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Building and Testing an Economic Faraday Cage for Wireless, IoT Computing Education and Research

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Abstract:

Internet of Things (IoT) technologies have been proliferating in the last decade. Societal reliance on IoT technologies has been increasing over the last 5 years and is projected to increase exponentially. Wireless communication is a core component of the IoT ecosystem. Cellular and wireless technologies are also foundational topics in the NICE (National Initiative for Cybersecurity Education) framework. Educational institutions have been increasingly adding IoT, cellular, and wireless courses to their curricula, to keep in line with societal and regulatory trends.

Faraday cages are instrumental in understanding and testing several aspects of the wireless paradigm. Faraday cages are also indispensable for wireless signal isolation, which is an important aspect of any IoT/Cellular/Wireless technology course. Commercially available Faraday cages that are suitable for use in teaching or research environments are priced in the range of $3,300 and beyond. Such pricing may disincentivize institutions from deploying Faraday cages in their classrooms. Unavailability of Faraday cages in classrooms can in turn lead to deficiencies in curricular effectiveness and assessment for IoT/Cellular/Wireless courses. Lower cost alternatives are needed.

We constructed a custom-made, low-cost Faraday cage using materials that are available over the counter at a local hardware store or an online superstore. We listed materials and their approximate costs required to build a Faraday cage from scratch. We presented a step-by-step guide with visual aids to walk readers through the process of constructing a Faraday cage suitable for classroom use. We presented comparative signal attenuation testing results of our custom-built Faraday cage. We discussed the challenges faced in our construction and curricular integration efforts. We discussed the suitability of our custom-built Faraday cage in teaching and research environments.

I. **Introduction**:

With more schools starting to offer cybersecurity degrees, it is important that these schools align with the National Initiative for Cybersecurity Education (NICE) Workforce Framework for Cybersecurity (NICE Framework) [1]. One part of that framework is developing a deeper understanding of cellular and wireless technologies. A deeper understanding requires a mechanism to isolate and test cellular and/or wireless signals. When testing the security of cellular and wireless devices, it is important to ensure that you are only analyzing the signals of the device in question. This can be difficult as cellular and wireless signals from other devices exist everywhere. To maintain cellular and wireless isolation a Faraday cage must be used. Purchasing a Faraday cage for educational, research settings is costly. Cages that can be used in a teaching environment are priced at $3,300 and beyond [2].

II. Background and Related Work:

A Faraday cage is an enclosure used to block electromagnetic fields. It is constructed with a conductive metal, usually a copper mesh, that will distribute charges or radiation. Such a distribution helps keep externally generated wireless signals on the outside of the cage and internally generated wireless signals on the inside of the cage. As such, a Faraday cage helps provide an isolated wireless signal test environment.

We found limited prior published work when surveying literature on the topic of custom-built Faraday cages. Our literature survey included an extensive search of the ACM Digital Library, the IEEE Explore Library, and Google Scholar. The searches yielded two related articles on custom built Faraday cages. Trefethen discusses the surprises in understanding the mechanics of a Faraday cage [3]. The article does not detail the construction process for building a Faraday cage. Hill discusses utilization of an inexpensive Faraday shield for forensics analysis [4]. Although the work uses a custom-built Faraday cage, it doesn't discuss steps, materials, and costs involved in building a custom Faraday cage.

III. Materials and Costs:

Table I presents a list of materials required and their costs to custom-build a Faraday cage that is 19 inches wide, 20 inches deep, and 28 inches high. All the materials listed in Table I can be purchased at most hardware stores. The prices listed in Table I were obtained from Amazon.com between the months of February and April of the year 2019.

Table I: Materials required and their costs to custom-build a Faraday cage.

