Low Frequency Synthetic Aperture Radar Data-Dome Collection with the Bright Sapphire II Instrument

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The ability to use Low-Frequency microwave sensing techniques to see through optically opaque objects is of great interest. One potential solution to the problem of seeing inside buildings and facilities is the use of low frequency synthetic aperture radar (LF SAR). This provides the advantage of remote sensing and greater coverage than existing through-wall observation techniques. The Bright Sapphire II instrument is a low frequency wideband quad polar SAR and offers such measurement capability. The first results of airborne trials are presented.

INTRODUCTION

The ability to use Low-Frequency sensing techniques to see through optically opaque objects is of great interest for intelligence, law-enforcement and humanitarian reasons. One potential solution to the problem of seeing inside buildings and facilities - determining activity occupancy and structure within a building - is the use of low frequency synthetic aperture radar (LF SAR). This provides the advantage of remote observation and greater coverage than existing through-wall observation techniques.

The use of low frequency RF for communications applications (mobile, Wi-Fi) requiring building penetration is well established [1]. As well as proving the potential for the sensing concept discussed it also presents a potential issue in terms of interference of the spectrum of interest - one of the key challenges in implementing this concept.

The Bright Sapphire II instrument has built upon the original Bright Sapphire instrument and the Airbus Defence and Space Ltd airborne multi-frequency radar demonstrator. The instrument operates over the 150-1300MHz frequency band with quad polar operation offering the potential for 12cm slant range resolution. A COTS (commercial off the shelf) sinuous antenna is used as the radiating element offering a constant phase centre with frequency.

It is integrated and certified onto a Beechcraft B200 Super King Air aircraft with a large underbelly radome housing the antenna at an angle of 55° from nadir. This offers a highly capable, remote stand-off, low-frequency system.

The collection methodology of the trials is specifically concerned with ensuring that multiple SAR collections are collected in such a way that they can be coherently combined to form a single ‘data dome’. The term ‘data-dome’ refers to a collected dataset that covers a hemisphere over the target area defined in ‘K-Space’ (Figure 1). This results in the sensor system performing circular acquisitions around all azimuths of the target over the incidence angle range 20-70° at spacing suitable to avoid height ambiguities of the target. The data-dome collection enables tomographic and volumetric information to be extracted about the building.

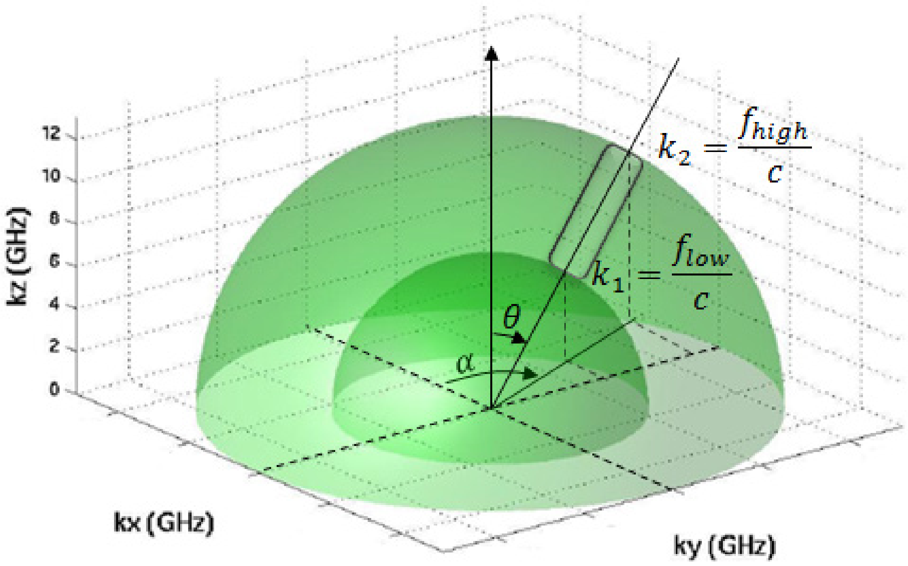

Figure 1: Visual representation of data-dome in k-space.

