

Investigating Optimal Settings for Distance Calculation with a Low Frequency Low-Power RF system

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Abstract—This paper focuses on the application of low power and low frequency Received Signal Strength Indication (RSSI) based localization system. The transceiver presented will wake-up by a modulated magnetic field that is emitted from the transmitter module. This enables the receiver to have low power consumption when not in the range of the transmitter. The goal is to provide an empirical relationship between the RSSI and the relative distance between two modules. To determine the optimal settings required to reliably and consistently obtain the RSSI.

Index Terms—Radio Frequency (RF), low power, magnetic coupling, Received Signal Strength Indication (RSSI), Positioning Systems (PS)

I. INTRODUCTION

In the Network of Things, knowledge of the exact position of each node in the network is critical. For positioning assets, humans, or animals, different principles based on the application are used. Range, power consumption, accuracy, overall system complexity, and finally, the price are critical role players. [1] In this paper, we are presenting a low power radio frequency (RF) positioning system. The magnetic coupling effect between an active transceiver and the coils wakes up the transceiver. As a result, decrease the power consumption of the transceiver. Using low frequency provides substantial advantages such as enhanced diffraction around environmental clutters (i.e., corners), less vulnerability to multipath confusion, superior penetration depth, and low probability of intercept (LPI). [2] In addition, using this frequency, the system operates in an environment with high water content and can provide accurate positioning in the range of few centimeters. Like radio frequency identification (RFIDs), this system will be activated once it is in close proximity of the coils, which will provide unique opportunities to use it for security purposes. Originally, navigation was used to describe the movement of ships on the sea [3]. In modern times, it has included much more such as human, car, robot, airplane and spaceship navigation. navigation is defined as the process of successful orientation by a human, object or vehicle from point of departure through a pre-determined and well-planned path or route to a desired or known destination in outdoor, indoor and even more

challenged spaces without inhibitions or quality-loss [3], [4]. In order to achieve the goals, first some scientific backgrounds are discussed within the next few sections.

RF positioning system is a self-explanatory term. The technology utilizes RF signals and infrastructures to determine the position of a person or object for tracking and navigation purposes [5]. Inherent properties of RF enable signal to penetrate walls and obstacles leading to a wide coverage area [6]. Attracting many researchers, the RF positioning system is categorized as proximity detection and RSSI measurement systems. Utilizing the triangulation, trilateration or fingerprinting techniques [7].

Even though limitations exist especially in complex nature of indoor spaces, low frequencies have substantial advantages such as enhanced diffraction especially around environmental clutter including doorways and corners, superior penetration depth, less vulnerability to multi-path confusion, long-range of operation and low probability of intercept [5].

The RF technologies including Bluetooth, Ultra-wideband (UWB), Wireless Sensor Network (WSN), Wireless Local Area Network (WLAN), Radio-Frequency Identification (RFID) and Near Field Communication (NFC).

RFID is an automatic identification process that uses RF wireless communication technology based on electromagnetic transmission between RFID readers and RFID tags for tracking purposes [8]. The tags are classified to passive and active tags. An active tag which is powered by a battery, will provide wider transmission range. While the passive tag has a shorter range and it responds to the reader signal after being activated by one. This system is capable of tracking and determining the position and the orientation of the tag via radio waves [9]. Nowadays the passive tags are part of daily lives which are used in many bank cards or road toll tags and in portals for monitoring the cargo goods.

II. THE TRANSCIVER SYSTEM

Initially, taking advantage from the magnetic coupling effect, a mobile node is designed to trace the movements.

Three fixed coils are fed by a transmitter module to create a modulated magnetic field. As a result, 3D information about the position of the mobile node is received from each channel of the receiver.

To minimize power consumption, one way is to wake up the receiver system once it is in close proximity with the transmitter. So, the receiver will go to sleep mode with low power consumption when there is no wake-up interrupt. The system consists of three 125 KHz coils with a driving circuit and a transceiver figure 1. A modulated magnetic field will wake up the microprocessor. Once it is awake, it will connect to WiFi. The latter will send the (RSSI) to a PC for calculations to determine its position.

