REAL TIME ANALOGUE SELF TRACKING RECEIVE ANTENNA COMPATIBLE WITH INMARSAT BGAN MODULATION SCHEMES

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ABSTRACT
This paper presents first practical results for a retrodirective array tracking off-air signals from Inmarsat BGAN. The antenna employs analogue phase conjugation, which offers real time tracking on receive, with minimum complexity and low power consumption. The retrodirective circuits are shown to be able to track very weak Inmarsat BGAN global beam signals, at levels as low as -130dBm per element. The challenges in phase tracking QPSK/16QAM modulation schemes are also overcome, with tracking performance similar, or better than, previously reported architectures which could only track CW signals.

1. INTRODUCTION
A retrodirective antenna has the distinct advantage of offering automatic tracking of an incoming signal without prior knowledge if its position. This means that complicated automatic tracking systems can be replaced by a much simpler retrodirective system. This is particularly important for communications from satellite to mobile terminals and can offer the prospect of extremely fast tracking with relatively simple circuits. The technique is well suited to mobile terminals on unstabilised vehicles where a lot of movement is expected, and power and weight of the antenna must be kept to a minimum. This provides for higher bit rate tracking ground terminals where previously only omnidirectional antennas could be used.

This paper presents a simple analogue retrodirective tracking array solution suitable for use on ground terminals for SATCOM systems such as Inmarsat BGAN. Currently available tracking antennas for Inmarsat BGAN often use arrays with motorised positioners which may also be coupled with digital beamforming techniques. The system proposed in this paper is based on the principles of the analogue retrodirective array [1] and has no moving parts. QUB has already developed a 5 element retrodirective array prototype for the ESA project AO/1-6168/09/NL/JD “Self Focusing Retro-Reflective Antennas for Mobile Terminal Applications”, this was presented in [2]. This array operated at 2.4 GHz with circular polarisation, and could real time track CW signals of levels as low as -120dBm per element, typical of that expected within a system such as Inmarsat BGAN. This prototype, required additions to its specification in order to allow it to be compatible with Inmarsat BGAN. The most challenging of these enhancements is the ability of an analogue tracking PLL to track the phase of very low level QPSK/16QAM signals that are present in the Inmarsat BGAN system. To facilitate this requirement, a new prototype retrodirective array has been designed, its block diagram is shown in Figure 1. This array has the ability to receive a weak signal, optimally combine it, using 160MHz phase aligned IF’s, which always provide in-phase combination, regardless of angle of arrival. The tracking PLL employs significant enhancements carried out at QUB under ESA Contract Change Notice No. 01 to ESTEC Contract No. 22893/09/NL/JD/al. These enhancements allow it to efficiently track the phase of low level QPSK and 16QAM signals in real time. The PLL has extremely low power consumption (less than 50mW for the tracking PLL block, shown in Figure 1).
2. TRACKING COMPATIBILITY REQUIREMENTS FOR INMARSAT BGAN

Inmarsat BGAN ground terminals receive and transmit respectively in the frequency range 1525 to 1559 MHz and 1626 to 1660 MHz. To facilitate initial pointing of the user ground terminal the BGAN system transmits an ‘always on’ global beam at 1537 MHz which is modulated with QPSK at 8kbps. The BGAN system’s three satellites also support 256 spot beams per satellite, which are service activated from the user terminal. For a typical land portable ground terminal, the user is required to first manually align the terminal. The initial direction can be determined via the use of software fed with information from a GPS receiver. Final alignment is then carried out by a visual C/N₀ display, which displays the C/N₀ of the global beam. Only after this alignment does the user terminal transmission occur to initiate a spot beam signal from the satellite.

The challenge of tracking Inmarsat BGAN with a retrodirective array, is that the array must be capable of initially acquiring the global beam signal, which is typically 20dB lower in signal strength than a spot beam. This is due to the fact that before the user terminal initiates the spot beam, the only signal reliably available is the global beam. The global beam is intended to be received with relatively high gain user terminal antennas, of around 12-20 dBi. With this amount of antenna gain it is fairly straightforward to get a good visual indication of C/N₀ at the antenna. The challenge with the retrodirective array, is that for wide field of view (zero alignment requirement) each individual low gain element must be able to track the global beam signal phase independently. For a broad steering retrodirective array, each element may only have a gain in the region of 4-5dBi. In reality this produces a power level, at the antenna element output, of around -130 dBm, which is close to the noise floor of the receiver. The tracking PLL (Figure 1) has been designed to operate efficiently at these low signal levels, and can track the phase of the global beam, in real time. When the user terminal initiates a spot beam, the received signal level increases by around 20dB, providing highly reliable tracking during the duplex communication.

3. RETRODIRECTIVE ARRAY PHASE CONJUGATION MEASUREMENTS

The block diagram of Figure 1 provides phase conjugation of the retransmitted signal by using a transmit local oscillator frequency (F_{TXLO}) which is greater than the retransmit frequency. This has the effect that the input phase at 160 MHz from the tracking PLL IF becomes phase conjugated, i.e. the sign of the phase is reversed. This allows the retransmit signal to be sent back in the direction of origin of the received signal, ideal for a duplex communications application.

Phase conjugation was measured by applying a low level signal, in the 1.5 GHz range, to one of the antenna ports of the block diagram of Figure 1. The retransmitted signal, in the 1.6 GHz frequency range was then extracted from the same antenna port and its phase measured using a high frequency oscilloscope, by comparing it with a stable locked reference signal of the same frequency. The results of phase conjugation are shown in Figure 2, where it is seen that accurate phase conjugation is possible with 8kbps QPSK signals of levels as low as -130 dBm (typical of the Inmarsat global beam) and 150kbps 16QAM signals of -120 dBm (typical of Inmarsat spot beam).

