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Research Article

Posthumous Numerical Study of DTV Broadcast Antenna Integration with Prototype Stratospheric Airship Gondola

Derek Gray, Mamoru Nagatsuka, Mikio Suzuki, and Ryu Miura

Space Communications Group, National Institute of Information and Communications Technology (NICT), 4-2-1 Nukui-Kitamachi, Koganei-shi, Tokyo 184-8795, Japan

Correspondence should be addressed to Derek Gray, gray@nict.go.jp

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As a follow-on to the 2002 digital television (DTV) broadcast demonstration from a solar-powered stratospheric flying wing, a prototype stratospheric airship was used for a more realistic DTV broadcast demonstration in 2004, albeit at a lower altitude. The DTV signal was occasionally lost at the receiver directly below the airship during the demonstration. Adverse antenna-vehicle integration effects were investigated using a commercially available antenna simulation software, because the radiation pattern of the antenna on the airship could not be measured directly. The ground handling bars on the airship gondola were found to introduce deep and sharp nulls into the radiation pattern of the broadcast antenna. Some mitigation techniques that would have fitted within the constraints of the time are discussed. Changing to nonconductive ground handling bars and a multiturn helical antenna would have avoided the problem, according to the simulation results.

1. INTRODUCTION

Aircraft flying in the stratosphere offers numerous advantages as communications platforms compared to present day terrestrial and satellite infrastructure [1–4]. An aircraft loitering, in the relatively stable weather conditions of the lower stratosphere, would have a line-of-sight (LOS) horizon of approximately 500 km which is much greater than that of any terrestrial broadcast tower. Being 20 km above the earth's surface, a stratospheric platform will suffer significantly less propagation loss and delay compared to a satellite-based communications system. The high look angle and consequent avoidance of blockage by buildings and trees is an advantage, as is the ease with which such aircraft can return to the ground for servicing [4]. Potential radio communications applications are UHF broadcast, supplementing the existing terrestrial mobile telephone network [5], and low infrastructure cost mm-wave broadband delivery.

Applicable aircraft types are manned fixed wing aircraft, tethered aerostats, unmanned fixed wing aircraft (UAVs), and unmanned lighter than air nonrigid airships. Free-flight or partially steered weather balloons, despite being low cost and readily available, are considered to only be applicable to scientific and low-data-rate missions due to lack of precise flight control [4, 6, 7]. Manned aircraft are another mature technology, having been developed over the last 55 years for military surveillance applications, but are limited to a maximum of about 6 hours on station due to pilot endurance. Tethered stratospheric aerostats are attractive as the tether gives crude position control and a means of supplying power to a communications payload without the weight penalty of a regenerative power supply. However, the tether requires an exclusion zone of 27.5 km radius during launch/recovery and of 5.5 km radius during flight in the stratosphere to ensure that no aircraft collide with it [8]. Unmanned robotic aeroplanes (UAVs) avoid the need for both pilot and tether, and have been shown to be practical as communications platforms, but suffer from highly restricted payload weights [2, 5]. Consequently, stratospheric airships of about 200 m length fitted by solar cells capable of carrying payloads of multiples of 1000 kg are the ideal platform [2].

The Japanese National Stratospheric Development Programme aimed to develop a 200 m long solar powered airship. A milestone in this development programme was a 67 m autonomous airship capable of station keeping at an altitude of 4 km, which was designed and operated by

Figure 1: Photograph of the prototype stratospheric airship.

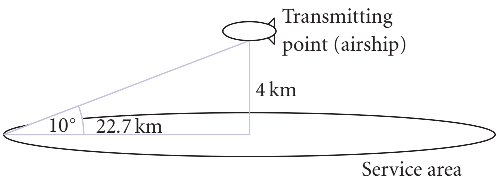


Figure 2: Illustration of the demonstration service area.

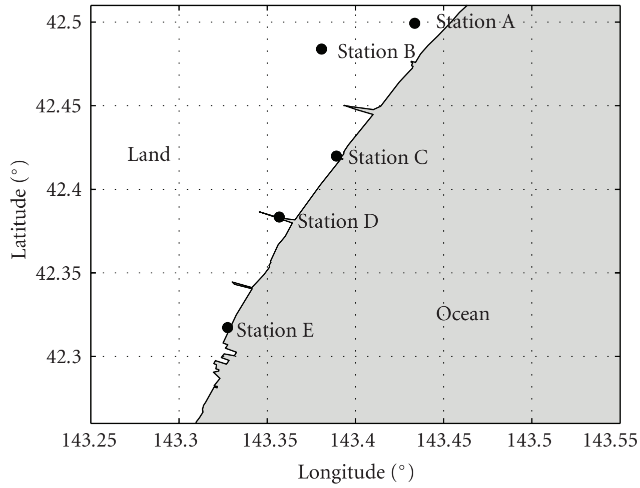


Figure 3: Map of the demonstration area in south eastern Hokkaido, with ground station positions and coastline marked.

the Japan Aerospace Exploration Agency (JAXA). During flights in November 2004 over south eastern Hokkaido, Japan, a high-speed optical link to ground was demonstrated, as were a radio localization system and a UHF digital TV (DTV) broadcast. The DTV broadcast demonstration was an advance over the prior 2002 demonstration using the Pathfinder Plus UAV [9], in that a defined service area with multiple receivers was used. The size of the nonrigid airship and the UHF band used has some similarity to a maritime exercise conducted as part of the Sentinel 5000 development programme [10]. The 2004 demonstration differed from the previous maritime exercise in that a higher altitude was used and an attempt was made to deliver equal signal strength across a service area within the LOS horizon of the airship.

In the following sections, a brief overview of the DTV broadcast demonstration is given, the random signal loss experienced at the receiving station directly below the airship is described, and the simulation results identifying a possible cause of the signal loss are discussed. Several possible mitigation techniques and alternative antenna designs which would have fitted within the constraints of the 2004 demonstration were then compared.

2. OVERVIEW OF THE 2004 DTV BROADCAST TRIALS

2.1. *Stratospheric airship prototype*

An autonomous airship capable of station-keeping flight at an altitude of 4 km was built as a milestone of the programme to develop 200 m long airships able to operate in the stratosphere (see Figure 1). The prototype airship was 67 m long, of nonrigid type, employed helium as the lifting gas, and had an optional facility for remote human pilotage [11]. In October and November 2004, the airship was used for traffic monitoring and communications demonstrations around its base at Taiki-cho airport in south eastern Hokkaido, Japan. The autonomous airship made 2 flights carrying the communication demonstration payload in November, 2004 [11]. The total flight time on November 19th was 3 hours and 15 minutes, with altitudes of 3600 m to 4000 m. On November 22nd, the total flight time was 3 hours and 49 minutes, at an altitude of 4000 m.

The demonstration service area was defined as the radius at which a ground station receiver antenna would have an elevation angle of greater than 10°, to avoid blockage by trees and buildings [11]. With the airship loitering at 4 km altitude, the demonstration service area thus had a radius of 22.7 km (see Figure 2). This radius fitted onto the flat coastal plane to the south of the Taiki-cho airport and 5 ground station receiving locations were scattered across this distance to the south of the airport (see Figure 3). Station A was on the roof of the Taiki-cho airport control tower, and thus directly below the airship during station keeping. Station D was on the LOS horizon of the control tower, while Station E was 22.7 km from the control tower.

