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Characterizing the RF Performance of the eZ430-Chronos Wrist Watch

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***Abstract*—The Texas Instruments eZ430-Chronos development kit is a popular wireless platform for researchers, commercial developers, and hobbyists. Built into the form factor of a standard wrist watch, the Chronos is ideal for wireless body area networks (WBANs), indoor localization, and activity detection. Many of these applications requires knowledge of the RF performance of the platform, which has never been characterized by Texas Instruments nor any third parties. Here, we provide experimental data characterizing the RF performance of the eZ430-Chronos watch in various configurations, including when worn by a person while sitting, standing, and reaching. The RF performance of the Chronos watch is compared with an Angelos Ambient wireless mote that uses a common type of ceramic chip antenna. Our results indicate the Chronos has excellent omnidirectionality and reasonably good RF gain in all tested configurations.**

I. Introduction

The eZ430-Chronos is a reference platform and development kit made by Texas Instruments targeting smart watch applications that require wireless communication. The heart of the Chronos watch is a CC430F6137 microcontroller, integrating Texas Instrument's popular MSP430 core with a sub-GHz CC-series wireless transceiver borrowed from the company's Chipcon wireless portfolio. There are two different versions of the watch where the only difference is the operating frequency. One is shipped with out-of-the-box support for the US FCC 915 MHz ISM band and European EC 868 MHz license free operating band. The second version only operates on the 433 MHz European EC license free operating band. The watch also has an LCD as well as an accelerometer, pressure sensor, temperature sensor, battery/voltage sensor, buzzer, and user buttons – making it a popular research platform. The Chronos watch has been used to develop wireless sensor network (WSN) routing algorithms [1], protect endangered species [2], help people with Down syndrome [3], and perform indoor radio signal strength indication (RSSI) localization [4].

In many of these applications, knowing the transmit and receive power of the platform is important to evaluating its suitability for the application. While the datasheet for the microcontroller contains information about the receiver sensitivity and transmit power (when operating at various voltages, data rates, and radio configurations), this data only reflects the capabilities of the MCU – not the actual Chronos watch. The most important factors that influence the RF performance of the platform are the antenna gain pattern and the antenna efficiency.

One application where this information is critical is RSSI-based localization. The Chronos watch appears to be an ideal platform for localizing people indoors – the watch form factor is convenient to wear and, assuming it is programmed to behave like a watch, provides useful functionality for the participant. These two facts strongly enhance patient compliance. Its on-board accelerometer could also enable localization refinement via data fusion. Unfortunately neither Texas Instruments nor any third-party researchers, have ever characterized the RF performance of the Chronos watch.

II. Background

Antennas that do not produce a uniform radiation pattern (i.e., are not omnidirectional) cause the signal strength recorded by the receiver to be dependent on the orientation of both receiver and transmitter antennas. Modern RSSI localization algorithms use fingerprinting techniques to calibrate the system after it is deployed by mapping known locations to received signal strength vectors from the system [5]. This calibration process accounts for several position-dependent effects on the signal strength: multipath fading, line-of-sight obstruction, anchor mote antenna non-uniformity, and anchor-to-anchor variances in sensitivity. While this calibration process eliminates the omnidirectionality requirement for anchor nodes, it does nothing for the tag; all known algorithms assume the tag has a uniform antenna gain, and no known RSSI localization algorithm attempts to compensate for tags which have non-uniform antenna gain.

Antenna radiation patterns are usually not discussed in the field of RSSI-based localization because it is widely thought to contribute insignificantly when compared to other effects (such as fast fading). However, experimental results confirm that non-uniformity in typical antenna configurations has noticeable affects on signal strength [6].

Because of this, those interested in RSSI localization should consider the omnidirectionality of the antenna in the tags they use in their system.

