**Effects of RF Emissions on Clock Drift**

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**EE4340 Fall 2015 Team 3**

**Abstract**

While most microcontrollers can be used with a variety of clock sources, the device's internal oscillator is the preferred source if it is present, and if application requirements allow for its use. The internal oscillator is the smallest and least expensive option for clocking, as it adds no additional cost and requires no additional space, unless an otherwise appropriate device is available at lower cost without an internal oscillator. However, the R-C circuit usually used for this purpose is less accurate than a ceramic resonator, crystal, or oscillator; it also drifts more with temperature and other environmental factors. However, the more data is available on its performance, the more applications it can be used for. With adequate data, the source selection is based on known risk and performance, rather than a conservative approach to an unknown. This could be useful to anyone who uses microcontrollers in a high-interference environment, such as an RF testing lab, near a radio transmitter, or even near Wi-Fi devices.

This experiment is designed to determine what, if any, effect radio-frequency emissions from external sources have on clock drift, and the consistency of that drift within different examples of the same MCU. MCUs from 4 popular vendors will be tested in this manner: Microchip Technologies, Texas Instruments, STMicroelectronics, and NXP Semiconductor. 5 part numbers from each manufacturer will be tested, and 6 examples of each part (3 under test and 3 control.) The MCUs will be tested under RF radiation of varying frequency and power density. Several treatments will be applied to each of the experimental units, in which the temperature will be held constant, all MCUs will be powered from identical power supplies, and RF radiation of 7 selected frequencies and 4 different power densities will be applied, one treatment at a time. For each treatment, a random selection of half the IUs under test will be placed in the test chamber at a time. Frequencies will be selected to correspond to commonly used radio services or other sources of RFI, and will range from 48 KHz to 5GHz. A set of power densities will be selected for each frequency, again to correspond with common real-world scenarios.

**Objectives**

There is a significant body of work on how radiation causes faults in electronics and embedded systems [1]. However, there is no quantitative data on how common RF (radio frequency) emissions in the range of 1 MHz to 5.5 GHz (inclusive) affects clock drift in an internal RC (resistor-capacitor) oscillator found in many microcontrollers. Usually, a clock source for a microcontroller is selected based on known factors, such as required accuracy, cost, availability of board space, and expected temperature level and variation. Without any data on the effects of RF radiation, selection of an appropriate clock source is limited to a conservative approach to this unknown. Therefore, in order to remove any guesswork associated with this unknown, the main objective of this experiment is to collect data on the effect on the dependent variable, the microcontroller’s internal RC oscillator clock drift, due to the independent variables of common frequencies and corresponding power densities of RF emissions.

The implications of new data will affect the viability of the internal RC oscillator in embedded systems. Quantitative data on the effects of RF emissions will determine the viability of internal RC oscillators in applications where heavy RF emissions are expected to be present. Since RF emissions are extremely common due to the communications industry, designers will be able to understand how their systems will be affected by RF emissions for the first time. In addition to new data being collected, we hope to answer whether frequency or power density has more of an effect on clock drift.

* Primary Objectives
  + To gather data on microcontroller internal RC oscillators exposed to RF emissions by recording the frequency of oscillation every second for an hour, totaling 3600 data points per chip.
  + To test 6 units of 5 microcontroller part numbers from each of the 4 vendors (20 different microcontrollers with a total of 120 parts in all). Out of the 6 units for each part number, 3 units will make up the control and test groups each. Add treatment amount etc.
  + To apply treatments of RF emissions of 7 common frequencies in the range of 1 MHz to 5.5GHz inclusive and 4 power densities per frequency based on the power densities received at different distances from the source.
* Secondary Objectives
  + To present the data collected in terms of the percent drift of the final frequency relative to the nominal frequency for each unit tested. These values will be grouped to their part numbers, and an average and standard deviation will be given to both control and test groups for each part number.
  + To present the data collected graphically for each part number with time as the independent variable and the frequency recorded at that time as the dependent variable for each set of data points from the 6 devices tested.

