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Low-cost RF 802.11g telemetry for flight guidance system development

Philip A. Catherwood[1] ✉, Paul Hughes[2], James McLaughlin[1]

[1]*Ulster University, Shore Road, Jordanstown BT370QB, Northern Ireland, UK*
[2]*Thales Air Defence, Research and Development, Alanbrook Road, Belfast BT6 9HB, UK*
✉ *E-mail: p.catherwood@ulster.ac.uk*

Abstract: This work investigates the potential for off-the-shelf hardware to be used as a very low-cost replacement to the expensive missile test telemetry currently used by military equipment suppliers to develop flight guidance systems. Missile tests are essential to create highly accurate simulation models of the missile flight controls to ensure accuracy of live missile fire and fully controlled stability throughout the flight to ensure the missile only strikes intended targets. Since test missiles are expensive one-shot devices the telemetry gathered must be transmitted robustly over the full flight. Development of bespoke telemetry units is expensive; thus the potential for using off-the-shelf components and sub-assemblies to provide telemetry based on the Wi-Fi communications standard is investigated. Over the course of missile development, this would create remarkable financial savings. This work details the design, development, and testing of a Wi-Fi missile telemetry system with the solution being evaluated against required performance requirements. Received signal strength and packet error rate, indicators of communication link quality, were investigated for increasing distance and for multi-frequency vibration. These tests replicate in-flight parameters for the transmitter's operation. Conclusions are presented along with recommendations for future development work.

1 Introduction

For decades radio frequency telemetry has been used in the design, development and qualification of missiles [1–3]. During testing the missile's warhead is replaced with a RF telemetry unit, as shown in Fig. 1. The telemetry unit transmits data from the missile's flight guidance system, its target acquisition system, and the control systems back to a base station until final impact occurs. Invariably the impact is so violent that the telemetry units are destroyed. In some cases, the missile is fired out to sea and is unrecoverable. The telemetry unit needs to be robust enough to withstand the initial shock of launch and the intense vibrations during flight. Since these items are expensive one-shot devices the data needs to be transmitted in a timely manner and with great integrity to be useful for determining the missile performance and further design iterations.

The current telemetry unit used by Thales Advanced Weapons Systems is due for replacement. The majority of parts for the current telemetry systems are difficult to source and are now considered obsolete so a complete redesign is necessary. Designing and developing a novel RF telemetry unit is an expensive and protracted process; for this reason it was proposed that commercial off-the-shelf components could be used to provide a low-cost telemetry unit based on the IEEE 802.11 communications standard.

Issues of obsolescence and cost reduction have been significant themes in missile development. The USA has experienced missile radio system sub-assembly obsolescence issues with attention on reducing cost as part of developing a replacement solution [4]. Advanced modelling of missile test trajectories is now common place to increase accuracy of flight information and reduces the number of tests required [5, 6]. Further pursuit of reducing missile communication system cost has been through compression of
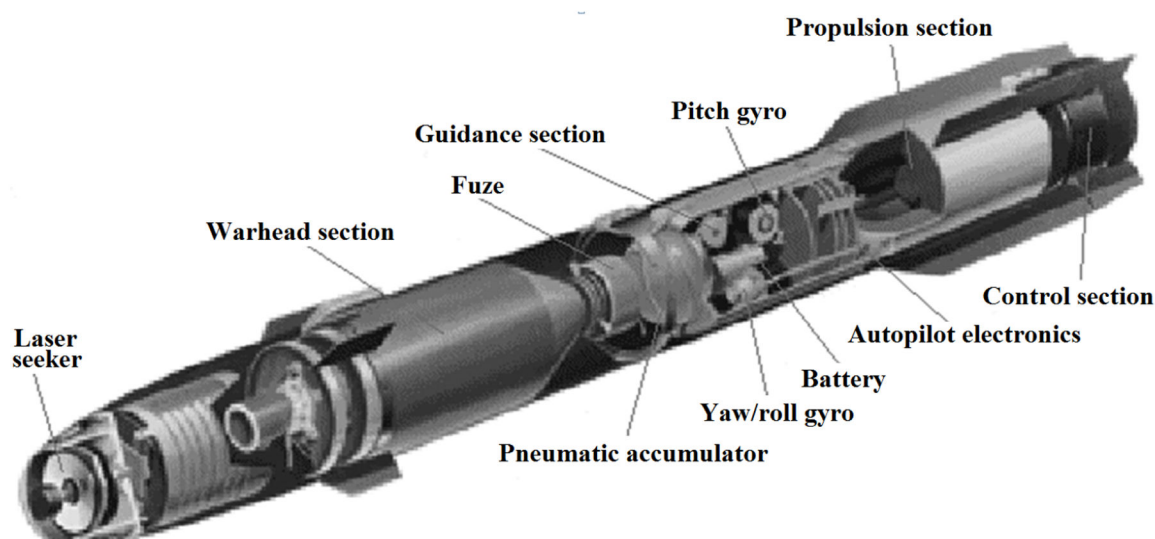

Fig. 1 *Typical missile structure (Lockheed Martin)*

telemetry data to increase the RF communication range [7]. The UK is currently cutting their defence and military development budgets with cutbacks in the army, navy and air force [8], while other regions such as Canada and Europe are increasing their budgets [9, 10]. Whether budgets decrease or increase there is a continual pressure to attain value for money and reduce costs where possible.

