Dyson Foundation Undergraduate Bursary Report

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Project Overview

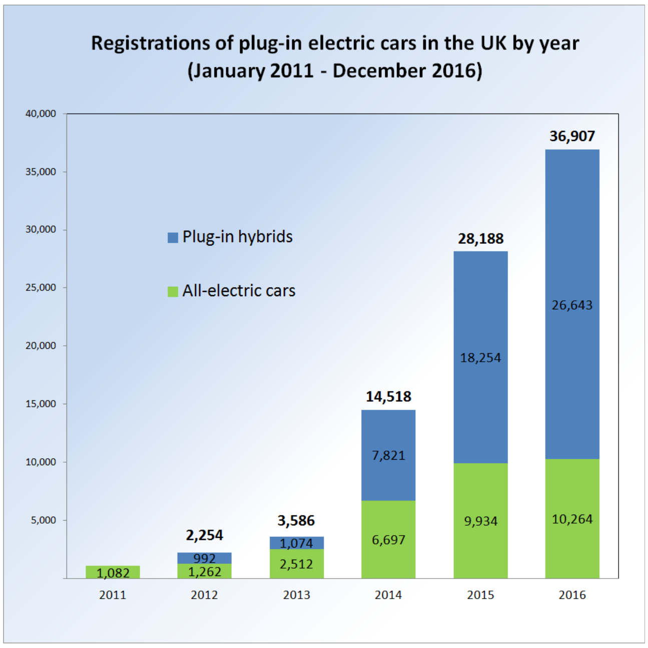

Fig.1: EV Registrations in the UK

Over the last couple of decades electric vehicles (EVs) have seen a rapid increase in popularity. In the UK alone the number of registrations of EVs has risen from just over 1,000 to almost 37,000 between 2011 and 2016 (Fig.1), which is indeed an impressive result. The numbers are only expected to increase further should the Government proceed with their plans to ban petrol and diesel cars from 2040.

However, before EVs can compete with traditional petrol cars in terms of practicality and performance, they need to overcome a number of technological limitations that they currently have. One of such limitations is slow battery charging.

An obvious solution could be to simply use larger batteries. Yet larger batteries would weigh more *ceteris paribus*, and carrying too much weight around would inevitably reduce the efficiency of the vehicle. A different approach would be to use high voltages and currents to recharge the batteries faster and hope that in the future the technology improves and recharging times would be compatible to the duration of an average petrol station visit.

However, there is another technology that might offer a potentially neater solution to the problem, and it is wireless charging. Wireless charging has the advantage that it can be done automatically, without any action required from the driver at all. In principle, this allows to envisage a ubiquitous network of wireless charging stations, whereby there is a station by your home, office, and your favourite grocery shop, and the vehicle is charged every single time it is parked. That way the vehicle is kept as fully charged and ready-to-go at all times as possible.

Wireless charging also has a major disadvantage, namely its reliance on good alignment of the charging coils. If the coils are misaligned, the effectiveness of the wireless power transfer will drop, potentially down to a point where no energy would be transmitted.

One way to overcome this is to use a large transmitter coil covering the whole area of the parking slot. However, this is likely to be costly due to the scale of installation works required. This ultimately leaves the alignment problem with the driver. Achieving perfect, or even good enough alignment might be time-consuming and stressful, especially in urban conditions. Therefore, automating the task is very worthwhile, and this was the aim of the project.

It was suggested to develop a system that would perform the alignment automatically. The system would drive the vehicle along the parking slot until it detects the charging coil, align the receiver coil on the vehicle with it, and initiate charging. A major design objective was to achieve this by sensing the magnetic field around the charging coil alone, without using any additional sensors.

To prove the feasibility of the concept, a model of an electric vehicle was developed, as shown in Fig.2. It was mounted on a RC toy car chassis, had four wheels, a rechargeable on-board battery, charging circuitry, and a control unit. To model a charging station, a transmitter coil was installed under the track, and the receiver coil was installed between the front wheels of the model car. The car would then be launched along the track, detect the charging coil, stop, align itself with the coil, and charge.