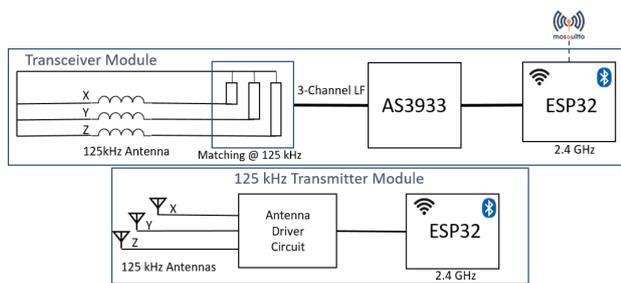


Fig. 1. Schematic of the transceiver and the transmitter module design used to wake-up the AS3933 chip and the ESP32 microprocessor to control the interrupts.

A. The Transceiver Module

A prototype is built to be used as the node in the whole system. This module is a mobile node to communicate remotely with the reference points (the transmitter) and the server. This module consists of three 125 kHz coils as a receiver, an AS3933 wake-up chip, ESP32 microprocessor, 2.4 GHz antenna for WiFi, a Qi charger module, a Shaker, a battery. The whole module is then covered in a 3D printed custom case (figure 2).

AS3933 chip is a 3D low-frequency wake-up Amplitude-Shift Keying (ASK) receiver with three channels as receiver. The chip detects the wake-up data signals with a low carrier frequency between 15-150 kHz by using an integrated correlator. The wake up signal is a programmable 16-bit or 32-bit Manchester pattern as presented in figure (3). The chip can operate using one, two, or three active channels. The AS3933 provides a digitized RSSI value for each active channel. The programmable features of AS3933 optimize its settings for achieving a longer distance while retaining a reliable wake up generation. The sensitivity level of AS3933 can be adjusted in the presence of a strong field or noisy environments.

Each channel of the AS3933 chip is consists of a three important parts as follows: variable gain amplifier (VGA), automatic gain control (AGC) and, a frequency detector. the gain of all channel amplifiers is set to maximum When the chip is in listening mode (waiting for RF signal). The frequency detector counts the zero crossings of the amplified RF signal to detect the presence of the wanted carrier. As soon as the carrier is detected the AGC is enabled, the gain of the VGA is reduced and set to the right value. The RSSI (Received Signal Strength Indicator)

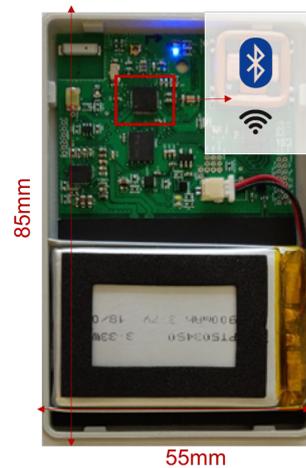


Fig. 2. The mobile transceiver module so called Tag

represents how strong the input signal is and it is the inverse representation of the gain of the VGA.

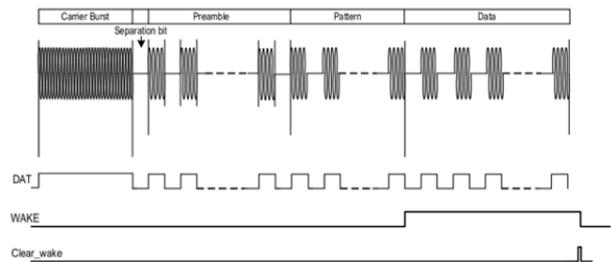


Fig. 3. The wake up pattern to activate the transceiver

B. The Transmitter Module

The transmitter module consists of three 125 kHz coils and a control system for creating the wake-up pattern figure 4. Then this pattern figure 3 is used to wake up the transceiver module. To provide superior control over the whole system, this module also includes small sub-modules (figure 4) to monitor the battery status and the current. The signals to derive the coil switches is imposed by a delay of 1.2 us for each MOSFET bridge to derive the coils. Each coil is emitting for total of 70ms which the data rate is 457 bit/s.

