

Casing Prototype Design for Portable Electromagnetic Radiation Detector using 3D Printing Technology

Muhammad Akmal Hanif Azman¹, Mohd Fahrul Hassan^{1*}, Syarfa Zahirah Sapuan², Yee See Khee³

¹ Faculty of Mechanical and Manufacturing Engineering,
University Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

² EMTEX CTS Sdn. Bhd. Incubator Space, Aras 2, Bangunan Penyelidikan, Blok F6,
University Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

³ Faculty of Electrical and Electronic Engineering,
University Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author: fahrul@uthm.edu.my

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Abstract

This research aims to design and develop a casing prototype for portable electromagnetic (EM) radiation detectors that apply to outdoor environments conditions by using 3D printing technology. The investigations involved water ingress inside the casing, resistance due to prolonged UV irradiation exposure and determining shielding effectiveness from material characterization of ASA material. The findings of this research indicated that the shielding effectiveness (SE) of the casing prototype is as low as 7 dB at the range operating frequencies. Next, the designed casing prototype can resist water ingress into the hardware compartment. The result also shows good UV resistance of the material selected for the casing. Thus, the casing prototype design has been successfully developed and is ready for a real-case application.

1. Introduction

The rapid expansion of mobile telecommunications networks around the world has raised public concern about potential health risks from exposure to electromagnetic (EM) radiation emitted by both mobile phones and base station antennas [1]. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has published technical guidelines on exposure limits for all EM fields. EM radiation should not exceed the radiation limit proposed by ICNIRP. Therefore, this maximum allowable EM field limit must be followed for human safety [2].

A previous study innovated a real-time portable EM radiation level and monitoring system that can detect EM radiation from mobile base stations and the environment. The radiation detector was successfully designed and experimentally verified which is able to operate on mobile frequencies of 0.9 GHz, 1.8 GHz, and 2.1 GHz [3].

The EM radiation detector that can fulfil the current demand and limitation of the existing product is worth to be developed. Based on the previous study where the radiation detector was successfully designed, and its functionality in terms of hardware and software was verified experimentally, a further investigation on proper device making is good for the next step. However, before being ready for up-scaling and mass production for the whole system, there is a need to design and develop a prototype to accommodate this device. This prototype must be able to withstand the real outdoor environment and ensure that the complete system can process numerous data from several devices.

Therefore, a portable EM radiation detector that applies to outdoor environments is a necessary and crucial device. Thus, this study conducted a casing prototype design for the portable EM radiation detector using 3D printing technology. Next, the step is to develop the casing prototype to integrate with the hardware. Several tests are conducted to verify the casing design effectiveness in outdoor applications.

2. Methodology

This section provides a detailed description of the methods employed in the investigation. The objective of this study is to develop a casing prototype for a portable radiation detector that will be used for outdoor applications. Since it will be exposed to extreme weather conditions. Thus, the designed experiment is the replication of the real case problem.

2.1 Water Absorption Test

Fused Deposition Modeling (FDM) is a widely used 3D printing technology known for its cost-effectiveness and versatility. However, creating truly waterproof parts using this method presents several challenges. One significant limitation is the layer-by-layer construction process inherent to FDM, which can result in microscopic gaps between individual layers. These inter-layer spaces make it difficult to achieve a completely watertight seal, as water can potentially seep through these tiny openings. Thus, this test is to check if there are any gaps and if any water absorbs through the layer gaps. First, the initial mass of the casing is measured. The casing is then submerged 0.3m underwater for 30 minutes. After 30 minutes, the casing is wiped down and the casing mass is taken to calculate the water absorption rate.

2.2 Rainwater Ingression Test

This test was identified as a probable situation during the casing's use. This test will be conducted while placing the casing under the rain for an hour, as shown in Fig. 1 (a). Tissue paper is put inside the casing which will be scaled before and after the test. The acceptance conditions are fulfilled when there is no visible penetration of water or moisture inside the enclosure that could adversely impact the safety or functionality of the electronic hardware.

2.3 UV Exposure Test

UV exposure test is conducted to determine the degradation of the selected material after prolong UV irradiation exposure. The test will be conducted by placing several samples under UV exposure for a duration of time. The test is done by using a UV Accelerated Weathering Tester machine as shown in Fig. 1 (b).



Fig. 1 (a) Rainwater ingress test setup; (b) UV accelerated weathering tester machine

2.4 EM Shielding Effectiveness Test

Material characterization measurement is conducted to test the shielding effectiveness (SE) of the casing. The measurement is done by using co-axial probe method, as shown in Fig. 2, to determine material electromagnetic characterization of the selected material for the casing prototype.