Dozens of telemetry missile firings are required throughout the development of a missile. The current Thales Advanced Weapons Systems RF telemetry unit transmitter alone costs in the region of £20k each; using commercial off-the-shelf hardware there is the potential to reduce this cost to ~£1k. Over the duration of a missile development programme this would accumulate to significant savings and improve the cost/benefit ratio for data capture by allowing more telemetry firings to take place. For these reasons alone, it is worth investigating the feasibility of using commercial off-the-shelf hardware to develop a Wi-Fi telemetry solution.

There are alternatives to developing missile telemetry systems in-house and rocket telemetry systems can be purchased that may potentially satisfy some or all of the required criteria [11]; however, these solutions are essentially hobbyist in nature and military test houses typically develop their own proprietary solutions that remain unavailable to those outside the military community. This allows them to retain full control over updates and ensures the details of the systems are not in the public domain.

Over the last 15 years, the establishment of static long-distance Wi-Fi networks has proven the effectiveness of such unlicensed, communications systems. In most cases, this technology is used to provide Internet connectivity, especially in developing regions. The use of the IEEE 802.11n/ac standard to provide 'real-time applications' has been investigated [12] with throughput of up to 36 Mbps over a distance of 7.1 km. Furthermore, Flickenger et al. [13] demonstrated that strategic use of antennas, environment, and commercially available equipment can be used to make point-to-point links over hundreds of kilometres. A 101 km Wi-Fi link was successfully established in Italy and two other extra-long Wi-Fi links were successfully established in Venezuela measuring 279 and 382 km [13].

Other work by [14, 15] also highlights the potential for high-throughput long-distance Wi-Fi links for outdoor network deployment. Such research establishes the potential of implementing Wi-Fi as a viable long distance communications mechanism. It is notable that these projects used high gain transmit and receive antennas to achieve long range performance and mitigate against inherent transmission losses. The antennas were mounted on large elevated masts to achieve an unobstructed Fresnel zone and the use of accurate antenna alignment as well as using very large antennas and fixed compass bearings enabled the long-range communications.

This paper aims to demonstrate that these static achievements over long distances could be applied to a moving Wi-Fi transmitter integrated into the telemetry unit of an in-flight missile. The effectiveness of IEEE 802.11g telemetry monitoring when using decommissioned ships as missile target practice has been studied [16], with the impact force of the missile impacts being monitored over a range of 7.49 km. This study would have experienced some form of dynamic telemetry as the ships were free to move. The extent of the movement and its effect on the telemetry system are not significantly addressed, except to determine the choice of antenna. The combination of these studies gives credibility to the application of a RF 802.11g telemetry system for missile development. While 802.11g is normally used in a star topology point-to-point links (Wi-Fi Direct) are also feasible [17].

Novel aeronautical air to ground communication links continue to be developed across a range of wireless platforms. Authors of [18] investigated low altitude links at 915 MHz using multiple antenna arrays, [19] modelled such antenna array solutions, and [20] studied radio links between unmanned aircraft and ground stations for the L- and C-bands. The authors of [21] utilised existing cellular networks to create novel unmanned aerial vehicle (UAV) links, while [22, 23] who explored the VHF-band with [23] employing software defined radio for cost savings through software realisation instead of hardware.

We thus investigate the feasibility of using RF 802.11g telemetry as a novel alternative to traditional technology for military missile development. The rest of the paper is organised as follows; Section 2 reviews design of the equipment, Section 3 elaborates specification of key tests required for the equipment, Section 4 discusses results and discussion of the tests, and Section 5 gives conclusions and further work.

2 Experimental equipment design and development

To examine the feasibility of Wi-Fi telemetry, a point-to-point Wi-Fi transmitter and receiver were designed using commercial hardware and open source software.

2.1 Transmission protocol

The transmission protocol had to be defined before the transmitter could be designed. This would determine the data packet size and system overheads in regard to transmission rates, time and reliability. Due to the short period of transmission, based on ~30 s of missile flight, there is very little time for handshaking (acknowledgements in the transmission protocol) between the transmitter and receiver.

