The Development of a Remote Wireless Meter Reading System

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ABSTRACT

This paper describes a remote utility meter reading system providing multi-point to point data transfer within residential areas. It comprises meter located transmitters and base station receivers used to receive and relay the transmitted data. Packet transmissions from the meters are at a nominal data rate of 870bps with payloads typically in the range 32-64 bytes. The system uses narrow band, phase modulation. Transmissions from the meter are on a randomised time and frequency basis, which ensures that the risk of a collision in time and frequency at the receiver is minimised and avoids the need for the additional complexity of synchronising all of the meters. The basestation receiver utilises an advanced, wideband multichannel DSP architecture able to decode up to twenty simultaneously received signals allowing a single basestation to support several thousand remote terminals. The system was designed for a maximum capacity of 6500 terminals per cell, a transmitter battery life of 10 years and a ½ km range for 99% probability of communication.

1 INTRODUCTION

The ability to remotely read utility meters not only dispenses with the problems of owners being out when the meter needs to be read, it also allows detailed usage profiles to be generated and so aids predictions of demand. This paper describes the development of such a system. It uses a micro cellular approach whereby the utility meters within all houses in a neighbourhood are connected to a local Micro Cellular Controller (MCC) via a wireless data path. Each utility meter would periodically take a reading and transmit it to the MCC receiver; the receiver would then forward the meter reading for each house in its coverage area onwards to the utility company. Large areas would be covered by overlapping cells.

This wireless meter reading system is generic but the detail focuses on the version for Gas metering. Section 2 discusses the design challenges and the large number of design variables and section 3 explains the reasons behind the choice for the architecture. Section 4 covers the design of the residential transmitter and the MCC receiver. Section 5 discusses the system trials that were undertaken between BCN and British Gas, and this is followed by conclusions in Section 6.

2 SYSTEM DESIGN

The development of a wireless meter reading system is very challenging, not least because there are a large number of interacting and conflicting goals within the design. These are discussed below.

Product cost. At the outset of the project it was clear that the total system costs had to be minimised whilst the number of meters that could be read should be maximised. Clearly the cost of the wireless meter readers should be as low as possible since these would be produced in vast quantities. To achieve an appropriate level of communication through the system a more complex MCC base receiver architecture was envisaged to compensate for limitations in the low cost transmitter.

Product lifetime. The wireless utility meters should be powered by an on-board battery which will not be recharged throughout the ten-year lifetime of the product. The reader should therefore be extremely economical in power consumption.

Amount of information to be transmitted. The amount of data contained in a meter reading is small, and typically requires 32 to 64 bytes to transmit. It includes the address of the utility meter, the meter reading, additional bits for forward error correction and bits for symbol and packet synchronisation.

Period between data transmissions. The frequency of transmission is low and programmable dependent on application from several times an hour to daily or even weekly. Consequently the channel capacity required to transmit a single meter reading a few times per hour is very small.

Frequency allocation and limits on transmitted power. The UK regulatory authority has allocated the 183.5-184.5MHz band for the purposes of wireless meter reading. Within this band, the system was designed to operate with a 100kHz allocation throughout the country on which any one utility system may operate. The maximum effective isotropic radiated power (EIRP) for this band is 100mW.

Coverage. The MCC receiver should receive transmissions from as large an area as possible. The perimeter of the coverage area will depend on the propagation conditions, the receiver sensitivity, the permitted transmitter power and the capacity limits; data throughput increases as the coverage area increases but the allocated radio channel is of fixed capacity.

Multiple Access. Each wireless transmitter operates in isolation from all others and therefore transmits its data unsynchronised with respect to the others. In the version of the Gas utility system described in this paper, the transmission path is one-way; there is no receiver in the residential unit to receive acknowledgements that a reading has been received by the MCC. Consequently with the need to maximise coverage area, there is a good chance that some transmissions will collide with those from other houses and readings will be lost.

3. CHOICE OF ARCHITECTURE

Figure 1 illustrates the operation of the wireless meter reading system within one micro cell. Each utility meter is modified to include a data connection to a wireless transmitter. The transmitter periodically takes a reading and broadcasts it to nearby MCC receivers that are in range. An MCC receiver then forwards all readings on to the utility company by various means such as wireless link or landline connections.

