Development of a low-IF Receiver and a Fixed Wireless Utility Network

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***Abstract* — We present the design and development of a low-IF receiver and a fixed wireless utility network. This receiver is designed to achieve a dynamic range of 80 dB, a sensitivity of –105 dBm and a noise figure of 5 dB for a narrow band spread spectrum modulation scheme at 900 MHz. We demonstrate the feasibility of the low-IF receiver for low-cost implementation that alleviates the issue of 60 Hz power line in wireless electricity meter networks.**

I. INTRODUCTION

Real-time pricing and processing can provide major cost-savings in today's market. Recently, the report on Utilities E-business indicates that real-time pricing could provide $10 billion to $15 billion annual savings for the U.S. electricity market [1]. The CellNet system developed by Schlumberger is an example of a powerful network that provides capabilities for collecting, processing, and delivering valuable information quickly and reliably [2,3]. In this fixed wireless system, shown in f1, the architecture comprises of a hierarchy of three tiers of integrated networks: (1) system controller network – for managing the overall system, (2) wide area network (WAN) – for managing a regional area, and (3) microcellular local area network (LAN) – for collecting and managing data from hundreds of endpoint transceivers and communicating higher up the network hierarchy.

The CellNet system deploys narrow band spread spectrum radio technology with built-in cyclical redundant checking error protocols to provide high data reliability. The centralized servers collect data from numerous endpoint transceivers using two-way communications within a radius of 0.2-0.3 mile. Although direct conversion receiver architecture is attractive to design low-cost [4] endpoint transceivers, its implementation is not very feasible in utility networks. The DC-offset is a major issue that is complicated by the 60 Hz power line. The alternative low-IF receiver apparently lessens the DC-offset by selecting the downconverted data in the MHz regime.

In this paper, we present the design and development of a low-IF receiver and a fixed wireless utility network. The network has been designed using a narrow band spread spectrum technology that provides highly reliable data transmission for automation of utility billing and management [3]. We demonstrate the feasibility of this receiver architecture for low-cost implementation in the wireless utility network.

II. ARCHITECTURE RATIONALE

The low-IF receiver, given as a block diagram in Figure 2 eliminates many of the off-chip components thus reducing the complexity of an end point receiver.

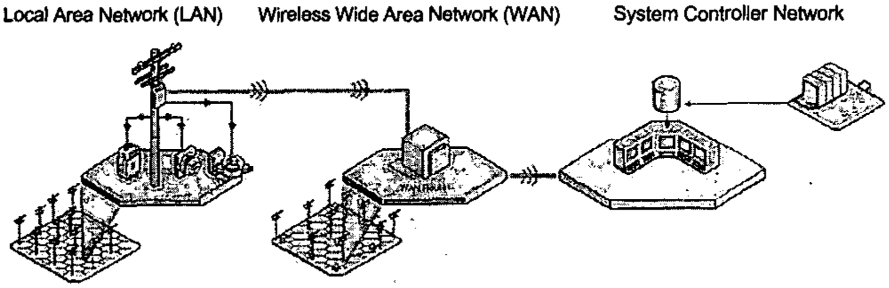

Fig. 1 Schematic representations of a fixed wireless utility network for electricity meters

A direct conversion receiver could be another economic solution with comparable advantages in providing for higher levels of integration [5,6]. In direct conversion receiver, the RF input signal is down converted directly to the baseband frequencies. The direct conversion architecture is limited by LO-leakage to either the mixer input or to the antenna, which causes a varying DC-offset component that limits the dynamic range performance [7]. Another unforeseen difficulty could be the interference of the down-converted baseband data with the electrical signal frequency of 60Hz.

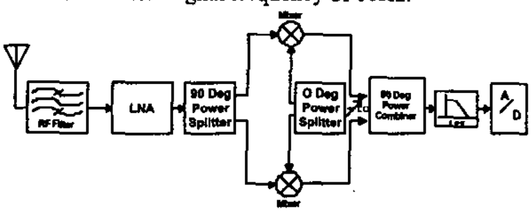

Fig. 2 Subsystem level block diagram of the low-IF receiver

The low-IF architecture is a similar single mixer stage architecture, which down converts the RF input signal to a frequency of the same order as the bandwidth. Hence, it inherently alleviates many of the DC-offset problems of the direct conversion architecture [8,9]. Hartley's image reject architecture is implemented in this work to annul the image problem associated with this type of receiver architecture [7,10]. The image along with the signal are shifted by 90° and processed differently using 2 mixers. Both the signal components are recombined again allowing the cancellation of the image by its negated replica. This cancellation is possible as the image and the signal lie on either side of the LO frequency.

