A Low-Cost GNSS Repeater for Indoor Operation

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***Abstract*—GNSS hardware can only be used outdoors as reception is strongly attenuated by buildings. We present a cost-effective way to build a GNSS repeater that can be used to test GNSS hardware indoors. Its design comprises two GNSS antennas and four extra passive components. We evaluate the performance of the circuit and show that it can be used to relay GPS, GLONASS, and Galileo signals to a GNSS receiver with its antenna being indoors, close to the GNSS repeater.**

I. Introduction

Global Navigation Satellite Systems (GNSSs) can hardly be used indoors, as the required satellite signals are attenuated by the building structure. Especially when implementing applications that need a GNSS signal to function properly, this becomes an obstacle for developers. There are two viable options: to test and debug the application outdoors or attach a GNSS antenna with a long cable, so that the antenna can be placed outdoors while the device remains indoors as depicted in Figure 1 (top). However, this is not possible for all devices. Highly integrated electronics like smartphones or wireless sensor nodes might not allow to attach an external antenna.

Vector signal generators can be used to generate arbitrary GNSS signals to simulate arbitrary locations. Such devices however are very expensive. This cost can be reduced by using a Software Defined Radio (SDR). For development it is often sufficient to use the actual signals available at the developer's location. These signals only need to be available indoors by relaying them. Commercial GNSS repeaters are available that allow relaying of GNSS signals. They can be used as shown in Figure 1 (bottom) and can be used with devices, that cannot be attached to the outdoor antenna directly.

In this paper, we show how we implemented a simple and low-cost GNSS repeater that picks up the signals outdoors via one antenna and reradiates the signal indoors via a second antenna. It can be build from readily available low-cost components and requires no particular knowledge about high frequency circuit design.

II. Related Work

GNSS repeaters are used to enable the use of GNSS devices for Indoor Positioning Systems (IPSs). To facilitate this, multiple repeaters are placed at different locations, reradiating satellite signals. The signals of these so called pseudolites are used by a mobile device for localization. However, special algorithms or modifications to the GNSS receiver are needed for successful localization.

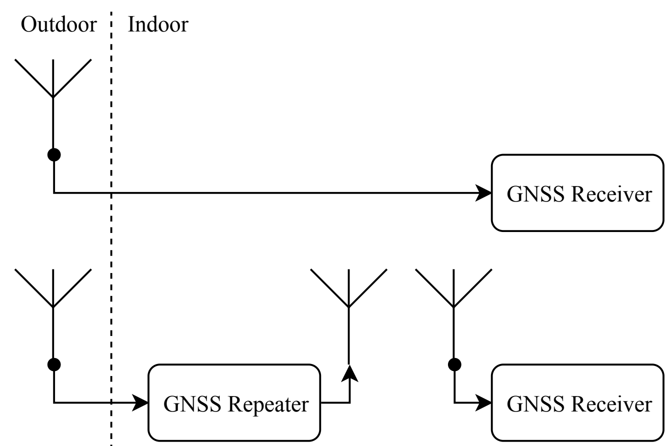

Figure 1. System overview. Top: *Direct* connection of the GNSS receiver to an outdoor antenna. Bottom: The GNSS *repeater* is attached to an outdoor antenna and relays the signal to the GNSS receiver.

Jardak and Samama present an IPS based on Global Positioning System (GPS) repeaters [1]. They use a single external antenna to relay the GPS signal to multiple indoor antennas that reradiate the signal. To avoid interference between the different antennas, they transmit in a round-robin schedule. To allow localization, the GPS receiver needs to be modified. However, as their system is only tested in simulations, the paper does not disclose how the GPS repeater would be implemented.

Riwa et al. use pseudolites that reradiate a GPS signal to locate a robot indoors [2]. To facilitate localization of the robot, a special GPS algorithm is implemented as SDR. A commercial GPS repeater is used in their experiments.

Özsoy et al. present a 2D IPS that uses multiple GPS repeaters [3]. The system uses a standard GPS receiver. However, its received raw data is processed on a computer to allow localization. As the repeaters will introduce additional delays to the signals, the positioning engine inside the GPS receiver returns erroneous results. They use specially designed directional antennas to radiate the GPS signal indoors. The antennas are attached to specially designed Low Noise Amplifiers (LNAs).

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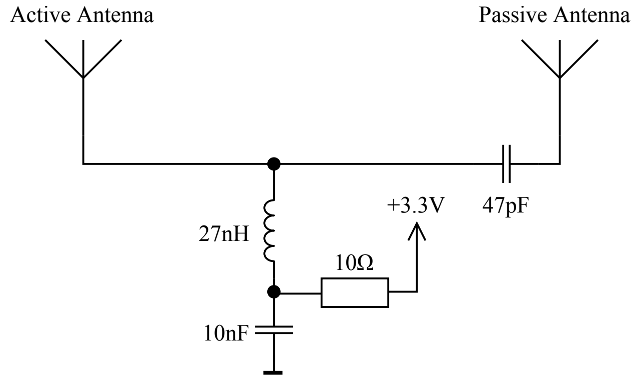

Figure 2. Circuit diagram of the GNSS repeater.

III. Hardware Design

The hardware of our GNSS repeater design mainly consists of two antennas. One receives the signals outdoors, while the other reradiates the signals indoors. The outdoor antenna is active. It contains an LNA, which amplifies the received signal. This ensures that the signal is strong enough for another (active) GNSS antenna to pick it up after being reradiated by the passive antenna, see Figure 1. It is crucial to use a passive antenna at the output of the repeater, as the LNA in an active antenna would not allow transmission of a signal.