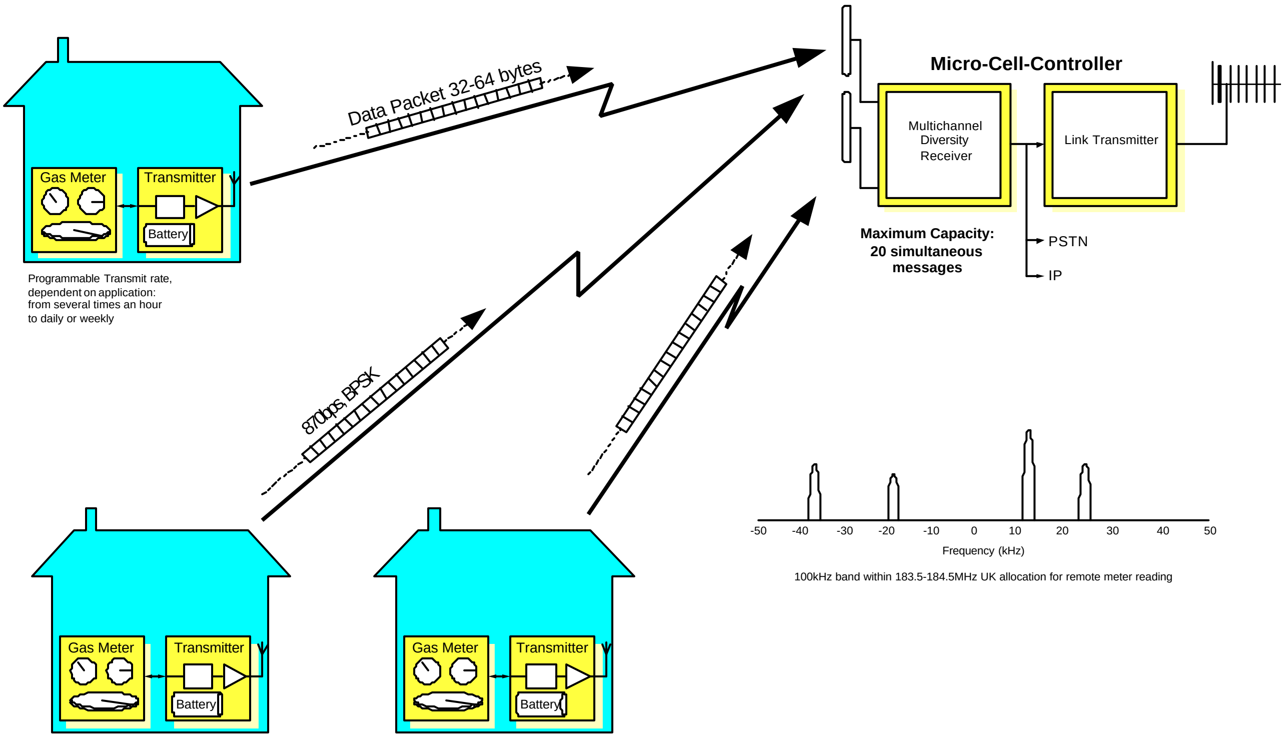

Figure 1: Micro Cellular based remote meter reading

Cellular coverage. Multiple micro cells are used to cover a particular area such as a small town as depicted in Figure 2. Since all MCC receivers operate within the same 100kHz wide frequency channel, there will be some transmissions from houses that are received by more than one MCC receiver. These will usually be from houses on the edge of one or more cells. In these circumstances, the utility company will receive multiple instances of the same reading.