The data collection has taken place over various buildings ranging from simple tents and sheds to more modern and complex wooden and brick built buildings. Ground truth has been performed in all of them, and calibration targets were placed inside and outside.

A number of challenges exist to exploitation of the data – namely the congested spectrum requiring a reduction on the transmitted spectrum to abide by Ofcom radio regulations in the UK and the presence of significant interferers from other sources such as Digital TV, radio, mobile telephony, wifi and radio communications.

The first results of the airborne trials are presented, indicating the potential for building interior remote sensing at large standoff.

INSTRUMENT DESIGN – LFSAR SENSOR

The payload is a low-frequency synthetic aperture radar instrument, based on the core elements of the instrument used for the previous Bright Sapphire trials and the Airbus DS Ltd multi-frequency airborne radar demonstrator. A low frequency front-end equipment has been developed to be paired with a COTS antenna complementing the existing back-end equipment; optimising operation and performance over the frequency band of interest.

The development poses some challenges; the large bandwidth-to-carrier ratio makes component selection more difficult with fewer components available. Additionally the large wavelength increases the size of the elements. Conventionally in monostatic radar a circulator is used to separate transmit and receive paths; however at the frequencies and bandwidth used within this system this approach challenging and would be extremely large. Instead a high power switching network is employed as a substitute.

Due to the expected presence of interferers careful consideration must be paid to the receive chain. To avoid saturation of the system, a large dynamic range ADC is required with careful position of the signal level into the receiver.

The basic system parameters can be seen in Table 1 below.

Table 1: Bright Sapphire II characteristics.

Parameter	Value
Operating frequency band	200-1300 MHz
Centre frequency	750MHz
Maximum Bandwidth	1.1GHz
Polarisation	Quad polarisation
HPA peak transmit power	80W
Tx Duty Cycle (max)	CW
Rx Duty Cycle (max)	20%
System Noise Figure	2.6dB
System losses	12.1dB
Instrument mass	101.5 kg
Power consumption (at max operation)	800W
Tx Notching ability	Yes

AIRCRAFT INSTALLATION

The sensor is installed onto a B200 Super King Air trials aircraft. The instrument electronics are mounted inboard the cabin within a dedicated 19" E-rack attached to the seat rails as shown in Figure 2.

Figure 2: Instrument E-rack mounted inboard.

The sinuous antenna is mounted outboard within a large underbelly radome at an angle of 55° from nadir. The size of the antenna is challenging to mount onto a relatively small trial aircraft resulting in design and development of the largest radome in existence in Europe for this type of aircraft (Figure 3).

Figure 3: Trials aircraft with large underbelly radome.

The aircraft installation has undergone a thorough certification process to enable trials, including a dedicated electromagnetic interference (EMI) test regime.

The LF SAR sensor integrated on-board the trials aircraft offers a highly capable, remote stand-off, low-frequency radar sensor.

KEY CHALLENGES ON THE INSTRUMENT OPERATION

A number of key challenges exist with the development and operation of such a sensor, these are described below.

Antenna Performance and Accommodation

The possible choice of wideband antennas covering the frequency range is limited; with the main solutions being log-periodic or sinuous antennas. The sinuous exhibits the favourable characteristic of constant phase centre with frequency and crucially is also more compact. The higher gain afforded by the log-periodic is positive but accommodation proved challenging due to the much larger volume. Analysis was performed on accommodation within an underbelly radome as well as being mounted directly onto the side of the aircraft; in the end it proved too challenging for an aircraft of the size used in the trials for the side mounted option.

The sinuous antenna selected is basically a single radiating element, and as such has a very wide beamwidth. The main issue of this is that at low incidence angles (i.e. steep viewing) the ambiguous return from the opposite side of nadir is present on the main beam. This increases the apparent noise (unwanted signal) of the imagery.

OfCom Licence

A license is required for radio transmission in the UK, managed by Ofcom. Due to the congested spectrum the allowable frequencies are significantly reduced, requiring ‘notches’ in the transmit signal. Testing to prove non-interference with existing services is required for some access. The instrument has to be able to implement flexible notching on transmit to not transmit over the declined frequencies; this causes a non-ideal impulse response function in the SAR processing.