III. Methods

To measure the antenna radiation pattern of the Chronos watch, testing was conducted at the electromagnetic compatibility testing facility at the Nebraska Center for Excellence in Electronics (NCEE), which consists of a $64 \times 44 \times 31$ ft semi-anechoic chamber, a computer-controlled rotating turret, precision antennas, and test receivers. Both the anechoic chamber and the control room are fully shielded, which isolates the rooms from environmental electromagnetic interference.

Figure 1. Horizontal (top) and vertical (bottom) orientations of Chronos watch

Before taking any measurements, a custom firmware image running on the Chronos watch was configured to transmit random data continuously with a center frequency of 917.996 MHz (we chose to use the watch with support for the 915 MHz frequency). The watch was configured to use 2-GFSK modulation with a deviation of 128.9 kHz from the carrier frequency. An EMCO hybrid antenna (Model No: 3142B, Serial No: 1654) was situated three meters away from the center of the turntable. In between the watch and antenna, polyurethane foam was set on the floor to help absorb electromagnetic energy that would otherwise reflect from the ground and skew the observations at the antenna. As the turntable rotated in increments of $10°$, an e-field strength measurement was made at every increment until the turntable completed a $360°$ rotation.

The radiation pattern for the Angelos Ambient wireless mote was also measured in the same manner as the watch.

All measurements were made with a CISPR 16.1 compliant Rhode & Schwarz EMI test receiver (Model No: ES126, Serial No: 100037). Environmental conditions varied slightly throughout the test: Relative humidity of 60 ś 5% and Temperature of $22 \pm 2°$ C.

The watch is also shipped with out-of-the-box support to operate on the 868 MHz frequency band but we did not perform measurements in those frequencies. The differences in antenna gain pattern for the operating frequencies are commonly negligible.

IV. Experiment

The Chronos watch was tested in four different configurations. The first configuration tests the watch's free-standing radiation pattern – i.e., when the watch is mounted to a non-conductive surface with line-of-sight radiation to the test antenna. This result will show the baseline omnidirectionality of the watch, and is useful to researchers who intend to mount the watch onto non-conductive structures. The second, third, and fourth experiment test the watch's performance when worn by a person in different orientations.

Additionally, the USB dongle was tested only in the free-standing configuration similar to the watch.

A. Free-Standing Watch

The antenna was elevated 90 cm above the ground plane to align it with the center axis of the Chronos watch. Non-conductive adhesive tape was used to fasten the watch and prevent unwanted movement. The Chronos watch was taped in both vertical and horizontal orientations (as seen in Figure 1) on a wooden pedestal in the center of the chamber's turntable 90 cm above the floor. The antenna radiation pattern was collected.

B. Person And Watch

For this experiment, the antenna was characterized while worn by one of the authors in several different geometries as seen in Figure 3. The first experiment shows the watch's characterization when the author stood with his arms by his

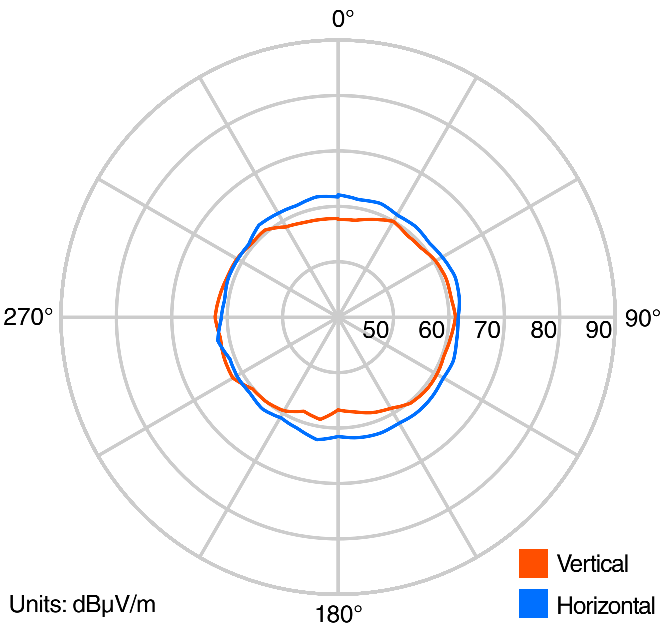

Figure 2. The Chronos watch exhibited relatively uniform radiation patterns.