Vertically polarised monopole antennas were used for the UHF relay demonstrations using the Sentinel 1000 airship [10]. These antennas, despite being of light weight and of simple construction, were crude in that the radiation pattern could not be shaped with any sophistication; there was a deep null directly below the airship preventing reception, and orientation changes due to pitching and rolling of the airship in flight caused polarisation losses. Overcoming these problems would be necessary for commercial digital TV (DTV) broadcasts from the airship where a high degree of service availability was required. The antenna should have ideally had 15.2 dB more gain in the direction of the edge of the service area (80°) than directly below the airship (0°) due to the difference in free-space loss, "ideal" trace of Figure 4. The intermediate angles of the ideal radiation pattern shape were similarly the difference in free-space loss between those angles and that for directly below the airship. A single turn, conical beam, circularly polarised, backfire helical antenna was designed and built by a subcontractor

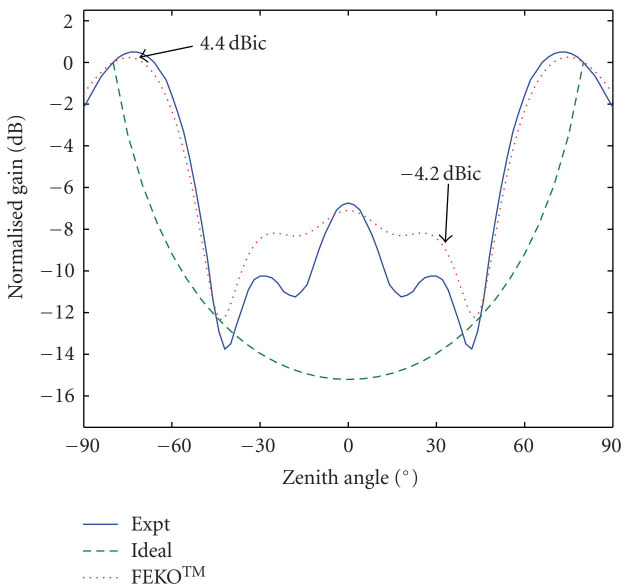


Figure 4: Radiation pattern of the helical antenna on 1.8 m sided square ground plane at 479 MHz, normalised to zenith 80° gain; "ideal" trace would compensate for free-space loss.

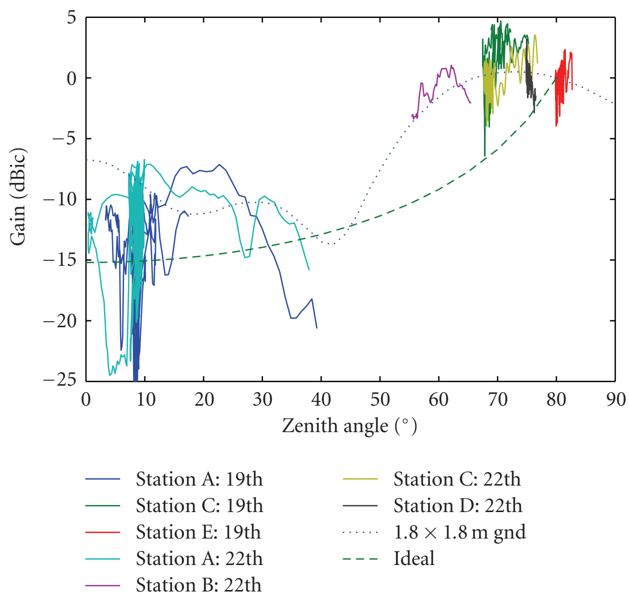


Figure 5: Reconstructed helical antenna gain paired with zenith angle; normalised to 83° gain level.

for this UHF broadcast demonstration. This antenna fitted within a 56 cm long, 6 cm radius cylindrical fibre reinforced plastic radome and had an operating frequency of 479 MHz. On a 1.8 m sided square gain compliance ground plane, the helical antenna gave a rough but acceptable approximation to the ideal radiation pattern shape (see Figure 4). A better fit to the ideal radiation pattern shape could have been achieved by increasing the number of turns of the helix to either 3 or 5 [12], but the length of the antenna would have exceeded the limit imposed by the length of the airship landing gear (see Table 1).

Table 1: Requirements for DTV broadcast antenna.

Quantity	Requirement
Height	<90 cm
Radius	<45 cm
Weight	Low
Frequency	479 MHz
Bandwidth	2%
Radiation pattern shape	−15.2 dB conical
Polarisation	Circular

2.2. Broadcast demonstration results

A full description of the DTV broadcast demonstration is given in [11]. In summary, the DTV demonstration signal was broadcast for 1 hour and 6 minutes during the flight on November 19th, and for 1 hour and 11 minutes during the flight on November 22nd. The received signal at each ground station was recorded every 10 seconds by a data logging computer attached to a spectrum analyser. No demodulation failure due to signal degradation, such as Doppler shift, was observed. The signal power level fluctuations were generally less than 5 dB, and were likely a product of the pitch and roll of the airship causing variation in the zenith angle of the broadcast helical antenna seen by each ground station. However, on both days, the signal power received at Station A suffered severe drops of greater than 15 dB at random intervals. The frequency selective attenuation observed in the received signal just before a reception failure occurred suggested that there was a multipath reflector within 25 m of the broadcast antenna. Thus, some structure on the gondola is a likely cause of the intermittent signal loss experienced at Station A.

Unfortunately, no attempt was made to measure the radiation pattern directly while the airship was in flight. Having the radiation pattern of the broadcast antenna installed on the gondola would aid in identification of the structure on the gondola that caused the signal loss experienced at Ground Station A. The gain of the broadcast antenna on the airship for each received data point was calculated from the link budget. The zenith angle of the broadcast antenna radiation pattern for each received data point was calculated from the separation and airship altitude [11] (see Figure 5). These relatively simple calculations give a crude reconstruction of the radiation pattern of the antenna installed on the airship during flight. While there is no azimuth information and the roll and pitch of the airship are not accounted for, the reconstructed gain variation with zenith angles roughly indicates where the gain was excessively low without having had to perform complex calculations. The reconstructed radiation pattern sections for both days (other than Station A) are in reasonable agreement with the radiation pattern of the helical antenna measured on the gain compliance ground plane in an anechoic chamber (see Figure 5). The majority of the zenith angles at which the reconstructed antenna gain was much less than the measured anechoic chamber gain and the ideal pattern shape are within the 0° to 10° range (see Figure 5). Thus, some structure on

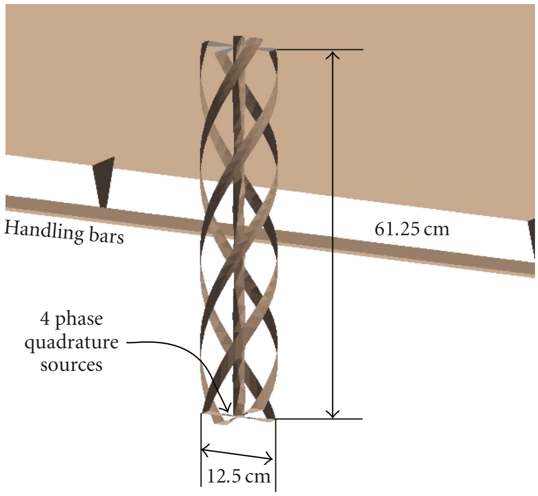
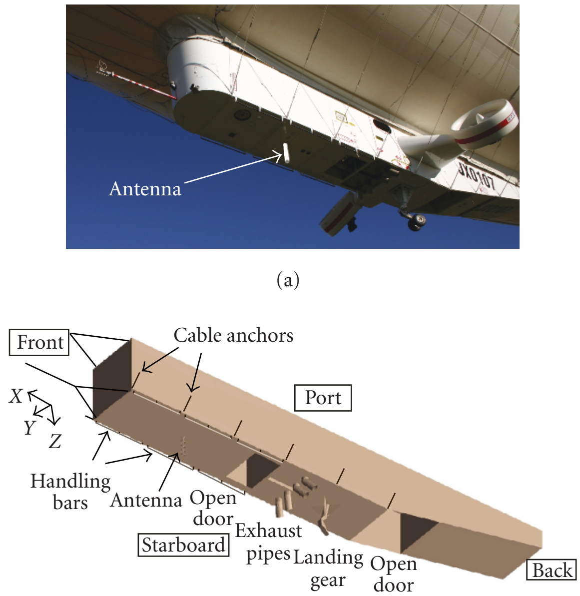


Figure 6: Model of the single turn helical antenna; from FEKO.



