Passive Retranslation with Space Wave Coupled Antennas

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***Abstract*—This paper presents an easy to apply approach to extend the range and improve the data speed of a cellular phone in areas with poor coverage or provide access outside the planned coverage. The system is based on passive retranslation (passive repeater) and inductive (space wave) antenna coupling. Sample designs are presented and measurement results delivered.**

***Keywords*— passive retranslation, antennas, mutual coupling, propagation in rural area, LTE, 5G**

I. INTRODUCTION

Modern mobile communication frequently experiences a cellular signal drop or a slowdown in data delivery. Mobile operators must therefore deploy base stations closer together in densely populated areas. The stations in remote locations, such as hilly regions and isolated small villages, frequently have inadequate service due to the characteristics of the mountain landscape. Both the poor base station signal and the slow data transmission speed are common occurrences there. Moreover, there might occasionally be either a deficiency in this signal and a very high drop call rate. This study presents a technique for UE (user equipment) reception improvement. The signal will be passively retransmitted as the technique suggests.

In this paper, a method for reception improvement of the user's UE (user equipment) is presented. The method that is used is passive retransmission of the signal. To achieve the desired results, one antenna is used for directional transmission and reception of the signal toward the base station and another – a microstrip antenna which will transmit the signal through inductance coupling to the internal antenna embedded in the enclosure of the user's UE

II. THE PRINCIPLES AND THEORY BEHIND

A. Passive retranslation

A reflective or sometimes refracting panel or other item that aids in closing a radio or microwave link in locations where a signal route obstruction prevents direct line-of-sight contact is known as a passive radio repeater or passive radio deflection. A passive repeater is far easier to set up, takes less maintenance, and doesn't need electricity on the premises in comparison to a microwave radio relay station with active components. In contrast to active repeater stations, which use distinct transmit and receive frequencies to avoid feedback, it also doesn't call for any additional frequencies. Without amplification, the returning signal is substantially weaker, which is the equivalent drawback.

A parabolic (or Yagi) antenna to receive the signal and a waveguide (coax) to feed it to a second parabolic antenna can be used to build vertical passive radio relay link deflection systems. Another option is employment of a flat metallic surfaces placed such that the angle of the incoming wave and the angle of the outgoing wave correspond are used for passive deviations of a microwave radio relay link in the vertical plane.

Such technologies are sometimes employed as tunnel transmitters or television relay transmitters. In these circumstances, a Yagi antenna captures the broadcast signal and sends it to a second Yagi antenna through a coaxial cable. Contemporary approach to the problem is proposed in [1].

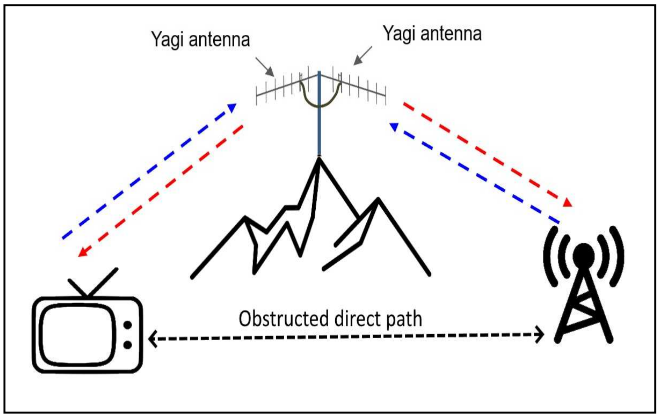


Fig. 1. Example of passive repeater system

B. Mutual coupling between antennas

Detailed research of mutual coupling between antennas is done by Pozar [2]. When the elements are positioned collinearly along the E-plane and H-plane, as shown in Figure 2. For end-to-end separation, the E-plane shows the smallest coupling isolation for a very small distance (typically s < 0.1λ) while the H-plane shows the smallest coupling for a large distance (typically s> 0.1λ). The distance at which one planar link connects another depends on the electrical properties and geometrical dimensions of the microstrip antenna. The fields can be decomposed into space waves, waves of higher order, surface waves and leaky waves. Due to spherical radial variation, space and higher order waves are most dominant for very small distances, while surface waves are dominant for large separations. Surface waves exist and propagate in the dielectric and their excitation is a function of substrate thickness. In this case, there is no dielectric to support surface waves, so the coupling is solely to near field space wave and high order waves (magnetic coupling).