TRIALS

Trials were undertaken over a range of targets, of differing nature and construction, including:

- Tent
- Sheds – wooden and plastic
- Wooden lodges
- Brick building
- Multi-storey buildings

Access had been agreed to all of these buildings for the trials and a range of calibration targets were utilised in the scene, both inside and outside of the building (Figure 4). Square and triangular trihedrals, dihedrals and spheres were deployed, covering a range sizes from of 1-1.6m side length.

Figure 4: Calibration scene with targets inside and outside the imaged constructions.

During the trials the data was collected as a data dome, to enable the possibility of 3D tomographic and volumetric exploitation. This results in the sensor system performing circular acquisitions around all azimuth of the target over a large range of the incidence angles (20-70°) at spacing suitable to avoid height ambiguities of the target.

Linear runs were also performed to validate operation of the instrument, to enhance the SNR by flying closer to the target and to acquire imagery as a back-up when high wind conditions didn't allow circulation operation due to inability for the aircraft to maintain the required lateral position.

RESULTS

Initial assessment of the data shows that interferers will represent an important challenge of low-frequency SAR but also the potentials for remote sensing in buildings interiors.

Interferers

The frequency band of operation contains a lot of strong in-band interferers as shown in Figure 5 - this plot shows the sample bins of the Fourier transform of the received signal where the radar echo is the low level signal at the bottom of the plot and the strong spikes are interferers. It can be seen that strong interferers are at least 30dB higher that the radar backscatter echo.

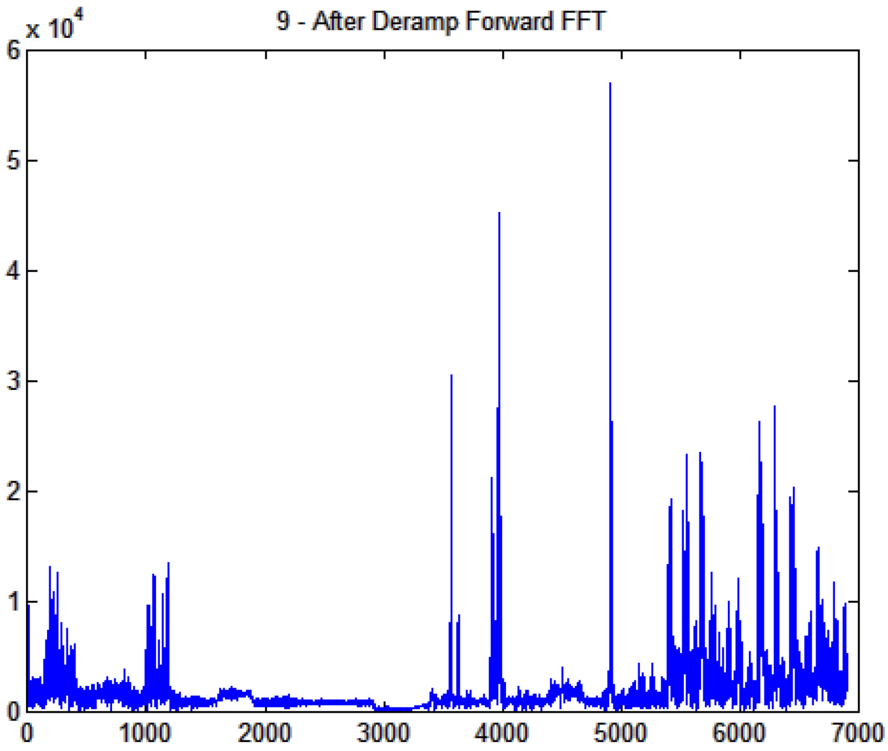

Figure 5: Interferer spectrum (FFT shifted).

A simple method of nulling bins in the data containing interferers has been used for these preliminary results. However due to the number and range of strengths of interferer, a robust method is ultimately required to avoid removal of large amounts of useful data along with the interferers. Robust methods of interferer removal allow recovering good quality images without significantly increasing the side-lobe levels or degrading the SNR [2].