This process detracts valuable time between data transmissions. Although handshaking in protocols such as the transmission control protocol ensures the reliable transmission of data packets using acknowledgements to confirm delivery and order (including reliability by retransmitting any dropped or delayed packets that were not acknowledged) this decreases the amount of useable data per second which is a fundamental disadvantage in this particular time-limited application.

The user datagram protocol (UDP), a very lightweight protocol defined in RFC 768, was selected to transmit data between the transmitter and the receiver as UDP messages (datagrams) do not use handshaking, does not rely on acknowledgements from the receiver, and does not retransmit delayed datagrams. UDP, which works on top of the IP protocol, thus offers low-latency and loss-tolerating connections to deliver messages between applications which is most important when data is from a short flight duration telemetry missile. However, the reliability, ordering, or duplication of the datagrams needs to be confirmed after receipt. This is acceptable for such an application as the data transmitted from the missile telemetry unit is analysed off-line, although if too many packets are lost then data becomes truncated and unusable.

The UDP packet structure contained an 8-byte header detailing the source port, destination port, length of packet and a checksum. The size of the data transmitted ultimately determines the overall packet size and is constrained by the maximum transmission unit, which relates to the parameters of the Ethernet communication interface. The UDP receiver software on the laptop recorded the packet transmission time (ms), packet count, received signal strength indicator (RSSI), and a text message. Lost packets are identified by analysing the packet count and time, thus determining the packet error rate (PER) of the link. The PER is the ratio of number of packets in error at the receiver to the number of packets sent. It relates to bit error rate (BER) by the following association, where n denotes number of bits in a packet:

$$PER = 1 - (1 - BER)^n \qquad (1)$$

The PER and RSSI (dBm) provide a good indication of the data throughput rate and reliability of the established Wi-Fi link. It is typically expected that as the RSSI decreases, the PER will increase for a given modulation scheme as the signal-noise margin decreases. The RSSI gives an indication of the equivalent data rate in Mbps achieved by the connection at 2.4 GHz [24].

2.2 Telemetry transmitter

Wi-Fi transmitter for the telemetry unit of the missile (programmed as a UDP transmitter) was designed to be self-contained and portable to ease testing. The transmitter was built from an Arduino
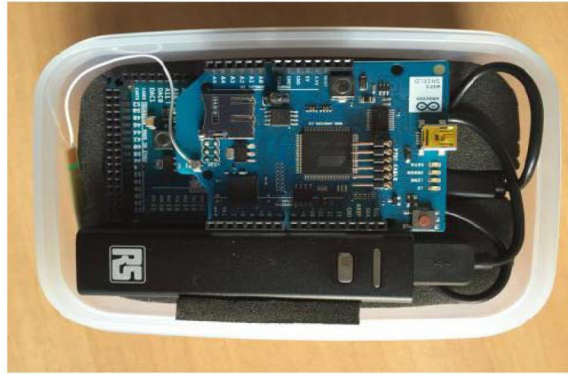
Fig. 2 *Arduino Wi-Fi transmitter (based on the Arduino Due) packaged with battery*

Due and a Wi-Fi shield (IEEE 802.11g) with a Siretta 2.4 GHz PCB antenna (https://www.arduino.cc/documents/datasheets/ X000006-Antenna_Wifi-Echo1_%28Rev1.0%29.pdf). The transmitter was designed to transmit data as soon as a Wi-Fi link was established with the receiver's access point (AP).

The transmitter was programmed to run a 'set up' and establish a network connection to a soft access point provided by the laptop base station. Once a successful network connection was established the transmitter enters a loop and continuously broadcasts UDP packets until it is powered off (or destroyed at missile impact). The transmitter was packaged with a lithium ion battery connected to the native USB port to provide power, as shown in Fig. 2. A half-wave dipole micro-strip 2.4 GHz antenna was added to the transmitter to improve the gain and range.

The data contained in the UDP packet was limited to 51 bytes (408 bits) including header and data. The transmission time was also set to 10 ms to ensure stability of the UDP transmitter, the throughput was therefore 40.8 Kbps. As the throughput is a fixed value the throughput performance cannot offer a good indicator of the system. Instead RSSI levels and packet error rate suitably act as system performance indicators.

2.3 Telemetry receiver

The receiver used a laptop with a high gain directional antenna (2.4 GHz 24 dBi grid parabolic directional antenna (TL-ANT2424B)) along with a 150 Mbps wireless high gain USB adapter (TL-WN722N – https://www.tp-link.com/uk/products/ details/TL-WN722N.html) to create a temporary access point for the transmitter. This antenna and adapter facilitated long-range connection to the transmitter due to its high gain. The AP on the base station laptop provided a Wi-Fi network for the transmitter to send the UDP packets. The packets received are then recorded by the UDP receiver running on the laptop. A UDP receiver and GUI were developed using the Microsoft C# programming language and implemented on a laptop running Windows 8.1. The GUI provided real-time feedback on the telemetry data being received.