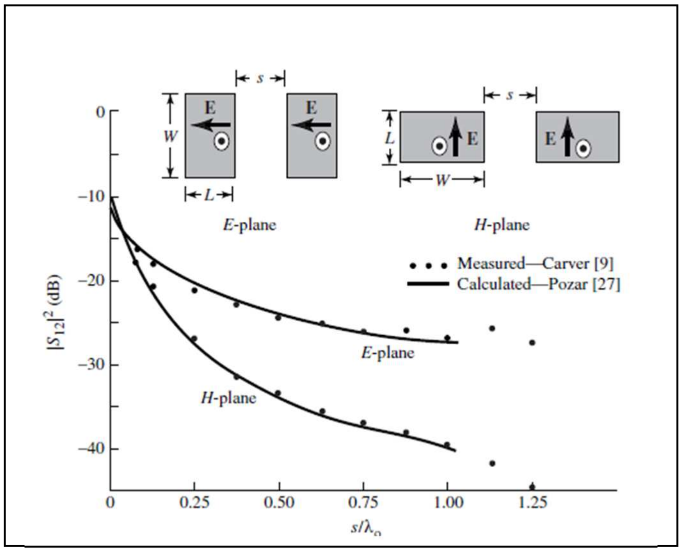


Fig. 2. Mutual coupling (S_{21}) between adjacent antennas

III. PROPOSED ANTENNA DESIGNS

A. The Uda-Yagi Antenna

The Uda-Yagi antenna is a practical solution for transmission in the HF (3–30 MHz), VHF (30–300 MHz) and UHF (300–3000 MHz) bands. This antenna consists of a number of linear dipole elements, as shown in figure 2.1, one of which is fed directly from a transmission line, while the others act as parasitic radiators (directors) whose currents are induced by mutual coupling. A common feed element for the Yagi-Uda antenna is the folded dipole [3]. The antenna is designed, simulated and optimized with Method-of-Moments software 4NEC2 [5]. Dimensions are stated in Table 1.

TABLE I. THE UDA-YGI ANTENNA DIMENSIONS

Element, No	***Length ln, mm***	***Spacing Sn, mm***
-1	160	-67
0	154	0
1	134	25
2	132	60
3	130	72
4	129	83
5	127	93
6	126	100
7	124	104
8	123	110

The calculated gain is 12.8 dBi and return loss: -25dB@850MHz. Antenna is balanced and matched to the coaxial line with U-shaped loop balun (300 to 75 Ohm).

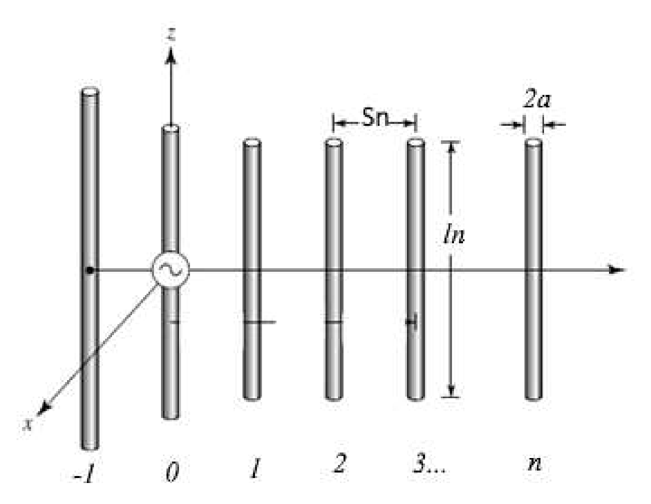


Fig. 3. Proposed design of Yagi antenna for LTE-900 band. The driver (0) is a folded dipole. The antenna elements are made of aluminum tubing, 8mm dia.