(a)

(b)

Figure 7: Photograph of the airship gondola from below and FEKO model.

the airship gondola caused the insertion of one or more deep nulls into the radiation pattern. Identification of the structure that caused the nulls is useful for preventing a repeat of this type of vehicle integration problem in the future.

As the airship is no longer available for flights (which would be prohibitively expensive in any event) and the construction of an accurate 10% scaled model being extremely difficult due to the relative size difference between the gondola and its fine features and the antenna, an antenna simulation software model was used as a labour saving device.

3. NUMERICAL MODEL

3.1. Model of the antenna

The helical antenna was attached directly to the airship gondola; lacking any significant standoff as has been used with similar antennas installed on satellites [13] and could be expected to cause significant coupling to the gondola and any resonant structures on it. The antenna was a proprietary design and was structurally complex, with internal foam supports, baluns, and a plastic radome, and could not be modelled exactly in the commercially available Method of Moments (MOM) software FEKO (see Figure 6). Thus, a simple top fed design was created on the gain compliance 1.8 m-sided square ground plane in FEKO [14]. The helical antenna model consisted of 4 single turn helical strips with a thin axial cylinder, which represented the baluns and balun sheath (see Figure 6). The helical strips were connected by radial strips to the axial balun cylinder at both top and bottom, with a small gap separating the bottom radial wires from the ground plane (see Figure 6). The radius and length of the helix model were adjusted until the radiation pattern matched that measured in an anechoic chamber as closely as possible. The helix radius was 6.25 cm, helix height was 61.25 cm, balum cylinder radius was 1 cm, and the gap separating the helix cross-arms from the gondola was 1.5 cm.

The height of the antenna was 0.98 wavelengths (0.9λ) at 479 MHz. The far field radiation pattern of the helical antenna model in FEKO was in reasonable agreement with the radiation pattern of the actual DTV broadcast antenna measured in an anechoic chamber on the gain compliance ground plane (see Figure 4). The beam peak at 72°, the null at 42°, and the 0° gain level were in good agreement. The major difference was between zenith angles of 10° to 20°, where there was a gain difference of 3 dB. As that part of the radiation pattern could not be reproduced with the simple metallic strip model in FEKO, it is assumed that it was influenced by the dielectrics used for structural support and the radome. Thus, it was not possible to match the FEKO model exactly to the antenna used in the DTV demonstration.

3.2. Model of the gondola

In common with the manned Sentinel 1000 airship [10], the prototype stratospheric airship was of nonrigid configuration. The envelope enclosed no significant electrically conductive structures, such as supporting trusses or aluminium foil lined bollutes, and was thus assumed to be entirely transparent to UHF radio waves. Similarly, there was very little electrically conductive material in the ducted fans on either side of the gondola and the nose section, which were thus ignored. So, the numerical model of the airship consisted solely of the gondola (see Figure 7).

The main features of the FEKO model were ground handling bars, exhaust pipes of the diesel generators, landing gear, cable anchors, and hollows representing open cargo bays and the slot between the engines (see Figure 7). The length of the gondola was 15.4 metres, while the width and

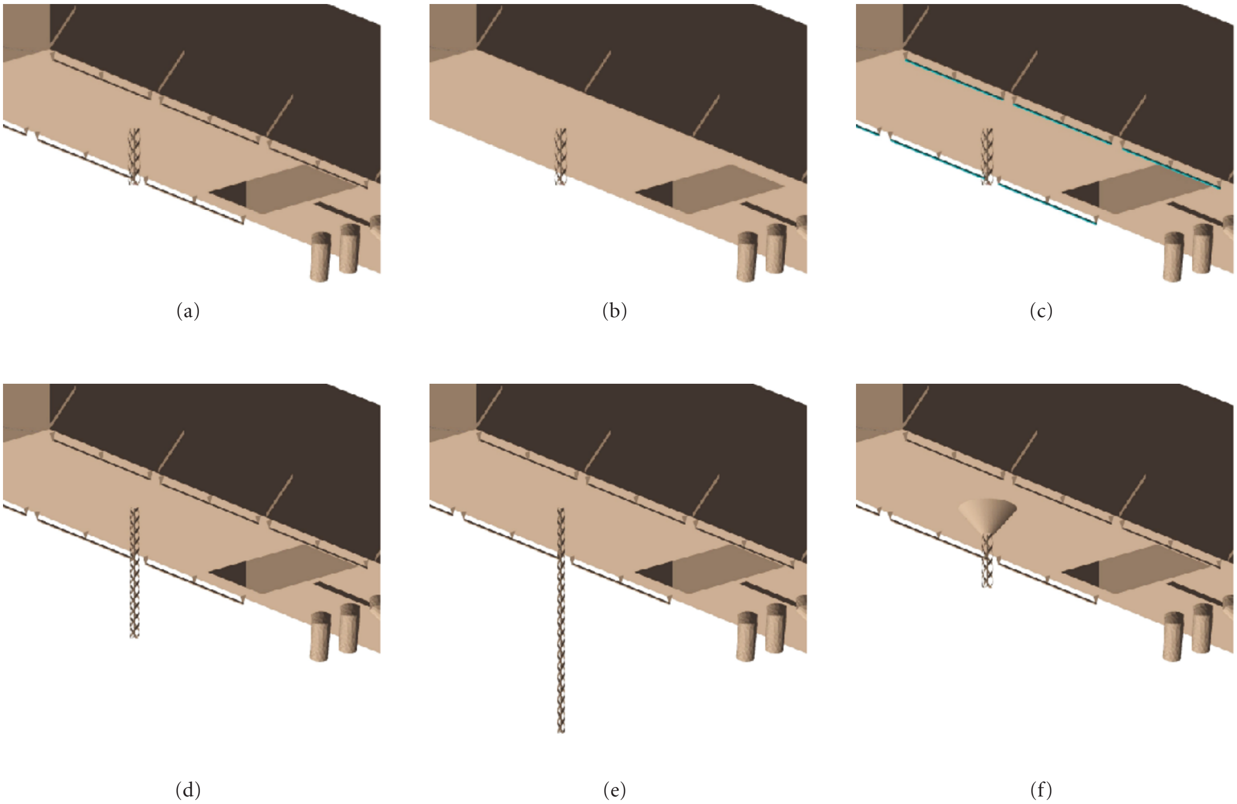


Figure 8: FEKO models of helical antenna variations; (a) single turn, (b) no ground handling bars, (c) plastic ground handling bars, (d) 3-turn helix, (e) 5-turn helix, (f) single turn helix on standoff cone.

height were 1.8 metres; making the gondola a 2.8 × 2.8 × 22.8λ structure at 479 MHz. The helical broadcast antenna was installed 20 cm forward of the centre of the second bay (see Figures 7 and 8(a)).