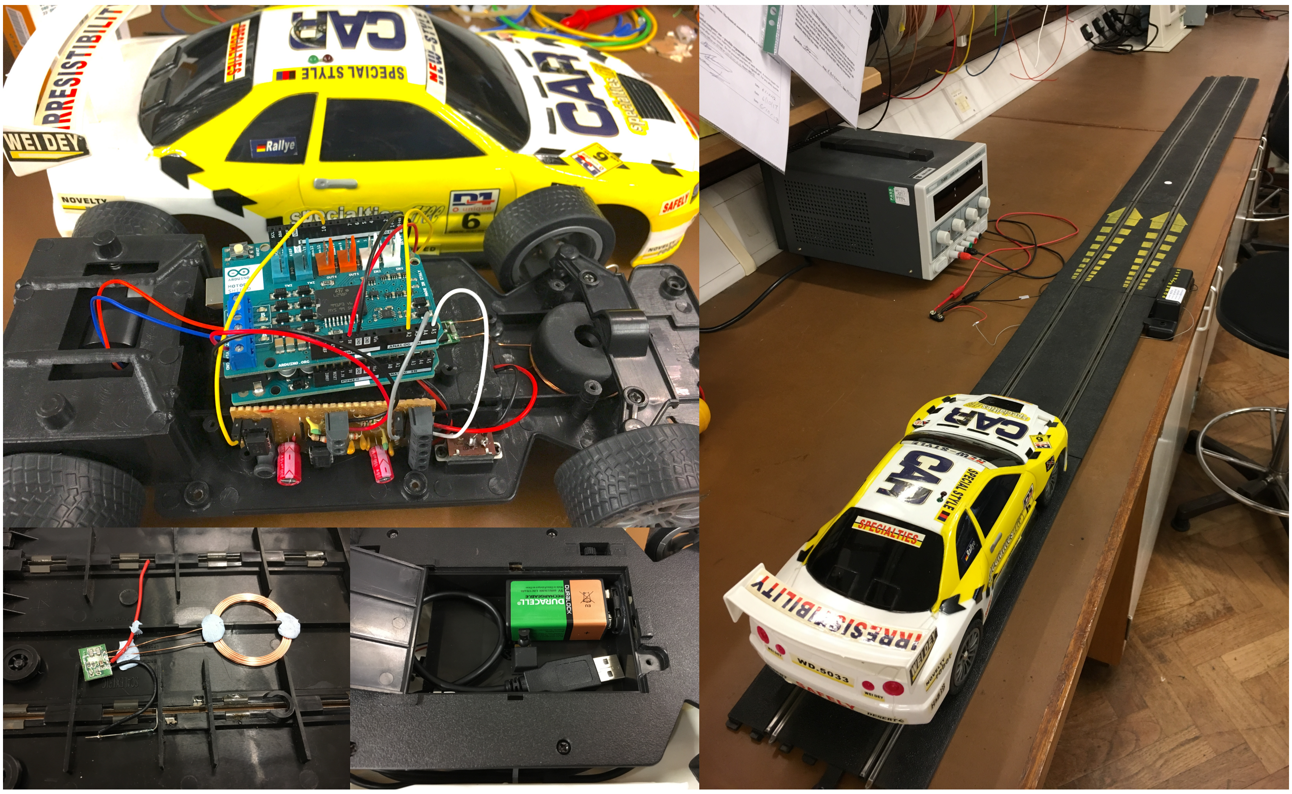

Fig.2: EV model overview *(clockwise from top left)*: the chassis and the circuitry; track setup; battery compartment; charging coil

The idea behind this was based on the fact that the degree of alignment can be detected by the coils themselves, as was verified experimentally. It can be seen from the graph in Fig.3 that in the upper working region the variation of the receiver coil voltage is smooth, with the only inflection point being the maximum itself. This proved two important things. First, the optimal position for most effective wireless charging exists, and second, it can be found uniquely by searching for the maximum on the received voltage graph. The idea was then tested on the model car.