**Background**

“The majority of clock sources for microcontrollers can be grouped into two types: those based on mechanical resonant devices, such as crystals and ceramic resonators, and those based on electrical phase-shift circuits such as RC (resistor, capacitor) oscillators” [2]. Crystal, ceramic resonator, and RC oscillators are all sensitive to electromagnetic interference; however, only the RC oscillator has the additional disadvantage of poor temperature performance. One of the few advantages of the low accuracy RC oscillator is that it is the lowest cost option available, and is also typically available onboard a microcontroller with no extra circuitry necessary. This makes RC oscillators the desired source for non-critical or “low-budget situations” [3].

Issues involving EMI effects on electrical systems have been known about for a long time. Documents addressing how to handle these issues often cite typical sources of where the EMI may be coming from. For example, in an application note on erratic behavior in power-driven wheelchair due to EMI, the document cites that “common sources of EMI [include] cellular phones, CB radios, TV and radio stations, amateur radios and fire and ambulance radios” [4]. This citation provides justification for the frequencies we will be testing including: 1 MHz (AM radio stations), 100 MHz (FM radio stations), 600 MHz (UHF TV), 850 MHz, (Cellular), and 1900 MHz (Cellular). The widespread presence of Wi-Fi signals at 2.4 GHz and 5 GHz in 2015 justifies its inclusion to the test frequencies.

Methods for establishing temperature sensitivity on frequency for RC oscillators and mechanical oscillators are well established, and may provide insight on how to properly present data and errors after measurements have been taken. Since temperature variation in a crystal oscillator is small, “the frequency error of a crystal oscillator (denoted ε) is expressed in ppm (parts per million)” [5]. If the drift due to RF emissions is too much, the ppm method will become ineffective, and the drift will be presented as percent error.

Solutions to measure to RC oscillator’s frequency include using a spectrum analyzer or a frequency counter. Using a spectrum analyzer involves connecting the analyzer’s 50 ohm input to an antenna port to measure the output frequency error on the RF carrier and hence, ε. For most chips with a clock-out function, using a frequency counter is the simplest solution. Frequency counters measure the frequency of a signal by counting how many times a signal passes past a threshold value. Selecting a longer time base interval allows for more samples to occur, which in turn results in a more accurate result. To ensure the accuracy of the instrument it must be brought up to operating temperature. This will require leaving the instrument on for sufficient time before measurements are taken. A frequency counter with a data port will be need for data collection, such as a RS232C port on the B&K Precision 1823A, 1856D frequency counter [6].

Despite the large amount of data available on temperature drift, there is no standard time to expose the devices to temperature that could be equated to the amount of time we should expose the devices to RF radiation. Therefore, it is reasonable that exposure should occur for an hour to account for the potential of long term effects. Frequency counter sweep time will be set at an interval of 1 second to capture short term drift effects. For an oscillator operating in MHz a sweep time of 1 second will ensure plenty of counter samples for accuracy of measurement, while still allowing for many data points (3600 for a hour of testing) to be collected over the testing period.

RF test chambers are anechoic chambers and “are used today for performing EMC measurements,” and provides shielding from unwanted environmental EMI as well as highly reducing [7]. These chambers are typically rated for emissions in the frequency range of 30 MHz up to 40 GHz [7]. We will be testing frequencies as low as 1 MHz. “While, there are standard that call for radiated measurements down to the low kHz or even to the low Hz range, these standards do not specify any need for absorption or anechoic behavior” [7]. “In most cases, at these low frequencies where current absorber technology cannot deliver any level of absorption, the chambers are going to be too small (electrically) for resonant modes to appear” [7].

The basic equipment needed to produce RF emissions in the frequency range we need is a signal generator, a power amplifier, a transmission line, and a radial antenna. Signal generators are limited on frequency range and output power, so an RF power amplifier is needed to reach the desired power densities.