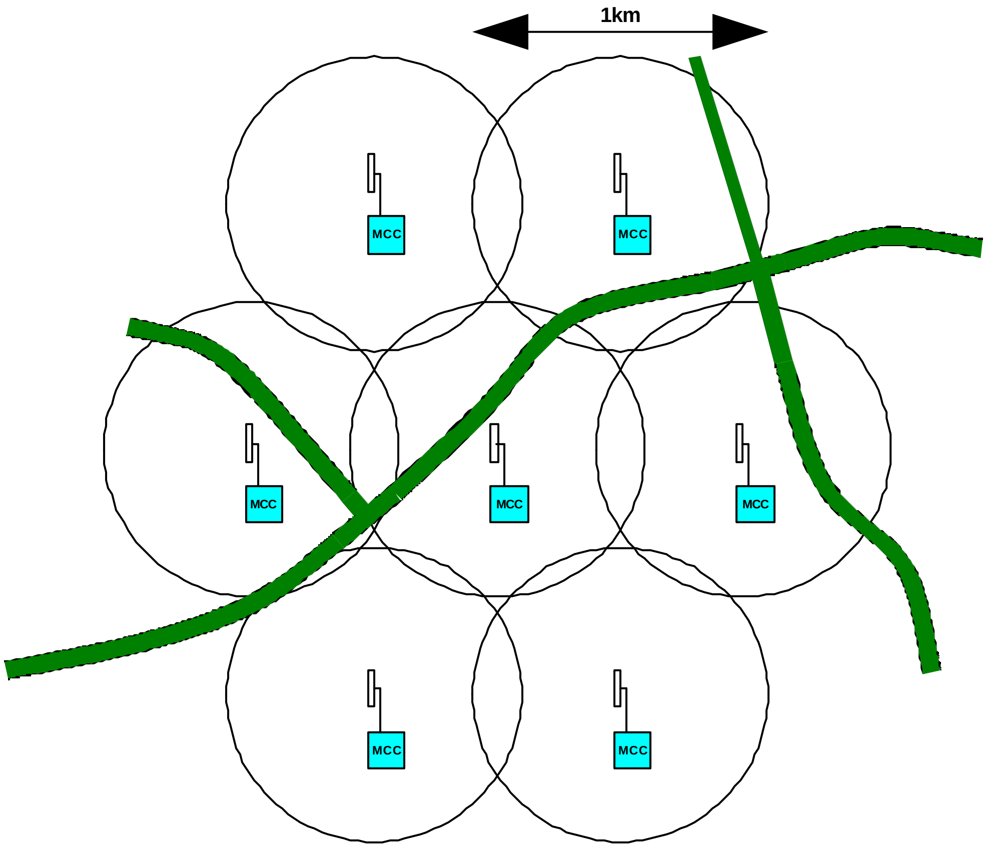

Figure 2: Micro Cellular coverage of an urban area

A one-way communications path from the meter to the receiver simplifies the design and keeps the cost down of the house located unit, which is vital in ensuring that the system is commercially viable for the utility groups deploying it. However it means that the communications link cannot be verified – there is no return path for an acknowledgement. As a consequence, there is a finite probability that some meter readings will not get through to the MCC receiver. This is not a critical issue for utility companies: if sufficient oversampling is made, the probability of receiving a reading within a particular time period can be set to an acceptable level, provided the channel has sufficient capacity for the number of meters in its coverage area.

Path Loss. Modelling the wireless communications path and accurately predicting the path loss from transmitter to receiver is not easy and is subject to some uncertainty. Experience from earlier propagation surveys suggested an inverse cube relation with distance should be applied when calculating the drop in signal level in urban environments. To this should be added an allowance for building penetration: although almost all modern properties have meters located on the outside of the house, many older properties still have the meter inside – and an allowance for clutter loss – the impact of building density in an estate. Further allowance should be made for variations caused by both large-scale (log normal) fading and small-scale (multipath) fading. The aim here is to add sufficient margin to ensure the link is available for 99% of the time.

It is possible to soften the impact of multipath fading by applying spatial diversity in the form of two co-located receivers receiving signals from two separately located antennas. Should the propagation path to one antenna be poor, for example because of a multipath null, there is a good probability that the propagation path to the second antenna does not include a null and therefore a better quality signal is received. Furthermore, at the edge of range, where path loss is worst, the cellular structure of the coverage scheme means there could be three MCC stations (six receivers) that can hear the transmission. This greatly improves the performance of the communications link for multipath.

Taking into account all these factors, it is possible to predict a path loss for 99% coverage of 136dB in an urban environment for a 0.5km range.

Transmit Antenna Efficiency. Physical size restrictions on the wireless utility meter installation will obviously impact on the efficiency that can be achieved from an antenna in the 184MHz band. A quarter wave antenna at these frequencies is too long at 40cm for the product dimensions. A shortened version must be used with the disadvantage of lower efficiency. The antenna emits +17dBm EIRP for a transmitter output stage consumption of 1W.