Figure 3. Phase conjugation recovery circuitry response

4. MEASUREMENTS WITH OFF-AIR INMARSAT SIGNALS

To measure the system with off-air Inmarsat signals a two element CP patch array was used, mounted on an azimuth positioner (Figure 3). The CP patch array had been previously shown to give a high level of CP performance [3], and was designed for the Inmarsat 1.5-1.6 GHz frequency range. The LNA’s were mounted as close to the antennas as possible, to reduce the noise figure, 2m connecting cables were used to connect the antennas to the tracking PLL circuits.
An Inmarsat spot beam signal was initially received using a single patch antenna by first checking the entire frequency band of 1.52 – 1.57 GHz to determine a suitable signal. Figure 5 shows a typical Inmarsat spot beam signal, at a frequency of 1.5354 GHz. The signal is approximately 10dB above the noise floor, the one shown was received with a single patch element of 5 dBi gain.

4.1. Self tracking measurement with Inmarsat Signal

The purpose of this experiment was to show that the retrodirective array could yield a high quality of Error Vector Magnitude (EVM) from an actual Inmarsat signal over a broad range of azimuth angles, thus proving the potential for reliable self tracking operation. EVM was used as the measurement metric, since it relates directly to the quality of the 16QAM Inmarsat signal, taking into account signal to noise ratio as well as signal strength. It is also possible to directly relate EVM to bit error rate [4]. For comparison, results were also obtained using the two element array as a passive, non-steered, broadside pointed array. This configuration involved the two elements being combined with a passive power combiner, instead of the retrodirective tracking circuits.

For self tracking operation, the retrodirective tracking circuits (Figure 1) were connected to the two element antenna array (Figure 4). After a suitable Inmarsat spot beam signal frequency had been found, results were recorded of the EVM of this signal versus Azimuth angle. The result shown in Figure 6 show that a lower level of EVM is possible over a wider azimuth range for the self-tracking case, compared to the basic non-steered array. The graph of Figure 6 shows that for a 1% deterioration in EVM the beam width is -28° to 30° for self-tracking and -12° to 12° for the basic array. These results are summarised in Figure 6, and show that the beam steering range from the basic array, compared to the self tracking array has increased from 24° to 58°, based on the 1% EVM beamwidth.
Figure 6. EVM Vs azimuth angle of two element array receiving off-air Inmarsat signal

Table 1. Steering range possible with 2 element basic array and self steered array

<table>
<thead>
<tr>
<th></th>
<th>Beamwidth for 1% deterioration of EVM</th>
<th>Steering range (Calculated from 1% EVM beamwidth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Array</td>
<td>-12° to 12°</td>
<td>24°</td>
</tr>
<tr>
<td>Self tracking</td>
<td>-28° to 30°</td>
<td>58°</td>
</tr>
</tbody>
</table>

4.2. Array factor improvement for successful 16QAM demodulation

Now, based on the EVM results obtained above we determine, what size of an array would be required for low Bit Error Rate (BER) demodulation of an Inmarsat spot beam signal, for the practical retrodirective array. Table 2 shows the predicted improvement in BER based on the array size. An EVM of 17% is assumed for a two element array, which is based on the previous result of Figure 6. The EVM for given signal levels was determined from measured values of the retrodirective circuit of Figure 1 at various input signal levels. The corresponding Bit Error Rate (BER) was determined from [4]. This shows that reasonable operation, with a BER of $10^{-6}$ could be obtained with as little as 8 elements. The physical dimensions of this array, based on the patch antennas of Figure 4, would be around 27x27cm for a 3x3 array (9 elements).

Table 2. Array factor improvement assuming an EVM of 17% is received with a 2 element array

<table>
<thead>
<tr>
<th>Number of Elements</th>
<th>Array Factor</th>
<th>Combined input Signal Level from array</th>
<th>EVM (%)</th>
<th>BER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0dB</td>
<td>-111dBm</td>
<td>22%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3dB</td>
<td>-108dBm</td>
<td>17%</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>4</td>
<td>6dB</td>
<td>-105dBm</td>
<td>13%</td>
<td>$10^{-3}$</td>
</tr>
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<td>8</td>
<td>9dB</td>
<td>-102dBm</td>
<td>10%</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>16</td>
<td>12dB</td>
<td>-99dBm</td>
<td>7.3%</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>32</td>
<td>15dB</td>
<td>-96dBm</td>
<td>5.6%</td>
<td>$10^{-3}$</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

This paper has been shown that a two element retrodirective array is capable of tracking off-air Inmarsat signals at received levels as low as -130dBm. In addition, the ability to phase track signals containing QPSK or 16QAM modulation was demonstrated. The retrodirective antenna showed a beamwidth of 58° (for a 1% deterioration in received EVM), compared to 24° for the same array operating as a passive, non self-steered, array. These results suggest that a mobile Inmarsat BGAN self-tracking receiver, operating at a high bit rate, could be viable using only 3x3 low gain elements.

6. REFERENCES


[2] N. Buchanan, V. Fusco, M. Van Der Vorst “Practical Demonstration of a 1x5 element retrodirective array for fast tracking satellite ground terminals” 33rd Antenna Workshop, ESA/ESTEC, Noordwijk, The Netherlands, October 2011