B. The Meander antenna

The meander linear antenna (MLA) is an electrically small antenna that presents several performance issues such as narrow bandwidth, high VSWR, low gain, and high levels of cross-polarization. An electrically small antenna is defined as the

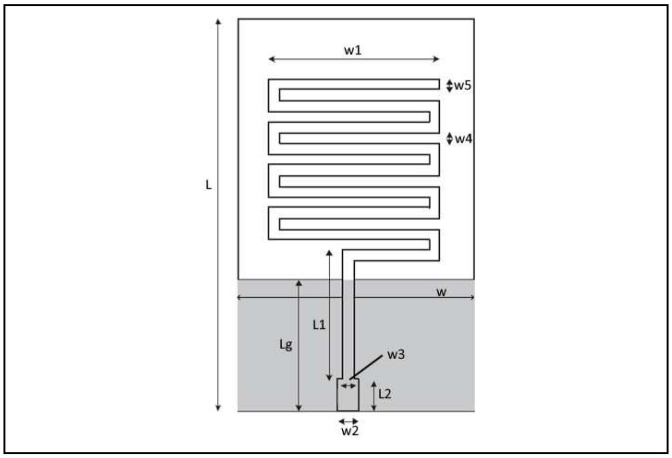


Fig. 4. Proposed design of the Meander antenna

largest dimension of the antenna being no more than one-tenth of a wavelength [4,6].

The meander antenna design is a set of horizontal and vertical lines. The combination of horizontal and vertical lines forming curves. The number of turns n increases the efficiency of the antenna.

Fig. 5. The fabricated Meander antenna

In the case of a meander line, if the distance between the meanders increases, the resonant frequency decreases. single-element antenna of the same length. The meander antenna is an extension of the basic folded antenna with frequencies much lower than the resonant frequencies of a dipole of the same physical dimensions. For the purpose of that experiment a meander antenna is designed, fabricated and tested Fig 5 [3,5]. The dimensions are stated in Table 2.

TABLE II. THE MEANDER ANTENNA DIMENSIONS

Element, No	***Length, mm***
L	43
W	23.5
Lg	16.2
L1	12.27
L2	5.93
W1	15.5
W2	1.65
W3	1

C. *Laboratory tests*

For the purpose of the laboratory bench study, a PIFA GSM antenna was purchased (Taoglass), that emulate the operation of real–life smart phone antenna. Both antennas (Meander and PIFA) are brought closer to a working distance to obtain the inductive space coupling between them. For this purpose and augmentation of the results, a simulation was made with specialized software, and S21 coupling of these two antennas were simulated as well (Fig.6).

Fig. 6. Laboratory test setup for measurement of space coupling between Meander and PIFA antennas on test ports of a VNA

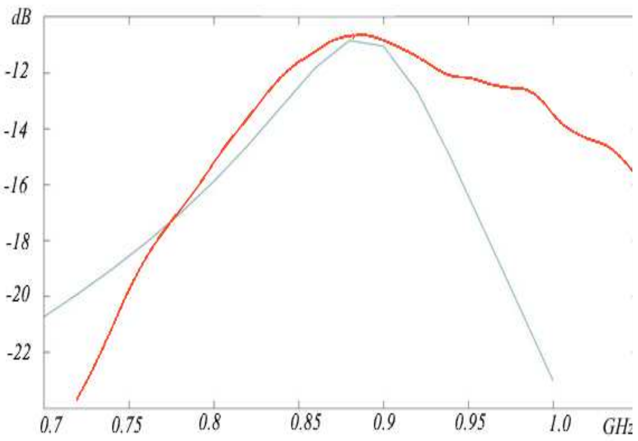


Fig. 7. Simulated (blue) and measured (red) mutual couplong (S_{21}) between Meander and PIFA antenna, in dB over frequency

The optimal distance between antennas was found to be 4mm. After the lab tests a field test was undertaken. The test was done with a test phone, hard locked to Band 8 of LTE (900). The test was done in non-urban conditions, with the distance between the base station and the receiving antenna being about 9km (Fig. 10). There is direct line of sight between the two sites. The receiving antenna (Uda-Yagi) is mounted on a tripod 1.5m above the ground and pointed at the base station. The microstrip antenna is attached to the test telephone, close to the approximate location of the embedded phone antenna (Fig. 8).

The difference in received signal strength is clearly evident from the following results. A signal improvement of about 20 dB is observed. The peaks on the graph represents the moments where phone antenna and meander antenna are coupled, and the valleys – the moments where both antennas are decoupled (Fig. 9). The average internet speed gain is about 10mbps in this particular location and time of the day (Table 3).