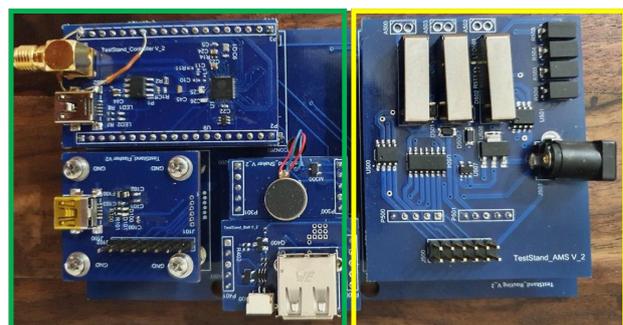


Fig. 4. The Transmitter (Yellow part) and control sub-module (Green part)

III. EMPIRICAL OPTIMIZATION AND CALIBRATION

Within the near field of an electrically small antenna, the propagation relation for like antennas (electric-electric or magnetic-magnetic) antennas is [10]:

$$\frac{P_{RX}}{P_{TX}} = \frac{G_{TX}G_{RX}}{4} \left(\frac{1}{(kr)^6} - \frac{1}{(kr)^4} + \frac{1}{(kr)^2} \right) \quad (1)$$

Which implies that the ratio of the received power (P_{Rx}) to the transmitted power (P_{Tx}) follows from the receive antenna gain (G_{Tx}), the transmit antenna gain (G_{Tx}), the distance (r) between antennas, and the wavenumber ($k = 2\pi/\lambda$). For indoor environments typically the first two terms are dominant. On the other hand, a corridor can act as a waveguide, resulting in path loss with the $\frac{1}{(kr)^2}$ to be dominant [11], [12].

In the Near-Field region of the 125 kHz coils, the inductive coupling between the coils enables the AS3933 to wake up the ESP32 and to receive an RSSI value from each channel in the chip. The maximum available power (P_r) of the receiver in the near field depends on the transmitted power (P_t), the permeability of the air μ_0 , the number of turns of TX and RX coil (N_t and N_r respectively), the radius of the two coils (R_r and R_t respectively), the frequency ω , and the distance between the two coils d . [13]

$$P_r = P_t \frac{\mu_0 \pi^2 N_t^2 N_r^2 r_t^4 r_r^4 \omega^2}{16 R_t R_r (r_t^2 + d^2)^2} \quad (2)$$

If we assume that there is no phase difference between the generated field of the source coil and the sensor coil, thus by modifications of the equation.1 so that $RSSI = 10 \lg(P_{RX})$ then the measured data by the AMS3933 enables us to find a relatively linear relationship between the recorded RSSI value and the position of the card. This relationship is modeled by:

$$RSSI = -10n \lg(d/d_0) + A + X_\sigma \quad (3)$$

Where d is the distance between the receiver and the transmitter, n is a parameter related to the specific wireless transmission environment. A is the RSSI value in the position of d_0 and the final term (X_σ), is a Gaussian distributed random variable with the 0 mean and variance of σ^2 . To compare the theoretical and the practical result, an experiment were set in the range of 1.5 meters away from the coil. In this experiment, the RSSI value of the tag were recorded and then compared to the expected value of RSSI with two theoretical formulas eq.(1) for near-field and far-field condition. Using the equation eq.(2) the specifications of the coils at receiver and transmitter side it is possible to calculate the transmitted power at each coil. The RSSI value were checked for all 3 coils on the tag. Each coil corresponds to certain direction. The receiver's coil at X and Y direction is identical (figure 5, 7). On the other hand the coil at Z direction (figure 6) is slightly different in the size.