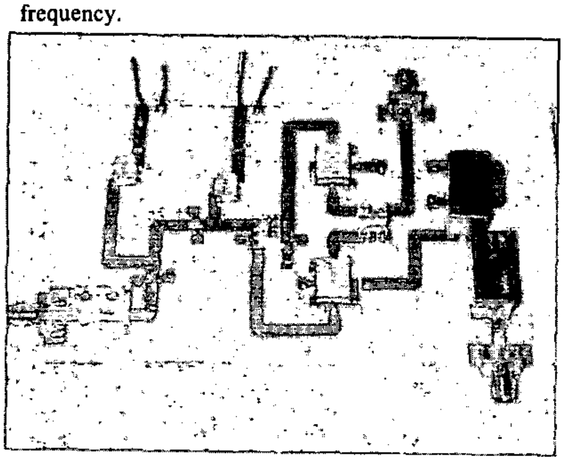

Fig. 3 Prototype of the receiver board

III. RECEIVER ANALYSIS

The low-IF receiver given in Figure 3 has an RF band pass filter, a gain stage, a down conversion stage and a baseband filtering stage. The low-IF receiver is designed to meet the specifications in Table I [7,11,12]. This receiver model has been built with off-the-shelf components to demonstrate the proof-of-concept. The receiver prototype has been analyzed using RF input signals with different modulation schemes to test its reliability performance. A possible limitation of this architecture could be the value of the intermediate frequency. A need for a high speed A/D converter becomes more prominent as the value of IF increases. On the contrary, the DC-Offset and 60 Hz power line becomes a problem with the reduction of the IF frequency.

TABLE I
RECEIVER SPECIFICATIONS

Parameters	Values
Frequency Range	911.58 MHz
Sensitivity	-105 dBm
Dynamic Range	80 dB
Input Power	-105 dBm to -25 dBm
Bit Error Rate (BER)	$< 10^{-3}$
Chip Rate	1.2137 Mchip/s
Data Rate	19.2656 kbps
Noise Figure	6 dB
Range	0.3 – 0.5 mile
Modulation	OOK, CCSK

To emulate the real time modulation schemes in our fixed wireless network, the HP E4433B ESG-D Signal Generator is used to generate OOK and BPSK modulated signals. This signal is up-converted to ω_{RF} with the required data rate of 19.265 kbps, which is fed into the receiver. The HP 89441A Vector Signal Analyzer with baseband signal processing capabilities is employed for spectral analysis and demodulation of low-IF baseband signals. Figure 4 demonstrates the downconverted ω_{RF} - ω_{LO} intermediate frequency from the RF OOK-modulated waveform using the low-IF receiver. The IF-waveform is then processed using the HP 89441 to produce the actual pulse data stream that corresponds to a bit rate of 19.2656 kbps (Figure 5).

The results in Figures 4 and 5 demonstrate the feasibility of this receiver for OOK modulation scheme, which is simple and reliable in this fixed network. Furthermore, we investigate a modulation alternative to increase the network capacity and sensitivity of the transceiver. In this case, we've developed a customized Cyclic Code Shift Keying (CCSK) modulation scheme to be used with spread spectrum technology to ensure the reliability and security of data transmission. This modulation is very similar to the conventional BPSK scheme.

