Scalable Active Metamaterial Cell with integrated gain, compensation and power

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***Abstract*—We report on a stand-alone, battery-powered active meta-material gain stage with integrated gain and self-coupling compensation. This meta-material stage does not require any external connection or power, enabling to be used to scale active metamaterials to large and complex arrays without the need for external power, connection, and gain or compensation.**

I. Introduction

Metamaterials (MM) are artificially structured materials which can realize electromagnetic properties not found in natural materials. Arrays of electric unit cell circuits [1] are assembled to direct and manipulate the electromagnetic waves which includes realizing negative permeability or permittivity, enhancing and focusing electromagnetic waves and cloaking an object with EM fields. Metamaterial is also applied in wireless power transfer (WPT) for its application in electro-magnetic field manipulation capabilities which enable a wide variety of new WPT structures and applications. Despite many successful applications, metamaterials are known to suffer of being lossy around its resonant frequency. It is critical to resolve this issue for practical wireless power transfer applications.

Inspired by Yuan's publish [2], active metamaterials have been shown to obtain the potential to counter the loss issue mentioned previously. The research demonstrates an active MM structure that provides sufficient gain to counter the loss at a particular range of permeability. However, a new challenge arise for it internal coupling in the unit active MM cell, which would lead to gain loss and limitations in achieving negative permeability. The compensation method presented in our previous work [3] has shown success to cancel out the coupling effect and restoring the output gain. However, in order to implement the active MM unit cell into an metamaterial array, modifications in the system design are necessary.

Presented is an active metamaterial circuit with a self-compensating mechanism integrated on an wireless independent circuit board that includes circuit to resolve the reduction of the output magnetic field. The self-powered integrated circuit board further improves the original design since it enables convenience in manufacturing and debugging as well as flexibility in revisions of the unit cells without effecting the conventional metamaterial array design.

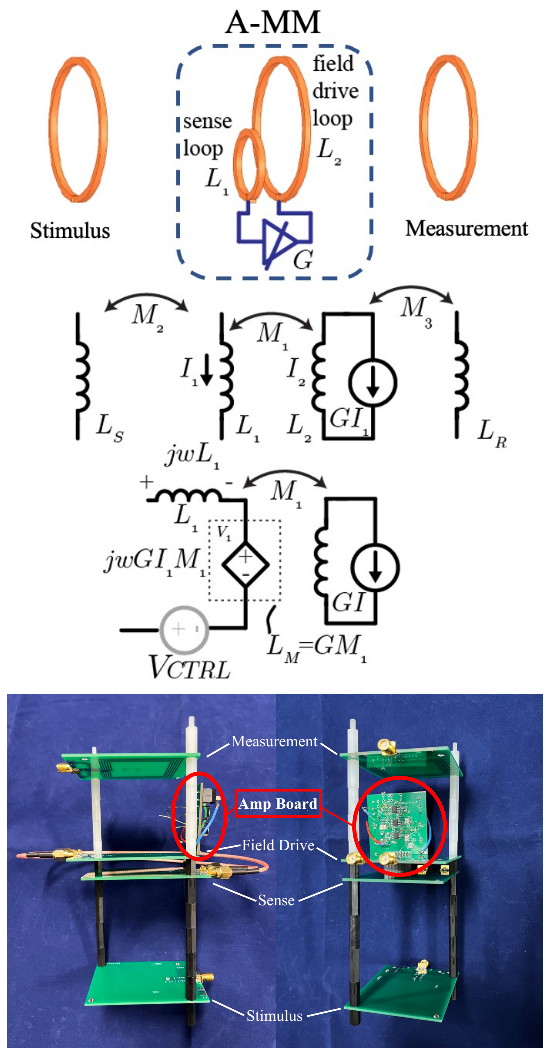

Fig. 1. The top is an active MM single cell schematic. The middle section shows a more detailed schematic of the active MM cell and the active integrated circuit board. The bottom figures is the prototype of the active MM system with the integrated amp board.

II. Independent Integrated Amp board in an Active MM system

The initial design of an active MM system with self-compensation [3] is presented to counter the issue of an attenuated output field gain which resulted in not being able to achieve a negative permeability, defeating the purpose of the application of this type of metamaterial. The self-compensation circuit applied an 180 degrees out of phase sine wave compared to the coupled signal and successfully canceling out the effect, restoring the output field gain.