**Research Plan**

Carrier board: The first step will be the design of carrier boards to provide regulated power and other necessary support to the chips, such as voltage regulation capacitors, programming connections, etc. Each MCU model will have a custom board, except where a board design can be shared between multiple pin-compatible devices and remain within the manufacturer's specifications. Power will be provided via a linear regulator (LM317T,) with all manufacturer-specified capacitors for power quality as detailed below. Input to the regulator shall be provided by a 120V AC to 9V AC transformer, bridge rectifier, and 220μF, 16V electrolytic capacitor, in addition to the other capacitors specified for the LM317T: 0.1μF ceramic between input and ground (CI), 1μF ceramic between output and ground (CO), and 10μF electrolytic between adjust and ground (CA). A discharge diode shall be provided for CA, allowing current flow from Adj to Out. The MCU shall be provided the recommended/suggested supply voltage in the manufacturer's datasheet, or the center of the recommended range if no specific voltage is given, or the lowest level if several discrete levels are suggested. A temperature sensor will be installed through the bottom of the board, so that it will contact the bottom of the chip package to measure the chip's temperature. The clock out connection from the MCU, 9V power, and ground will be connected via a connector on the back of the board, to ease placement during testing and minimize interference to and from the cable. The MCU shall be obtained in the package highest in the following list in which it is available: 1. QFP / LQFP / TQFP, 2. SOIC, 3. SSOP, 4. BGA. The MCU shall be soldered to the board by IR reflow if surface mount, or wave soldering if through-hole mounted. Each board shall be made no larger than necessary to accommodate the components specified, to minimize manufacturing cost and area for potential interference.

Testing Conditions: The RF energy shall be applied to the top of the chip package, to minimize shielding and variability by other components. The bare board, with nothing covering the top surface of the package, shall be used in testing. As many concurrent tests will be run as possible, to minimize the total amount of time taken running trials (and thus cost.) Each example of the various models will be placed into a different trial, to account for variation within MCUs of the same model. Data is to be analyzed for common variation among the different MCUs in a trial, versus those in other trials at the same frequency and power level. Thus, overall, the 3 MCUs under test of each model, 7 frequencies, and 4 power densities per frequency will add to a total of 168 trials of 28 treatments, with ten MCUs in the test chamber at a time. In addition, 60 control MCUs will be tested in a further 6 trials. Each set will be selected at random to avoid confounding error, and to minimize effects of transient conditions or other changes not factored into the experiment. Each MCU will be run at its maximum specified clock speed that can be generated by the internal oscillator, with default tuning settings. Half-wave dipole antennas will be used for 100MHz and above, as they are small enough to be used in a test chamber. For 1MHz, an inductively-loaded half-wave dipole will be used, to allow the antenna to be small enough for the chamber. A testing structure will be constructed to allow 5 chips to be tested at one time, as well as to get equal amounts of power to be transmitted to the devices under test. Under the constraint that PCB length dimensions do not exceed the lengths of the sides of the test structure, and that there is a gap on either side of the PCBs, 2 pentagons with a diameter of 1m from a vertex to the opposite side will be 3D printed from a non-conductive plastic. The dipole antenna producing RF emissions will be positioned in the geometric center of the structure, split evenly down the height of the extruded pentagons. 1 PCB per side will be attached on the inside of the pentagon using non-conductive clamps to receive treatments. While one pentagon is being used for testing, the other pentagon will be populated with the next set of boards to be tested.

Treatment Details: The experiment tests the effects of 2 factors, frequency and power density, on one dependent variable, clock drift of an MCU's internal oscillator. The 7 frequencies used represent common radio communications, broadcast, and microwave oven bands. The frequencies are 1 MHz, 100 MHz, 600 MHz, 850 MHz, 1900 MHz, 2400 MHz, and 5500 MHz. These were selected to correspond to AM broadcast, FM broadcast, UHF television broadcast, the two most common cellular bands, and the two common wireless networking (Wi-Fi) bands. For each test frequency, a set of 4 test power density levels was selected. These correspond to power density expected at typical distances from transmitters. Calculations were made using estimated typical antenna gain for each application, along with typical transmit power levels. The distances and associated power levels (rounded to 2 significant digits) are as follows:

**Table 1: Transmitter Distances for Power Calculation**



**Table 2: Power Density Levels**



Testing Location: The testing will be performed at a commercial RF testing facility, to be selected based on cost, number of suitable small test chambers available, ability to control other factors (such as temperature and unintentional RF entry into the testing facility,) and past performance working with researchers. A minimal standard will be control of temperature within ± 1º Celsius, and measurement accurate to ± 0.1ºC to allow for correction of drift caused by temperature fluctuation. Temperature measurements will be logged to allow temperature effects to be accounted for. RF measurements will be performed in the test chamber during control trials (when no RF is being generated for testing,) to determine what, if any, undesired RF interference is present. Results from prior testing of this kind will be obtained from the testing facility for evaluation of the facility, and comparison with later testing data if that facility is selected.

