated model is shown in Figure 7(a) in which the antenna geometry consist of four slot antenna and two slots of antenna are made reconfigurable by embedded MEMS switches. The MEMS switches reduce antenna efficiency to around 45%. In [24] frequency reconfigurability was achieved using PIN diode installed

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into the patch. The slot is then loaded with a single PIN diode. The switching of PIN diode creates open and short circuits resulting in resonant frequency shift. The antenna operates at ISM band when the switch is ON and at WLAN band when the switch is OFF as shown in Figure 7(b). In [28] this concept tuning of the two resonant frequencies is realized by varying the effective electrical length of the slot arms by embedding varactor diodes across the slots.

ii. *Optically reconfigurable Antenna*

An optically reconfigurable antennas uses lasers which incident on semiconductor materials like silicon, gallium arsenide. An optically shorted stub frequency reconfigurable antenna is illustrated in Figure 8. Sarang Pendharker et al. [29] achieved multifrequency switching of the patch by using three photoconductive switches.

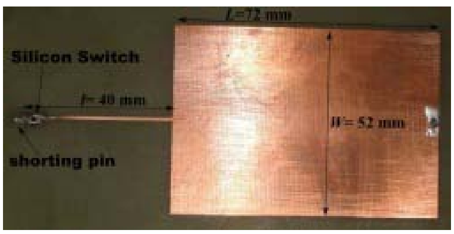


Fig. 8: Optically shorted stub-loaded frequency-switching patch antenna [29].

iii. *Physically Reconfigurable Antennas*

By physical alteration of the radiating structure of the antenna, reconfigurability can be achieved. It has some disadvantages like antenna size increases, the tuning speed is very less, and that is why it cannot be used in cognitive radio system. Y Tawk et al. [30] in this frequency reconfigurability achieved by the three antennas which reconfigures based on its operating frequency or radiation pattern based on a physical movement of some of its radiating parts. The antennas vary from a frequency reconfigurable quadrifilar helix to a frequency reconfigurable sector monopole as well as a radiation pattern reconfigurable patch.

iv. *Smart Materials Based Reconfigurable Antenna*

Materials for example liquid crystals or ferrites are used in making substrate which can change its characteristics. A Double Negative (DNG) material with negative permittivity and negative permeability is used for this reconfigurable antenna. The metasurface design is proved to be a metamaterial with negative refractive index, as both relative permittivity and relative permeability are observed to be negative in the desired frequency range to achieve frequency reconfigure ability [31].

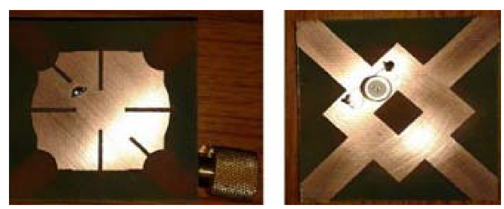
c) *Defected Ground Structure*

Defected Ground Structure referred to Slots or defects integrated on the ground plane of microwave planar circuits. Using DGS in antenna design leads to size reduction, gain or bandwidth enhancement. DGS opens a door to microwave researchers of a wide range of applications like miniaturization, multiband performance, bandwidth and gain enhancement, mutual coupling suppression between two elements, higher mode harmonics suppression, cross-polarization suppression, notched band creation, and circular polarization achievement.

There are different configurations have been explored below:

i. *Multiband Circularly Polarized DGS Antenna*

Multiband frequency operations can be achieved by Circular polarized antennas. The multiband circular polarized antenna can integrate various frequency bands in a single antenna and cover many wireless applications on single platform. The multiband circular antenna can also be used with microstrip antenna in order to achieve small size, less weight and low cost. Jay et al. implemented Defected ground structures (DGSs) under the feed lines for circular polarization of the patch antenna [33]. Jieh-Sen Kuo et al. achieved circular Polarization using a novel approach of the gain-enhanced microstrip antenna with three triangular slots in the ground plane [34] shown in Figure (a) and (b). Similarly with integration of the DGS, return loss bandwidth enhanced by 64% in multilayered antenna [36].