The coil was placed vertically at Z axis, while the tag were moved horizontally along the X axis. The tag's

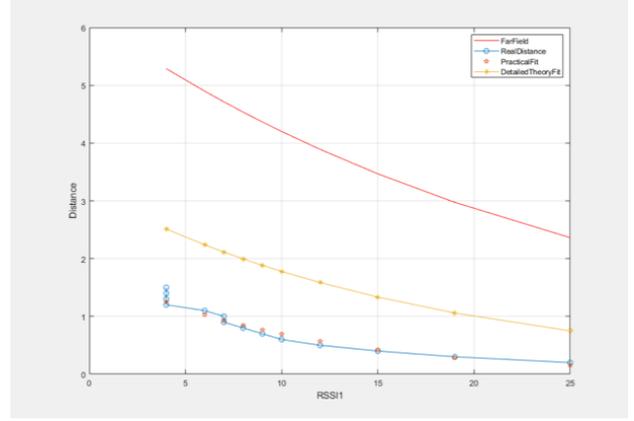


Fig. 5. Compression of the RSSI values for coil-x

orientation stayed the same in all measurements. The experiment were performed in an RF-friendly environment with wooden structures to hold the coil and to tag.

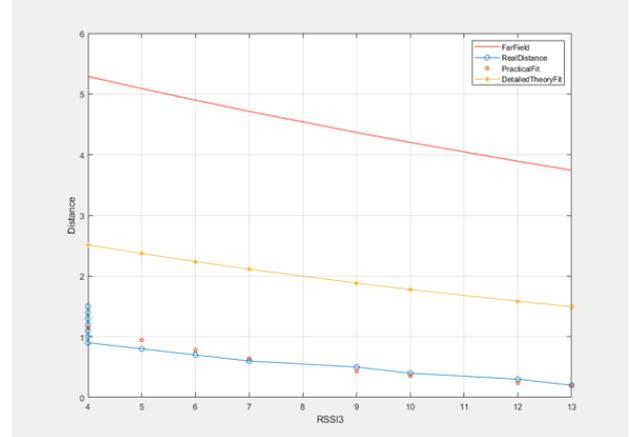


Fig. 6. The digitized RSSI value vs. the distance from the coil in meter from the coil-Z

The difference between the two theoretical equations and the practical measurements reveals that in real-life experiment, the an empirical fitting is required. In this measurements, the calibration was done at 1 meter.

A. 1D Movement and Calibration

For different settings, we tried to calculate the best linear fit by changing the antenna damper and gain reduction. In the tag, we get RSSI as a digitized value between 0-31 for each channel. By changing the specifications of the tag, we are able to decrease or increase the operation range of the tag and it's resolution. The goal is to find the optimal value for both the gain and the antenna damper so as to use the system in a range of approximately 1 meter. As a result, an experiment were set to move the tag away from one antenna and then measuring the RSSI value every 10cm. This experiment provides basic information about the operation range of a single tag and an antenna.

The R is the r value of the fitted linear curve while S and I are the values of the slope and the intercept of the fit. Finally the standard deviation of each group is presented by STD. This table enables us to choose between various options and specifications due to our needs and the

TABLE I
RSSI vs. $20\lg(d)$ LINEAR FIT

RSSI1	-4dB				-8dB				-12dB			
	R	S	I	Std	R	S	I	Std	R	S	I	Std
3K Ω	0.049	-1.32	-13.86	0.55	0.09	-2.28	-14.80	0.68	0.65	-15.37	-12.11	1.47
9K Ω	0.002	-0.26	-13.48	0.48	0.41	-2.86	-14.02	0.32	0.095	-2.60	-14.42	0.77
RSSI2	R	S	I	Std	R	S	I	Std	R	S	I	Std
3K Ω	0.25	-3.98	-13.63	0.66	0.14	-2.07	-15.15	0.48	0.52	-9.19	-13.11	0.845
9K Ω	0.02	-1.51	-11.78	0.95	0.40	-7.49	-12.46	0.875	0.003	-0.60	-12.73	1.038