The receiver was initiated using a start button in the GUI and a message (similar to 'Got Data 611036') displayed if the transmitter is transmitting. The received packets are stored in memory and written to a text file for analysis offline. Recording continues until the 'Stop' button is pressed or the transmission is terminated.

3 Specified system parameters

For security reasons, the original military RF telemetry unit specifications cannot be fully disclosed; however, a summary of the revised generic specifications for the Wi-Fi telemetry unit include a high bandwidth (2 Mbps is desirable), a minimum communication link range of 5 km (between 7 and 10 km is more desirable), the receiver station antenna positioned <5 m above the ground level, 99.9% reliability with <60 packets lost during the 30 s flight with packet transmissions at 0.5 ms intervals, and the ability to withstand missile launch and flight vibration. The main determining factor to evaluate the potential of the concept is in the ability to provide long range, reliable Wi-Fi communications over a short period of ~1–2 min. This period exceeds the overall launch and flight time of the missile, which is ~30 s out to a range of 7 km. The system must be capable of transmitting large quantities of data few errors due to the short window of opportunity to capture telemetry data.

3.1 Data capture

The data captured during a missile flight is used to update the simulation models which develop and optimise the control systems for the missile guidance. The real-world telemetry data is compared to the modelled data to determine the accuracy of the model. Any deviations between the model and the telemetry data are rigorously investigated to ensure that the missile functions as expected, especially before any live firings take place. Accurate simulations are a vital aid to developing a new missile system.

3.2 System link budget parameters

To understand if a theoretical range of 7 km can be achieved in line with requirements 1 and 2, a link budget for the systems was calculated. This system is based on one client (the UDP transmitter) and one host (the laptop AP) with a clear LOS. A clear light of sight (LOS) is normally guaranteed for a missile telemetry flight, although this does not ensure a clear Fresnel zone [25]. For the purpose of this project the radius of the Fresnel zone at its widest point can be calculated by

$$r = 17.3\sqrt{\frac{d}{4f}} \tag{2}$$

where r is the radius of the Fresnel zone in metres (m), d is the distance of the link in km and f is the frequency in GHz [25]. Therefore at 7 km the Fresnel zone will be 14.8 m.

The free space loss of the system as the 2.4 GHz RF signal propagates over the desired 7 km distance between the antennas can also be calculated by

$$L_{fs} = 32.45 + 20\log(f) + 20\log(d) \tag{3}$$

where L_{fs} is the free space loss expressed in dB, f is the frequency in MHz, and d is the distance in km. Therefore at 7 km the free space path loss will be 116.96 dB. A table of Fresnel zone radii and free space path loss can be generated over the desired range, from 0.1 to 7 km, as shown in Table 1.

The transmitter is connected to the Siretta 2.4 GHz PCB antenna with voltage standing wave ratio (VSWR) of 2.5:1 and a gain of 2.6 dBi. The Wi-Fi shield had a transmission power of 14 dBm and the cable loss is assumed to be 0.5 dB. The laptop receiver (AP) is connected to the TP Link 2.4 GHz grid parabolic antenna with a gain of 24 dBi, through the TP Link 150 Mbps High Gain USB Adapter. The adapter has a receiver sensitivity of −85 dBm at 11 Mbps with a maximum possible transmission power of 20 dBm. The three meter extension cable supplied with the antenna has an insertion loss of 2.2 dB. The system link budget is calculated (Fig. 3) and predicts a link margin of 9.0 dB at 7 km.

Table 1 Fresnel zone radius and path loss for full missile range

Range, km	Fresnel zone radius, m	Free space path loss, dB
0.1	1.77	80
0.5	3.95	93.98
1	5.58	100
2	7.9	106.02
3	9.67	109.54
4	11.17	112.04
5	12.49	113.98
6	13.68	115.56
7	14.77	116.9
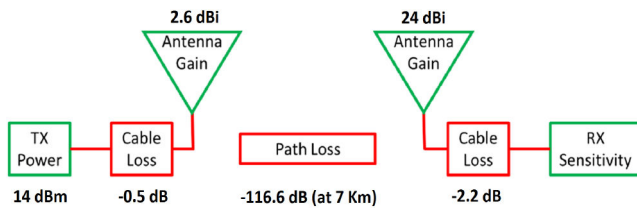
Fig. 3 *Link budget – transmitting unit to access point*

4 Experimentation, results, and analysis

4.1 Range testing

The range testing of the UDP transmitter and receiver was carried out at Silent Valley, located in the Mourne Mountains, Northern Ireland. This location provided a Wi-Fi free environment with LOS ranges up to 7 km, as shown in Fig. 4. This was used as an initial testbed to understand the long-range potential. The packaged UDP transmitter was mounted on a 2 m high tripod and the receiver antenna was also mounted on a 2 m high tripod, as shown in Fig. 5. The weather conditions for testing were dry with little humidity. Data was collected at 100 m, 150 m, 250 m, 300 m, 400 m, 450 m, 680 m, 1 km, 2 km, 3 km, 5 km, and 8 km. These test points generally reflect a missile's increasing speed as the flight progresses, as well as being geographically advantageous test positions. These ranges were verified using a laser range finder.