The effects of interferers vary with the altitude, location, orientation and time of acquisition. Receive only acquisitions were added within each collection to aid characterisation and removal of interferers.

Two different types and impact of interferers are observed. For continuous interferers such as Digital TV transmission then an increase in the noise floor of the image is observed. For other pulsed radar systems (such as ships radars) then streaks and blobs are observed in the image.

In Figure 6 three different portions of the spectrum are assessed for interferers, shown as sets of three. Each image in the set is the same data but processed with a different interferer removal threshold applied. It can be seen that removal of the interferers enables recovery of the imagery.

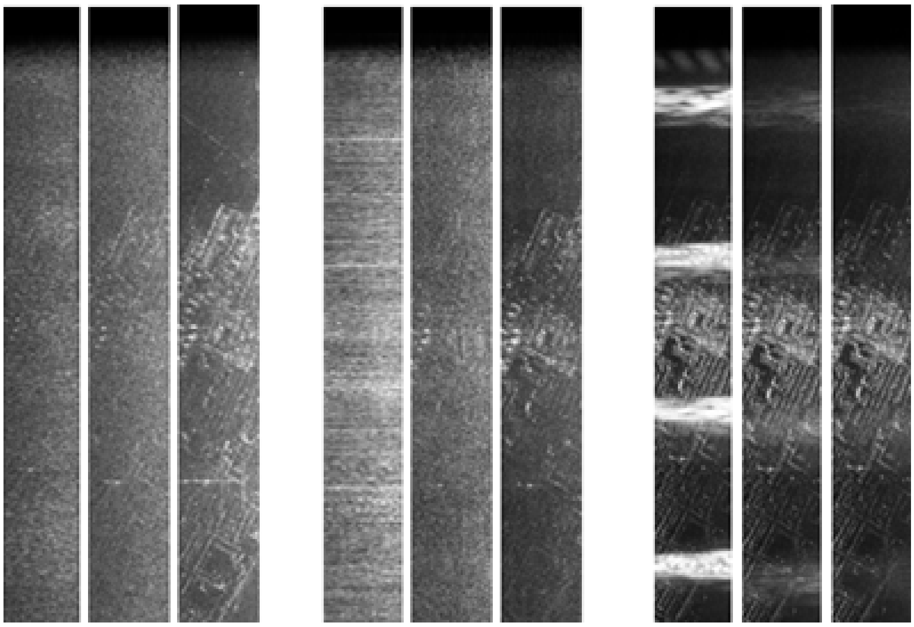

Figure 6: Interferers observed in the processed data. Each set of three images corresponds to a different part of the spectrum - each image within the set has a different threshold applied for interferer removal (left: no threshold, middle: high threshold level, right: low threshold level)

Remote Sensing in Building Interiors

An initial simplified processing of the data has been applied to show the possibility of building interior remote sensing.

During the trials a calibration target was placed within each target structure (e.g. shed) to allow simple estimation of the possibility of building penetration.

Figure 7 is a collection of interest as it has different types of structures in the scene including a tent, wooden and plastic sheds and the wooden lodge in Figure 8. As shown in Figure 7 the calibration targets in each of the constructions can be detected, even when processing only the upper half of the spectrum.