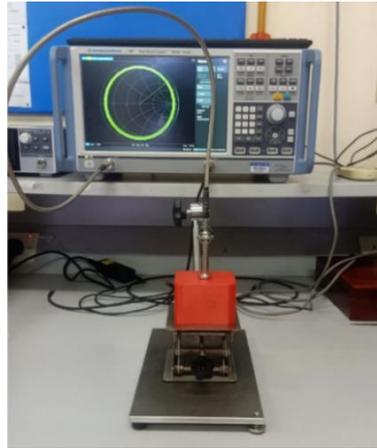


Fig. 2 Coaxial probe setup apparatus

3. Casing Prototype Design

3.1 Product design specifications

This section elaborates regarding the steps taken in the design process. First, design planning such in product design specifications in Table 1 is set to guide the engineering design activities and results in a set of product design specifications for developing a product.

Table 1 Initial product design specifications

Aspect	Objective	Criteria
Functional & Performance	Assembly	Easy to attach and detach
	Radiation detection	Allow electromagnetic waves to penetrate for radiation measurement by the receiver device
	Water-resistant	Protect hardware from any contact with water
Material	Suitable for outdoor application	Long-lasting performance under extreme weather
Design	Minimise size	It must be compact but allow hardware integration
	Simple	Keep simplicity but at the same time optimise the casing functionality and performance.
	Thickness	The thickness should be able to comply with the desired shielding effectiveness.
	Number of components	As less as possible

3.2 Waterproofing

The objective is to protect the hardware device from being damaged. Once deployed the casing will be continuously subjected to outdoor weather such as sunlight and rain. In order to ensure the long-term viability of the casing, Acrylonitrile styrene acrylate (ASA) was chosen since it possesses strong resistance to the outdoor environmental conditions. The casing also has specifically designed to prevent water from seeping by applying static radial seal with the using of O-ring. It to make the water tricky to get in. The water must come in through a gap sideways, then go up, pass a seal, go to the top, and move sideways again before it reaches the electronics, as shown in. The main idea was to make sure the O-ring doesn't directly touch the water. The body casing and the lid also have a tight tolerance gap of only 0.05mm which doable to be printed by using 3D printer.

Next, there are two radial seals applied, one for the inner lid and another for outer lid as in Fig. 3. The outer lid function is to give extra protection to the casing. Hence, it requires water to go for a long path to reach the hardware compartment. Thus, this would ensure the safety of the electronic hardware from any damages due to water ingress.

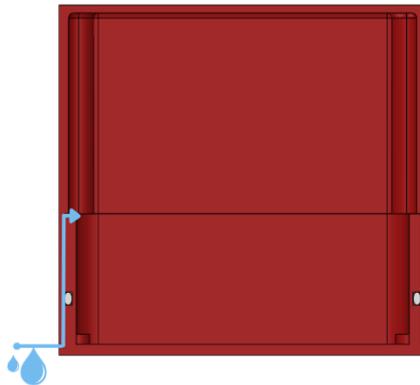


Fig. 3 Water ingress path

3.3 Accessibility

Other than being designed to make the water ingress path more difficult, the design also provides ease of assembly. The casing is designed with a slide in method such in Fig. 4. Opening and closing the casing requires the user to just slide in and out the lid to fully seal the casing. Next, it also provides ease of access. The casing was designed with two sliding circuit boards. One for microcontrollers and one for antenna receivers. The body casing has a slot that allows the circuit board to be easily attached or detached. For general maintenance the casing can be easily taken out.

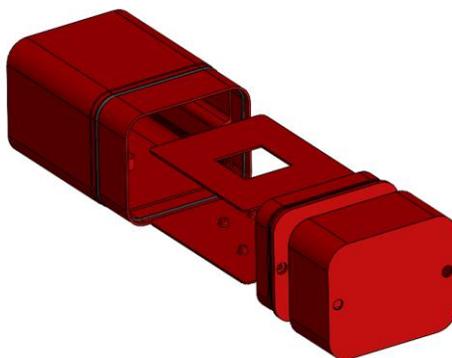


Fig. 4 Open assembly of casing prototype

3.4 Improve Printability with Gradient Bosses

3D printing is a layer-by-layer based manufacturing process. This technique requires each layer to have a layer beneath it, which means it cannot print a layer in midair with nothing below it [4]. Designing an overhanging feature is not recommended since it requires printing temporary support that will use more material usage, is time-consuming, and is costly. Printing external screw holes for the casing mounting bracket requires support since it is an overhanging feature. However, to make the casing as cost-effective as possible and to reduce

printing time, the screw bosses were designed with a gradient angle from the main body casing, as shown in Fig. 5.