Orientation	Mean (dBμV/m)	Variance (dBμV/m)
Horizontal	61.71	0.297
Vertical	60.14	2.080
Standing	62.25	5.414
Reaching	62.88	3.611
Sitting	61.5	2.711

Table I
MEAN AND VARIANCE OF THE CHRONOS WATCH ANTENNA CHARACTERIZATION

side, wearing the watch on his left wrist. This characterization is useful for simulating data of a person walking or standing still. The second and third experiment shows the author reaching and sitting in a chair respectively.

V. Results

The antenna radiation pattern for the eZ430-Chronos watch exhibits relatively strong omnidirectionality when free standing. As seen in Table I, the e-field measurements fluctuate around the mean value of 61.71 dBuV/m with a varience of 0.297 dBuV/m when the watch is placed in the horizontal position. When placed vertically, a slightly higher variance of 2.080 dBuV/m is observed but the e-field still fluctuates without abrupt changes in magnitude around its mean value of 60.14 dBuV/m. In both occasions, the strength of the e-field is similar in all directions implying excellent omnidirectionality which is close to an ideal isotropic pattern.

Radiation patterns were obtained for the Angelos Ambient for a comparative analysis. The Ambient is a wireless sensor

Orientation	Mean (dBμV/m)	Variance (dBμV/m)
Horizontal	76.32	26.614
Vertical	67.89	8.266

Table II
MEAN AND VARIANCE OF THE ANGLEOS AMBIENT ANTENNA CHARACTERIZATION

Figure 3. Pictures showing the geometry of one of the authors while conducting the standing, reaching, and sitting experiments, respectively.

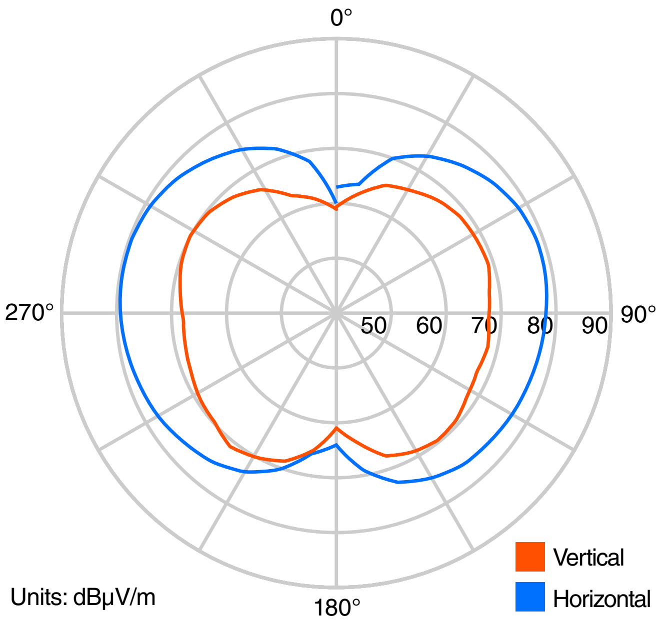

Figure 4. The Angelos Ambient wireless mote shows strong nulls at 0° and 180°, which lead to a nonuniform radiation pattern. The Ambient also has weaker gain