Item	Quantity/Price	Total
Cabinet 19" x 20" x 28"	(1) @ $5	$5
Cork Roll 1/2" x 4' x 25'	(1) @ $90	$90
Conductive Fabric	(5) @ $24.99	$124.95
Conductive Tape 2.5"	(2) @ $19.99	$39.98
Conductive Tape 1"	(4) @ $10	$40
Gorilla Glue	(1) @ $12.99	$12.99
Wood Glue	(1) @ $14.99	$14.99

Door Latch Pack	(1) @ $11.96	$11.96
2’ x 2’ x 8’ Wood	(3) @ $4	$12
1/2” x 4’ x 4’ Particle Board	(1) @ $12	$12
1/2” Foam Seal Tape	(1) @ $9.95	$9.95
Power Strip	(1) @ $44.95	$44.95
Used 20A Powerline Filter	(1) @ $130	$130
120V AC 120mm Muffin Fan	(1) @ $14.99	$14.99
Copper Mesh #120 13” x 40”	(1) @ $14.88	$14.88
1/2” x 36” Copper Pipe	(1) @ $10	$10
1/2” Copper Elbows	(2) @ $1.99	$3.98
1/2” Pipe Clamp Pack	(1) @ $8.60	$8.60
USB LED Light	(1) @ $7.29	$7.29
Fiber Optic Media Converter	(2) @ $39.99	$79.98
9’ Fiber Optic Cable	(1) @ $14.79	$14.79
Total	**33 items**	**$793.28**

IV. **Construction Process**:

Here we present a step-by-step process to custom-build a Faraday cage. We started with a metal cabinet, whose dimensions are 19” wide by 20” deep by 28” high. Figure 1 illustrates the cabinet that we started with. The steps in this manuscript can be applied to build larger Faraday cages by scaling the materials and dimensions specified here.

The first step is to line the inside of the cabinet with a layer of cork. We attached a layer of cork to the cabinet using gorilla glue. The cabinet we used had metal standouts, so we used two layers of cork to adequately cover all the metal. Figure 2 represents the inner state of our custom-built Faraday cage at this stage. Next, we installed a layer of conductive fabric around the inside of the cabinet. The conductive fabric sheets will hereafter be referred to as ‘fabric sheets’.

We used thumbtacks to keep the fabric attached to the sides of the cabinet. We covered the thumbtacks with conductive tape to minimize leakage of signals from the thumbtack punctures. To minimize signal leakage, it is important to overlap the fabric sheets a couple inches. Also important is using conductive tape to connect the sheets. We left a few inches of overhang for the fabric sheets so that they can wrap around the wooden supports that are about to be installed. Figure 3 represents the inner state of our custom-built Faraday cage at this stage.

Figure 1: Original Cabinet

Figure 2: Insulated Cabinet

Figure 3: With Conduction Fabric Ready for Installation

We installed top and bottom wood supports within the cabinet using 2’ x 2’ pieces of wood. We fortify the top, bottom wood supports using 4 pieces of wood as columns. The cabinet we used has a structural lip. To nullify the lip impacts, we used a 2' x 4' piece of wood for the front. We pre-drilled the holes in the wood to prevent splitting when screwing the wood together. Figure 4 illustrates the wood support pieces. We erected the wooden support structure inside the cabinet using the pre-drilled holes to connect the columns to the base and top supports. We were careful not to over penetrate the wood when nailing down the support structure. Figure 5 represents the inner state of our custom-built Faraday cage at this stage.

Figure 4: Supports for the Cabinet

Figure 5: Supports Installed in the Cabinet

Next, we covered the outside edge of the support wood using a 1/2" foam seal tape. We then wrapped the fabric sheets over the supports. And in doing so, we have created a padded seal for the door. Some types of cabinets may require incisions to be made into the sheets to fold the corners. If incisions are made, we recommend that the cuts be covered with conductive tape. Figure 6 represents the inner state of our custom-built Faraday cage at this stage.

Figure 6: Supports Insulated in the Cabinet

We cut out three layers of cork that fit the inner seal, to construct the door shielding. We then attached the three cut out layers of cork to the inner chamber using gorilla glue. Next, we covered the cork with two layers of fabric sheets and attached the 1/2” foam seal tape around the door. We covered the 1/2” foam seal tape using the 2.5” conductive tape. Figure 7 represents the door seal of our custom-built Faraday cage at this stage.

Figure 7: Door Seal for the Cabinet

We cut out a hole in the rear of the cabinet for the powerline filter using a 3/4” hole saw. Next, we cut out a hole on the other side of the rear using a 1/2” hole saw. We inserted a copper pipe into the cabinet using the hole cut out in the last step. We ran the pipe as close as we could to the front of the cabinet, leaving enough room to attach a 90-degree elbow to run the pipe down. We found that it is a good idea to transmit the optical cable through the pipe and the 90-degree elbows, before attaching the elbows to the pipe. Figure 8 represents the powerline filter connectors of our custom-built Faraday cage at this stage.