Due to the prototype airship no longer being available for experiments and the large relative size difference between the helical antenna and the gondola precluding the construction of a scaled model, the antenna was modelled on the airship gondola in FEKO. The bulk of the gondola model was meshed at 12.5 cells per wavelength ($\lambda/12.5$), while the helical antenna and the immediate area of the attachment point were meshed at $\lambda/25$. Typically, the FEKO model of the gondola consisted of 137 003 MOM triangles, and conveniently ran in under 145 minutes on a desktop personal computer using the Multi-Level Fast Multipole Method solver option. The peak memory usage was around 8.2 GB.

3.3. Numerical simulation results

If the broadcast antenna was unable to perfectly produce the ideal radiation pattern shape to compensate for the free-space loss, the imperfections must be compensated for by increasing the broadcast power level to ensure that the entire service area receives adequate signal strength to satisfy subscribers' requirements for high reliability of service. The compensation calculation entails normalisation of the broadcast radiation pattern to some low power point. Given that the edge of the service area requires the minimum ground receiver elevation look angle to the airship (10°) and has the longest path length to the airship, this position will suffer the most from blockage by ground clutter and rain attenuation, respectively. Thus, the minimum gain at a zenith angle of 80° was used to normalise the helical antenna FEKO model radiation patterns for comparison to the ideal.

The gain of the helical antenna at zenith angle 80° had a range of 4.6 dB, with the minimum at an azimuth angle of 315° (see Figure 9). In contrast, the helical antenna simulated at the centre of the gain compliance 1.8 m sided square ground plane had an 80° gain variation of 1 dB, 1.3 dB when moved 20 cm off the centre of the square ground plane towards the middle of a side, and 2.1 dB on a solid block model of the gondola lacking all of the fine features such as the ground handling bars, exhaust pipes, and landing gear (see Figure 9). Thus, the greater the complexity of the model of the gondola that the helical antenna was installed upon, the greater the variation in the 80° gain, which raises more of the angular range of the radiation pattern above the ideal upon normalisation (see Figure 10). Considering the principal planes (azimuth angles 0° and 90°) of the radiation pattern of the helical antenna installed on the gondola, the gain was always above the ideal radiation pattern shape (see Figure 10). The multiple narrow nulls in the 0° plane

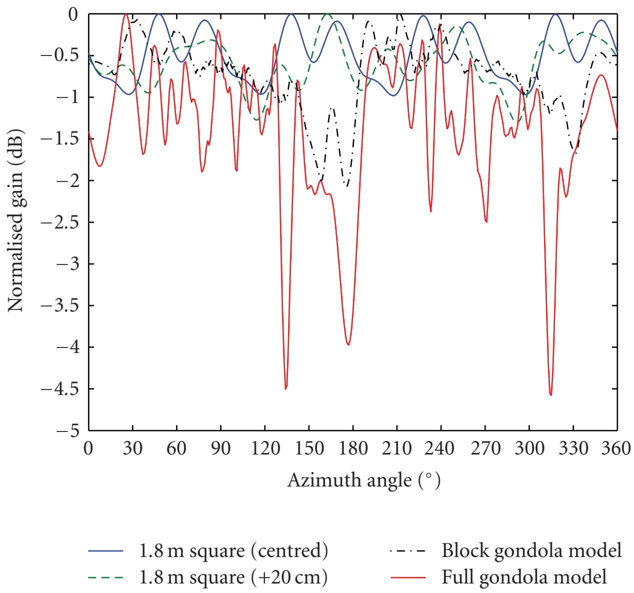


Figure 9: Variation of zenith angle 80° gain with azimuth angle of the single turn helical antenna on square 1.8 m sided ground planes and gondola models, from FEKO.

across ±15° of the simulation results are suggestive of the nulls in the reconstructed radiation pattern, but the null depth was less in the simulation results (see Figures 5 and 10). Both the reconstructed radiation pattern and the simulation result of the helical antenna on the gondola show that the greater than desired gain across zenith angles of ±45° seen when the helical antenna was on the gain compliance ground plane was significantly reduced when the antenna was integrated with the gondola. The nulls at 42° in both planes were also in agreement with the gain decrease across the range of ±30° to ±40° in the reconstructed radiation pattern in terms of angular position (see Figures 5 and 10).

An overall appreciation of the radiation pattern from the simulation of the helical antenna attached to the gondola can be gained by plotting the gain as a contour against the azimuth (XY) angle and zenith (XZ) angle of the data as the radius (see Figure 11(a)). Due to the shallow depth of the nulls and the normalisation process raising the gain, 99% of the power in the 0° to 80° zenith angle range of the radiation pattern spread across 97% of the angular range was more than 3 dB above the ideal radiation pattern shape (see Table 2 and Figure 11). Only 0.02% of the power in the radiation pattern spread across 0.4% of the angular range fell below the ideal radiation pattern shape, and was confined to zenith angles around 45°.

Normalisation of the entire radiation pattern with respect to the minimum gain at $\theta = 80°$ thus succeeded in moving most of the radiation pattern above the ideal pattern shape. In a practical situation, this would ensure that the signal strength received on the ground, even in nulled directions, would be sufficient for reception and thus decrease outages. Conversely, the disadvantage would be that the majority of the angular range of the pattern is more than 3 dB above the ideal, so greater signal strength would be delivered to most ground receivers which wastes the limited power available on the airship.

An antenna that produced a radiation pattern that was confined to a narrow power range about the ideal pattern shape would require less compensatory power offset in the link budget, and thus be more efficient. The majority of the angular range having normalised gain more than 3 dB above the ideal radiation pattern shape is highly wasteful, as more power would be delivered to the ground than required for reception of the DTV signal.

The simulation results do not show the deep nulls across the ±10° zenith angle range seen in the reconstructed radiation pattern. A more exact comparison of the reconstructed radiation patterns and the simulation results will be possible in the future when azimuth data for the former becomes available. Both the reconstructed and simulated radiation patterns show nulls around zenith angle of 42°. It is speculated that reception problems would have occurred during the DTV demonstration broadcasts, if there had been any receivers between 3 to 3.6 km from Ground Station A due to the nulls on the $\theta = 45°$ line, if the nulls were deeper than predicted (see Figure 11(b)). The remainder of this paper presents simulation results for various means of mitigating null formation in the radiation pattern of the helical antenna installed on the gondola.

4. MODIFICATION OF THE GONDOLA

4.1. Removal of the ground handling bars

There were ground handling bars 90 cm $(1.4\lambda_0)$ from the helical antenna during the broadcast demonstrations (see Figure 7). The ground handling bars were attached to the bottom edges of the forward 3 bays of the gondola and had horizontal sections 80 cm (1.3λ) long, and were potential resonant structures. These were shown to affect the return loss, radiation pattern, and current distribution induced on the gondola by a $\lambda/4$ monopole installed in the same position as the helical antenna [15]. Removal of the ground handling bars from the simulation model improved the performance of the helical antenna by causing the gain range of the zenith angle 80° and entire radiation patterns to decrease by 1 dB (see Table 2 and Figures 8(b) and 12). Consequently, there was a small shift in the power-angular spread of the radiation pattern into the range of ±3 dB of the ideal. Despite removal of the ground handling bars offering an advantage in that the transmit power could be decreased some small amount, the ground handling bars could not be removed in practice because the ground handling bars were essential for the capture and control of the airship by ground staff on landing. An absence of ground handling bars would likely infringe the airworthiness of the airship, and prevent it from flying legally.