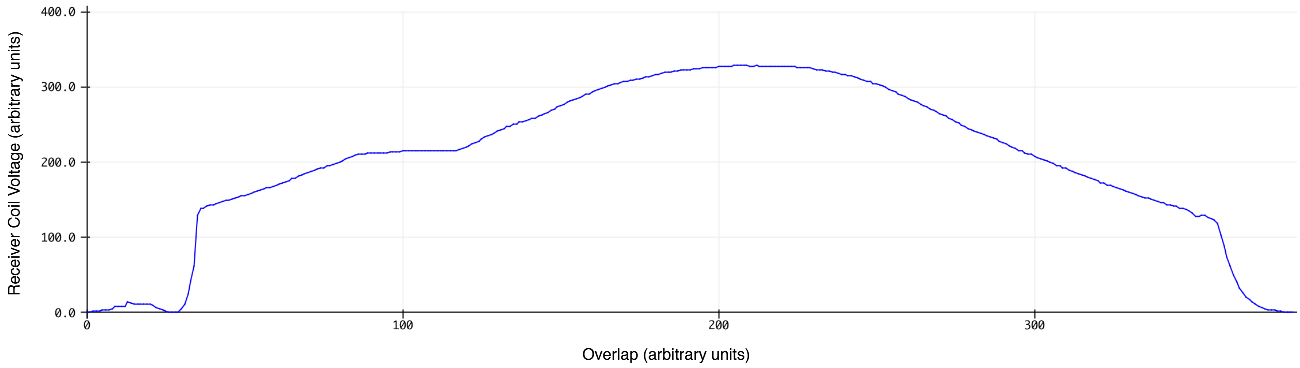

Fig.3: Variation of receiver coil voltage with coil overlap

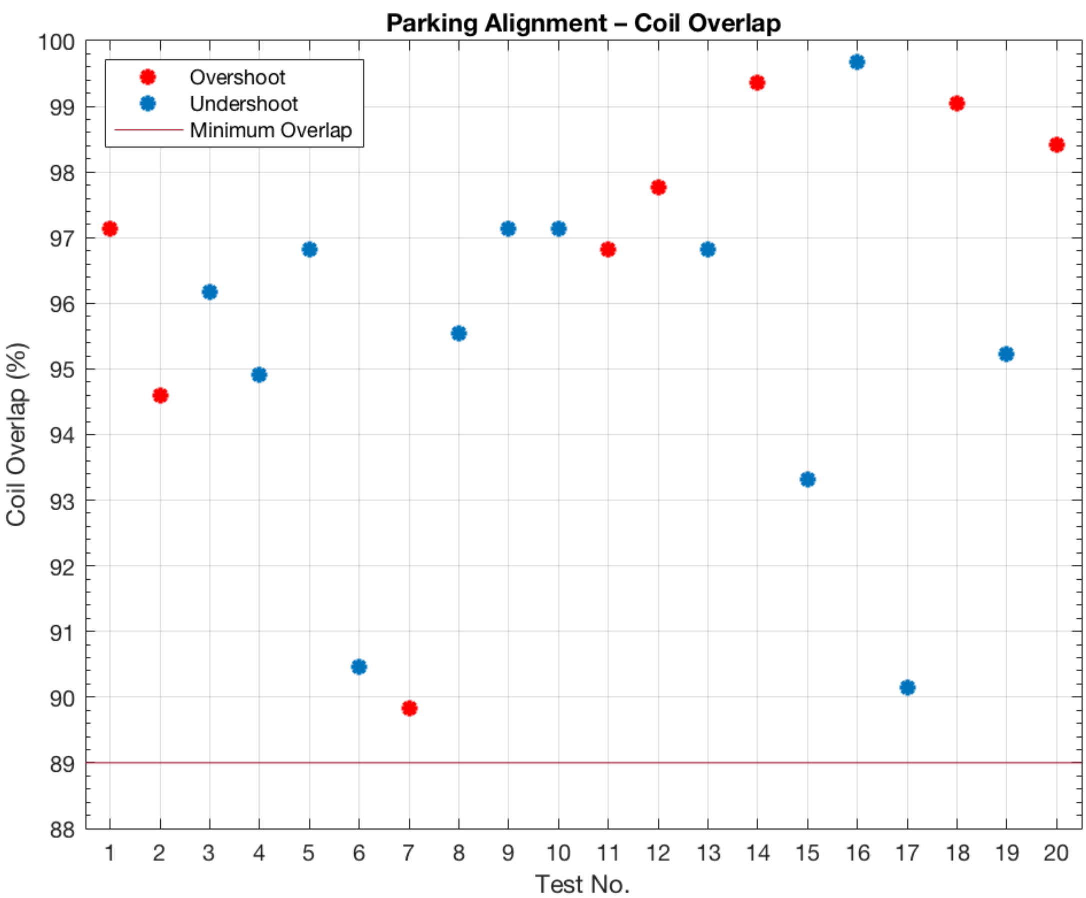

Fig.4: Alignment success, stability and reliability

The early version of the system failed to detect the charging station and simply went on driving. After further development, the system could successfully detect the charging station and stop, but could not align the vehicle properly. The final version of the system, however, was able to reliably detect the charging station, stop and align the car with it.
To provide a quantitative assessment of the performance of the system, 20 test runs were completed, and the results are summarised in Fig.4. The vertical axis represents what percentage of the coil area was actually overlapping once the model parked itself. The dots correspond to the parking position perceived by the model as “optimal”, as opposed to the true optimum, i.e. a 100% coil overlap, or perfect coaxial alignment. Blue dots denote an “undershoot”, i.e. the vehicle underestimated the optimal position and did not quite reach the station, and red dots denote an “overshoot”, i.e. the vehicle overestimated the optimal parking position and went over the charging station.
Data analysis reveals that the model exposed a slight tendency towards undershoot, however, this was due to the model calibration and was done to improve stability. Had the system be tuned to overshoot the station, under certain conditions the car could overshoot the station completely, and would then need to reverse to regain the optimal position. However, since it had been tuned to overshoot, the vehicle could overshoot again, leading to oscillations, extremely undesirable in real life.
Overall, out of 20 runs 17 ended up comfortably within the critical region which was defined as the minimum overlap required for the power transfer to be effective enough to enable successful charging of the vehicle. Three runs got somewhat close to the limit, which might imply a potential miss as the number of runs increases. Yet these results were achieved with a very simple EV model built around a plastic RC car frame, and the performance of the system is expected to increase significantly should it be tested on real-life EVs.