Figure 8: Powerline Filter Connectors for the Cabinet

We drilled a hole on the outside of the cabinet to insert the powerline filter, which has a 3/4" threaded tube. We attached the powerline filter to the cage using a 3/4" nut on the inside and 4 small-sheet metal-screws on the outside of the cabinet. Next, we connected the inner powerline wires to the power strip by splicing the cable. Then we used the plug end of the cable to attach to the outside connections of the powerline filter. Figure 9 represents the inner state of our custom-built Faraday cage at this stage.

Figure 9: Internal Penetrations in the Cabinet

Next, we add another layer of fabric sheet to the inside of the cabinet. We used conductive tape to seal the fabric to the copper pipe to minimize signal leakage. We ran the fabric on top of the first layer and wrapped it around the upper and lower 2” x 2” boards to allow a bottom shelf to be placed on top of the lower 2” x 2” boards.

We then attached a piece of particle board to the bottom of the cabinet using gorilla glue. The particle board was placed such that it was sitting on top of the 2” x 2” boards. We attached another layer of cork to the inside of the cabinet to protect the fabric from damage. Figure 10 represents the inner state of our custom-built Faraday cage at this stage.

Figure 10: Second Layer of Cork for the Cabinet’s Interior

Next, we drilled a hole in the top of the cabinet, using a 3” hole saw, to allow installation of an exhaust fan. We drilled another hole in the lower side of the cabinet for an intake vent. We used an air redirection vent for the top, and it did not work very well. Then, we used a hole saw to create a duct for the side air intake and it worked much better. Figure 11 represents the exhaust fan opening slot of our custom-built Faraday cage at this stage.

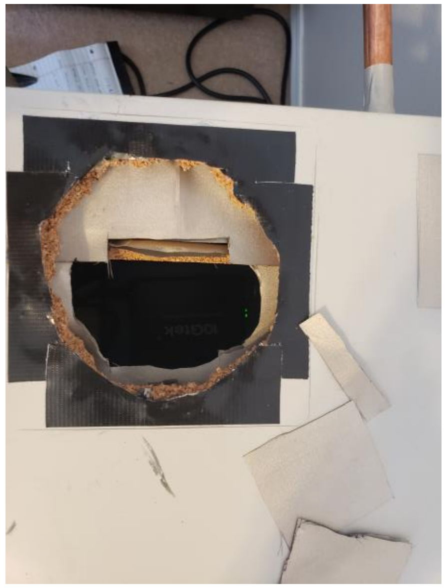

Figure 11: Exhaust Fan Opening for the Cabinet

We attached two layers of copper mesh to the fabric sheet to seal the hole at the top and on the side. We performed the attachment using the foam seal tape and the conductive tape. We used the foam seal tape to add spacing between the two layers of copper mesh to improve ventilation. We then attached a 120mm muffin fan to the top of the cabinet using short sheet metal screws. We found that it may be beneficial to attach a second fan on the intake vent to improve airflow. Figure 12 represents the inner state of our custom-built Faraday cage at this stage.

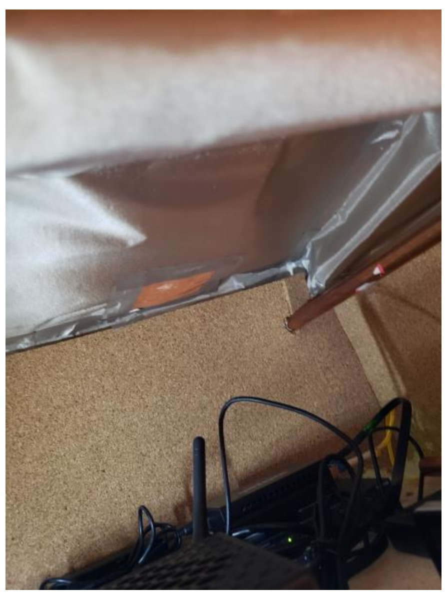

Figure 12: Copper Mesh for the Cabinet's Exhaust

Next, we added a second shelf at a height of 3/4 of the current inner chamber. We cut four 2" x 2" boards and a piece of particle board. We pre-drilled holes in the bottom of the 2" x 2" boards to allow them to be easily attached to the bottom particle board. We screwed in the 2" x 2" boards to the bottom and screwed from the top of the particle board into the 2" x 2" boards. We then used an expanding foam to fill the space between the boards and the cork and screwed the sides into the cabinet. This will keep the shelf stable without fixing the cabinet in one place. Figure 13 represents the inner state of our custom-built Faraday cage after installing the expanding foam.