Receiver Background noise. The MCC will be placed in suitable locations within housing estates. Such locations may include utility company sites such as electricity substations. Some sites will be electrically noisy and consequently an allowance for the MCC receiver noise floor of –155dBm/Hz was made. A simple calculation shows that the available carrier to noise is 36dB, relative to a 1Hz bandwidth, for 99% coverage at a distance of 0.5km from the MCC.

Modulation. The choice of modulation scheme is restricted by the available channel bandwidth, the required data rate and the required signal to noise ratio at the receiver for a given bit error rate. BPSK was chosen for this application at a data rate of 870bps: – it provides 4dB carrier to noise for a 10^{-3} bit error rate and means a modulation bandwidth of approx. 32dB with respect to 1Hz can be used for the link.
N.B. QPSK offers a similar error rate for twice the throughput and was a candidate during the early stages. Ease of implementation and simplification of design were the reasons for selecting BPSK in the final design.

Multiple access. The multiple access technique used to accommodate the meter reading transmissions from many houses has been chosen to be a combination of frequency and time division multiple access. The time division part of the multiple access technique is Aloha: the meter reader transmitter simply transmits its packet at random intervals and, as long as no other transmission occurs at the same time, the message will get through to the receiver. Should a broadcast from a second meter reading transmitter partially coincide with the transmission from the first, then one or both messages will be corrupted and received incorrectly. Clearly for a given number of transmitters, the likelihood of collision will be low if the transmissions are short and infrequent. Conversely if the transmissions are long and frequent, the number of collisions will be significant. For this system with no reverse channel, it can be shown that maximum channel utilisation occurs with 9% capacity.

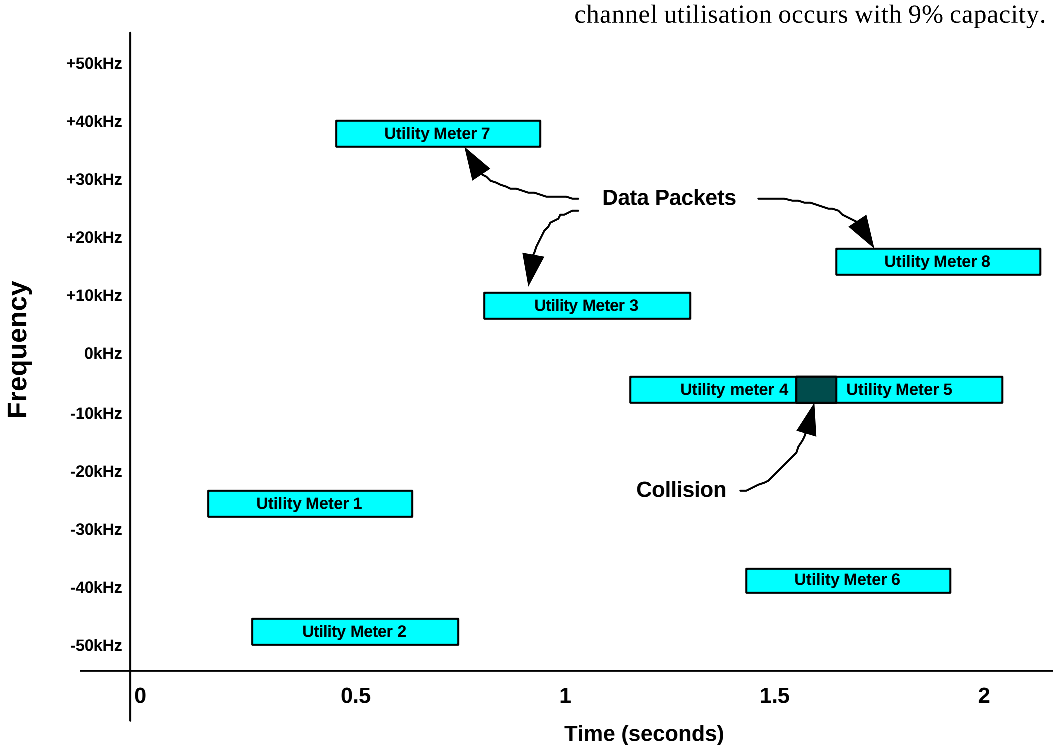

Figure 3: Multiple access in time and frequency

The capacity of the system is further increased by using frequency division multiple access. Since the modulation bandwidth of the transmission is low compared to the available channel width, it is possible to increase capacity by arranging for each packet to be assigned a carrier frequency chosen at random within the 100kHz band. The introduction of frequency division multiple access adds complexity to the MCC base station receiver; it must now be able to demodulate multiple transmissions received simultaneously on different frequencies. An example of the multiple access technique is depicted in Figure 3.

