

# **Small Radio Repeater System for Enhancement of Wireless Connectivity**

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## **Introduction**

For wireless network systems, the path-loss between the transmitter and receiver is a critical factor that determines the possible range between two communication nodes. In complex environments such as dense urban area, indoor environment the line-of-sight (LOS) cannot be established, thus wireless communication must rely on multi-path propagation (multiple reflection, diffraction, and penetration through obstacles). As a result, the propagation path-loss is much higher than free-space, and the communication range decreases. To overcome this problem, either the transmitter power has to be increased or the data rate should be lowered. Low power and high data rate communication is essential for ad-hoc networks and method that allows low-power communication in multi-path channel and highly desirable.

To address this problem and to improve the coverage of communication signals, radio repeaters have been extensively utilized in various scenarios. The main objective of the radio repeater is to achieve enhanced connectivity by proper placement and amplifying the radio signal. For the downlink communication, from a base station to an end-node/unit, the signal originating in the base station is linked through the Receive antenna (RX), amplified, and re-transmitted through Transmit antenna (TX), and vice versa for uplink direction. Existing radio repeaters use down conversion, amplification, and up conversion to a different frequency. But this scheme is complex and requires much power. A simple repeater scheme is shown in Fig. 1. However, the mutual coupling between repeater's RX and TX antennas can generate a positive feedback loop, and when the gain of the RF amplifier exceeds this isolation level, the system goes to oscillation. This will drop the gain of the amplifier, and the repeater can no longer perform its function. To circumvent this intrinsic problem, generally two approaches have been proposed. The first method is to utilize Frequency Division Duplex (FDD) to separate the frequencies of the uplink and downlink signals as mentioned before. And the second is to adapt Time Division Duplex (TDD) in time domain. However, both methods require complex circuitry and large dimension, which imply higher cost and power consumption.

In this paper, a new radio repeater is proposed to overcome the adverse effect of various complex environments by reducing the path-loss. To enhance radio connectivity and to maintain low-power consumption, a very small radio repeater with an omni-directional radiation pattern is proposed. The proposed radio repeater receives the LOS signal from the base station, amplifies it, and then re-transmits the amplified signal omni-directionally, which establishes a secondary LOS to arbitrary receiver nodes. The isolation between TX and RX is enforced using a novel meta-material isolator. A series of small radio repeaters can enhance radio connectivity by increasing a link of LOS nodes.

## Miniaturized Low-power Repeater for Near-earth Operation

Ad-hoc communication networks operate near ground. The optimum polarization for such system is vertical polarization as the path-loss for vertical polarization can be as high as 40 dB better than horizontal polarization. In this section, the architecture of a miniaturized low-profile radio repeater is described.

### a. Transmit/Receive Antennas

As shown in Fig. 1, the proposed repeater consists of two miniaturized planar antennas capable of producing vertical polarization and a simple RF circuitry. To prevent the system from oscillation, a miniaturized meta-material based channel isolator is also integrated between the two antennas. According to antenna theory, the excited current on an antenna contributes to the radiation intensity in the far field. In many practical miniaturized antennas, the level of the excited current is limited by the impedance mismatch between the feeding network and the antenna itself. To achieve a low-profile miniaturized antenna, a quarter-wave microstrip resonator fed near the short-circuited end is considered. In order to address the impedance mismatch a meandered quarter-wave open-transmission line was designed, and a resonant segment of short-transmission line was proposed to improve the impedance mismatch in [1]. Although it shows a good impedance match and radiation, this antenna has geometrical complexity. Since it requires two layers for open- and short-transmission lines, it causes fabrication difficulty and high cost. To be incorporated into the radio repeater, this antenna is further modified and optimized (see Fig. 2). By utilizing only two arms, the horizontal current cancellation can be achieved at the expense of an asymmetric radiation pattern on the E plane. Additionally, since the distance between two antennas can be reduced, the mutual coupling between TX and RX can also be minimized. Since the horizontal current is cancelled along the horizontal stripline, only the vertical pins contribute far-field radiation, which operate like a simple monopole antenna having a height smaller than  $\lambda_0/70$ .

### b. Meta-material based Channel Isolator

In practical antenna systems, the mutual coupling between adjacent antennas restricts compact integration of multiple antennas in a small area for applications such as multiple input and multiple output (MIMO) communication systems. To suppress the mutual coupling, an artificial structure such as mushroom-like structure or a meta-material insulator was presented in [2] and [3]. Since the artificial structure requires large physical dimensions and must be away from radiating structures, their implementation into a miniaturized sub-wavelength transmit/receive antenna pair is not practical. Although the meta-material insulator can achieve suppression at the desired frequency with small physical dimension, it requires complex fabrication process and high cost. To address these problems and to achieve compact integration, a meta-material based channel isolator was presented in [4]. The unit cell of the meta-material based isolator is shown in Fig. 3(a). In the proposed radio repeater, the miniaturized planar antennas are utilized. Since the vertical pins create Transverse Magnetic (TM) wave in the substrate with zero cutoff frequency, the magnetic field is parallel to the ground plane and perpendicular to the pins. Since the horizontal TM wave is linked properly through the resonant loops, an effective Perfect Magnetic Conductor (PMC) can be generated at the frequency of operation,

which suppresses the propagation of surface fields.