The data recorded from the UDP transmitter during range testing was analysed to determine the RSSI value and PER at each range over a 60 s duration. The results from this data have been summarised in Fig. 6. Testing revealed that the equipment could not reliably maintain a stable link beyond 680 m. It is noted that antenna alignment relied on LOS adjustment; future work would make use of long range laser links to increase accuracy of antenna alignment. The PER varied from 0.14% at 100 m to 1.98% at 680 m with a PER spike at 2.87% at 450 m. These results also show that the maximum PER of 0.10% not be achieved (desired 99.9% reliability i.e. <60 packets lost in 30 s of transmission at 0.5 ms intervals). The received signal strengths reported in Fig. 6 are lower than the theoretically calculated signal strength values predicted by the link budget analysis (Table 2).

It is considered that the limited antenna elevation of the transmitter unit was the main limitation to the unexpected results. Authors in [26] display how antenna height can directly affect the path loss due to Fresnel zones, Alam and Khan [27] exploring how communications operating in the Fresnel zone display a path loss decrease as antenna height increases. Within an open area, the direct ray between the transmitter and receiver experiences strong interference from a ground-reflected ray when operating within the first Fresnel zone, this impacts the measured path loss for increasing transmitter–receiver separation when transmitter and receiver heights are correspondingly low.

Taking into consideration that the antennas do not create single rays of electromagnetic radiation the receiver radiation pattern of the TL-ANT2424B indicates a vertical half-power beamwidth of 14°. To address the limited link power, it is possible to place the transmitter at height so that the elevation angle between the antennas is greater than the vertical beamwidth of the receive antenna. It is considered that the relatively low height of both the

Fig. 4 *Range testing at Silent Valley, UK*

transmit and receive antennas created a strong ground reflection whose arrival angle is within the main lobe of the receive antenna of 14° which can cause multipath fading effects - the primary limiting factor in the radio link.

For the given arrangement the two-ray model can be used to describe the signal paths; an effective mathematical description of the two-ray model with respect to Fig. 7 is defined as [28], where λ is the operating frequency wavelength (0.12 m), ε_r is the relative permittivity of the medium, and distances d_1, d_2, and d_3 are detailed in Fig. 7

$$PL(dB) = 20\log_{10}\left(4\pi\frac{d_1}{\lambda}\left|1 + \Gamma_\perp e^{-i\varphi}\right|^{-1}\right) \tag{4}$$

where

$$\Gamma_\perp = \frac{\sin\theta_p - \sqrt{\varepsilon_r - \cos^2\theta_p}}{\sin\theta_p + \sqrt{\varepsilon_r - \cos^2\theta_p}} \tag{5}$$

and

$$\varphi = 2\pi\frac{d_1 - (d_2 + d_3)}{\lambda} \tag{6}$$

For the geometry outlined the arrival angle and receive antenna gain at the arrival angle are shown in Fig. 7a. During testing, the transmitter could have ideally been affixed to an UAV to increase the effective height of the transmitter unit. However, as the transmitter–receiver distances increase the height of the transmitter would need to increase also. Indeed, for a link distance of 7 km the drone height required would be significantly higher than the 120 m (400 ft) limit imposed in the UK and USA. For the missile testing activities, this would not be an issue as the missiles fly at several
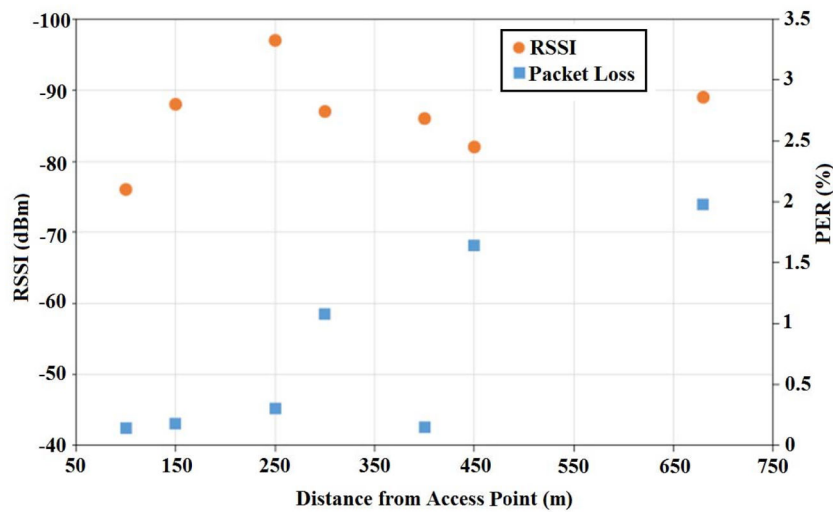
Fig. 5 *Receiver antenna fitted to tripod*

