

# Phonemeter: Bringing EMF Detection to Smartphones

Yang Zhou, Yuanchao Shu, Peng Cheng, Zhiguo Shi and Jiming Chen  
Zhejiang University, China  
{yangz, ycshu}@zju.edu.cn, {pcheng}@iipc.zju.edu.cn, {shizg, cjm}@zju.edu.cn

**Abstract**—In this demo, we propose Phonemeter which leverages the RF energy harvesting technologies to measure the strength of Electromagnetic Field (EMF). To this end, Phonemeter combines EMF sensor with the smartphone through audio interface without any modifications to the phone. We fully implement the low-cost Phonemeter and conduct extensive experiments to prove the functionality of Phonemeter. Phonemeter achieves about 13.7% relative error in average compared with the industrial-grade spectrum analyzer with significantly reduced the costs.

## I. INTRODUCTION

Recently Wireless Rechargeable Sensor Networks (WRSNs) are proposed to enable sensor nodes to collect RF power from the ambient environment through the energy harvesting technologies.

In order to guarantee the stable working conditions of WRSNs, different works have investigated how to optimize energy provision, such as static deployment [1] or the dynamic walking path planning [2] of the charger, where the fundamental problem is how to provide the wireless power in order to support the functionalities of the networks. One basic assumption in many existing works is that the wireless power almost follows the Friis transmission model.

However, this assumption may become invalid in various application scenarios. For example, for indoor sensing applications, multi-path phenomenon results in signals reaching the receiving antenna by two or more paths. Multi-path makes it inaccurate to estimate the wireless power intensity only based on the existing Friis transmission model. One intuitive method is to collect the real wireless power intensity values through extensive measurements. However, wireless power detection and measurement are mostly performed using particular sensors or probes, such as spectrum analyzers, which are either expensive or sophisticated.

To address the above challenges, we propose Phonemeter, a smartphone-based portable EMF detector. By using RF energy harvesting technologies, Phonemeter harvests power from ambient RF environment and presents the EMF intensity on the smartphone screen. We fully implement Phonemeter and conduct extensive experiments. Comparison results show that Phonemeter achieves nearly 13.7% relative error in average as the industrial-grade spectrum analyzer with much lower hardware costs.

## II. SYSTEM ARCHITECTURE

Phonemeter consists of three main modules: EMF sensor, Headset interface and App on the smartphone. Figure 1(a)

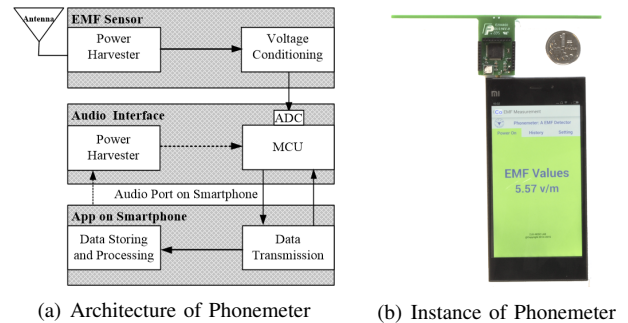


Fig. 1. Overview of Phonemeter.

shows the architecture of Phonemeter. Solid lines indicate the signal flow direction and dash lines show the power supply relationship among different modules.

EMF sensor transfers the intensity of electromagnetic into the voltage level of induced DC. A voltage is induced by the electric field of an electromagnetic wave at the antenna and boosted after the power harvester and voltage conditioning circuit. Firstly, a coin-sized EMF sensor produces the induced voltage and sends DC signal out. Secondly, Phonemeter measures the voltage level of the signal from EMF sensor and forwards data to the smartphone through the audio interface. Thirdly, we design an app on the smartphone converts the induced voltage from EMF sensor into the EMF intensity.

### A. EMF sensor

A high-frequency induced voltage is generated when the antenna is exposed into the electric field. However, the maximum conversion rate of ADC12 of the MSP430 F1612 manufactured by the Texas Instruments is about 200kps, that is far smaller than the frequency of induced voltage. Meanwhile the variation of the induced voltage of the antenna is small and not easy to be detected by the ADC12.