Despite the accomplishment of the work, several improvements could be made for an active MM array. The SMA cables and connectors increases the complexity and dimension of the unit cell and limits the size and practicability of designing a metamaterial array. The external power source also adds issues to assembling multiple unit cells as well as inflexibility to apply to different structures or testing environments.

The goal for this wireless integrated circuit board is to design a highly scalable solution to assemble the active MM unit cell design into a complete metamaterial array system . Decreasing the size of the board and switching out SMA connector into through-hole headers made it possible for tl each active unit cell to combine into an metamaterial arra Furthermore, using series coin batteries instead of an extern power source benefits the system making it truly "wireless meaning that it can be self-sustained and portable for wid metamaterial applications.

III. Theory and Experimental Results

An input signal of 1.5MHz sine wave is fed to the stimulı coil. It was coupled onto the input coil of the Active MM cell, which is the sense loop. The signal is then amplified by the Amp board and forward to the field drive coil. The measurement coil captures the output field generated through the active MM cell. The current running through field drive(output) coil is taken measurement for us to observe the coupling effect between the active MM coils and effectiveness of the compensation circuit.

As shown in Fig. 3, the amplitude of the current running through the output coil is around 7mA. This measurement was taken when the sense coil and field driven coil is far from each other, which is more than 70mm apart (left figure in Fig. 2), and no coupling within the active MM cell is present. When we decrease the distance between the two coils, the output current decreases accordingly. The field driven coil $L2$ coupled an in-phase signal $V1$ onto the sense coil $L1$. This results in a smaller current $I1$ generated on the $L1$ side and thus decreasing the current $I2$ going through $L2$. Fig. When the distance between $L1$ and $L2$ is close to 10mm (right figure in Fig. 2), the self-coupling occurs, compromising the output current to nearly 3mA, which is smaller than half its original value. The compensations circuit is then applied to the system. It generated a signal $Vctrl$ at $L1$, which is 180 degrees out of phase to $V1$, canceling the effect caused by the self-coupling within the active MM cell. As we increase the feedback gain, the gain of the active circuit is restored back to 7mm.

IV. Conclusion

A integrated amplifier board with self-compensation is designed and fully tested. It resolves the issue of an attenuated output field by applying a feedback mechanism to restore the output field of the active MM unit cell to achieve a negative permeability. Furthermore, the separated battery powered integrated board enables practical application in designing active MM array design. Future work on this direction is to minimize the board size and power consumption and assemble an active MM array using this active MM circuit board.

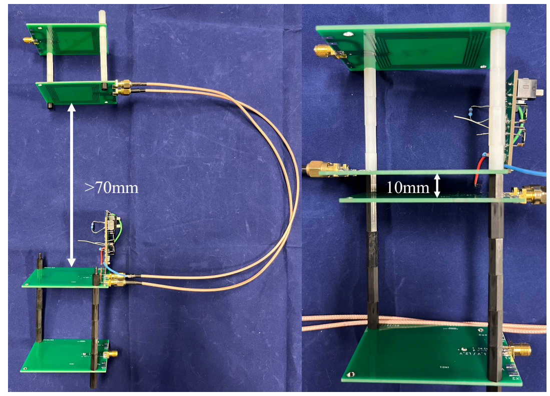

Fig. 2. Showing the two scenarios where on the left L1 and L2 are far apart, and on the right the coils are bring close together.

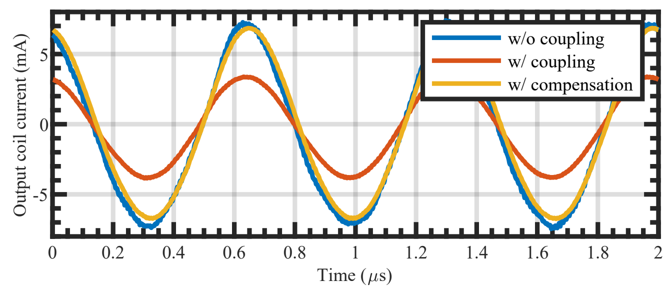

Fig. 3. The measurement of the current running through the output coil (field driven coil) before and after compensation.

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