Open Day Activity Summary

To provide an entertaining yet suitable activity for the school children, it was decided to demonstrate the basics of wireless power transfer.
The activity started with asking the audience if they were familiar with the concept of energy and/or power, and then asking them to name some examples of applications in which energy was transferred wirelessly rather than using electrical connections, such as cables. Most people mentioned wirelessly charged toothbrushes, some mentioned smartphones and headphones, and one of the demonstrators mentioned EVs. These are indeed the three most common applications of the technology today.

A brief explanation of the physics behind a typical wireless charger followed. The audience knew what electrical current was. It was explained to them that direct current flows in one direction, while alternating current flows "back and forth", and is used in the mains. If we connect a coil of wire to an AC source, it will produce an alternating magnetic field around the coil. If another coil is put nearby, the field lines would pass through this second coil and induce an AC voltage (and hence current) in the secondary circuit. A rectifier is necessary to convert AC to DC, although it is not required to understand how it works. The produced DC is used to power an LED.

Everyone in the audience was supplied with a kit (Fig.5) to build their own simple wireless charger, similar to the one in Fig.6. The kit contained a breadboard, a red LED, some single-cored wires to wind coils, and a bridge rectifier. The wires were pre-cut to a specific length to simplify the activity and ensure the ratio was fixed as 5 TX turns to 10 RX turns (i.e. 1:2). A single AC signal generator was provided by the demonstrator (me) and kept supervised on the desk for safety reasons.