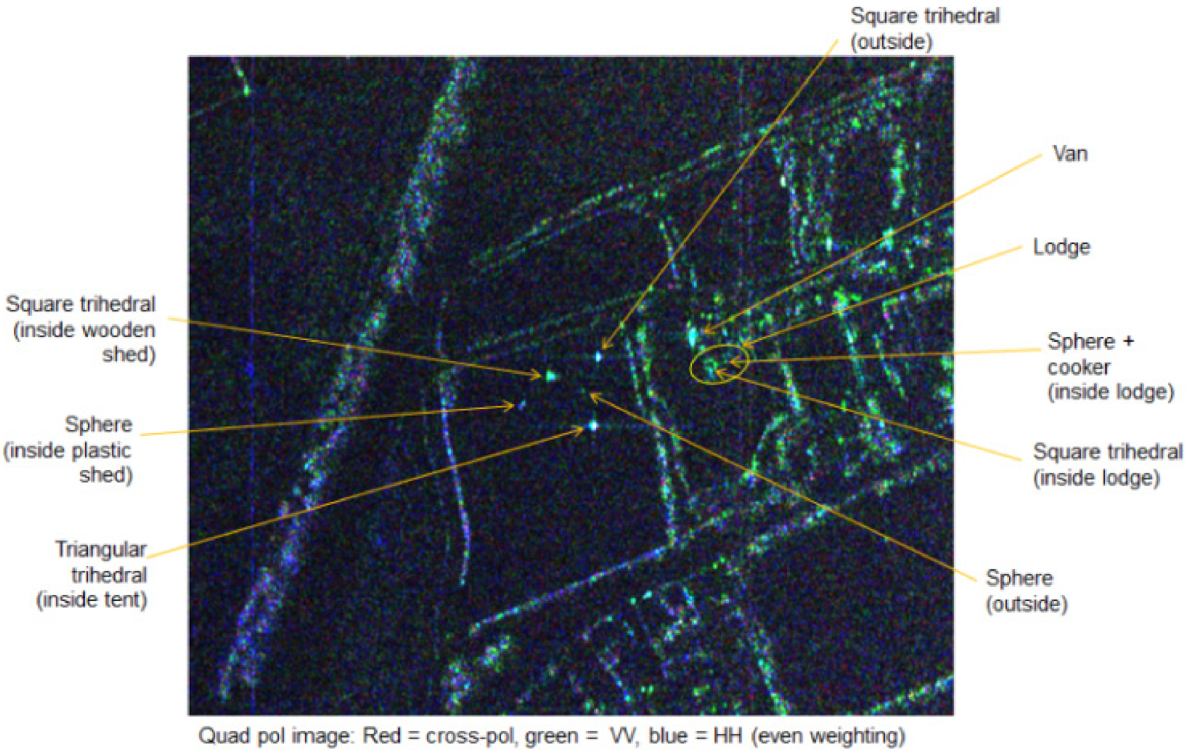

Figure 7: Imagery of tent, wooden shed, plastic shed and wooden lodge (upper half of spectrum).

Figure 8: Wooden lodge imaged with calibration target inside.

Figure 9 shows the imagery of a collection over the brick building in Figure 10, with calibration targets placed inside and outside. It can be seen in Figure 9a that at the highest frequencies (750-1300 MHz) only the external target and the building features can be seen. However, Figure 9b shows that when processing the image using the lower half of the spectrum (200-750 MHz) the internal calibration target is also detected through the brick walls.