4.2. Plastic ground handling bars

An alternative to removal of the horizontal sections of the ground handling bars would be to change the material

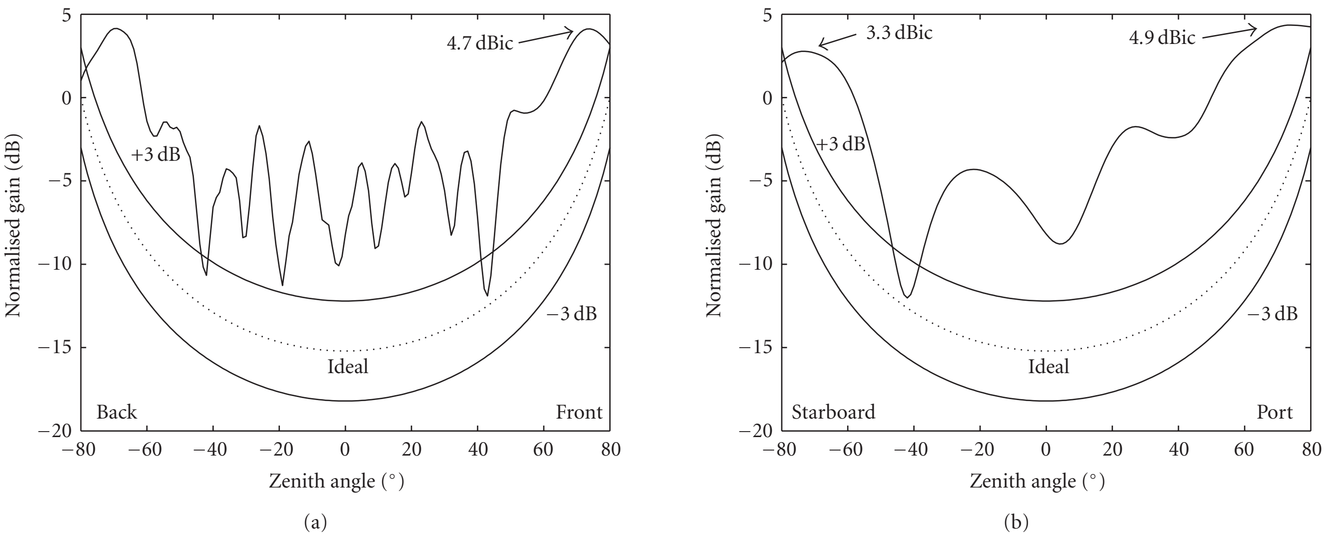


Figure 10: Principal plane radiation patterns of the single turn helical antenna on the gondola; (a) azimuth angle 0° {along the gondola}, (b) azimuth angle 90° {across the gondola}, normalised to minimum value of zenith 80° gain, from FEKO.

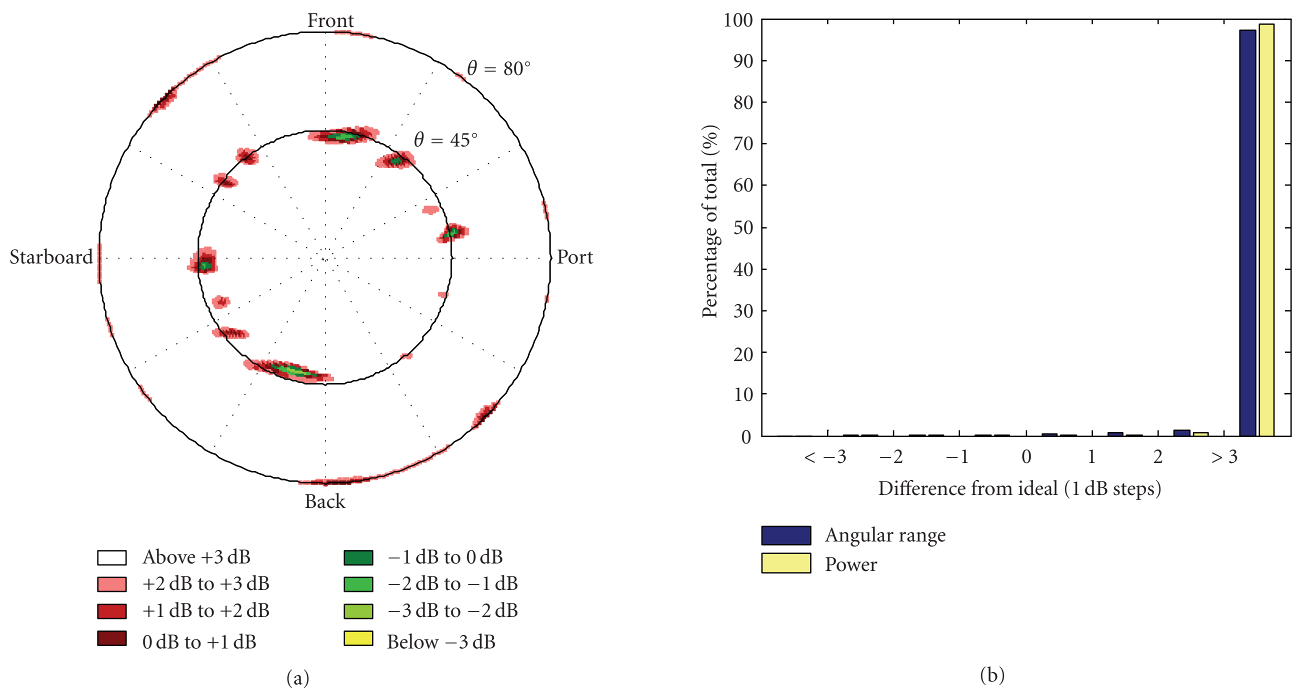
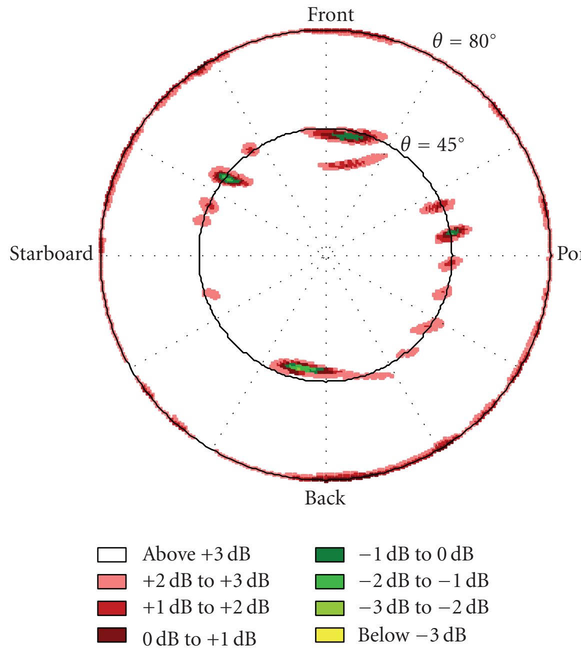


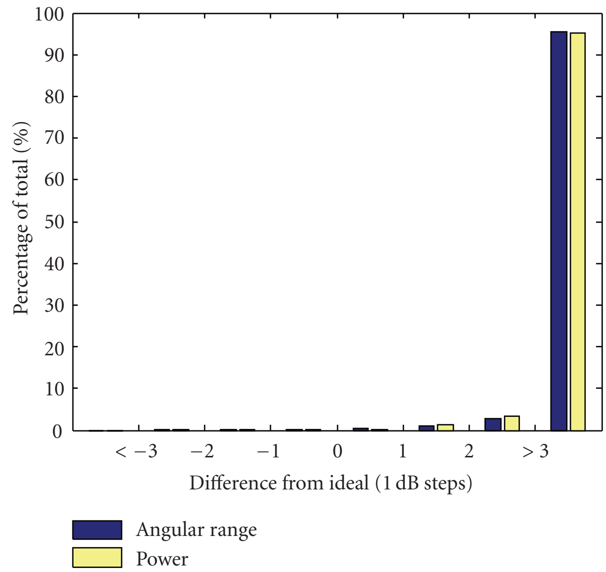
Figure 11: Assessment of radiation pattern of single turn helical antenna on the gondola normalised to $\theta = 80°$ minima; (a) flattened hemisphere plot of gain comparison to ideal radiation pattern shape, (b) radiation pattern power distribution in relation to ideal radiation pattern shape, from FEKO.