Fig. 6 *RSSI and PER against distance from access point*

Table 2 Comparison of measured RSS with calculated RSS using the link budget

d, m	Recorded RSS, dBm	RSS (link budget), dBm
100	−77	−39.66
150	−88	−40.90
250	−98	−45.34
300	−88	−46.92
400	−87	−49.42
450	−82	−50.44
680	−89	−54.03

hundred metres. Additionally, the vibration and movement of an UAV would have an indeterminate effect on the results. Had the height of the transmitter unit been raised the geometry would be more akin to Fig. 7b with the receive antenna aligned with the transmitter unit. The reflected ray would be much weaker due to the corresponding angle of the receive radiation pattern.

The two-ray model (4)–(6) was used to create a 2D simulation for the Wi-Fi missile telemetry system with a receiver height of 2 m and a transmitter height of 2 m as per the empirical tests. The same system design was simulated for a receiver height of 2 m and a transmitter at a height of 2000 m – this height was selected as it was greater than the minimum height of 1693 m required to avoid strong ground reflections from the vertical half-power beamwidth. Additionally, free space path loss model was developed and the three simulations compared over the full 7 km distance as well as a focus on the first 1000 m. These simulations consider the effects of operating in the Fresnel zone and can act as a comparison for the presented empirical results.

The simulations (Fig. 8) show RSSI against distance with the system parameters shown in Fig. 3 having been integrally implemented, with Fig. 8a presenting the full test distances and Fig. 8b focusing on the 100–1000 m portion (which reflects the empirical test results gathered). The simulation shows how a transmitter at a height of 2000 m ensures the system is operating beyond the Fresnel zone and the results are directly comparable with the free space simulations. The simulation for a transmitter height of 2 m depicts the system operating well within the Fresnel zone and shows some 30 dB additional losses at 7 km compared to free space.