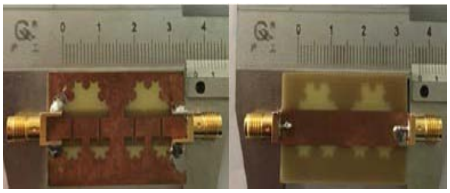
(a) (b)

Fig. 9: Multiband Compact CP Antenna with DGS [34].

ii. *Fractal Defected Ground Structure (FDGS)*

Fractal DGS is used to reduce the mutual coupling between microstrip antenna elements, but it has never been used to design CP microstrip antenna. FDGS will increase the Cross polarization XP level further more compared to the conventional DGSs. The increased XP level has almost the same magnitude as that of the main polarization level, which contributes to the design of the CP microstrip antenna. DGS provided more efficient size-reduction of the microstrip structure and better bandgap characteristics than the dumbbell-shaped DGS [38]. Kun Wei et al. achieved miniaturization using FDGS and mutual coupling is reduced between coplanar spaced microstrip antenna elements [39].

Zheng-lin Wen et al. [41] the geometry of the Koch FDGS has high frequency selectivity and a sharp cutoff response that can be achieved in only use of 1 or 2 unit cells. Koch FDGS with 2 unit cells has a more compact size and operates over an insertion loss of less than 1 dB and the rejection is better than 40 dB. The Koch FDGS geometry possesses several degrees of freedom, compared to a traditional dumbbell defected ground structure, that can be exploited to achieve further size reduction, better pass band rejection, and a larger stop band extension antenna is illustrated in Figure10 (a) and (b) .



(a) (b)

Fig. 10: Fabricated Koch FDGS with 2 cascaded resonators. (a) Bottom side (DGS). (b) Top side (microstrip transmission line) [41].

III. Critical Review of Literature

This section presents a critical review of the multiband MIMO, Smart Reconfigurable and DGS based antenna techniques used for next generation wireless communication for 5G networks. This paper contains the various methodology used earlier by researchers in the field of antenna designs. The aim of this paper to make knowledge of the various techniques used in designing of antennas and to fill the gap in literature for improving the current methodologies in depth which will be a major contribution for modern wireless communication in all aspects .

a) Critical Review of Multiband MIMO

Sl. no	Ref	Year	Focus of Study and Remark
1	[42]	[2017]	A design with multiple element of PIFA MIMO antenna has been proposed operating at 28 GHz which is good candidature for 5G .Gain is improved due to the insertion of parasitic elements. However, isolation between the antenna elements is poor, which makes the design more complex and the design also affect the resonant frequency.
2	[43]	[2017]	This paper aim is to design the MIMO 8×8 microstrip antenna with 2 H-slot rectangular patches array with 5G radio access system at frequency range 14.5 to 15.25 GHz. However, dealing with MIMO, there will be great challenge that is mutual coupling here it is affecting the antenna performance, the value of mutual coupling min -21.311 and max-65.072.
3	[13]	[2013]	This paper presents a multiband MIMO antenna which is operating at 0.77 GHz, 2 GHz and 2.45 GHz frequency bands and limited to three frequencies .However the size of the antenna is 50x110x0.8 mm3 and it is limited to LTE and WiMAX not suitable for 5G communications.
4	[10]	[2016]	The geometry of the proposed two MIMO antenna systems, one covering 4G bands and the other covers a potential 5G band. The 4G MIMO antenna systems consists of two elements ANT-1 and ANT-2 and the 5G MIMO antenna systems uses a 1*2 antenna array for each port ANT-3 and ANT-4. However Proper selection of radii of the slots to control the stop band frequencies.
5	[44]	[2014]	The proposed antenna is designed for multiband MIMO wireless communication using fractal Minkowski island curve and Koch curve. However, for the iterations higher than the second, the reduction of operating frequency is not achievable since the antenna design becomes quite complicated and its fabrication is difficult. There is difference in gain measured and simulated results due to different surface current.

b) Critical Review of Smart Reconfigurable

1111 Sl. no	Ref	Year	Focus on study and Remark
1	[45]	[2016]	In this paper frequency reconfigurable antenna is presented from wideband to multiband. Using two ideal switches antenna is operating in wideband or multiband. However, the measured gains are lower than the simulated gain presumably due to cable and free space losses that occur during the gain measurement process.