Table 2: Summary of figures of merit for gondola modification models.

Name	Single turn	No ground handling bars	Plastic ground handling bars
Peak gain (dBic)	6.18	6.24	6.33
Gain range (dB)	20.9704	19.0343	19.0106
80° gain range (dB)	4.5796	3.5088	3.482
Angles inside ±1 dB	0.64402	0.61632	0.63017
Power inside ±1 dB	0.11204	0.21028	0.21869
Angles outside ±3 dB	97.2369	95.388	95.3291
Power outside ±3 dB	98.8301	95.0423	94.9633



(a)



(b)

Figure 12: Assessment of helical antenna radiation pattern on the gondola with ground handling bars removed, normalised to $\theta = 80^\circ$ minima; (a) flattened hemisphere plot of gain comparison to ideal radiation pattern shape, (b) radiation pattern power distribution in relation to ideal radiation pattern shape, from FEKO.

comprising the bars from high electrically conductive hardened aluminium to fibre glass. The prisms representing the horizontal sections of the ground handling bars in the FEKO models were changed from perfect electrically conducting to solid dielectric prisms ($\varepsilon_r = 3$) to approximate air-filled fibre glass tubes (see Figure 8(c)). The resulting improvement to the gain range and power-angular spread was identical to that from removal of the ground handling bars (see Table 2 and Figures 12 and 13).

Thus, the use of fibre glass ground handling bars on the airship during the DTV broadcast demonstrations would have partially mitigated null formation according to the simulation results, and would not have compromised safe or legal operation of the airship. However, the simulation results suggest that the improvement would have been small. Modification of the broadcast antenna itself offers a means of affecting more significant improvements to broadcast system efficiency.

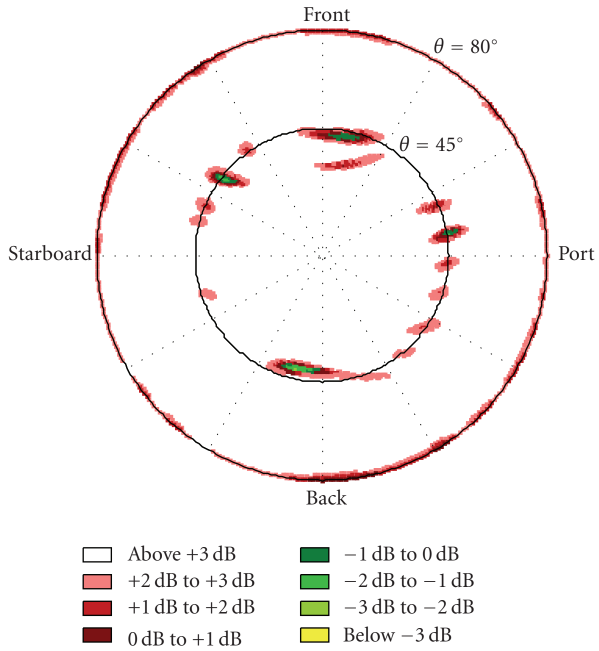
5. MODIFICATION OF THE BROADCAST ANTENNA

5.1. *Effect of number of helix turns*

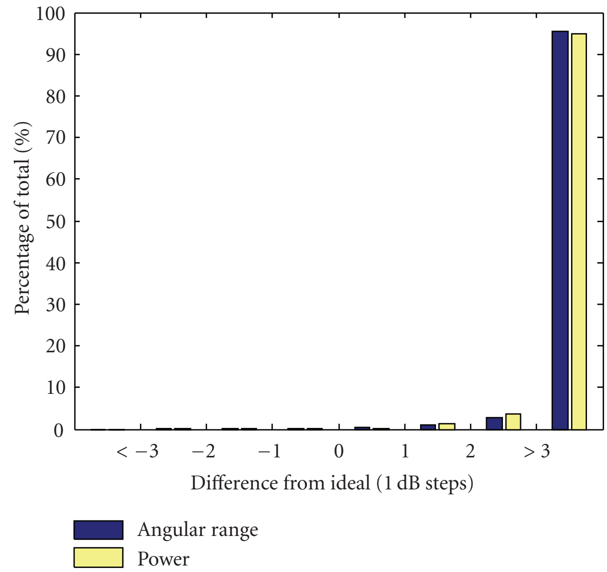
The greater the number of turns that a conical beam, circularly polarised, backfire helical antenna has, the better it is at approximating some required conical radiation pattern shape [12]. Increasing the number of turns of the helix from 1 to 3 caused a greater improvement to the power-angular spread than changing the ground handling bars to plastic (see Tables 2 and 3 and Figures 8(d) and 14). The fraction of the total power in the 80° zenith angle range outside of ±3 dB from the ideal radiation pattern shape decreased from 99% to 73%, representing a reasonable improvement in efficiency at the cost of increasing the antenna height by about 90 cm (see Table 2 and Figures 8(d) and 14). Further increasing the numbers of turns to 5, gave further improvement in the power-angular spread, and thus broadcast power usage efficiency, with the amount of power falling outside of ±3 dB from the ideal to 5.8% (see Table 3 and Figures 8(e) and 15). The majority of the power (64%) within the radiation pattern of the 5-turn helical antenna was within ±1 dB of the ideal. The deep nulls present in the radiation pattern of the single turn helical antenna were absent from that of the 5-turn helical antenna (see Figures 9 and 15). Also, the 5-turn helical antenna had its peak gain at 80° matching that of the ideal radiation pattern shape and, despite been installed on the gondola, had a highly rotationally symmetric radiation pattern (see Figures 15 and 16). Thus, according to the FEKO simulation results, a 5-turn helical antenna would have given greater broadcast power efficiency than the single turn antenna used during the demonstrations. The only disadvantage of a 5-turn helical antenna would be its 2.5 m length, which would have exceeded the length of the airship landing gear (see Tables 1 and 3). Folding the 5-turn helical antenna into the gondola in the fashion of aviation landing gear when the airship was on or near the ground would have been necessary.

5.2. *Truncated cone standoff*

Inserting a truncated cone between a single turn helical antenna and a vehicle body has been shown to isolate the



(a)



(b)

FIGURE 13: Assessment of helical antenna radiation pattern on the gondola with plastic ground handling bars normalised to $\theta = 80^\circ$ minima; (a) flattened hemisphere plot of gain comparison to ideal radiation pattern shape, (b) radiation pattern power distribution in relation to ideal radiation pattern shape, from FEKO.

TABLE 3: Summary of figures of merit for antenna modification models.

Name	3-turn helical antenna	5-turn helical antenna	1-tun helical antenna + standoff cone
Helix radius (cm)	5	5	4
Helix length (cm)	145	253	58
Total height (cm)	145	253	88
Peak gain (dBic)	6.43	7.66	5.38
Gain range (dB)	15.2794	14.6975	17.9666
80° gain range (dB)	1.0083	0.42748	3.3615
Angles inside ±1 dB range (%)	1.4542	41.1101	0.3047
Power inside ±1 dB range (%)	4.8989	63.7566	0.16915
Angles outside ±3 dB range (%)	84.0933	12.922	96.7383
Power outside ±3 dB range (%)	72.9452	5.8213	94.4259

antenna from adverse integration effects (see Figure 8(f)) [16]. The dimensions of the helical antenna and the cone were optimised in FEKO and the resulting antenna and cone had a total height of 88 cm which was less than the length of the airship landing gear (see Tables 1 and 3). Although 94% of the power was still more than 3 dB above the ideal radiation pattern shape after normalisation, the nulls around $\theta = 42^\circ$ were eliminated (see Table 3 and Figure 17). Thus, inclusion of a 30 cm high, 22 cm radius copper or aluminium truncated cone between the single turn helical antenna and the gondola would have offered some minor improvement in efficiency and mitigated some nulling without exceeding the length of the airship landing gear and thus avoiding the need for a folding deployment system.