Comparing the simulated results (Fig. 8) with the empirical results (Fig. 6 and Table 2) it is observed that the modelled losses were less than the measured during the tests. At 300 m, the simulated and measured results were −53 and −88 dBm respectively, for 680 m they were −66 and −89 dBm, respectively. It is noted that for very short antenna separation distances (100 m) there is still a significant difference between the simulated and
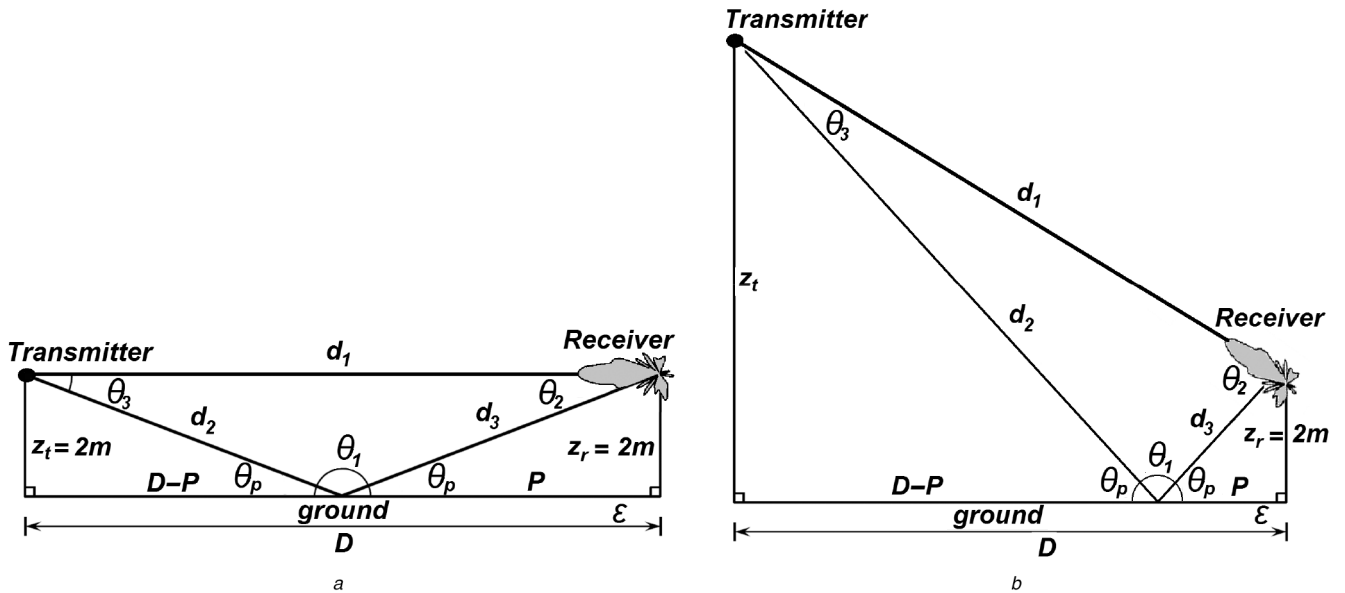
Fig. 7 *Geometry of the missile communications link*
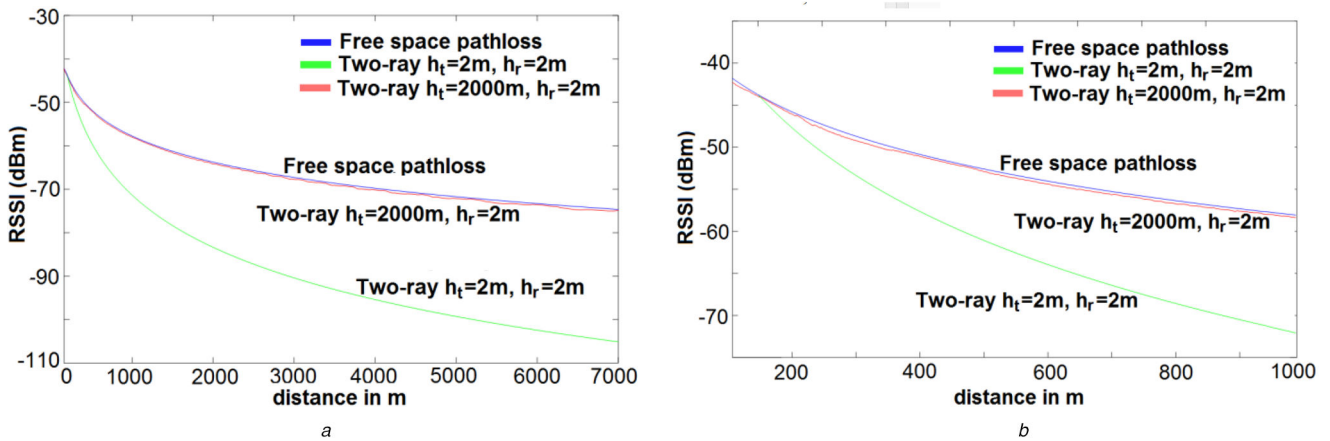*(a)* Transmitter and receiver at a height of 2 m, *(b)* Transmitter raised significantly higher than receiver

Fig. 8 *Simulated telemetry system for two different transmitter heights and free space communication for*
(a) Distances from 0 to 7 km, *(b)* Distances from 100 to 1000 m

measured (−42 and −77 dBm, respectively) which suggests alignment issues between antennas or additional internal losses. Using this difference of 35 dB as an adjustment offset, the simulated and empirical results are considerably more comparable. Additional fluctuations observed in the empirical results, but not the simulated results, are typically due to the limitations in the model to effectively describe the many characteristics of the actual test environment. These include the assumption of a smooth ground environment, consistent reflection coefficient across 680 m distance, additional reflections from nearby objects due to the 3D nature of the test environment, and imperfect alignment of the transmit and receive antennas.

4.2 Vibration testing

Throughout the flight from launch to impact the telemetry equipment is subjected to multi-frequency vibrations. To understand the robustness of the solution, the packaged UDP transmitter was mounted on a vibration table at Thales' testing laboratories (Belfast) as shown in Fig. 9. The UDP transmitter was allowed to transmit for one minute, at a range of 2 m, before being subjected to an 8 s random vibration test at frequencies from 40 to 2000 Hz with a power spectral density (PSD) of 0.04 g²/Hz. The vibration profile is presented in Fig. 10; the control line is the measurement from the unit, the alarm bounds are the upper and lower limit which trigger an audible alarm, and the abort bounds are the upper and lower triggers for automatic shut-down of the

test. This test is representative of low level vibration experienced during missile flight [29].

