

# ESA Measurements using the Hybrid Fibre-Optic Reflection Measurement System

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(Invited Paper)

**Abstract**—Since the introduction of the Wheeler Cap method to measure the radiation efficiency of an Electrically Small Antenna (ESA), there have been several techniques presented in literature that have either enhanced on the method or provided an alternative technique. This paper presents measurements of the radiation efficiency of an electrically small monopole using the Hybrid Fibre-Optic RF Reflection Measurement System (HRS) integrated into the Wheeler Cap. The HRS isolates the ESA from the measurement system [1]. The ESA's reflection coefficient can then be measured with the isolated ESA inside the Wheeler Cap and in freespace to determine its efficiency. The HRS is also integrated into a far-field measurement range to measure the far-field radiation pattern of the ESA.

**Index Terms**—electrically small antenna, Wheeler cap method, radiation efficiency, radiation pattern

## I. INTRODUCTION

ONE of the most important parameters characterising the performance of an ESA is its radiation efficiency. The radiation efficiency of an ESA defines its ability to radiate, rather than store, the Radio Frequency (RF) energy presented at its input terminal. It is notoriously difficult to measure and has been the subject of ongoing research since the introduction of the Wheeler Cap [2]. The Wheeler Cap is an effective method of measuring the radiation efficiency of ESA. Subsequently, this method has been investigated [3–5], adapted [6] and improved upon [7, 8]. The authors recently introduced the HRS that is a modified method which incorporates the use of a novel electro-optic system to isolate the antenna from the RF measurement system. The HRS has been integrated into the Wheeler Cap and a far-field measurement range to measure the radiation efficiency and radiation pattern of an electrically small monopole, respectively. The HRS has also been used to investigate ground plane effects on antenna efficiency [1]. In this paper, the measured radiation efficiency and radiation pattern of an electrically small monopole is presented.

## II. BACKGROUND

THE measurement of the  $Q$  of an ESA is made difficult by the presence of ohmic losses which are often of the same order as the radiation losses. Therefore, it is not possible to accurately determine the  $Q$  simply from a measurement of the input impedance of the antenna when the antenna is in an anechoic environment. A method for experimentally determining the radiation  $Q$  of ESA was developed by Wheeler [2]. This method has been further investigated by Newman [9] and Pozar [4]. In this method, the antenna is placed in a conducting sphere or hemisphere with the antenna placed on a ground plane. The sphere is known as a “Wheeler Cap” and is used to prevent radiation by

ensuring that all the radiated energy is stored in the static field, the measured impedance is then due to conductor and material losses.

The concept of a radiation shield in the form of a conducting shell the size of a radian sphere originates from 1959 [2], in which Wheeler states that, for an ESA, the radiation shield enables a separate measurement of radiation resistance and loss resistance. This method of measuring the radiation efficiency is now known as the classic Wheeler Cap method [3] and is widely used, as it is easy to implement in practice, requiring only two measurements of the input impedance. The Wheeler Cap method is modelled on an equivalent series RLC circuit, which may not be the case for all antennas such as microstrip antennas [10]. Consequently, a modified Wheeler Cap method was presented [8], which approximates the input impedance of an antenna near resonance with either a series or parallel RLC circuit model.

## III. THE HYBRID FIBRE-OPTIC RF REFLECTION MEASUREMENT SYSTEM (HRS)

ANTENNAS that are embedded in compact hosts, such as mobile communication handsets, are generally electrically small making them sensitive to the surrounding environment and vulnerable to detuning which results in loss of signal and poor quality of service. The detuning occurs because the host is in the antenna's reactive near-field or its radiating near-field, thus modifying the current distribution on the antenna's surface. Furthermore, a measurement system placed close to the antenna has the same effect and can act as a parasitic element becoming part of the antenna that can then contribute to the antenna's far-field radiation pattern, in a constructive or destructive manner [11]. The ground plane of an ESA also tends to be electrically small and plays a vital part in the overall efficiency and impedance bandwidth of the antenna. Interest in quantifying and mitigating ground plane effects has been the subject of recent research [12, 13].

In this paper, the HRS is used to isolate an electrically small monopole from the measurement system to characterise the ESA and to examine ground plane effects by measuring the ESA's efficiency.

## IV. INTEGRATING THE HRS AND FIBRE OPTIC TO RF MODULE IN TO THE WHEELER CAP.

THE HRS is used to measure the reflection coefficient to determine the radiation efficiency of an ESA. The reason for integrating the HRS and Fibre Optic to RF Module in to the Wheeler Cap is to enable repeatable efficiency measurements of host-embedded antennas and provide a benchmark for anten-

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nas developed in the future.