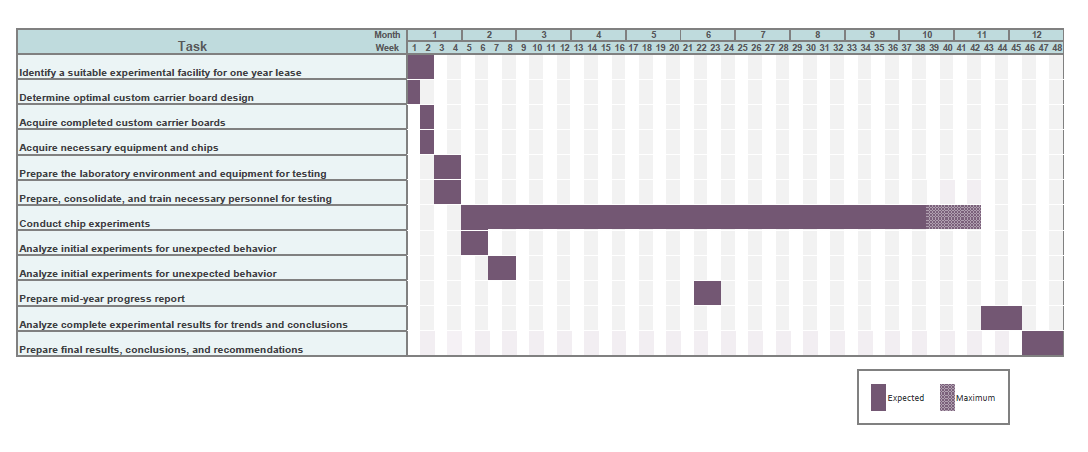
Device Selection: The devices selected for the experiment are produced by four of the largest microcontroller vendors in the world. They are chosen based on their feature sets, so that many applications may use the parts tested. Selection was also based on choosing newer parts more likely to be used in new designs, and in covering as many different chip families as possible, since oscillator designs are likely to be shared among different chips with otherwise closely related designs.

**Table 3: Microcontrollers to be Tested**



Procedure: The MCU will be placed, in its carrier board, onto the test stand. The external cable will be connected, consisting of 9V power, ground, temperature sensor signal, and clock out for measurement. A sheet of RF absorbent material (RAM) with a cutout for the chip, shall be placed onto the board to minimize interference with anything on the board other than the chip itself. The chamber will be closed, and the RF generator turned on. The power level will be allowed to stabilize for 5 minutes, then measurement will begin, using the frequency counters and data loggers for temperature. Measurement will continue for 1 hour, during which frequency and drift measurements will be taken every minute. At the completion of measurement, the total number of cycles will also be recorded, to obtain the overall drift. All measurements will be retained for analysis at the end of the experiment, as well as for quality control while it is proceeding. The data from the first tests shall be graphed and checked for any unexpected behavior, so this can be investigated to see if it indicates a problem with the experiment. These could include missing clock cycles (due to interference from the RF in the clock signal, or a connection problem) or complete lack of clock signal, for example. Temperature data will be used to correct for clock drift caused by temperature changes rather than RF, as the response of the clock to temperature is known.