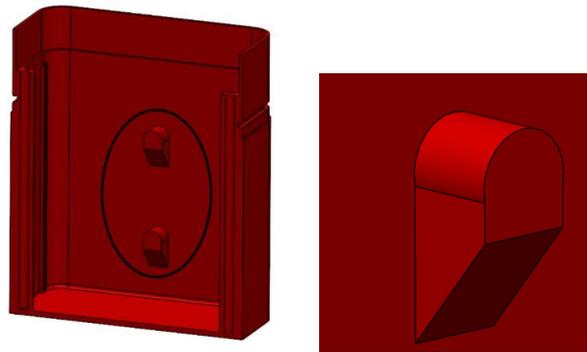


Fig. 5 Screw bosses supported by gradient to improve printability

3.5 Simulation

Simulation shows how effectively the model is working. In this case, it demonstrates the effectiveness of the design to integrate the radiation detector hardware inside of it such as Fig. 6. It also important as it determine the right sizing of sizing functionality of each components, fitting and tolerances.

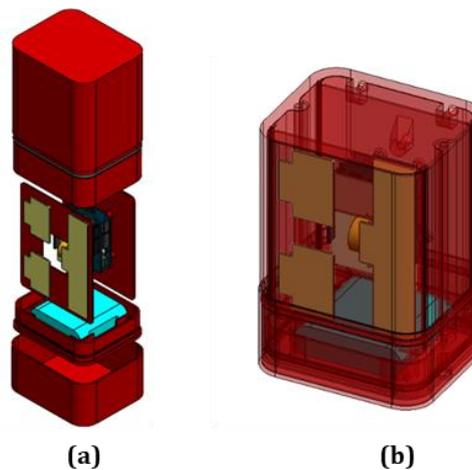


Fig. 6 (a) Exploded assembly of the integration; (b) Isometric view of integration

3.6 Prototyping

Developing prototype using 3D printing is conducted. With prototyping, validation of the design concepts can be made. This helps in understanding whether the theoretical design translates well into a physical form and functions as intended. Various changes have been made to correct the design flaw that was detected during prototyping. Fig. 7 shows the 3D printed prototype.



Fig. 7 Isometric view and front view of casing prototype for portable radiation detector

4. Result

This section discusses the result of the experiment. Then, the results will be related with the objective of the research whether it achieved or vice versa.

4.1 Water absorption

From Table 2, the mass of the casing is equal to the initial mass before immersion. This means there is no porosity between layer lines during printing process. Inter-layer mesh well between each other during printing process. Hence, it can be said that 3D printing casing prototype for portable radiation detector can be applicable for outdoor applications.

Table 2 Water absorption of casing before and after immersion

Test #	Mass of the casing		Water absorption (g)
	Mass, before (g)	Mass, after (g)	
1	201.47	201.47	0
2	207.50	207.50	0
3	207.50	207.50	0

4.2 Rainwater Ingress

In this test, the acceptance conditions are fulfilled when there is no visible penetration of water or moisture into the enclosure that could adversely impact the safety or functionality of the product. Table 3 shows that no water able to penetrate into the casing. The most vulnerable locations are the powerbank and hardware compartment, however there is no sign of moisture can be seen in these locations as in Fig. 8 (b). Fig. 8 (a) shows the lid part. It is observed that there is a little amount of water penetrates only just before the O-ring. This means that the O-ring has helped to seal the casing properly thus preventing further advancement of the water inside the casing.

Table 3 Water absorption of the paper before and after rain

Test #	Mass of the tissue paper		Water absorption (g)
	Mass, before (g)	Mass, after (g)	
1	5.41	5.41	0
2	5.43	5.43	0
3	5.41	5.41	0

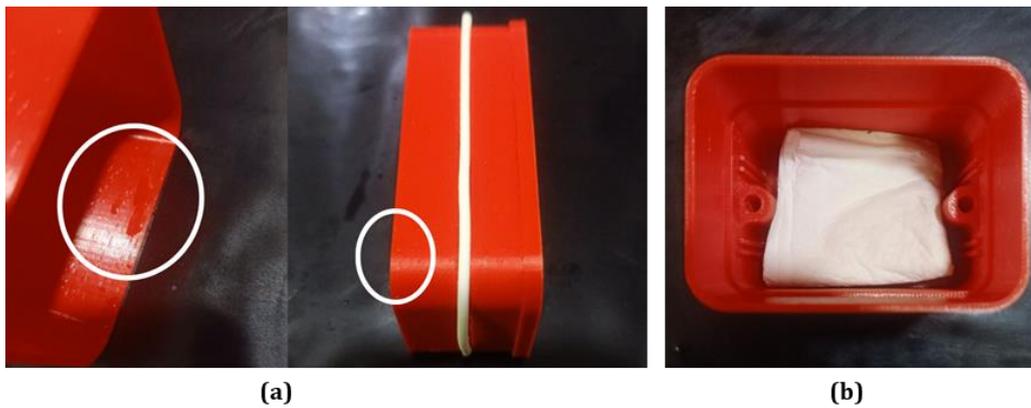


Fig. 8 Water ingress just below the O-ring; (b) No sign of water ingress in hardware compartment