To amplify the incoming signal, the LNA needs to be powered by a DC power source. Power is supplied directly via the coaxial cable. Most consumer GNSS antennas are actively powered by the attached receiver. Here we use an ANN-MS-0-005-0 [4] antenna by u-blox. According to its data sheet it requires 2.7-5.5 V operating voltage. The main purpose of the circuit shown in Figure 2 is to supply this operating voltage. Further, it blocks the DC voltage from entering the passive antenna that reradiates the signal via a decoupling capacitor. This is needed, as some passive antennas are designed to be a short circuit for DC signals.

The circuit is adopted from the u-blox hardware integration manual [5]. Instead of attaching a GNSS receiver directly, a second antenna reradiates the received signal.

IV. Evaluation

The performance of the GNSS repeater is evaluated regarding different performance metrics and compared with a reference setup. We evaluate the Time to First Fix (TTFF), Carrier-to-Noise-Density Ratio (C/N_0) and number of satellites used. As GNSS receiver we use a u-blox NEO-M8Q [6] connected via USB to a computer. It is configured to use GPS, GLONASS and Galileo satellites and reports its status at a frequency of 1 Hz.

A. Experimental Setup

We used two experimental setups to evaluate the repeater's performance, as shown in Figure 1. In both setups, the active GNSS antenna was positioned outside a window of our office building. Its integrated 5 m coaxial cable were run through the frame of the closed window into the building. The antenna had only limited Line-of-Sight (LOS) to the sky, as multiple buildings blocked the lower elevation angles and our own building blocked half the sky. All measurements were obtained in overcast weather conditions without rain.

In the first setup, we connected the GNSS receiver directly to the outdoor antenna. This setup is referred to as the *direct* setup. It serves as reference for the performance of the GNSS receiver in the evaluation environment.

In the second setup, we placed the (active) antenna of the GNSS receiver on a desk with 1 m distance to the next window. The receiver was again connected via 5 m of coaxial cable. It was unable get a fix, as the GNSS signals were attenuated by the building. The sending antenna of the repeater was placed in close proximity (5 cm) to the antenna of the receiver. The outdoor antenna was connected to the repeater. This setup is referred to as the *repeater* setup as shown in Figure 1 (bottom).

Table I
Time to First Fix

	min. [s]	max. [s]	median [s]
with repeater	22	68	33
direct connection	28	89	36.5

B. Time to First Fix

We compared the TTFF of both setups. We measured the time between the issuing of a cold start command to the GNSS receiver and the first 3D fix for GPS. This experiment was repeated 10 times in both setups. Table I shows the results. The median TTFF is comparable for both setups. Occasionally, the GNSS receiver requires more time to get a fix. However, this is not caused by the repeater device.

C. Receiver Performance over Time

We sampled GNSS data from the receiver for one hour with both setups as satellite positions and thus performance vary over time. This results in 3600 samples for each setup.

Figure 3 shows that the number of satellites used for positioning by the GNSS receiver is similar in both setups. The number of satellites increases in the first 15 minutes, as the receiver learns more satellite positions and starts receiving on the respective channels. We were able to receive signals from all tested GNSS systems (GPS, GLONASS, and Galileo) in both setups.

We also investigated the Carrier-to-Noise-Density Ratio (C/N_0) of both setups. As the repeater introduces a more complex signal path and additional amplification, it might also introduce additional noise to the system which might reduce performance. Figure 4 shows the C/N_0 over time for both systems. Again, the performance for both setups is comparable.

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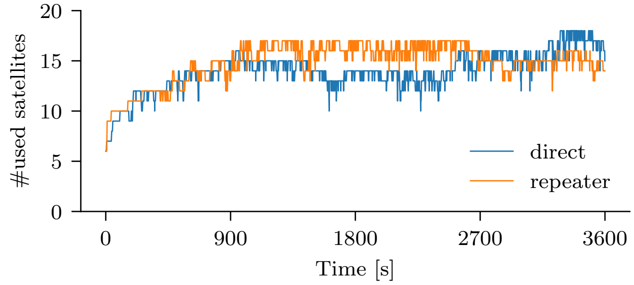

Figure 3. Number of used satellites over time.

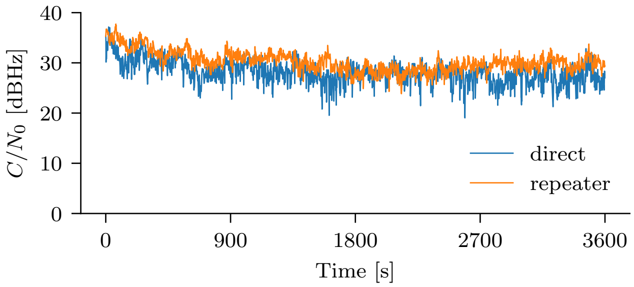

Figure 4. Carrier-to-Noise-Density Ratio (C/N_0) over time.

V. Limitations

As the GNSS signal is repeated from an outdoor antenna, the location inside the building cannot be determined with this setup. Instead, the location of the outdoor antenna is reported, independently of the position of the GNSS receiver. Further, as the signal path is longer, the time information will be late. However, as the signal is not digitally processed, but only forwarded from one antenna to the other in the analog domain, this time offset is negligible.

The maximum distance between the GNSS repeater and the receiver's antenna is limited. In our setup, the receiver was able to get a fix at up to 50 cm distance between the passive antenna of the repeater and the antenna of the GNSS receiver. This distance is limited by the amplification of the active outdoor antenna and losses in the repeater hardware and coaxial cables.

VI. Conclusion

We presented a low-cost GNSS repeater that can be built with readily available components. It does not require special parts other than one active and one passive GNSS antenna. Our evaluation shows that performance is comparable to using the outdoor antenna directly with a GNSS receiver. The repeater can be used to supply GNSS signals to devices inside buildings, where satellite reception is otherwise not possible. This allows to test and evaluate applications indoors which need a GNSS signal for proper operation.

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