In implementation, a pseudo-random generator is used to randomly set the time offset between packets and to randomly set the carrier frequency sub-channel of each packet.

Simulation of the multiple access scheme shows it is capable of supporting 6500 meters with a 99% probability that one message from each will be received successfully in a 30-minute period. This capacity is far in excess of the number of meters that can be expected in the coverage area of one MCC.

4 DETAILED DESIGN

Meter located transmitter.

For utility gas meters, there is no available electrical supply that can be used to power the wireless meter reader; it must be powered by its own energy source – an on-board battery. Furthermore this battery cannot be recharged – it must last for the life of the product: 10 years. This is a very demanding requirement and selecting the correct battery technology requires care.

The battery must be able to deliver sufficient current to periodically power the transmitter and it must have extremely low leakage so that it does not self-discharge over the ten-year lifetime. It was found that the best battery technology from the point of minimising self-leakage to an acceptable level would not be able to supply a high enough current for the transmitter during its transmission bursts. The solution to this was to use a DC-DC converter to trickle charge a storage capacitor during the period that the transmitter was “off” and then to use that capacitor to supply the transmitter power amplifier current during the transmit burst.

The selected battery was a low-rate Lithium Thionyl Chloride, $LiSOCl_2$, which has a long history of use in memory back up and metering applications. The D sized cell provides 3.6v with a capacity of 15Ah. The discharge curve is essentially flat which means powering the microcontroller directly was an option. A ten-year shelf life is normally quoted and the typical capacity loss at 20^{o}C is around 1 to 1.5 % per year, though higher storage temperatures will result in a higher capacity loss, typically doubling at 45^{o}C. It offered an approximate 2:1 cost advantage over competing chemistries.

It was also necessary to select an appropriate large value storage capacitor to receive the trickle charge, one guaranteed to have a ten-year lifetime without significant degradation in its capacity. An aluminium electrolytic type having a non-solid dielectric construction was selected. The life of such capacitors is very dependent on environmental and electrical factors, and of these, operating temperature has the most influence (ambient temperature and internal heating due to ripple current). The main failure mechanism for these capacitors is electrolyte loss due to evaporation through the capacitor seal; it is accelerated with temperature and gives rise to an increase in ESR with age.

Battery energy calculations were made, including allowances for losses in the DC-DC converter and took into account the predicted self-leakage of the battery. The spreadsheet indicated that a 10-year life should be achievable from a single $LiSOCl_2$ ‘D’ cell if the transmission interval is approximately 1 hour or more.

Figure 4: Photograph of Gas meter transmitter unit

Figure 4 shows a photograph of the Gas meter transmitter unit. On the left hand side is the transmitter PCB including helical antenna and storage capacitors. The right-hand side shows the case works. The complete unit attaches to a standard Gas utility meter.

MCC Base Station Receiver

The simple functionality of the residential transmit units is in sharp contrast to the complexity of the MCC receiver. Whereas the transmitters have to only periodically transmit a low rate BPSK signal, the receiver must be able to receive data packets broadcast asynchronously on a multitude of sub-channels within the 100kHz channel. Furthermore, it must be able to receive multiple packets at the same time on different sub-channels since there will be many occasions when transmissions from two or more residential transmitters overlap. This means the receiver must simultaneously listen for signals on all the sub bands and attempt to demodulate any it finds.

The receiver architecture, depicted in Figure 5, is a highly linear two-channel diversity receiver with a single down conversion to a 21.4MHz IF and followed by an undersampling 10bit ADC. The two channels are multiplexed together and each signal is complex mixed down to a zero-IF and decimated by a factor 170. The decimation process removes out-of-band quantisation noise introduced during the A to D conversion process and effectively increases the dynamic range by 22dB.