6. FUTURE ANTENNA DESIGNS

The 3-turn and 5-turn helical antenna designs suffer from lengths greater than that allowed by the landing gear length, and would have required some deployment mechanism (see Tables 1 and 3). Some recent work on helical antennas has shown that application of fractals via computer optimisation can shorten the length by up to 38% without compromising performance [17–19], at least across a narrow bandwidth. Shortening the 3-turn helical antenna by 38% would reduce its length from 145 cm to an acceptable 89.9 cm, and would be worth investigation for future airships.

Higher order mode microstrip patch antennas are another option, and will give conformal antennas that have

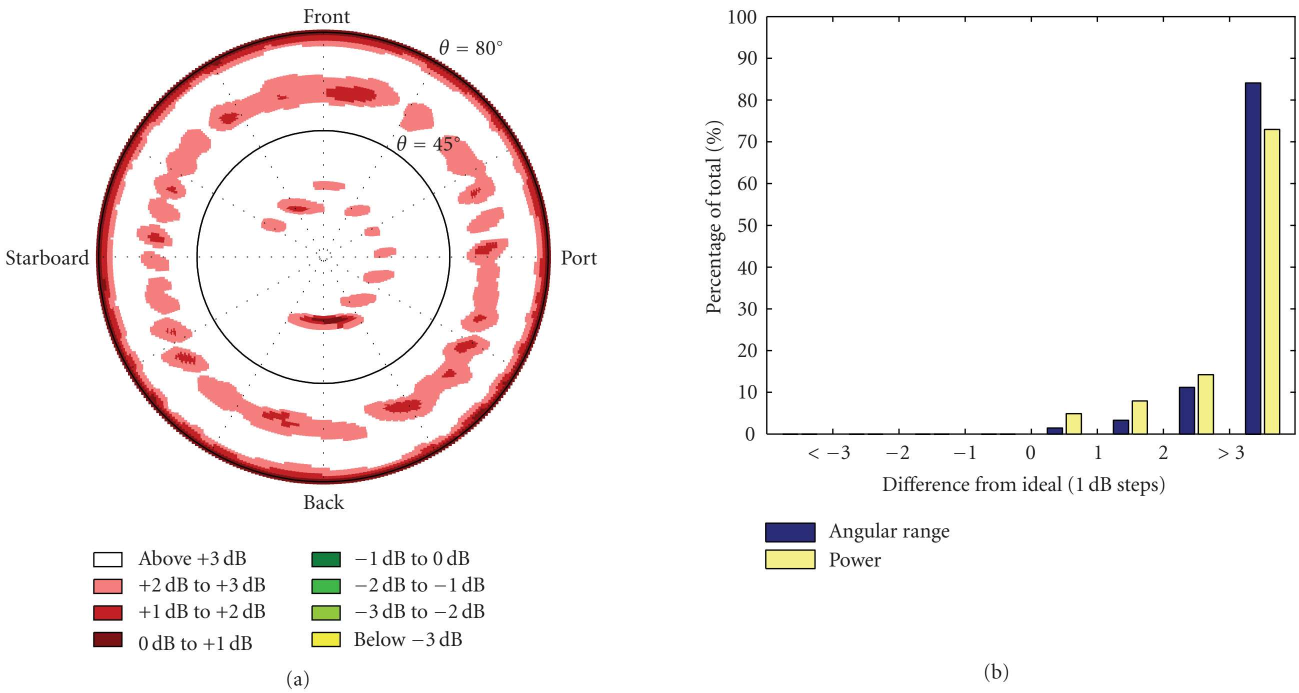


Figure 14: Assessment of 3-turn helical antenna radiation pattern on the gondola normalised to $\theta = 80^\circ$ minima; (a) flattened hemisphere plot of gain comparison to ideal radiation pattern shape, (b) radiation pattern power distribution in relation to ideal radiation pattern shape, from FEKO.

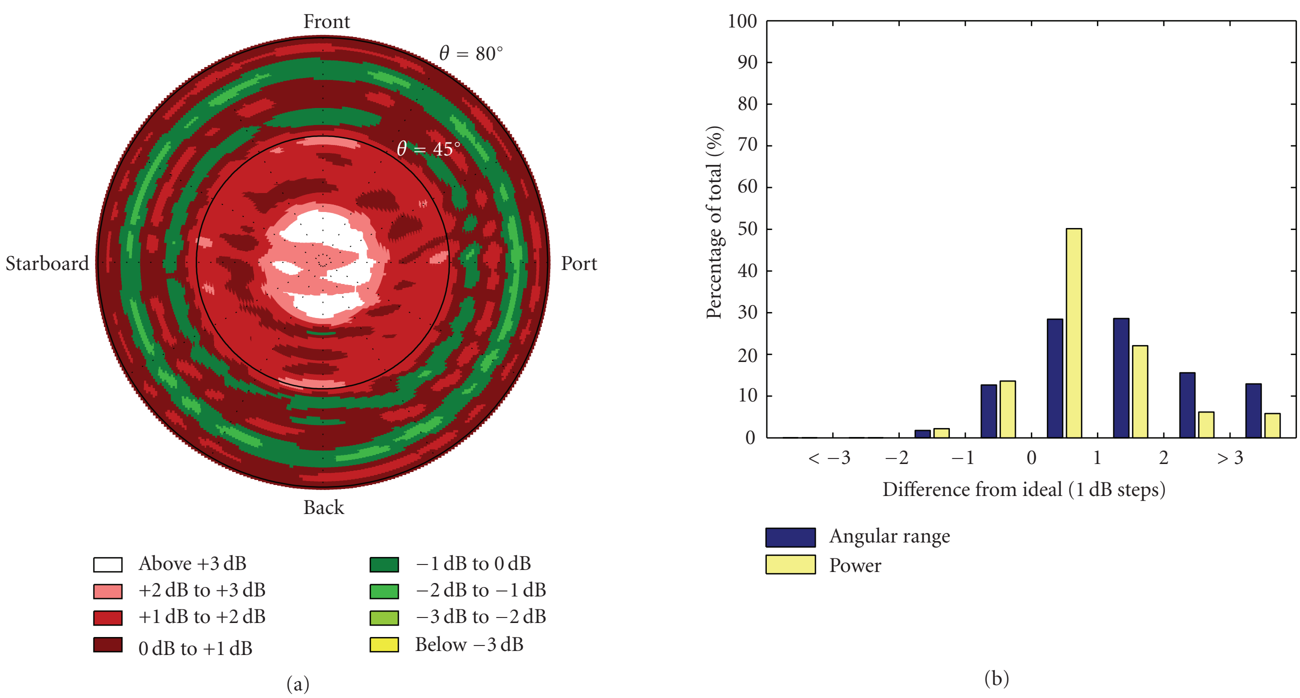


Figure 15: Assessment of 5-turn helical antenna radiation pattern on the gondola normalised to $\theta = 80^\circ$ minima; (a) flattened hemisphere plot of gain comparison to ideal radiation pattern shape, (b) radiation pattern power distribution in relation to ideal radiation pattern shape, from FEKO.