**Project Timeline**



**Key Personnel**

Dr. Jason Dykes, Project Manager/Lead Engineer: Dr. Jason Dykes received his undergraduate and graduate education in Electrical Engineering at Stanford University. He joined the Aerospace Simulation Research and Development Branch at NASA in 1992. There, he led a team that pioneered research critical to the launch and maintenance of the International Space Station including the Station to Shuttle Power Transfer System. For this research effort, Dykes will lead the project team to ensure that the experimental methods, operations, and results will meet the specifications and goals of the sponsors. This includes organizing team meetings, direct collaboration with sponsors/suppliers, and financial planning. In addition, he will provide technical knowledge to the team and resolve issues when necessary.

Bryan Luu, Electrical Engineer: Bryan Luu received his undergraduate and graduate education in Electrical Engineering at Oxford University, specializing in the field of Radio-Frequency Engineering. Luu will be responsible for preparing the lab environment to mitigate unintended interference from any source including RF radiation, temperature fluctuations, and EMI power sources in order to maintain the integrity of the experimental results.

Brian McRee, Maintainability Engineer: Brian McRee received his B.S. in Electrical Engineering at Cornell University and his Graduate Degree Systems Engineering at Harvard University. McRee will be responsible for creating and implementing the procedures for consistent setup, operation, and maintenance of hardware, lab test equipment, and microcontroller firmware. In addition, he will complete routine maintenance and equipment troubleshooting. His responsibilities also extend to the safety of the lab test equipment operators and all personnel involved.

Jacob Sanchez, Software Engineer: Jacob Sanchez received his undergraduate and graduate education in Computer Engineering at Massachusetts Institute of Technology. Sanchez will be responsible for the design and implementation of all software involved in the project including those involved in experimental control, data acquisition, and data analysis.

Daniel Lee, Lab Technician Lead: Daniel Lee received his B.S. in Physics from Princeton University. Lee will recruit, orient, select, and train three lab technicians. These lab technicians will be responsible for operating test equipment, carrying out routine tasks, and assisting other members of the research team with any other necessary tasks.

**Management Plan**

Organizational Structure

* All Engineers and Leads will be in charge of their spheres of influence, but will report to the Project Manager/Lead Engineer when necessary.
* All lab technicians will report to the Lab Technician Lead.

Routine Procedures

* Monthly Team Meetings
  + The Project Manager/Lead Engineer will provide a summary of current progress of different areas of the research project for the entire team every month.
  + These meetings will allow current and potential issues to be brought up early and to be discussed between all relevant team members.
* Weekly Situation Report
  + The Weekly Situation Report will be an internal briefing of any and all things worked on or accomplished during a given week. The report will include time spent and progress on individual tasks.
  + The Project Manager/Lead Engineer will be able to use these reports to identify efficiency problems.
  + The reports will provide documentation and feed into the Monthly Team Meeting and the Mid-Year Progress Report.
* Mid-Year Progress Report
  + The Mid-Year Progress Report will provide an update of accomplishments and a rough timeline of future plans, halfway through the intended project’s timespan.
  + The research plan may change multiple times in the future, and the Mid-Year Progress Report can update the plan to reflect such changes.
  + The report will mainly be intended for external use by sponsors.

Communication Procedures

* Long distance/Telecommute
  + Under normal circumstances, once the experiments begin, no main team members will be required to leave the site. However, offsite/telecommuting team members can video-call into the Monthly Team Meetings.

Potential Risks and Potential Solutions

* Personnel cannot continue working with the team
  + There will be careful documentation of the experimental methods and procedures required to run the experiment.
  + New lab technicians will be recruited and trained by the Lab Technician Lead.
* Data Errors
  + There will be an analysis of early experimental results to identify unusual behavior.
  + The experiment procedure uses multiple trials, which reduces the chance of error.
* Equipment Breakdown
  + One spare of each test equipment will be kept in stock at all times.
  + Consistent equipment problems can be dealt with by changing equipment brand.

**Available Resources**

* 3 B&K Precision 1823A available to us to use during our research
* Miscellaneous wires and connecting cables for the equipment.

The facilities and equipment needed for the research is very specialized and needs to be bought in order to finish the research.