A 128 point FFT running at four times the bit rate is applied to both channels and results in 114 effective sub-channels with a frequency bin width of approx. 870Hz and equal to the transmission data rate. The FFT processing is implemented in an Analog Devices ADSP21061 SHARC DSP. Two further SHARC DSPs operate on the two sets of 114 sub-channels – one for each receiver channel – and perform a PLL demodulation followed by message reconstruction for each sub-channel. A fourth SHARC DSP receives the demodulated messages from the two channel processors, performs error correction and diversity arbitration. It then communicates with the Host processor providing demodulated messages when received and spectra at a requested rate.

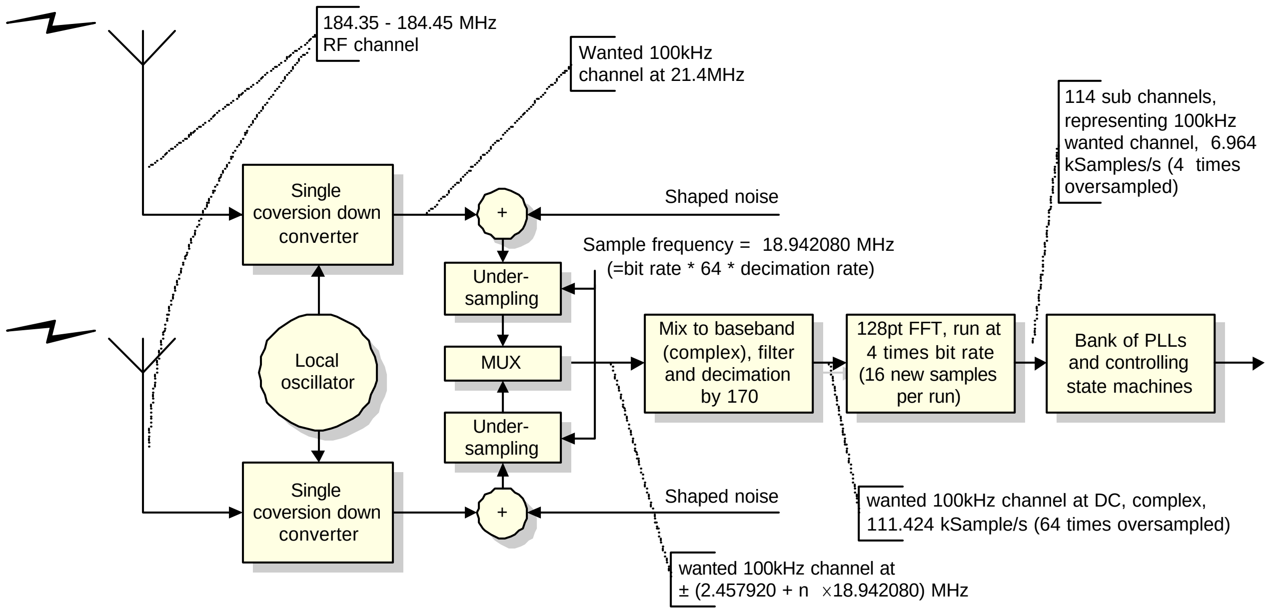

Figure 5: Micro Cellular Controller receiver architecture

Figure 6 shows a photograph of the MCC receiver. The analogue RF board is shown in the foreground. It includes the RF front ends, channel filters, synthesisers for local oscillator generation, IF amplification, ADCs and decimator. The digital processor board in the background contains the four SHARC DSPs and the host processor.