### c. Integration of Antennas and Isolator

The geometry of the proposed radio repeater composed of two miniaturized low-profile antennas capable of radiating vertical polarization and a meta-material based channel isolator is shown in Fig. 3(c). Since close spacing between the antennas and the isolator causes mutual coupling and affects the performance of the repeater, the current distribution on the ground plane is used to evaluate the optimal placement of subcomponents and to minimize this interaction. As all of the physical parameters are related to each other through various electromagnetic interactions, optimization is achieved through adjusting the length of the isolator loop and the strip iteratively using HFSS. As shown in Fig. 4(a), this design was fabricated and tested carefully. Fig. 4(b) shows the measured responses of the fabricated radio repeater. It indicates that the isolation level can be suppressed up to  $42\text{ dB}$  at the desired frequency, providing  $28\text{ dB}$  of improvement in channel isolation between these two antennas.

## Conclusion

In this paper, a new concept for implementation of a miniaturized radio repeater is presented. To construct the radio repeater, two miniaturized low-profile antennas radiating vertical polarization and a thin meta-material channel isolator are integrated in a compact configuration. The overall dimensions of the proposed radio repeater are  $\lambda_0/5.5 \times \lambda_0/2.7 \times \lambda_0/70$ . A commercially available RF amplifier and battery are used to verify the operational feasibility of the repeater. The fabricated repeater was operated with a miniaturized low-power amplifier with more than  $30\text{ dB}$  gain.

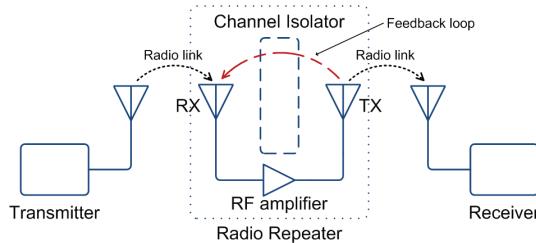


Figure 1: Schematic of radio link using Radio Repeater.

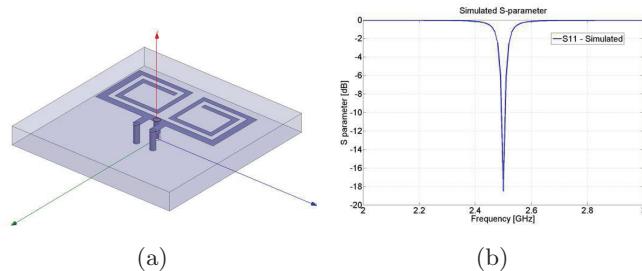


Figure 2: Modified Multi-element Monopole Antenna: (a) topology of modified MMA; (b) simulated S-parameter.

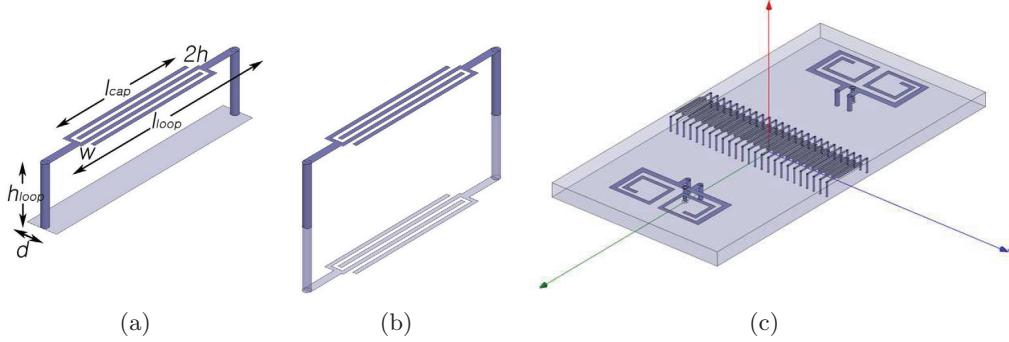


Figure 3: Topology of small radio repeater: (a) geometry of unit cell; (b) square loop by image theory; (c) geometry of repeater platform.

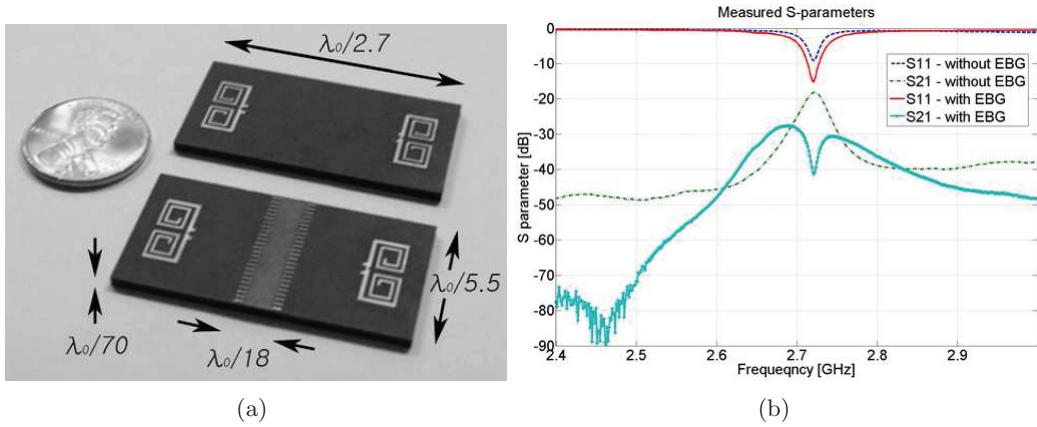


Figure 4: Repeater platform with channel isolator: (a) fabricated repeater platform; (b) measured S-parameters.

## References

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