Early Wheel Train Damage Detection Using Wireless Sensor Network Antenna

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1. Introduction

In the transportation sector especially in railway systems, it is a must to take into account when revolves to the predictive diagnostics and security. The most common reasons of railways accidents are derailment of a freight car caused by wheel train damage [1]. Due to the numbers of coach of the train and immense in level of noise, the train crew will be unnoticeable about the derailment. Derailment will cause severely damage kilometers of track and hit the train at opposite site of track [2]. To improve the railway security, a lot of creations have been done in designing and implementing a detector device of the wheel trains. It can then possible to maintain before a major breakdown occurred. The traditional approached is a device that purely in mechanical technique that located in the two ends of train coaches and touched with the train brake line. But, these types of detector are come out with drawbacks which are very costly and complexity in their installation [2]. Thus, to improve the traditional method, an onboard wireless sensor networks (WSNs) was introduced. This method is
capable in monitoring the functioning conditions of the train’s wheel bearing and provides the indicator of realtime warnings in case of faults. This system is consisted of sensors which notified about diagnostic information in wireless mode, the process will operates the same from the whole carriage and all the information will collected by the central router. The sensors that placed in pair are attached inside the wheel’s bearing housing of the train [3].

This project is focus on one part of wireless sensor network which is antenna where it will be implemented in communication part. Antenna is a passive device designed for transmitting and receiving radio frequency signal which need to transceiving a high degree of performance over the entire potential environment range [4]. For these project’s environment, antenna need to be designed in small size, low losses, high performance and not sensitive to the metal. A small patch antenna design by CST Microwave studio simulation is proposed to achieved all those characteristic as well as will be attached to the detector device.

Other focuses in these project is the detection part where a detector will be develop to sensing the current temperature and instantly been monitored by the loco pilot (train pilot) using installed android phone application. The detector device and the application are connected wirelessly to an access point or wireless fidelity.

2. Antenna Design

2.1. Initial design

Initial design is made by calculating the dimension of the antenna based on the frequency, wavelength and material’s relative permittivity. The initial design uses equation (1) for the patch width. It was then followed up with equation (2) and (3) which is needed to find the patch length using equation (4).

An initial guess at the patch width:

\[
\text{Width (mm)} = \frac{c}{2fr} \sqrt{\frac{2}{\varepsilon_r + 1}}
\]  

(1)

Effective parameters:

\[
\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}}
\]  

(2)

\[
\frac{\Delta L}{h} = 0.412 \left( \frac{\varepsilon_{reff} + 0.3}{\varepsilon_{reff} - 0.25} \right) \left( \frac{W}{h} - 0.264 \right)
\]  

(3)

Patch length:

\[
\text{Length (mm)} = \frac{c}{2fr\sqrt{\varepsilon_{reff}}} - 2\Delta L
\]  

(4)

The parameters calculated by equation (1-4) are applied in the antenna as seen in Figure 1.
The FR-4 material has a relative permittivity value of 4.8 and the initial height is 1.6 mm. The result of the calculation is as follows:

| Parameters         | Calculated value |
|--------------------|------------------|
| Effective permittivity, $\varepsilon_{reff}$ | 3.494 |
| $\Delta L$        | 0.75 mm          |
| Patch width, W     | 36.7 mm          |
| Patch length, L    | 28.2 mm          |

To obtain the S11 graph that falls on the desired frequency, all the calculated values obtain in Table 1 are adjusted. For antenna simulation, a transmission line with the width of 1.3 mm from the edge of the substrate to the patch was added. The resulting antenna is shown in Figure 2.

**Figure 1. Antenna dimension.**

**Figure 2. Initial design of antenna**

### 2.2. Design modification

In order to achieve the main objective of this project, modifications are needed. The method used is by altering the design of the antenna in CST Software and simulate them to observe the reading. The modification is made based on the previous result. In each modification, several parameter sweeps were made. However, the overall parameter sweep results are not included here. Only the best parameters are taken based on the criteria stated in objectives of this thesis. Chronologically, the steps of the antenna’s modification are as follows:

i. Adding slot in the top of patch as shown in figure 3.
ii. Adding inset feed at the connection of the patch and transmission line shown in figure 4.
iii. Adding stub in transmission line as shown in figure 5.
iv. Final adjustment to all parameters shown in figure 6.

**Figure 3.** Slot added in the top of patch.

**Figure 4.** Inset feed added at the connection of the patch and transmission line.

**Figure 5.** Stub added in transmission line.

**Figure 6.** Height of transmission line and inset were increased

2.3. Antenna fabrication process

The designed antenna in CST is then fabricated into an actual antenna as seen in Figure 8. The antenna is then analyzed using the network analyzer equipment. The flow of fabrication process is shown in Figure 7.

**Figure 7.** Flow of fabrication process
Figure 8. Fabrication antenna

2.4. Antenna results and discussion
After fabricating the antenna, the antenna is being analyzed by using network analyzer. S11 graph, VSWR and smith chart are the parameters analyzed by using network analyzer. Figure 9 shows the S_{11} result of simulation and measurement antenna. It can be seen that both simulation and measurement return loss of the antenna in good agreement. Both results manage to obtain less than -10dB at their resonance frequency. Based on the result, it shows that the measurement result is slightly different with simulation results. The simulation result drop exactly at 2.45GHz, while the measurement result drop at 2.46GHz with -29.81.

Figure 9. Simulation vs measurement of S_{11} result.