Figure 13: Shelf and Foam for the Cabinet's Interior

We then trimmed the foam, installed the rest of the copper pipe and mounted the power strip. We ran the optical cable through each of the pieces of pipe before connecting them together. After connecting the copper pipe, we placed conductive tape over the connections. We used two 1/2" pipe clamps to secure the copper pipe. Figure 14 represents the finished interior of our custom-built Faraday cage. Finally, we mounted the door latches using short sheet metal screws and covered the side air intake using conducted tape. Figure 15 represents the finished exterior of our custom-built Faraday cage.

Figure 14: Completed Interior of the Cabinet

Figure 15: Completed Exterior of the Cabinet

V. Signal Attenuation Testing:

To test the effectiveness of our custom-built Faraday cage, we used an Alfa AWUS1900 Dual Band USB 3.0 Wi-Fi Network Adapter, Netgear R6250 WiFi Router, and the Kismet [5] application on Kali Linux. We used the comparative signal strength measurement method for testing the attenuation efficiency of our custom-built Faraday Cage. Figure 16 represents our testing devices.

Figure 16: Testing Equipment

We applied 2.4 and 5.8 GHz signals with the door open and the AWUS1900 outside of the door the 5.8 GHz signal was measured at 17 dbm and the 2.4 GHz signal was measured at -9dbm. Figure 17 represents the measured signals with the door of the custom-built Faraday cage open. After closing the door, the measured 5.8 GHz signal strength dropped to 82 dbm and we were unable to detect the 2.4GHz signal. Figure 18 represents the measured signals while the door of the custom-built Faraday cage was closed. Our tests show an attenuation of 99db which is similar to many commercially available enclosures. The lowest attenuation was measured at 96db above the exhaust fan.