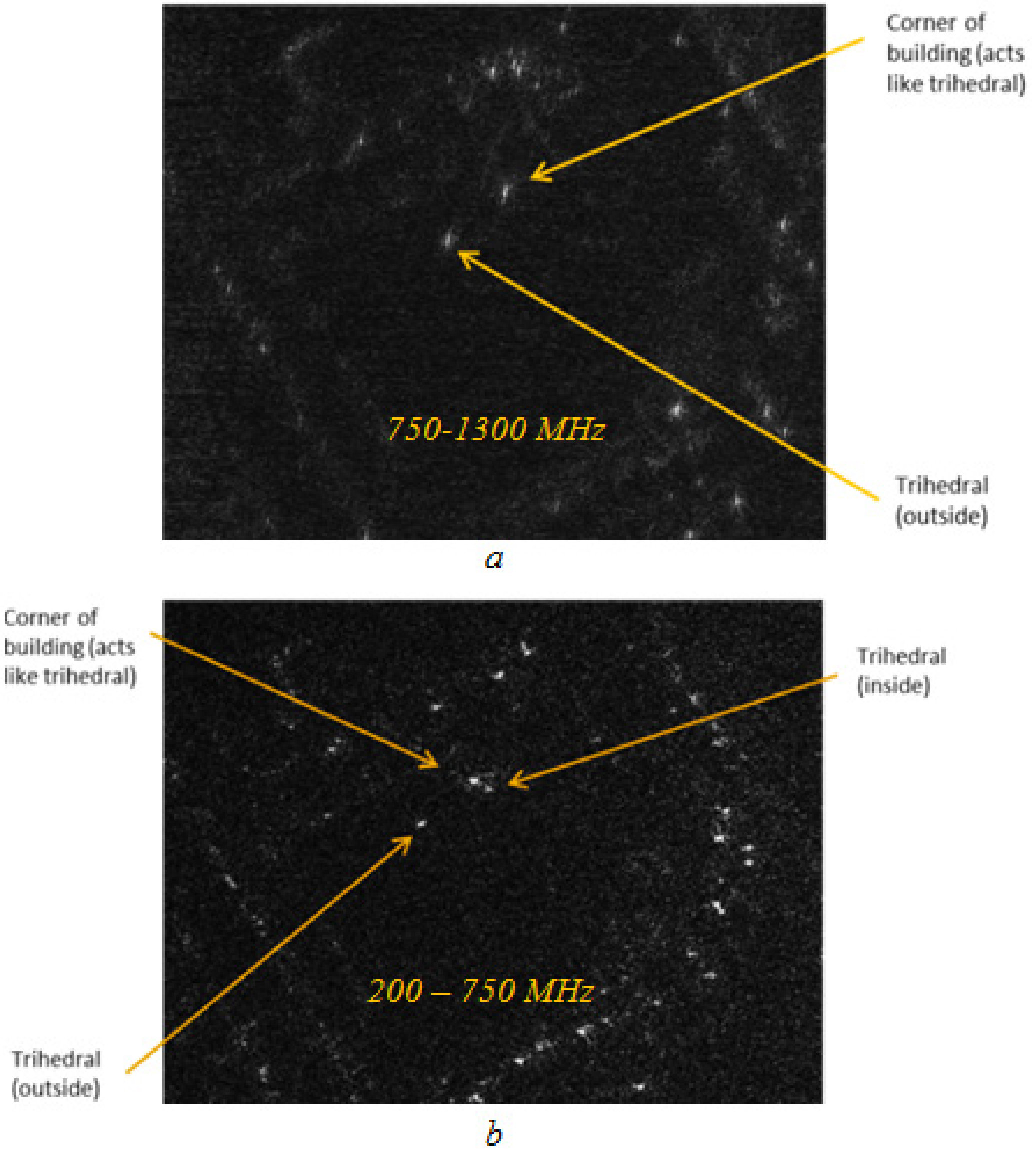

Figure 9: Imagery of a brick building using the upper half of the spectrum (a) and lower half of the spectrum (b). The internal calibration target can be seen through the brick walls with the lower frequencies.

Figure 10: Brick building imaged with calibration target inside.

Clearly the potential for within building remote sensing from the presented sensor is shown. Further enhanced processing of the data should allow better resolution, the extraction of additional features and generation of tomographic data of the inside of the building.

CONCLUSIONS

The airborne trials undertaken with the Bright Sapphire II sensor have proven the instrument capability to see through optically opaque objects and detect targets inside buildings of different construction types. Further analysis is required to fully exploit the data acquired into fine resolution imagery.

The data has been collected in such a way to enable the possibility of 3D tomographic and volumetric exploitation of the building. The large amount of interferers present within the spectrum of operation represents the first challenge to face in the data processing. A robust method of interferer removal is required to be able to recover high quality imagery from the data collected.

The current sensor has the ability to also add S-band and X-band capability to that presented whilst enabling simultaneous operation. This multi-frequency system would require only the installation of the existing front-ends and antennas into the aircraft, which was not performed as part of this work. This multi-frequency operation would provide additional contextual information to aid the data exploitation.

ACKNOWLEDGMENTS

An acknowledgement to Dstl for funding the Data Dome trials and supporting the data exploitation.

REFERENCES

[1] Rudd, R., Craig, K., Ganley, M., Hartless, R.: ‘Building materials and propagation’, *Ofcom*, 2014, Ref: 2604/BMEM/R/3/2.0.

[2] Doerry, A.W.: ‘Apodized RFI Filtering of Synthetic Aperture Radar’, *Sandia National Laboratories,* 2014, Ref: SAND2014-1376.