The integrated set-up is shown in Figure 1. Fibre optic cables are used to interface with the Wheeler Cap. The RF signal is generated from within the Wheeler Cap, thus isolating the Wheeler Cap from the external RF source. The radiation efficiency is then calculated from the free-space and shielded reflection coefficient of the ESA.

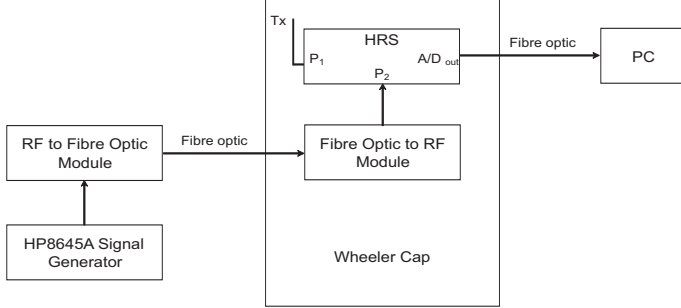


Figure 1. Wheeler Cap isolated from the RF measurement system.

## V. RADIATION EFFICIENCY MEASUREMENTS OF AN ELECTRICALLY SMALL MONOPOLE.

The integrated system was used to determine the radiation efficiency of an electrically small monopole; its reflection coefficient,  $S_{11}$ , was measured in freespace with and without a RF feed-cable. The feed-cable, which is  $61cm$  in length, positions the antenna in the centre of the Wheeler Cap; without it the antenna would be placed against the top surface, which would act as a ground plane and possibly give rise to spurious readings. Although the operating frequency is chosen to be  $350MHz$  it is beneficial to know what happens to the reflection coefficient over a wider bandwidth. Therefore the measurements were taken from  $345MHz$  to  $355MHz$ .

Two separate measurements were undertaken and the results compared; one using the Vector Network Analyser (VNA) and the other using the HRS. In both cases, the measurements were undertaken with the antenna in freespace and then placed in the Wheeler Cap. A lookup table is used to calculate the  $S_{11}$  measurements from the HRS. A linear gradient calibration factor is used to calibrate the HRS to the specific antenna.

The Fibre Optic to RF Module is used to effectively isolate the antenna from the RF source. The HRS is used to measure the reflection coefficient of the antenna, revealing the impact made on the performance of the antenna.

The reflection coefficient measurements for the electrically small monopole when placed in freespace is shown in Figure 2 and Figure 3. The reflection coefficient measurements for the antenna when placed in the Wheeler Cap are shown in Figure 4 and Figure 5.

The HRS measures the magnitude of the reflection coefficient, therefore the phase was reconstructed by differentiating the magnitude with respect to frequency. The phase reconstruction error was determined by applying the process to the measured VNA reflection coefficient for each antenna. This was then used as the correction factor for the HRS measurements. The reflection coefficient magnitude and reconstructed phase was then

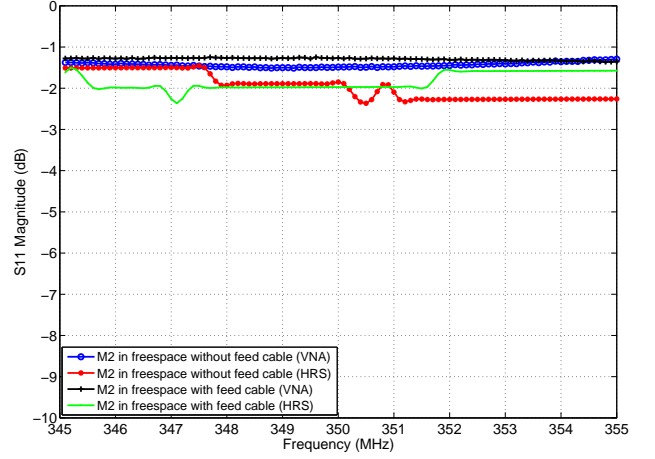


Figure 2. Freespace  $S_{11}$  magnitude of the electrically small monopole.

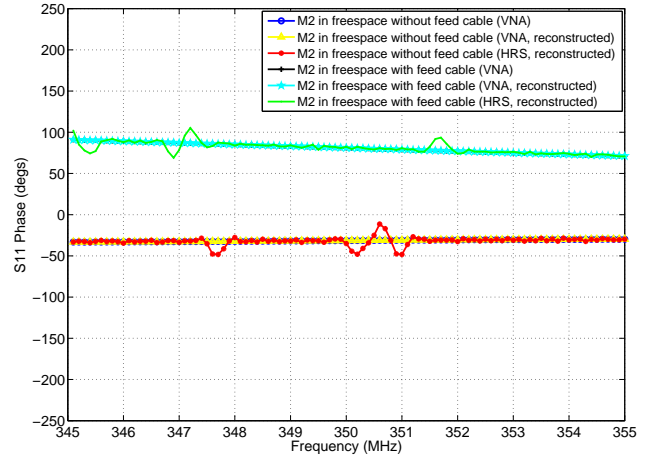


Figure 3. Freespace  $S_{11}$  phase of the electrically small monopole.