To tackle these problems, in power harvester module, we use 5-stage voltage multiplier circuit to convert the RF signal to DC signal and multiply the DC signal by 5 times. To reduce the cost, the voltage multiplier circuit consists of 9 capacitor and 5 low threshold Schottky diodes and only costs 7 dollar. Low threshold Schottky diodes are applied to increase the sensitivity to the small signal and increase the maximum of measuring distance. The maximum of measuring range is constrained to the reference voltage of ADC12. So an simple resistor voltage conditioning circuit is needed to adjust the

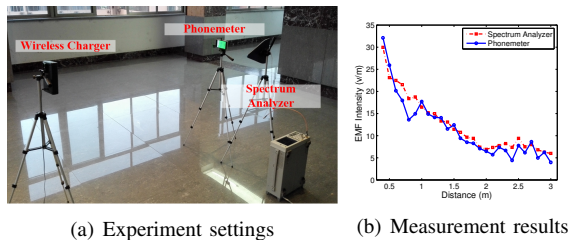


Fig. 2. Evaluation of Phonemeter.

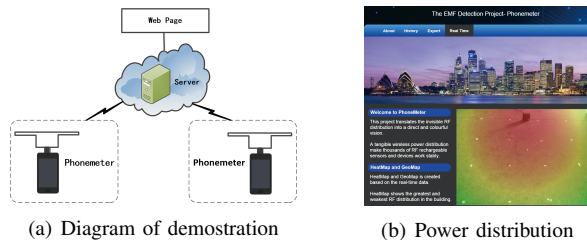


Fig. 3. Demonstration of Phonemeter.

amplitude of the DC signals to meet the measuring range of the ADC port.

Finally, we can get an voltage level of DC signal. However the conversion factor between the input electric field and the output DC signal of EMF sensor is unknown. So several calibration experiments are needed to get the conversion factors.

### B. Audio interface

Phonemeter uses an audio interface solution based on the component Hijack [3] to read the voltage level and transfer data to the smartphone. A power harvester component collects the energy transferred on the right channel of audio port by the smartphone to power the MCU. In order to make the smartphone easy to detect every bit on the audio port, phonemeter encodes the data stream with the Manchester encoding rule, which guarantees each data bit has one transition. Through our experiment, audio interface could achieve up to 100Bps without any errors. Thus the maximum of sampling rate of Phonemeter is 30Hz.

### C. App on the smartphone

To reduce the making cost of Phonemeter and simplify the operation procedure of the users, the computing tasks are completed on the smartphone. Data transmission module decodes data received from the microphone based on the Manchester encoding rule. The initial data received from the EMF sensor is the voltage level of the DC signal. The voltage of DC signal with unit  $v$  is converted into the intensity of electric field with unit  $v/m$  based on the conversion factors get from the calibration experiment by the processing module. Then the intensity of EMF are displayed on the screen and stored into local database for further use.

## III. IMPLEMENTATION AND EVALUATION

We implement the hardware and software design of Phonemeter and evaluate it compared with a spectrum analyzer. An instance of Phonemeter is plugged into an android phone as shown in Figure 1(b). The size of the Phonemeter is as small as an coin. App displays the real-time EMF measurement with the 0.01 precision.

We take the measurements by Agilent N9322C spectrum analyzer with the Aaronia HyperLOG 7060 log periodic antenna as the groundtruth and compare the measurement results between the benchmark and Phonemeter. We use Powercast TX91503 as the wireless charger, which work at 915 MHz with

the 3W output power. Measurement equipment are both installed on the tripods, like the Figure 2(a) shown. We increase the distance between equipment and the wireless charger from 0.4m to 3.0m and documents the results every 0.1m. Before this experiment, a calibration experiment is accomplished with the help of spectrum analyzer to get the conversion factors of Phonemeter to convert voltage readings into electric field measurements. The measurement results in Figure 2(b) show that Phonemeter gets about 13.7% relative error in average with much lower cost (around 32 US dollar v.s. 13000 US dollar) compared with the industrial-grade spectrum analyzer.

## IV. DEMONSTRATION SETUP

A demonstration system consists of Phonemeter, server and web page, which is shown in Figure 3(a). This demonstration is built to fuse measurements from different Phonemeters to display the wireless power distribution of the wireless charger. With the help of existing indoor localization system, like G-Loc [4], both the EMF intensity measurement and the corresponding position results are uploaded to the server by Phonemeter. The server will periodically update the data and visualize the EMF intensity distribution by utilizing the open source tool heatmap.js. A visual page that shows the EMF intensity distribution of wireless charger could be demonstrated like the Figure3(b).

## V. CONCLUSION

In this demo, we propose Phonemeter, a smartphone-based portable EMF detector. Given the good system performance as well as low cost and considering the fact that it can be implemented based on the widely used smartphone. We believe that Phonemeter can have a significant impact on the WRSN research projects.

## REFERENCES

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