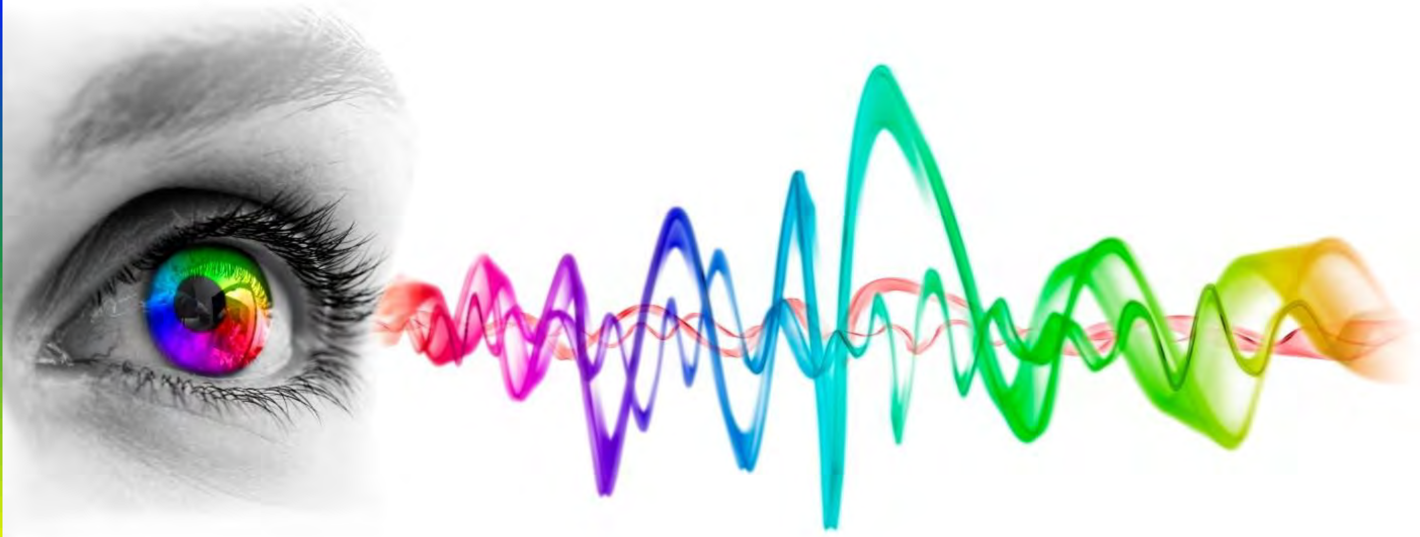
WHITE PAPER ON UAV BASED TRANSMIT ANTENNA MEASUREMENT SYSTEM



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1 INTRODUCTION

LS of South Africa, part of the International LS Telcom group with Headquarters in Lichtenau Germany, had the privilege to embark on a Cross Country UAV (Unmanned Aerial Vehicle) Antenna Radiation Pattern Measurement Campaign in the United States of America in partnership with its local LS US office, based in Bowie, Maryland.

The project was awarded to LS Telcom US, to measure Frequency Re-Packed TV stations. These measurements were done mainly for TV Broadcast Repack antennas. The main purpose for these measurements is to conclude that the stations are functioning as expected and that the actual measured antenna patterns match the theoretical patterns for the planned coverage area.

2 DESIGN CONSIDERATIONS

In the design of a UAV based measurement system there are several components which are non-negotiable. All these components are interdependent and finally forms the antenna measurement system. Failure to comply to these basic rules will result in inaccurate measurement results as well as life threatening situations. The various components of the measurement system include the following:

- Measurement vehicle
- Payload of measurement vehicle
- GPS system with centimeter accuracy
- Absolute RF characterisation of the measurement vehicle
- Measurement Software
- Real time data feed
- RF screening of the measurement against EMI
- Accuracy of measurements

2.1 Measurement vehicle

The measurement vehicle is a crucial component in the measurement system. The fact that the measurement system is designed to measure radio frequencies, demand that the vehicle has low levels of RF radiations. At the same time, it is also crucial that the user of the vehicle is aware of the RF radiation that is generated by the airborne vehicle. For this reason, it is important that the vehicle is analysed in an anechoic chamber to determine the levels of radiation originating from the measurement vehicle. It is also very important to ensure that the measurement vehicle's RF radiation does not impact on the measurements which is performed on the antenna systems.