used to determine the complex input impedance,  $Z_A$ , of the antenna. The efficiency of the antenna was then determined by substituting the real part of the impedance from the freespace and Wheeler Cap measurements using Eqn. 1. The efficiency of the antenna is shown in Figure 6.

$$\eta = \frac{R_r}{(R_r + R_l)} = 1 - \frac{R_{cap}}{R_{fs}} \quad (1)$$

where,  $R_r$  is the radiation resistance and  $R_l$  is the loss resistance. The real part of the antenna input impedance is the quantity  $R_r + R_l$ , which can be measured using a VNA.

## VI. FAR-FIELD RADIATION MEASUREMENTS OF AN ELECTRICALLY SMALL MONOPOLE.

The HRS was integrated into an out-door far-field measurement range. The far-field radiation of the electrically small monopole was then measured using the HRS and the conventional methods.

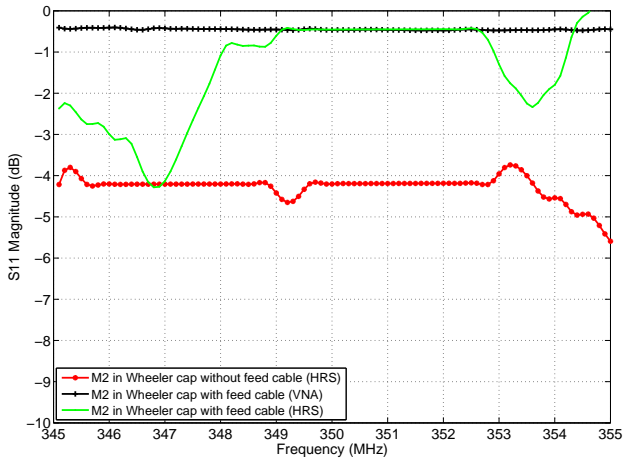


Figure 4. Wheeler cap S11 magnitude of the electrically small monopole.

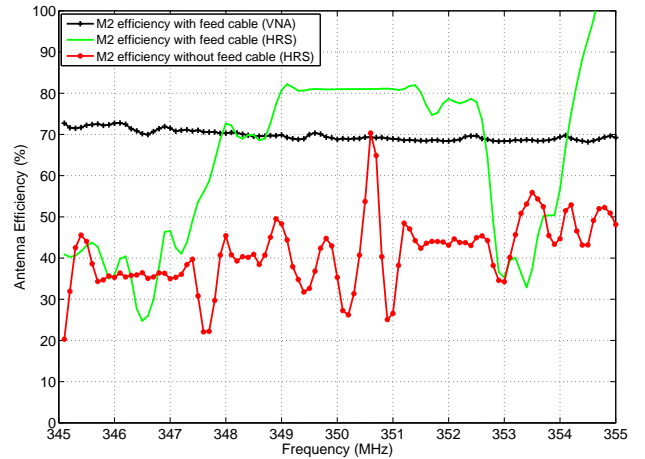


Figure 6. Radiation efficiency for the electrically small monopole.

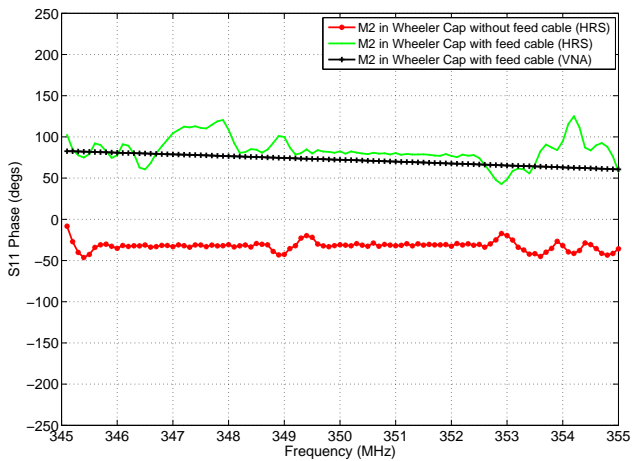


Figure 5. Wheeler cap S11 phase of the electrically small monopole.

The electrically small monopole is not mounted on a ground-plane and has a poor match at  $350\text{MHz}$  of  $S_{11} = -1.5\text{dB}$  such that 70%<sup>1</sup> of the power delivered to the antenna is reflected back to the source, exciting a common-mode current along the RF cable.