4.3 UV Exposure

After prolonged exposure of UV under sunlight ray, casing might show colour degradation or another surface defect. Thus, this test is to determine the degradation of the selected material after prolong UV irradiation exposure. Fig. 9 demonstrates the result after 1000 hours of UV exposure. There are not any changes detected. The colour has no degradation, and no surface crack or defect can be detected. To conclude, the casing colour can be long-lasting as ASA material can endure UV exposure for a long duration.

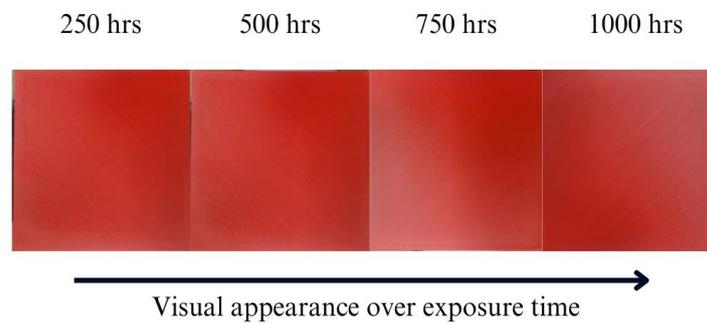


Fig. 9 Visual appearance due to UV exposure time. Excuse for light interference.

4.4 EM Shielding Effectiveness

Shielding effectiveness (SE) refers to the ability to block the penetration of EM fields. This is particularly relevant in the context of EM interference. SE is commonly used to prevent unwanted EM interference or to protect sensitive electronic devices from external electromagnetic fields. However, in this study, the SE must be as low as possible to ensure the antenna inside the casing can receive the EM wave from the environment.

Table 4 shows SE values ranging from 7.52 dB at 900 MHz to 21.75 dB at 1500 MHz. This range is very low which indicates it is very easy for EM wave or radiation to penetrate within the casing. This can be compared with aluminium foam which has better shielding effectiveness that range from 25 dB to 75 dB within 130 to 1800 MHz [5]. Moreover, common electronic casings have a shielding effectiveness more than 40 dB at 1 GHz in most applications [6].

Since the reasonable target for this project is to get as lowest as possible SE values, thus, this test passes the requirement. This also means the thickness of the casing at 4.6mm is reasonably designated. Other than that, the selection of ASA which has low electromagnetic shielding characteristic contribute to the low SE value. Low value of SE means the hardware can detect and measure more accurate data of radiation.

Table 4 EM characterization and shielding effectiveness of material

Frequency (MHz)	Permittivity, ϵ'	Permittivity loss, ϵ''	Electrical conductivity, σ (S/m)	Reflection resistance, (Ω)	Reflection current, (I)	SE (dB)
900	1.291	1.45×10^{-5}	7.25×10^{-7}	1.00	-0.016	7.52
1500	1.331	3.43×10^{-5}	3.25×10^{-6}	1.00	-0.031	21.75
1800	1.335	3.76×10^{-5}	3.76×10^{-6}	1.00	-0.033	13.85
1900	1.333	3.83×10^{-5}	4.05×10^{-6}	1.00	-0.035	16.83

2000	1.335	4.06×10^{-5}	4.51×10^{-6}	1.00	-0.037	15.61
2100	1.336	4.23×10^{-5}	4.94×10^{-6}	1.00	-0.039	16.14

5. Conclusion & Recommendations

All the parameters and criteria for designing a required casing have been identified. This casing is meant to accommodate portable radiation detector hardware, which can protect it from any element that might cause harm and damage to the parts. The casing has low shield effectiveness of 7 dB to 21.75 within the range of frequencies of 0.9 MHz to 2.1 MHz. This means that the casing is totally acceptable for the use of portable radiation detectors. The casing effectiveness in outdoor applications has also been verified.

The sealing performance of the enclosure worked with satisfaction. In the real case scenario, the casing will be placed under the rain conditions. During the rainwater ingress testing, the casing was able to prevent the ingress of water into the hardware compartment. The selection of ASA material also contributes to getting water-resistant casing. As there is no water leakage due to porosity between layer lines and last-long ability under high temperature and long UV irradiation exposure.

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