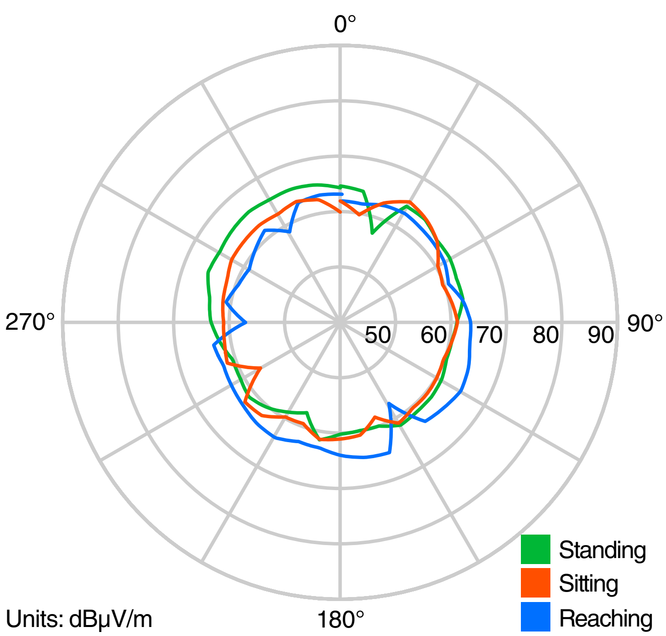

Figure 5. The radiation patterns of the Chronos watch when worn by an individual while standing, sitting, and reaching.

mote designed to localize tags, and uses the CC1101 radio, which is extremely similar to the radio in the CC430 – the Chronos's MCU. It uses a ceramic chip antenna (JTI, 0915AT43A0026E) that can be commonly found in wireless devices from many areas of industry. The Angelos Ambient antenna radiation pattern can be seen in Figure 4. Unlike the Chronos watch, it possess a non-uniform radiation pattern with a higher variance. The calculated variance of the ceramic chip antenna pattern can be seen in Table II. It clearly displays nulls at 0ř and 180ř reponsible for the high variance seen. Although these nulls may create complications in some applications, this is a phenomenon commonly seen in antenna designs and known as the figure-of-eight shape. It is important to notice that the Chronos watch does not exhibit nulls in its radiation pattern such as the Angelos Ambient does.

Innately, a person will be wearing the watch in the majority of applications involving this platform. Thus, it is advantageous to know the influence on the antenna characterization by the presence of a person. Figure 5 contains results for the author wearing the watch while standing, reaching, and sitting. Compared to the results of the freestanding watch, Figure 5 displays anisotropic radiation patterns possessing greater variance. As can be seen, there is a 6.74 dB drop when the person's body is between the watch and the test antenna. There is a corresponding 6 dB drop when the sitting person interferes between the watch and the test antenna, and once again a 6.4 dB drop when the standing person interferes. The distortion in the radiation pattern is seen from the human body absorbing electromagnetic energy and causing fluctuation in the e-field measurements. This is a common phenomenon seen in antenna characterization for devices when held by a person [7][8].

There are a multitude of applications where prior knowledge of the antenna characterization can prove to be useful such as RSSI localization. As previously discussed, with regards to existing RSSI localization, no known algorithms attempt to compensate for tags which have non-uniform antenna orientation and assume the tag has a uniform antenna gain. For example, if the watch is not omnidirectional it would introduce error in a subject's estimated position when the orientation of the watch is changed but it is kept in the same location. Since an isotropic radiation pattern is ideal for RSSI localization, these results indicate that the watch is a well-suited candidate where the assumption of a uniform antenna gain is considered valid due to the omnidirectionality of the watch's radiation pattern. This allows those interested in the field to dismiss inconsistencies in readings seen from nonuniform antenna gains as measurements in the signal strength vary due to the transmitter's orientation relative to the receiver.

VI. Conclusion

In this paper, antenna radiation patterns are obtained and analyzed to assess the RF characteristics for the poplar eZ-Chronos platform from Texas Instruments. Results show that the watch exhibits strongly omnidirectional radiation patterns, which make the watch a suitable candidate for several application where uniform RF gain is desired or needed. This work provides an additional resource for researchers in the absence of existing documentation for the watch's RF performance

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