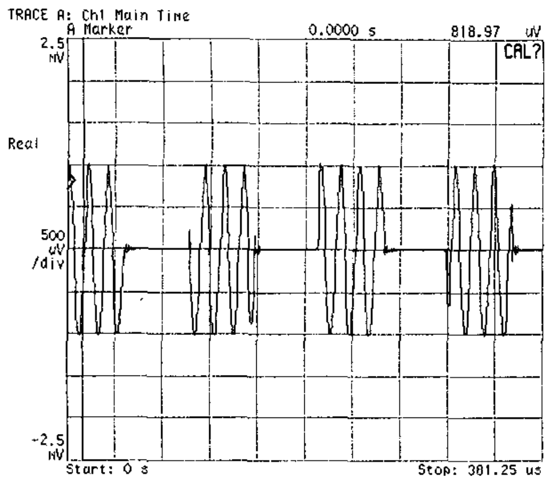

Fig. 4 OOK modulated output signal at IF

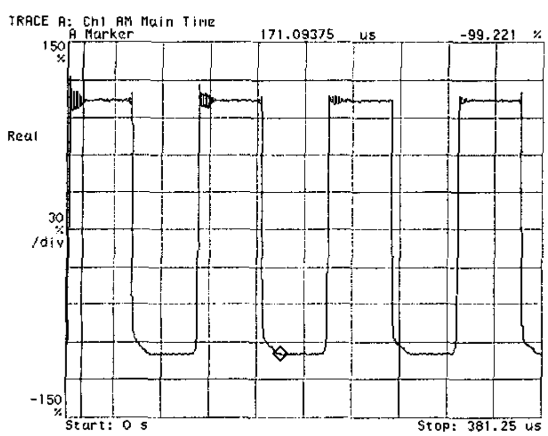

Fig. 5 OOK demodulated output signal at IF

Figure 6 shows the time domain plot of the BPSK modulation for a bit pattern of 1111 1001, showing a phase shift after the time interval corresponding to 6 bits with a data rate of 19.2656 kbps. Figure 7 gives the demodulated bit pattern and the constellation diagram of 2 states.

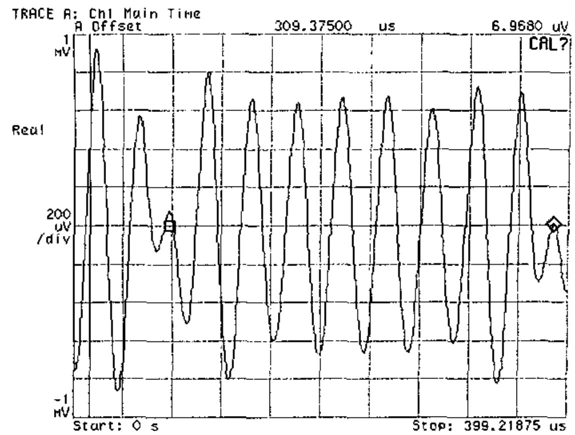

Fig. 6 BPSK modulated signal at IF showing the phase change

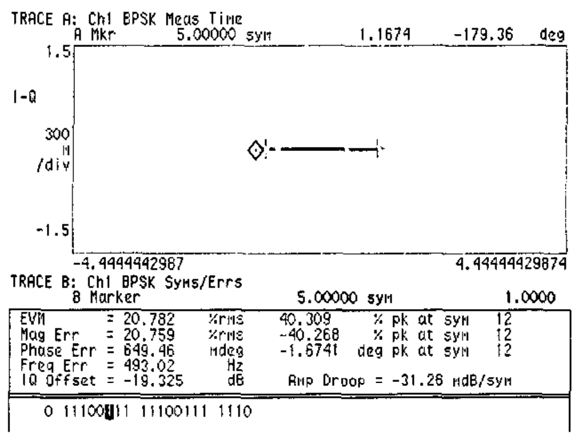

Fig. 7 Demodulated plot giving the bit pattern 1111 1001 and the constellation diagram

The receiver proves to be a full working model when the specification of bit error rate (BER) is met. BER is measured by comparing the input bit stream to the downconverted demodulated output bit stream over a large number of bits. The measured bit error rate (BER), meets the requirement of 10^{-3} (Figure 8) across the dynamic range of input powers for a particular value of IF frequency. The BER measured meets the required specification for the specified sensitivity. The measurement results demonstrate and substantiate the functioning of the low-IF receiver.

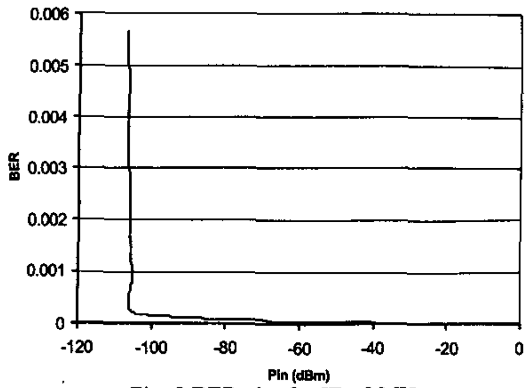

Fig. 8 BER plot for IF =5 MHz

IV. Conclusion

We present the design and development of a low-IF receiver for a fixed wireless utility network. We demonstrate the feasibility of the low-IF receiver for wireless utility networks. We have achieved a dynamic range of 80 dB and a BER of less than 10^{-3} over the dynamic range of –105dBm to –25 dBm.

V. Acknowledgement

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VI. References

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