The flight paths we use for our measurements range between vertical flights to horizontal to spiral flights. It is therefore important to make use of a multi rotor vehicle that supports the type of flights that is required to perform the required measurements. The antenna measurements also require take-off in areas where there is very little space with uneven terrain conditions.

The vehicle shall include distance sensing, anti-collision avoidance in different directions, parachute that will deploy automatically and any aviation features as required by the aviation authority.

2.2 Payload of measurement vehicle

The measurement system contributes a lot to the payload on the UAV. It remains a challenge to find measurement equipment that can be installed on the UAV that will not add to much payload. Several manufacturers are producing extra light weight measurement devices. This made the viability of building a small size airborne measurement system a reality. The flight time is directly linked to the payload. Low frequencies require larger antenna elements especially if a directional antenna is required for the measurement that is performed. A measurement vehicle that can measure frequencies in the VHF band normally require larger antennas with accurate antenna gain figures and this will require a larger vehicle to mount and carry the larger antenna size. Omni directional antennas add reflections to the measurement which can affect the accuracy of the pattern measurement.

Safety systems such as parachutes also add weight to the system and it is always a challenge to reach the correct balance between the vehicle size, payload, frequency measurement range and flight time.

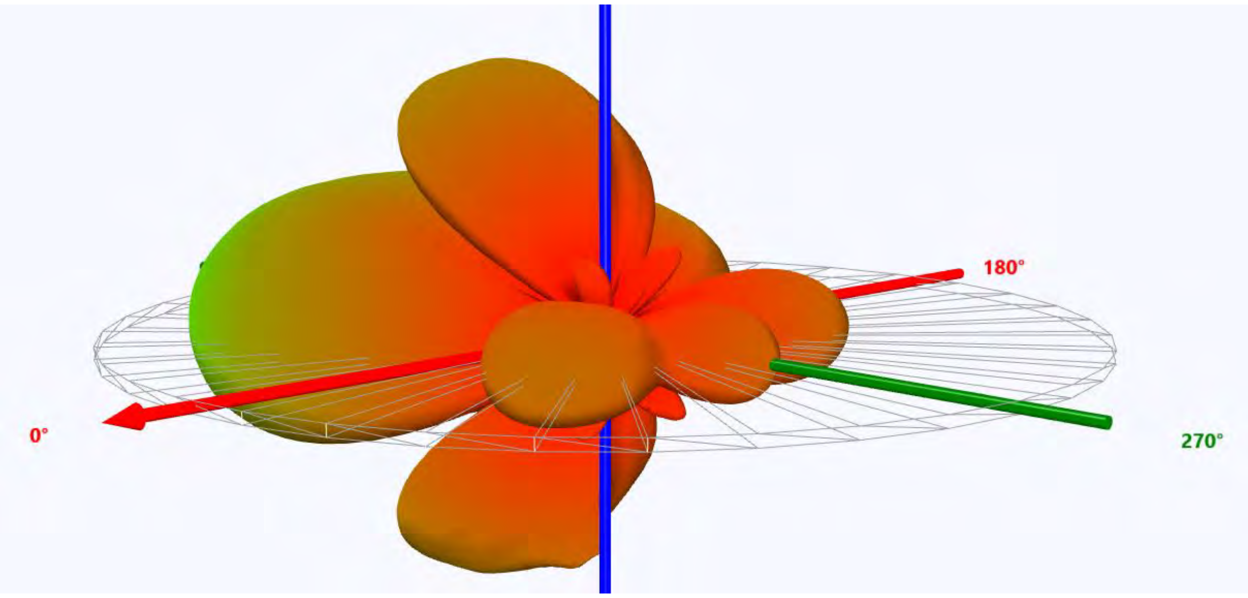
2.3 GPS system with centimeter accuracy

The measurements we perform require a GPS system that provides centimeter accuracy during flights and measurements. This will contribute to the measurement accuracy and the measurements that can be undertaken. The closer the flight takes place to the measured antenna device the more critical the position accuracy become. It is very important to ensure that the mid antenna height, mast base height and position and the measurement points are all measured with the same GPS system. This will reduce offsets between the measurements that can lead to inaccurate distances and heights. We have learned very quickly that it becomes a major problem if the measurement system and the flight controller use different GPS systems. Our measurements which are performed on an open test range produce more accurate antenna patterns and measurement results than can be achieved in our anechoic chamber, mainly due to the measurement distances which are more forgiving. Reflections can however become a problem on an open test range.

To produce the measurements results with accuracies better than 1 dB we use one RTK GPS system for both the flight paths and the measurement system.

2.4 Absolute RF characterisation of the measurement vehicle