The data from the vibration test was analysed to determine the RSSI and PER. The RSSI, at a range of 2 m, was −44 dB. During the initial one minute of transmission the PER was 0%. Once the vibration profile was applied the PER increased to 45%. This falls below the required standard and it is typically due to the low-quality oscillator on the test board. Replacement with a high-grade oscillator during the future in-house re-spin of the electronic circuitry should hopefully address this. Additionally, it may be possible to encapsulate the equipment in such a form as to reduce the vibrational effect upon the transmission characteristics, such as packaging it in a silicone elastomer, epoxy, or urethane wrapper. Testing would be required to understand the impact encapsulation may have on the propagation characteristics of the transmitter antenna. It was noted that the transmitter continued to work as intended after the vibration testing was complete which indicates the selected circuitry did not fail during vibration testing and increases confidence that with better packaging and an increase in robustness of selected key components, the solution may have operational merit for military testing.

5 Conclusions

This work investigated the potential for off-the-shelf hardware to be used as a very low-cost replacement to the typically expensive missile test telemetry currently used by military suppliers to reduce development costs and increase the number of missile tests for a
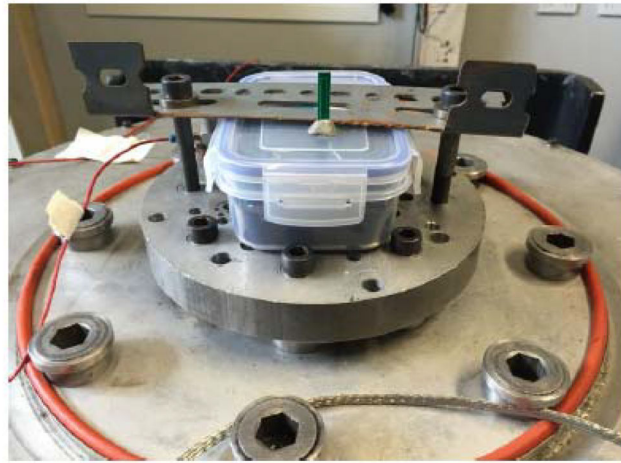
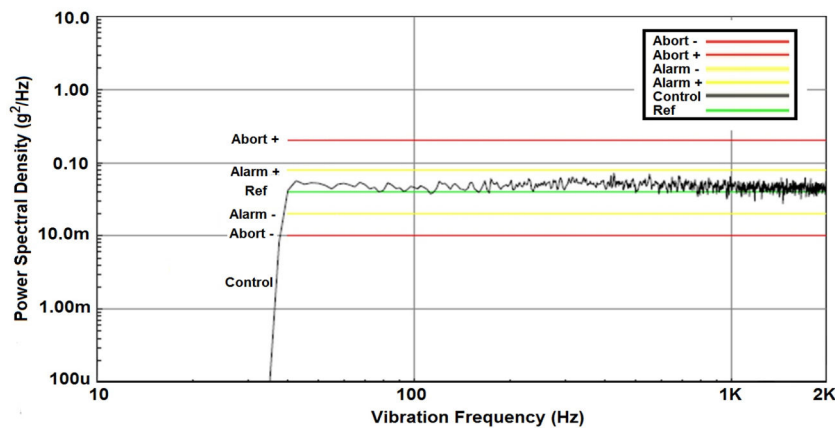**Fig. 9** *UDP transmitter mounted on vibration table*

Fig. 10 *Vibration profile at 40–2000 Hz, with a PSD of 0.04 g²/Hz*

given budget. Such tests are essential to correctly simulate and develop the flight controls of the missile to ensure accuracy of every launch, stability throughout the flight, and to reduce the likelihood of missiles striking an unintended target to an absolute minimum. In theory, the calculated link budget for this equipment indicated that there was sufficient margin to establish a link at the desired 7 km range. To investigate this supposition testing was divided into two main categories; range testing and flight vibration resistance testing. Results from testing revealed that, in its current form, the off-the-shelf equipment does not yet meet the specification for the required task. The transmitter unit did not achieve the desired communications range of 7 km from the receiver. Also, the transmitter did not maintain the desired packet error rate during multi-frequency vibration resistance testing.

Several factors may have attributed to this inadequate performance, including the very low cost of the selected equipment (<£200), limitations in the Arduino Wi-Fi shield firmware which restricted the UDP data throughput, less than optimal alignment and elevation of the antennas (potentially compounded by the presence of a narrow band of water at the test site) [30], and under-damped packaging of the transmitter assembly. Future work recommends a bespoke Wi-Fi shield, a better transmitter antenna (perhaps with significant directionality and use of MIMO antenna technology), higher transmitter elevation (perhaps using a balloon or other aerial platform) to better simulate the operational height of an in-flight missile, and tailored packaging of the transmitter to reduce the packet error rate. The receiver solution was deemed adequate for the testing and would continue to be the employed arrangement for receiving the incoming telemetry data, although the use of multiple receive antenna technology may help to increase the operational range and link stability. In summary, a Wi-Fi radio solution could still provide a suitable telemetry replacement that will generate significant savings for missile development in the coming years.

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