Referring to the radiation plot shown in Figure 7, directly connecting a horizontally positioned RF cable to the antenna, as shown in Figure 8, reveals that the reflected power from the antenna is radiated along the cable and is measured in the far-field as nulls and peaks. However, when the RF cable is positioned vertically and concentric to the axis of the monopole the radiation from the cable is less prominent, being more evenly distributed in the vertical plane. The RF cable was then replaced by the HRS, as shown in Figure 9. An improvement is seen when the HRS is used to isolate the antenna from the RF source. The radiation from the antenna is significantly lower than that measured by the conventional method as the common-mode current has been eliminated by the HRS.

<sup>1</sup> 70% in this case is 7dBm

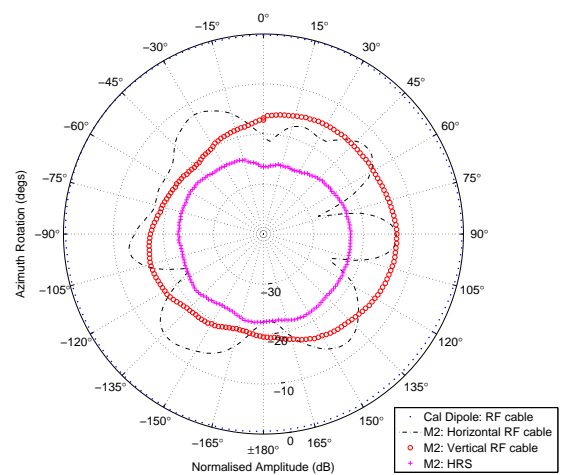


Figure 7. Radiation plot for the electrically small monopole.

## VII. CONCLUSIONS

THE HRS has been integrated with the RF over fibre-optic measurement system to improve the sensitivity of ESA radiation pattern measurements. The measurement system isolates the antenna from the RF source while enabling the measurement of its reflection coefficient. Consequently, the radiation from the antenna rather than from the RF cable and the antenna is measured.

The HRS has been used to measure the radiation efficiency and far-field radiation of an electrically small monopole. The technique effectively isolates the ESA from the measurement system to measure its radiation pattern and efficiency to explore the effects of ground plane on the efficiency of an ESA.

In this paper the measurements of an electrically small monopole have been discussed. These measurements have revealed the importance of isolating the ESA from measurement system for radiation pattern and radiation efficiency measurements.

The radiation pattern measurements show that radiation from the common-mode current on the feed cable contributes signi-

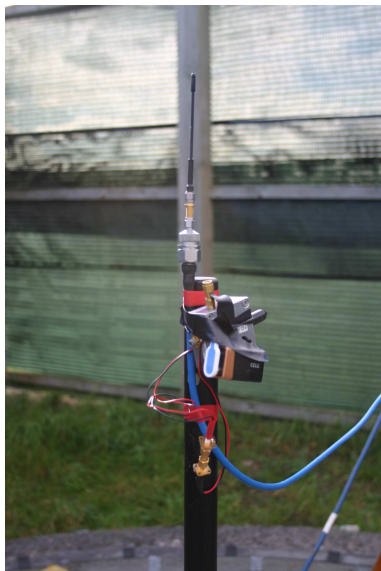


Figure 8. The electrically small monopole connected to a horizontally positioned RF cable.

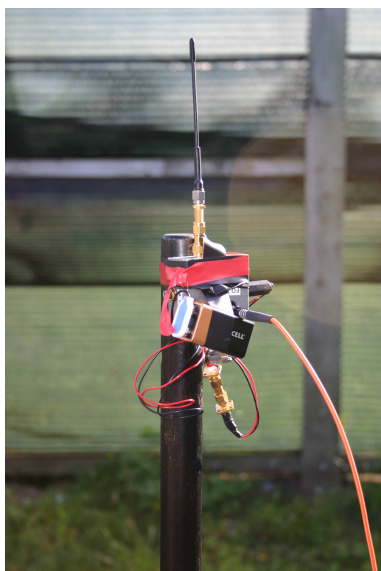


Figure 9. The electrically small monopole connected to the HRS.

ificantly to the far-field pattern of the antenna; at some azimuth angles the difference is as much as  $10dBm$ . This biases the measurements toward the antenna having a higher gain. Thus the gain of the electrically small monopole is dominated by the RF measurement technique used in characterising it. Isolating the antenna from the RF measurement system by using the HRS system reveals these effects and measures the gain of the ESA, which tends to be significantly less than when measured in the conventional manner.

When the antenna is placed in the Wheeler Cap, the influence of the feed-cable is clearly seen, and the antennas radiation efficiency is high than expected. Therefore, when measuring ESA's it is essential to ensure that the Wheeler Cap is isolated from the RF measurement system. The radiation efficiency of the electrically small monopole is significantly reduced when it is isolated from the RF measurement system.

## VIII. ACKNOWLEDGEMENTS

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