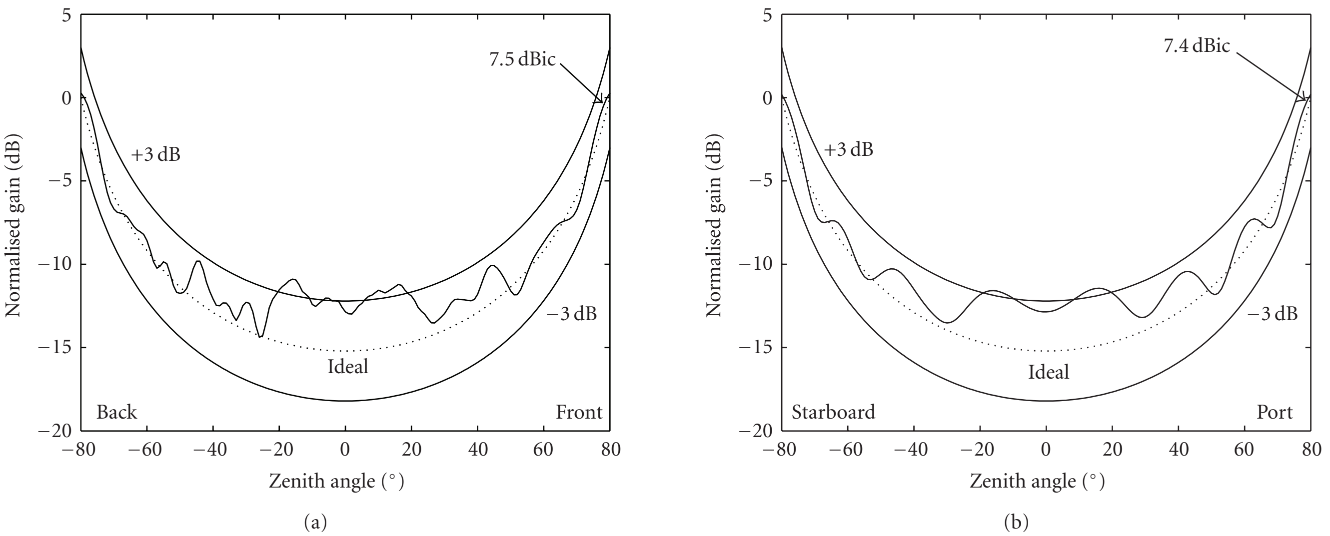


Figure 16: Principal plane radiation patterns of the 5-turn helical antenna on the gondola; (a) zenith angle 0°, (b) zenith angle 90°, normalised to minimum value of zenith 80° gain, from FEKO.

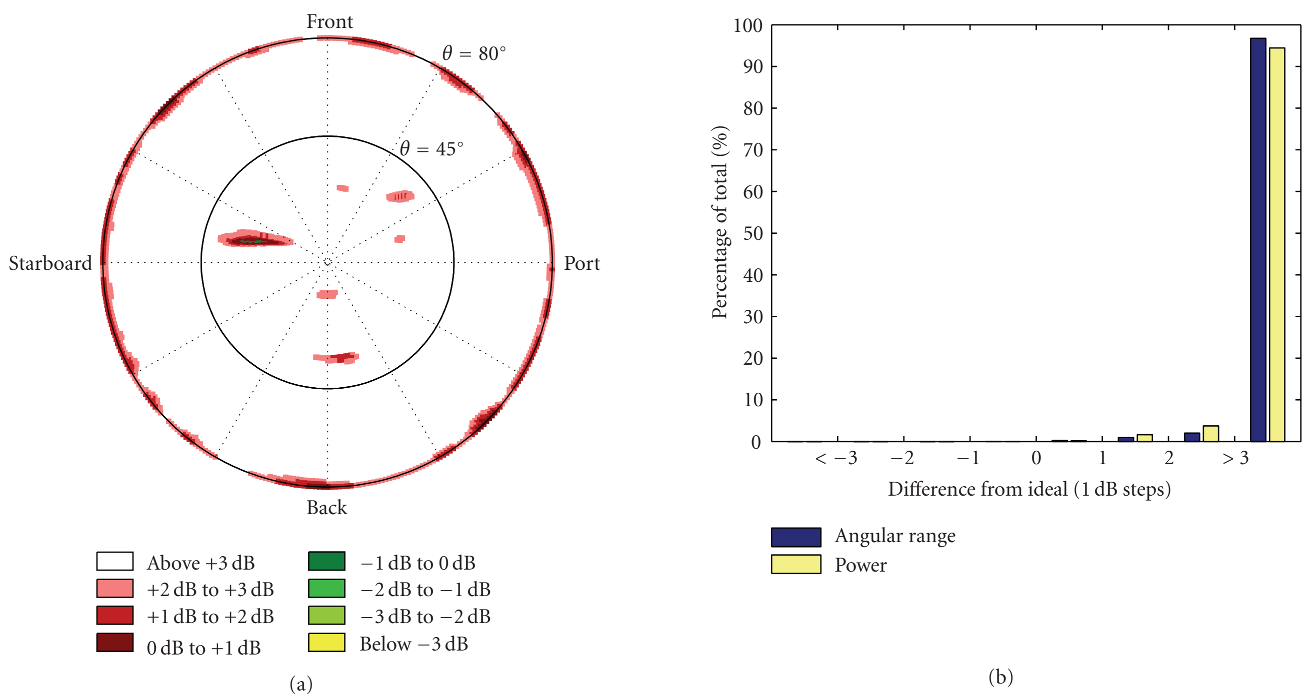


Figure 17: Assessment of radiation pattern of single turn helical antenna with standoff cone on the gondola normalised to $\theta = 80°$ minima; (a) flattened hemisphere plot of gain comparison to ideal radiation pattern shape, (b) radiation pattern power distribution in relation to ideal radiation pattern shape, from FEKO.

controllable peak gain angles [20]. However, the antennas operate in coaxial modes and have unacceptable deep nulls on axis that would deliver no signal directly below the airship. Addition of a lossy rubber ring around a higher order mode microstrip patch antenna will fill the axial null and enable a sharp gain roll-off past the peak gain [21]. An obvious disadvantage of this type of antenna is the requirement for large lateral space, which led to its rejection for use on the Canadian Space Agency's Quicksat demonstrator. Likewise, scaling the dimensions of the 2.3 GHz design of [21] to 479 MHz would give an antenna that covered an entire bay, which would have been unacceptable for the 2004 DTV broadcast demonstration (see Table 1). Use of some standoff between the microstrip patch antenna and the gondola might mitigate the lateral size problem for a narrow band application, but would not cover the entire DTV 49% bandwidth as would be required for a commercial broadcast system. Conical log-spiral antennas have been shown to produce circularly polarised, conical beams across bandwidths of this order [22], but have lengths of the order of the helical antennas considered here.

7. CONCLUSION

As a postdemonstration fault-finding exercise, the DTV broadcast helical antenna installed on the gondola of the airship used in November 2004 was studied using a commercially available antenna simulation software. It was found that the ground handling bars introduced some nulls into the radiation pattern of the helical antenna, and may have caused the random signal loss experienced at the Ground Station directly below the airship. Within the physical and monetary constraints of the 2004 DTV broadcast demonstration, the use of fibre glass ground handling bars and/or placing a 30 cm standoff cone between the helical antenna and the gondola would have prevented the random signal loss. It was also found that increasing the number of turns of the helical antenna to 3 or 5 would have reduced adverse antenna-vehicle interaction, given a radiation pattern shape closer to the ideal and thus made better use of the broadcast signal power across the entire service area to the degree where the extraexpense of an antenna deployment mechanism may have been warranted. Some promising alternative antenna types were also discussed.

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