**Budget**

|  |  |  |  |
| --- | --- | --- | --- |
| Personnel | % Time | Year 1 | Total |
| Dr. Jason Dykes | 50 | $60,000.00 |  |
| Project Manager |  |  |  |
| Bryan Luu | 30 | $21,000.00 |  |
| Electrical Engineer |  |  |  |
| Brian McRee | 30 | $21,000.00 |  |
| Maintainability Engineer |  |  |  |
| Jacob Sanchez | 30 | $21,000.00 |  |
| Software Engineer |  |  |  |
| Daniel Lee | 60 | $24,996.00 |  |
| Lead Technician |  |  |  |
| Lab Technician 1 | 90 | $31,500.00 |  |
| Lab Technician 2 | 90 | $31,500.00 |  |
| Lab Technician 3 | 90 | $31,500.00 |  |
|  |  |  |  |
| Total Salaries |  | $242,496.00 |  |
| Fringe Benefits |  | $82,033.80 |  |
|  |  |  |  |
| Total Personnel |  | $324,529.80 | $324,529.80 |
|  |  |  |  |
| Equipment |  |  |  |
| 6 B&K Precision 1823A |  | $2,820.00 |  |
| RF Generator |  | $2,000.00 |  |
|  |  |  |  |
| Total Equipment |  | $4,820.00 | $4,820.00 |
|  |  |  |  |
| Travel |  |  |  |
| 2 person-trips per year |  | $1,200.00 |  |
|  |  |  |  |
| Total Travel |  | $1,200.00 | $1,200.00 |
|  |  |  |  |
| Supplies |  |  |  |
| Cables, Surface mounts, |  | $5,000.00 |  |
| MCU, and RF absorbent Material(RAM), |  |  |  |
| External hard drive, and structure materials |  |  |  |
|  |  |  |  |
| Total Supplies |  | $5,000.00 | $5,000.00 |
|  |  |  |  |
| Total Direct Cost |  | $335,549.80 | $335,549.80 |
| Indirect Cost |  | $99,218.94 | $99,218.94 |
|  |  |  |  |
| **Total Budget** |  | $434,768.74 | $434,768.74 |

**Budget Justification**

* Personnel
* Dr. Jason Dykes
* Project leader organizing the meetings and provide technical knowledge to resolve issues when necessary as stated in Key Personnel.
* Lab Technicians
* Three lab technicians are needed for the testing to go smoothly. It is essential that we have two peoples during the testing of the chips to ensure that the experiment and data collection goes smoothly. The third person will mainly focus on documentation of the experimental methods and will start on plotting the gathered data looking for possible trend lines to present at the weekly meetings.
* Equipment
* B&K Precision 1823A
* Extra are bought to follow the rule of “one is none and two is one”.
* Travel
* Two Person Trips
* This is for possible events where information could be given to help us in our research efforts.
* Supplies
* Misc. Equipment
* This is the equipment needed to build the device that is going to be used to hold the MCU’s, materials to house the MCU’s, external hard drives that might be needed to hold the data, and the MCU’s themselves.

**References**

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[4] Getz, Robin, and Bob Moeckel. "Understanding and Eliminating EMI in Microcontroller Applications." Texas Instruments. National Semiconductor, Aug. 1996. Web. 25 Sept. 2015. <http://www.ti.com/lit/an/snoa382/snoa382.pdf>. Literature Number: SNOA382

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[6] "Frequency Counters: Models 1823A, 1856D." B&K Precision Corp., 2014. Web. 25 Sept. 2015. <http://www.mouser.com/ds/2/43/1823A\_datasheet-181239.pdf>.

[7] Wiles, Martin, and Vince Rodriguez. "Choosing the Right Chamber for Your Test Requirements." ETS-Lindgren. Interference Technology, May 2010. Web. 23 Sept. 2015. <http://www.ets-lindgren.com/pdf/item\_mwvr\_0510.pdf>.

**Team 3 Research Proposal Assignment Responsibilities**

Abstract – Jason Dykes

Objectives – Brian McRee

Background – Brian McRee

Research Plan – Jason Dykes

Timeline – Bryan Luu

Key Personnel and Management – Bryan Luu

Available Resources – Jacob Sanchez

Budget and Budget Justification – Jacob Sanchez

Proofreading – Team

General Research – Team