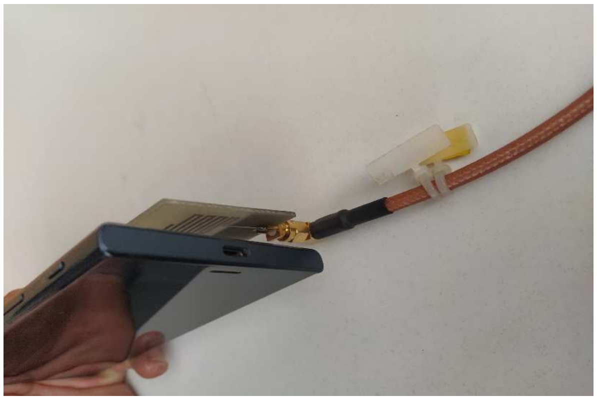
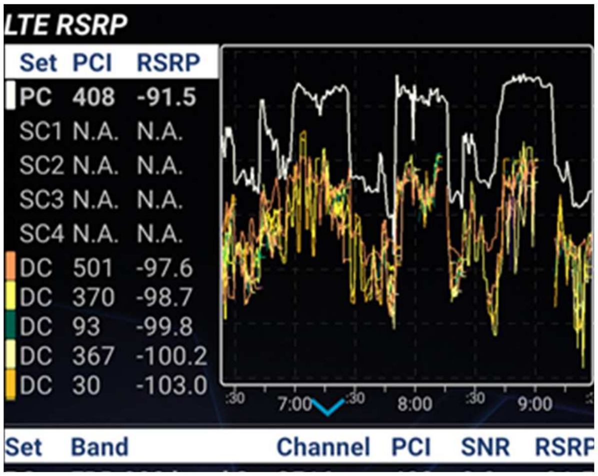


Fig. 8. Mutual coupling measurement



LTE RSRP

Set	PCI	RSRP
PC	408	-91.5
SC1	N.A.	N.A.
SC2	N.A.	N.A.
SC3	N.A.	N.A.
SC4	N.A.	N.A.
DC	501	-97.6
DC	370	-98.7
DC	93	-99.8
DC	367	-100.2
DC	30	-103.0

Set Band Channel PCI SNR RSRP

Fig. 9. Measured signal strength with (peaks) and without (valleys) passive repeater. Abcsissa is the time in min., ordinate is the signal level, dB

TABLE III. MEASURED TRANSFER SPEED

Polarization, Coupling	Download Speed, mbps	Upload speed, mbps
V, ON	16.5	11.9
H, ON	19.8	6.7
V, OFF	9.8	1.4
H, OFF	13.3	4.1

IV. DISCUSSION

The system design approach selected in this paper is suitable for modern mobile phones, that have no connector for external antenna, to extend the service range, as they use to have in the past. For this particular study, a meander antenna for inductive coupling was selected, due to its ease of design, prototyping and good performance over the desired frequency band. However other candidates may show similar or better performance and if their design includes a ground plane backing, they will perform stable in all positions of the handset, even placed on a table with coupling antenna downward to the table top.

There are no specific requirements for the Yagi antenna. It has to provide sufficient bandwidth and gain to close the link. For links that require high gain antenna, the Yagi can be substituted with parabolic (grid) reflector antenna, especially for the high frequency bands (1800, 2100, 2600MHz, etc.)

The measured results (Table 3) show almost twice increase of the downlink speed and several times increase of the uplink speed. Similar experiments were conducted in a span of a few weeks and the results shows consistency. The speed at particular time of the day may vary due to the varying load of the base station, but employment of the passive repeater improved the connectivity in all of the occasions.

As it was demonstrated in this feasibility study, the passive repeater (retranslation) presents an easy-to-make inexpensive alternative for improvement of communications in areas with poor cellular coverage. In some cases, the network operators have no incentives to expand the coverage in sparsely populated areas and in other – mountains, deserts or large forests – there are limited options to provide coverage at all. In these later cases, provision of communications by any means could be vital and proposed designs could be successfully implemented.

Fig. 10. The Yagi Antenna on a tripod, connected to the base station

ACKNOWLEDGMENT

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