One of the aspects that contribute to the measurement accuracy is the RF characterisation of the measurement vehicle. During the measurement flights the UAV is exposed to pitch, roll, and yaw offsets. These offsets cause receive antenna misalignments in azimuth and tilt towards the transmit antenna as well as polarisation discrimination. The measurement system needs to correct for these misalignments. The receive antenna is an integrated part of the UAV and for this reason the integrated system shall be fully characterised for all frequencies that are measured to compensate for these flight inaccuracies. The 3D antenna pattern diagram below characterises the complete measurement system for a specific frequency with absolute maximum gain and sidelobe values.



The measurement antenna rarely has a flat gain curve and constant pattern over a frequency range. The measurement system's antenna gain and pattern needs to be measured accurately for characterisation for each frequency measurement of a transmit antenna system. The standard gain and antenna pattern curves of the measurement antenna is no more applicable as the UAV will affect it, especially if an omni directional antenna is used for the transmit antenna pattern and gain measurements.

During the measurement process the following parameters need to be corrected because of flight inaccuracies or measurement misalignment i.e.:

- Integrated receive antenna polarisation inaccuracies
- Integrated receive antenna azimuth inaccuracies
- Integrated receive antenna tilt inaccuracies
- Integrated receive antenna gain corrections per frequency

We have managed to design a UAV based antenna measurement system that apply corrections to the standard field strength results to ensure that the absolute patterns are measured by correcting the individual components that make-up the final measurement pattern which is derived. We have worked with various antenna manufacturers around the world and the measurement results we produce have revealed numerous installation faults, antenna pattern modifications because of the antenna mounting as well as design inaccuracies.

2.5 Measurement Software

The software consists of a range of modules that contribute to the complete measurement task. The software can be divided into the following components:

- Transmission technology configuration module with power measurement algorithm settings
- Receive antenna and cable selection module
- Receiver system selection module for different polarization setups
- Site parameter module
- Frequency measurement module
- Measurement instrument selection and setup module for technology and control of measurements
- Vehicle RF characterisation module for measurement accuracy corrections
- Auto report generation module
- Databases (receive antenna, cables, results, reports)

2.6 Real time data feed

To ensure that accurate measurements take place a real time data feed is in place to be able to see the measured pattern formation in real time. Having access to a real time data feed allows the on-site personnel to react quickly if a fault is detected on the measurement system or on the measurement itself. This speeds up the analysis of the patterns and allows clients to view their active RF transmissions in real time.

Some challenges implementing a real time data feed include:

- Communication path distance
- Noise floor and on-site interference
- Frequency band for link equipment

The measured information is stored on board the UAV system to overcome this problem and for post processing of the measured data.