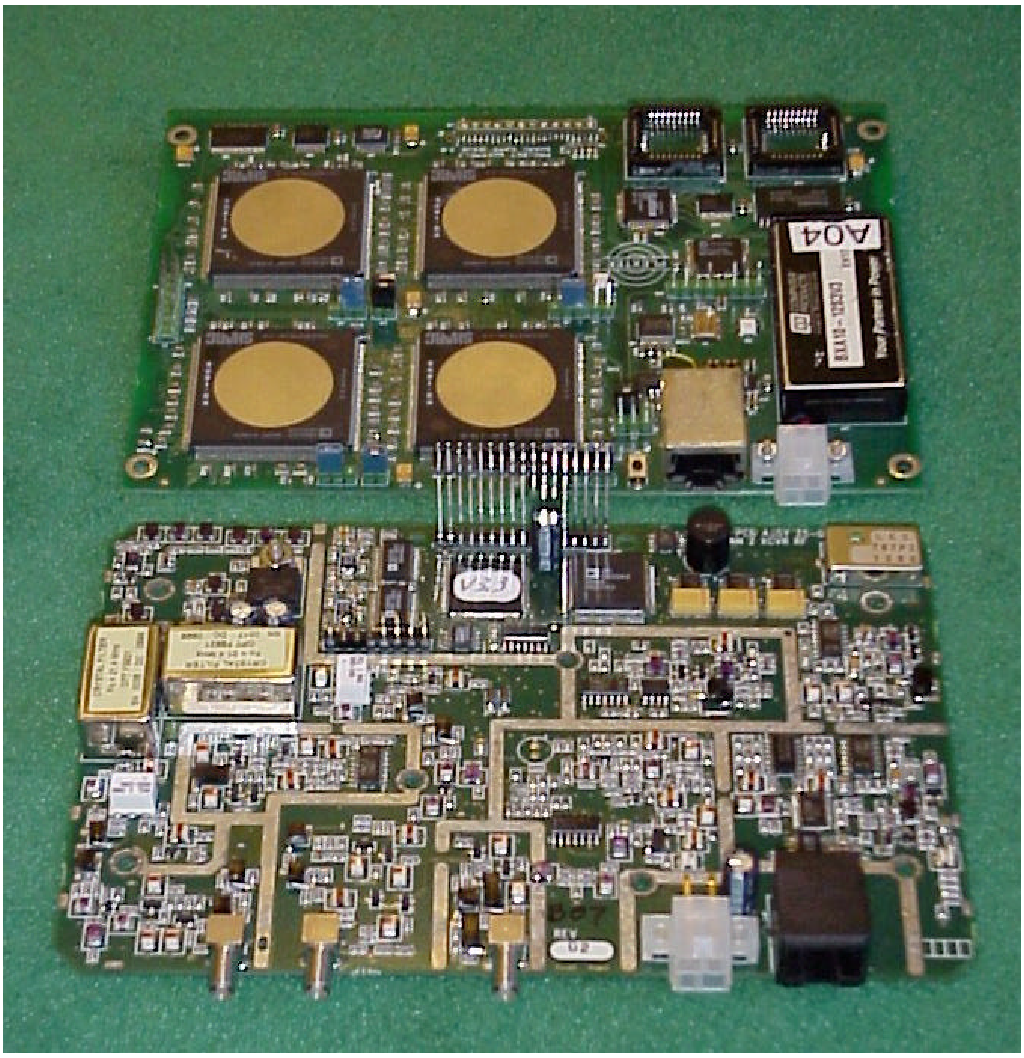

Figure 6: Photograph of base station transceiver

5 OPERATIONAL SYSTEM PERFORMANCE

The meter reading system development was commissioned by BCN who subsequently conducted trials of the technology in conjunction with British Gas. Some 46,000 consumer units were deployed in London and Manchester alongside some 300 MCC stations. The trials were run successfully for a two-year period after which it was expected that British Gas would make a decision on the technology. However, despite the successful demonstration of the technology, as of yet no UK utility group has taken the decision to deploy wireless meter reading on a national basis.

In the future, matters are likely to change. There is pressure from Scandinavia where there are laws that say meters should be read, and in time this approach is likely to percolate into Europe, being pushed by the Green lobby. Currently the “will” is not strong enough to implement it, but meter readings every half hour will allow pricing based on peak loading to be introduced encouraging consumers to minimise energy usage at these times.

6. CONCLUSIONS

This paper has covered the development of a wireless utility meter reading system suitable for nation-wide deployment. The considerable system design challenges have been discussed, reasons for the choice of system architecture have been justified and aspects of the detailed design have been covered. The system has been successfully demonstrated in trials; wireless meter readers have been introduced into some 46,000 homes, operating successfully for a two-year period.

7. ACKNOWLEDGEMENTS

The development of this wireless utility meter reading system was a complex task and many engineers within Plextek Ltd. contributed to its development.