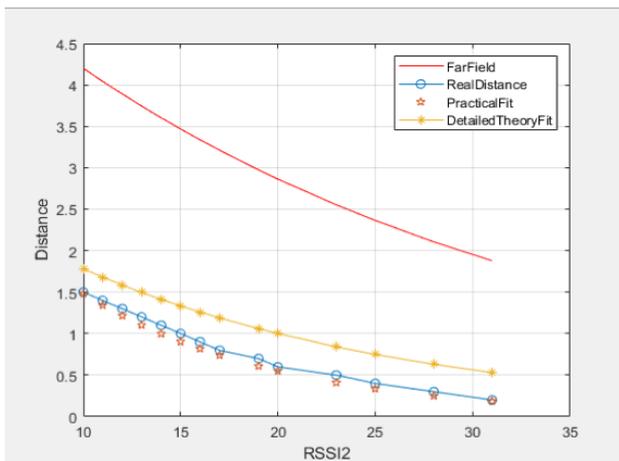


Fig. 7. The digitized RSSI value vs. the distance from the antenna in meter from the coil-Y

expected range. This table reveals that using 3k Ω damping factor and 12dB gain reduction is the most linear setting in the range of approximately 1 meter away from the coil.

IV. THE LOCALIZATION PROCESS

For real-time tests and device validation, a frame were made to fix the coils and to accurately collect data. A frame of 80cm by 80cm width and length with the height of 2.5m we made out of PVC to be able to move the card within the area and measure the RSSI value in the card. The coils were set at fixed position 8 at the height of 1m above the ground.

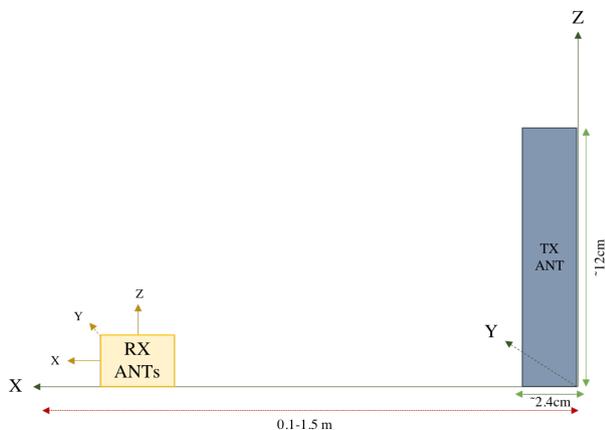


Fig. 8. The 1D movement of the tag towards the transmitter coil. The tag coils has the size of 15.6mm \times 17mm \times 3.7mm

In the AS3933 gives control over gain reduction and antenna damper. The antenna damper is a set of internal resistors that can be connected to the external resistors

which allows the chip to deal with higher strength. The gain reduction feature tightens the frequency detection tolerance. The shunt resistors of the antenna damper degrade the quality factor of the external resonator by reducing the signal at the input of the amplifier. In this way, the resonator sees a smaller parallel resistance (in the band of interest) which degrades its quality factor in order to increase the linear range of the channel amplifier (the amplifier doesn't saturate in presence of bigger signals).

V. CONCLUSION

The acquisition of this formula allows the use of this specific RF system for localization purposes. Unlike passive or high frequency (MHz, GHz) RFIDs, low frequency (kHz) RFIDs barely studied for RSSI based localization. This paper provide an application to use low power active RF system in semi-enclosed and complex environments for localization purposes with optimized settings.

This paper demonstrates that our positioning system is a feasible solution for positioning purposes specially in short ranges and semi-enclosed environments. The linear-logarithmic relationship between the received signal indicator and the distance for the 125kHz coil, depict the possibility of using the same system to determine the position of an unknown object in the region of transmitter's magnetic field. This system, benefiting from magnetic coupling effect enables the tag to wake up once it's in the field. This feature comes handy while trying to maintain the low power consumption for the whole system.

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