2.7 RF screening of the measurement against EMI

The measurement system, the measurement vehicle and the flight controller are exposed to huge RF fields during the measurement flights. Measurements, especially on high power transmitter sites expose the UAV to megawatt of transmission power in numerous cases. Certain frequencies have a much larger affect on the UAV flight controller and GPS system, and this can lead to a crash or loss of control of the vehicle during the flight measurement. Our vehicles have been thoroughly tested and we have applied the necessary screening against EMI.

External and internal screening are applied to further protect our vehicle from uncontrolled failure. These precautions are in addition to our on-board parachute that can be activated at any time.

We have an in-depth knowledge of our UAV's performance under interference conditions for various frequency bands. This allows us to carefully plan our flight paths to ensure the least exposure to threatening interference conditions.

The above precautions have allowed us to fly in the nearfield of the antenna systems in cases where it is not possible to attain flight permission from the authorities that control such permissions. Such flights are then performed in the space next to the mast where no waiver for flights is required as it will not cause any life-threatening situation to persons or equipment.

2.8 Accuracy of measurements

The accuracy of the antenna radiation measurements is determined by several factors of which some are more crucial than others. We have been involved in antenna measurement since the 80's and 90's where we made use of Jet Ranger helicopters to measure the radiated signal. Although such airborne vehicles made it possible to perform antenna measurements, it would have been extremely difficult to perform measurements at the time if the manufacturers antenna pattern was not available to the measurement engineer/technician. Evaluating the shortcomings of such systems is perhaps the easiest way to analyse the importance of certain aspects which is crucial for accurate antenna measurements. We will comment on the following aspects:

- Optimisation of the power measurement formulae
- Accurate navigational systems
- Accurate control systems to stabilise the vehicles position
- Size of vehicle and material of which the vehicle is manufactured
- Ability to calibrate the complete measurement system
- Safety relating to onboard personnel when performing flights
- Cost of flights to perform measurements and measurement repeats

2.8.1 Optimisation of the power measurement formulae

The antenna radiation power measurement is based on a very simple free space loss formulae which is given below:

Pt = Pr +FSL

therefore

Pt = Pr + 20log (d) + 20 log (f) + 27.77

where

d = distance in meters

f = frequency in MHz

Pr = power received in dBm

Pt = power transmitted in dBm

The formulae can be extrapolated to allow for corrections to improve the measurement accuracy relating to the following parameters:

- Roll correction factor in dB
- Yaw correction factor in dB
- Pitch correction factor in dB
- Gain of receive system per frequency in dB
- Transmit Antenna Height correction factor in dB (if correction is required after measurement)

therefore

Pt = Pr + 20log (d) + 20 log (f) + 27.77 + Roll Correction(dB) + Yaw Correction(dB) + Pitch Correction(dB) + Receive System Gain per frequency + Transmit Antenna Height Correction expressed in dB

2.8.2 Accurate navigational systems

The navigational system that provides the necessary height and position information is extremely important. This provides information to both the flight path as well as the measurement system. If this is not accurate the path loss and ERP can not be measured accurately and can produce the wrong field strength value at a specific point in a 3D environment. This will also lead to the wrong calculation of the radiate power in a specific direction in space.

We put emphasis on using the best navigational system available to ensure that all navigational points are as accurately recorded, and we therefore use a RTK system that allow for centimeter position accuracy during the flight. This also allow us to ensure that the systems measured e.g. mast position is captured as accurate as possible.

We also use one RTK navigational system for the measurement position and flight path position. We are constantly busy with improvements to ensure that all position equipment including the mast height and location are captured with the same measurement system.