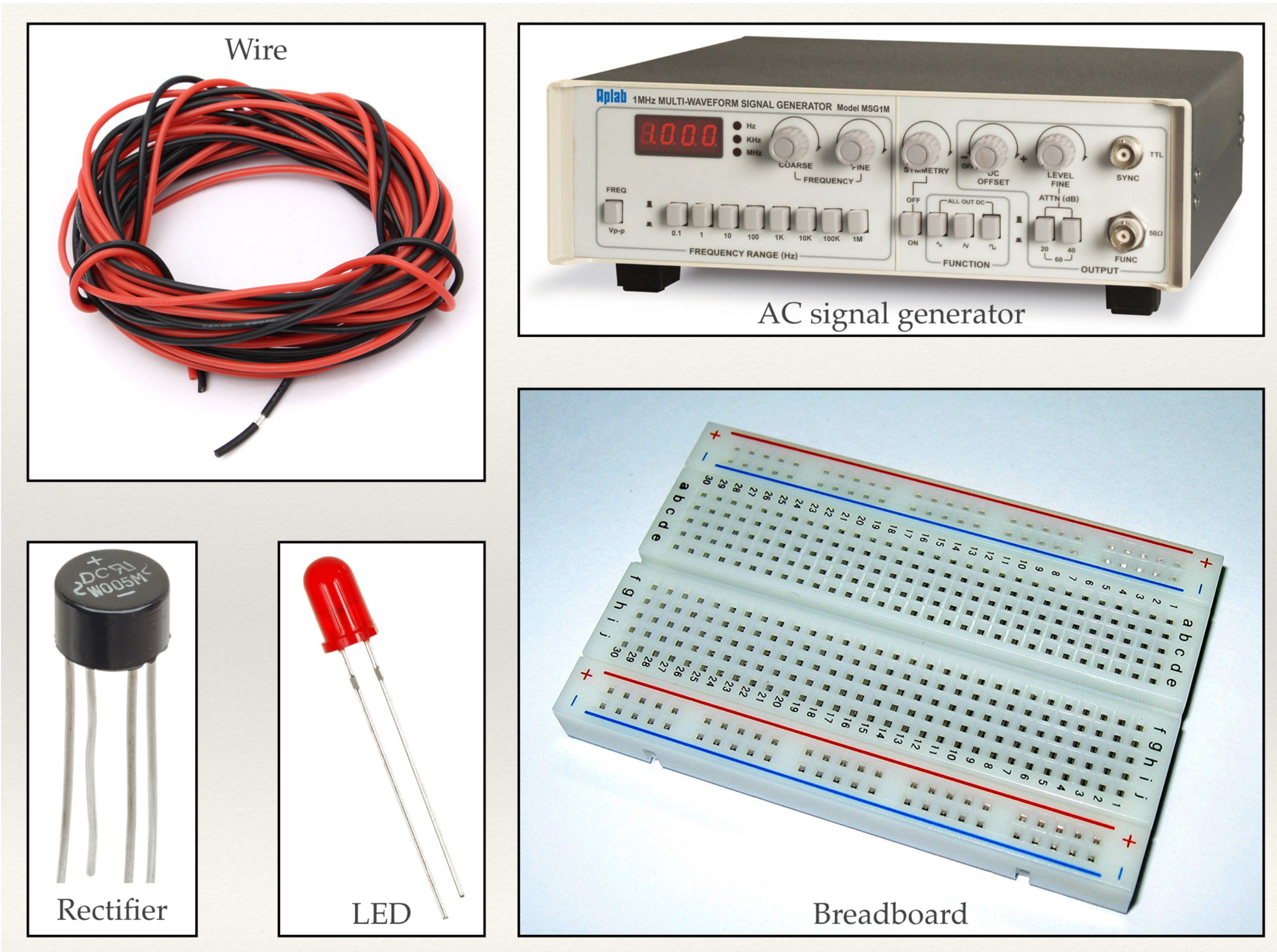

Fig.5: Kit contents

It was then demonstrated how to assemble a simple circuit, from winding coils to connecting components on the breadboard. The demonstration was shown on the screen and done live and step-by-step together with the audience. Other demonstrators were around to provide the necessary assistance.

Once everyone completed their circuits, they were connected to the signal generator for testing. The test was deemed successful if the LED started glowing.

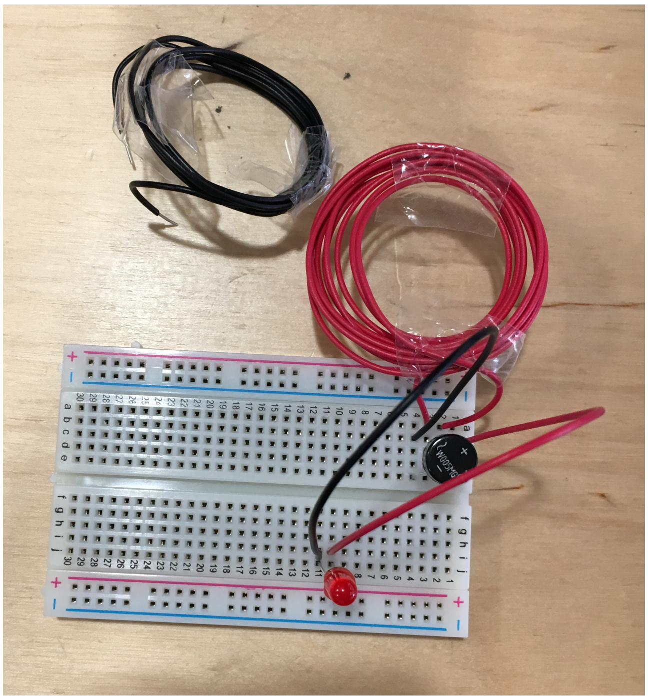

Fig.6: An example of a circuit assembled during the activity

Most people eventually succeeded in building their circuits. A couple of attempts suffered from wrong breadboard connections, but were quickly fixed with the help of the demonstrators.

Overall, the activity proved fun while still showing some powerful electromagnetic phenomena, and was completed within half an hour.