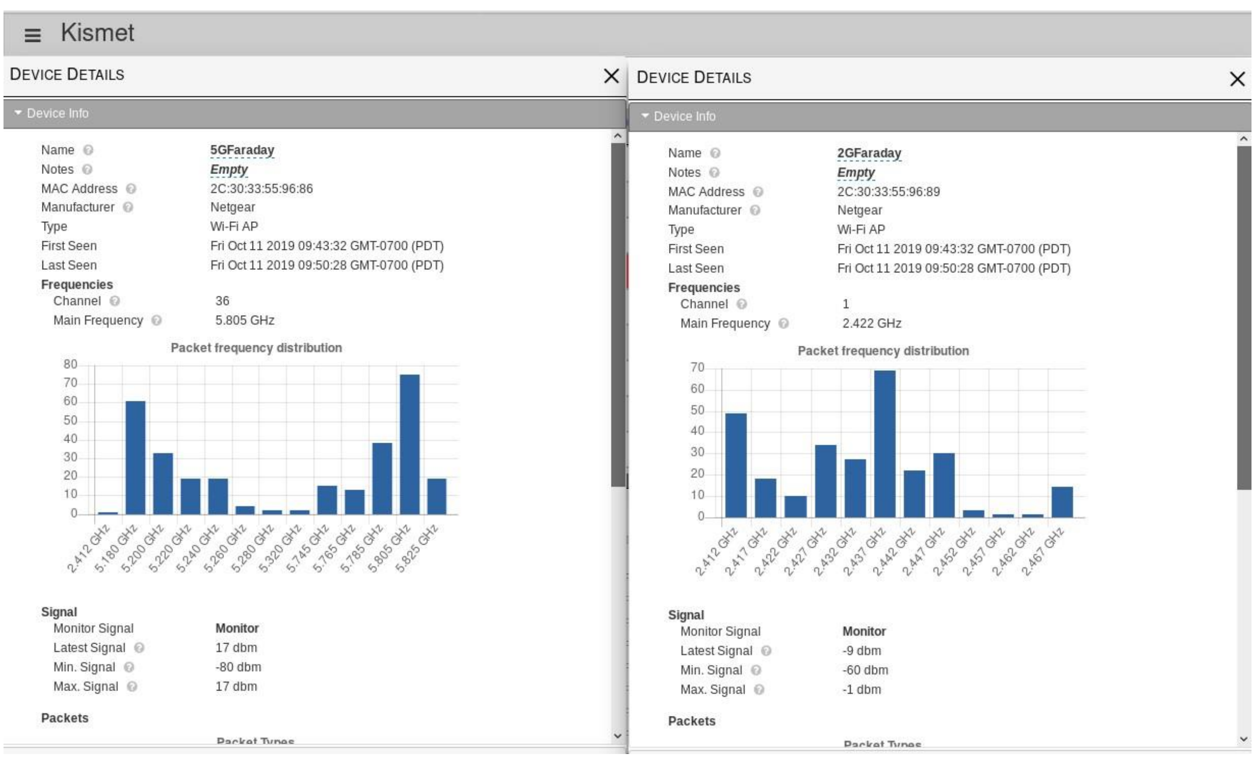

Figure 17: Signal Strength of Wireless Signals with an Open Door (5.8 GHz Signal on the Left and 2.4 GHz on the Right)

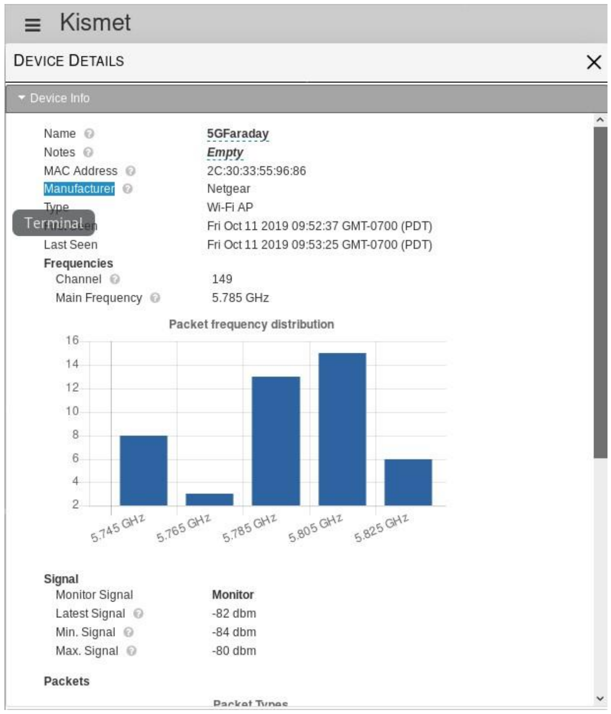

Figure 18: Signal Strength of Wireless Signals for 5.8 GHz sign with Closed Door (2.4 GHz Signal too Weak to Measure)

VI. Limitations and Challenges:

Results discussed in Section V indicate that our custom-built Faraday would be suitable for teaching and preliminary research purposes. We did not validate our custom-built Faraday cage for advanced research or commercial purposes. As such, our custom-built Faraday cage may not be suitable for advanced research or commercial purposes.

Section III does not include an exhaustive list of all tools used in our construction process. Appliances commonly found in engineering departments such as a power drill, and multi-tool Swiss knife were not included in Section III. Access to individual(s) with basic workshop skills is required for replicating the construction process described in this manuscript.

Individual(s) trying to replicate the process described in this manuscript may face circumstantial or contextual problems that we did not encounter. Reasons for potential differences in circumstantial problems include i) changes in the operating environment, ii) workshop skill level of involved personnel, and iii) variations in purchased material quality.

Instructors for courses with a large enrollment size may have to divide their class into multiple subgroups and schedule separate time slots for each subgroup. Which will ensure students in the subgroup can interact with the Faraday cage for an adequate amount of time. The size of a subgroup and duration allocated to a subgroup will depend on the overall class size and activities at hand. It would take a subgroup of three students at least 15 minutes to replicate the testing activities performed in Section V. As such, courses with large enrolment sizes may benefit from building multiple Faraday cages.

VII. Conclusion:

We have shown that a cost-efficient custom-built Faraday cage can be constructed that performs similar to costly commercial alternatives. The construction process presented in this manuscript can be scaled up to a larger enclosure by increasing measurements and associated materials in direct proportions. We demonstrated the functionality of our custom-built Faraday Cage by performing comparative signal attenuation testing on the cage.

VIII. References:

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