2.8.3 Accurate control systems to stabilise the vehicles position

In previous times the helicopter and UAV were controlled by either an onboard pilot or a pilot using a remote-control unit to steer the measurement vehicle around the mast. The auto pilot controlling the modern aircraft include control circuitry to stabilise the aircraft to a specific position during flights as well as during static measurements that are performed. The onboard controller reacts very fast and can stabilise the vehicle accurately in specified wind speeds and associated payloads. The onboard accelerometers and other circuitry monitor the pitch, roll, and yaw constantly and this information together with the RTK location information allow for the constant calculation of the flight position and the corrections necessary for misalignments of the receive antenna within some accuracy. If such misalignments are not corrected the measurement accuracy can lead to huge measurement inaccuracies which cannot be accurately corrected.

We place huge emphasis on the ability of the vehicle to accurately control its position and direction for the payload in define windspeeds. We also perform alignment corrections constantly to improve measurement accuracy in 3D environments.

2.8.4 Size of vehicle and material of which the vehicle is manufactured

The size of the UAV or helicopter in relation to the antenna and the choice of an omni antenna rather than a directional antenna has a huge effect on the measurement. Reflections can affect the omni-antenna pattern drastically and the effect of the UAV or helicopter can change the antenna pattern hugely. This effect can easily be measured in an anechoic chamber. Our RF characterisation of the UAV and antenna is constantly performed after any changes to our measurement vehicle to ensure that we can fully understand the effect of the UAV on the performance of the integrated antenna.

The above aspects urge us to use directional antennas wherever possible. Although we can characterise the influence of the vehicle there are other factors such as reflections that will influence the antenna pattern measurement which is not always predictable.

2.8.5 Ability to calibrate the complete measurement system

In the past it was impossible to calibrate the real helicopter system in an anechoic chamber. With more modern small UAV measurement systems it is possible to calibrate the UAV integrated measurement system in an anechoic chamber. This improves the characterisation of the complete systems and will contribute to the overall measurements. This will also reveal radiation from the UAV which might occur in the band of the frequency being measured and analysed.

Our UAV measurement systems are constantly being evaluated and calibrated in our anechoic chamber at our premisses. We also have a calibration certificate available for our measurement devices form the manufacturer.

2.8.6 Safety relating to onboard personnel when performing flights

A huge benefit from UAV's is the fact that we do not have to be concerned of human safety onboard the measurement vehicle. When real helicopters were used in the past for antenna pattern measurements, this human safety aspect was obviously the major concern during the flights. The vertical flight using helicopters are extremely risky with no forward movement and the UAV measurements eliminated this important aspect by multi-rotor UAV solutions.

Modern UAVs do not offer these particular risks and it is relatively easy to perform all type of flights and flight paths in even small spaces and at low heights as it is equipped with anti collision sensors to limit the risk of collisions.

2.8.7 Cost of flights to perform measurements and measurement repeats

We are constantly working towards a target of reducing flight costs. Helicopters are extremely expensive, and it is extremely expensive to ensure that all non-negotiable preventative maintenance tasks are performed in accordance with the schedule. The UAVs luckily have fewer movable parts, and the size is also much smaller. There are multiple rotors, and all of this will ensure that should there be a failure, the plane will come down in a controlled fashion.

The cost of a UAV operation is still expensive to run, and we are doing our best to find more applications to ensure that we can reduce the cost.

3 ADVANTAGES OF THE UAV BASED ANTENNA MEASUREMENT SYSTEM

- The UAV measurement system is the most accurate antenna pattern measurement system you can use.
- The measurement system measures the effect of the mast on the theoretical antenna pattern as designed.
- The measurement system can distinguish between electrical and mechanical tilt of a directional antenna pattern.
- The measurement system can measure antenna pattern and gain from various frequency ranges and various technologies (20 MHz to 6 GHz currently and to be extended to 30 GHz soon).
- Measurements are un-obtrusive and can be done during transmissions.
- The measurement system has been hardened against RF interference.
- The system can measure both the E and H plane of the antenna.
- Absolute ERP/EiRP of the transmission can be measured.