2	[14]	[2014]	The presented antenna is Miniaturization and multiband operation is obtained by the reconfigurable UWB antenna using RF-MEMS operating frequency range 5.15 to 5.825 GHz range. The measured results are satisfactory. However E plane pattern attenuates from 130 to 180 degree because of reflection.
3	[46]	[2017]	A simple optically controlled reconfigurable antenna based on slotted-waveguide antenna array and two photoconductive switches operated at 28 GHz and 38 GHZ frequency band for mmwave frequencies. How ever, here the reconfiguration is limited to only two bands and at the same time, the problem of mutual coupling would become increasingly serious when the distance among antennas dramatically reduces.
4	[15]	[2013]	A smart reconfigurable antenna using PZT material to reconfigure the PIFA structure has been investigated. However, it is resonating at very low frequencies and not suitable for next generation wireless communication.
5	[12]	[2016]	The reconfigurable antenna designed here, suggests a faster and low-cost inkjet printing for fabrication on a cost-effective material at high frequency. However, the radiation characteristics, gain and efficiency is not calculated for other modes. The research on the design of multi-antennas in mobile terminals for mmwave systems is not deep enough.

c) *Critical Review of Defected Ground Structure (DGS)*

1	[47]	[2016]	A multilayered circular polarized DGS antenna with a size of 346 mm^2 is proposed using asymmetrical slots and circular patch for bandwidth enhancement. However with the inclusion of DGS structure the gain of antenna reduces from 3.60 to 2.80 dB at 5.6 GHz.
2	[16]	[2016]	The proposed multiband antenna is circularly polarized using DGS and radiation pattern shown good characteristics. The maximum bandwidth of 44.89% is achieved. However, the efficiency and gain of the antenna is not obtained.
3	[37]	[2013]	In this paper six pairs of slits etched in the middle of ground plane. However, optimized length has to be chosen as increase in slit length changes the upper and lower band. Space between the slits affects the performance of antenna in lower band (2.70 GHz) than in the upper band (3.95 GHz).
4	[17]	[2015]	The antenna is designed using CPW fed dodecagram fractal using DGS. The antenna shows omni-directional radiation pattern, a good gain and high efficiency. However, after third iteration there was not much improvement observed in the antenna characteristics. The third iteration increased the design complexity, as well as the fabrication limitations restricted to third iteration.
5	[40]	[2014]	A compact circularly polarized antenna with Koch Curve Fractal Defected Ground Structure presented for frequency range 1.492GHz and 1.518GHz .Good reduction in the size of patch 44.74% .However, here the antenna is limited to only two operating band and reduction in gain 14.66%.
6	[35]	[2017]	The X-shaped fractal antenna is designed using defected ground structure operating for multiband operation with frequencies 1 GHz to 7 GHz. However, Poor radiation efficiencies obtained for higher band and little difference observed in simulated and measured results.

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IV. Conclusion

In this paper the three important tequniques to design the antenna in various applications are discussed. Also highlights unique design issues to help the researcher to be able to understand more advance research. The following points conclude from literature.

There is a need to improve the performance of multiband MIMO system by reducing mutual coupling between closely spaces antenna elements. It is difficult to compare the isolation techniques in MIMO due to individual characteristics like operating frequency, area covered etc. Some limitation found in present research given below:

- Strong radiation pattern distortion
- Shift in resonant frequency
- Changes in the input impedance

There is need to optimize the antenna parameters and design procedure using some techniques such as graph model, neural network to achieve the smart reconfigurability. By using smart material the size of the antenna can be miniaturized to achieve reconfigurability.

The Bandwidth of antenna can be enhanced by using various bandwidth enhancement techniques, like employing DGS and slot in patch. The designs can further be improved with various DGS in order to achieve good gain, efficiency, radiation pattern, current distribution and |S11| according to the application.

The drawbacks reported in the literature many of the antennas are designed for single band or dual for next generation wireless communication for 5G network. The design challenge is severe especially to covers all the things on a single platform like multiband operation, higher frequency range, less losses, less complexity, good gain, good efficiency, miniaturized size, circular polarized, but still the work is going on to improve the past and present research. However, in comparison to the all antennas with structural integrity motivates the researcher to improve the current research.

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