For VSWR, the simulation result VSWR is 1.0385692 while for the measurement is 1.07 as shown in Figure 7. From the value of VSWR, it can be conclude that there is no power reflected from antenna. The quality of an antenna can be defined by the value of VSWR, lower the value of VSWR more quality of antenna performance is matched to the Tx line - Transmission line and the high power is delivered to the antenna.
Lastly for the smith chart, the simulation results shows the impedance and transmission line is almost match with 50 Ω from the port. The result of the simulation is shown in figure 11 and measurement shown in figure 12.

Table 2 shows the summary of radiation pattern for simulation and measurement result. The radiation pattern of the antenna is shown in figure 13 and figure 14.

| Table 2. The result summary |
|-----------------------------|
|                           | Simulation | Fabricated |
| Gain                      | 4.95 dB    | 4.8 dB     |
| Directivity               | 5.7 dBi    | 5.1 dBi    |
| VSWR                      | 1.0385692  | 1.07       |
| Impedance matching        | 51.92 Ω    | 45.85 Ω    |
Figure 13. Farfield gain of simulation antenna.

Figure 14. Farfield directivity of simulation antenna.

There are three main characteristic about of radiation pattern. There are:

- **Efficiency**
  The antenna efficiency is the ratio of the directivity to gain. For this antenna, the total efficiency is 84.12%.

- **Gain**
  The gain of the antenna is closely related to the directivity. For this antenna, the gain is higher than 3dB which is 4.97dB. Thus, this antenna capable to transmit their signal in long distance.

- **Directivity**
  The directivity is a measure which describes the directional of transmitting properties of the antenna. The directivity of this antenna is 5.701dBi. The directivity of the antenna is the capability of antenna to focus the signal in particular direction as well as transmitting and receiving signal. This antenna radiated in one direction to penetrate more power and obtain maximum performance of the antenna.

3. Development of monitoring system

Monitoring the wheels train current temperature is main objective of this project. There are few hardware need to be used where there are Arduino Nano as microcontroller, ESP8266-07 as Wi-Fi Module, LM35 as temperature sensor and light-emitting diode (LED) for the threshold indicator. The reading of the current temperature will be monitored in Android Application. The full system overview is shown in Figure 15.
3.1. Data acquisition and processing

Figure 16(a) shows the connection of Arduino nano, LM35 and LED. The LM35 will acquire the reading of current temperature and the Arduino nano was programmed in Arduino IDE software using C language where to read instantly the reading as well as gain the output of LM35. For Figure 16(b), it shows the connection between Arduino nano and ESP8266-07, with AT-command and Hypertext Transfer Protocol (HTTP), the reading will be available in the ThinkSpeak.com cloud as mentioned in Figure 16(c). The ESP8266-07 was flashed with the latest firmware and has been configured as a station mode to connects to the train’s WiFi. The LED used to indicate the threshold level of the reading temperature where it will be turned ON if the reading was exceed 75°C, if below than 75°C, the LED will be turned OFF. Figure 13 shows the temperature reading in two condition where in Figure 17(a), the temperature was under GOOD condition and in Figure 17(b), the temperature was exceed the limit of GOOD condition.

Figure 16. Arduino nano, LM35 and LED connection (a) Arduino nano and ESP8266-07 connection (b) The cloud server used (c).

Figure 17. The temperature reading test using serial monitor of Arduino IDE (a) temperature was in GOOD conditions which is $\leq 70^\circ$C (b) temperature was exceed the limit of GOOD condition $\geq 71^\circ$C
3.2. Android application development
The reading that available in the cloud will be read by the android application where the application was developed in MIT App Inventor that using graphical programming as explain in figure 18. Same protocol with the microcontroller is a must where if not, the connection would not be success. The protocol used is HTTP and the transferred data of temperature reading will be programmed with generate a graph as shown in figure 19(b).

(a)

![Flow of android application development](image)

(b)

**Figure 18.** Flow of android application development.

This Android application will be installed in Android-based device and be placed in the train cockpit as well as been monitored by the train’s pilot. The device must connected to the Train’s WiFi where if not, it will not capable to read the temperature reading from the cloud server.

(a)

![Home interface of android application](image)

(b)

![The monitoring interface of android application](image)

**Figure 19.** (a) Home interface of android application (b) The monitoring interface of android application
As illustrated before in figure 15, the location of the device will be placed at the wheel train and to be exact is at the center bearing of the wheel train. In figure 20, shows how the electronic components, microcontroller, WiFi adapter and antenna are connected on the breadboard. For the future work, all that hardware will be fit into a customized casing which suits with the wheel train frame.

Figure 20. All the hardware connected to finalize the reading and measurement.

4. Conclusion
An antenna for a wireless sensor network for early wheel trains damage detection has successfully developed and presented. The new antenna was designed to operate in single band frequency at 2.45GHz. The antenna is totally achieved the specification and requirements in term of gain, directivity, radiation pattern and efficiency. This antenna is very special because it is compact in their size. Based on the result of S11 or return loss graph, the antenna manages to obtain -34.46dB for simulation and -29.81dB for measurement result at the resonance frequency. For the radiation pattern of this antenna are directional which capable to focus on power towards the transmitter or receiver. Besides that, the VSWR shows the almost an ideal value which is 1.04 for simulation and 1.07 for measurement. Whereas for the ideal case, the VSWR should be equivalent to 1 in order to make sure there is no power reflected back to the antenna. Furthermore, this project had achieved to create a detector device that capable to sensing the current temperature as well as sending the reading data into cloud wirelessly through Wi-Fi network. Thus this can ease the loco pilot to monitor the current temperature via android apps application. Last but not least, this project had been successfully compared the reading of current temperature between the detector and the android application.

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