Getting the message through – Reliability of UHF radio links between Short Range Devices

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Introduction

Short Range Devices is the generic term for licence exempt radios used in everything from car key fobs to security systems and industrial process control. The performance and quality of service of data links is traditionally expressed in terms of bit error rate (BER). SRDs, however, are usually sending very short messages with only a handful of significant data bits. Different measures of performance are needed, such as packet error rate (PER) or message failure rate (MFR).

This paper looks at some of the reasons for message failure and uncovers some practical examples of very poor MFR. It is shown how a means of testing MFR was devised and as a result the reliability of a particular system was raised from 90 to 99.9%.

Error Rates and Failure Rates

When analysing a radio data link it is common to work in terms of bit error rate. It is common practice in development to plot out curves of BER versus signal strength and BER versus frequency offset. This will give a lot of information about noise levels and the demodulation process, but for many radio links it is far from being the whole story.

Many radio links operate intermittently. One end of the link may wake up, send a short message and go back to sleep. Typical of these are Short Range Devices such as garage door openers and car key fobs but the same principles of very low duty cycle operation apply in many applications involving telemetry and remote control.

With these very short data bursts other measures of performance are needed. The term packet error rate is widespread, but if it is to be used it must be carefully defined. Consider the multi layered model of data communications, with the physical layer at the bottom. PER could be measured in a scenario where the data link is permanently established and a burst of wanted data occasionally travels across an idling channel. By contrast, the scenarios considered here are those in which the hardware is turned off between packets. The whole physical layer is, in effect, dismantled and reassembled between packets.

This brings with it a new set of possibilities for problems when a message is sent. These are characterised not by messages arriving with errors, which is usually a recoverable situation, and not even by framing errors, but by some messages being lost completely, which is not recoverable. Therefore the term Message Failure Rate is suggested instead.

Typical message and failure modes

The structure of a typical short message is shown in Figure 1. The first part is a preamble to allow the receiver to find the message, settle and lock its data clock. This is followed by frame marker or start of message sequence. The rest is mostly housekeeping and error detection. The whole message is quite commonly 50 bits or more, but contains only 1 or 2 bits of data to carry the actual information. Sometimes the data bits are not even there; the information being transferred is simply the existence of the message.

Figure 1: Typical message

Table 1 below lists various reasons why a message might fail

External Influences	Internal Effects
Clashes with other messages in the same network	Failure to acquire message Wrong channel, time
Other in band users	Failure to extract data Frequency offset Slicing level Clock recovery Framing
Out of band blocking	
Propagation anomalies	
Background noise	Random errors within message
Operator / Instruction Manual misalignment	Undetected errors
	Technical deficiencies
	Low battery

Table 1

Typical MFRs

People used to working with BERs on permanently established links may be surprised at the values of MFR in typical short burst systems. A standard car key fob for instance may well have an MFR in the range 20 to 50%. Ie, it might only be successful half the time. What makes this system work though, is that it is not just a unidirectional radio link. It is part of a closed loop system with automatic acknowledgment and retry. Press the button, and if the hazard lights do not flash, then the operator takes a step closer to the car and presses again. This is a classic example of the system software compensating for and masking poor performance of an individual component.

Torque Wrench Monitoring System

An example of a system that requires a very low MFR is a torque wrench monitoring system used on production lines. In this example, a small radio transmitter is fitted to each hand held torque wrench and a message is transmitted each time a nut or bolt is tightened correctly. The system is used, for instance, to monitor that all the cylinder head bolts on an engine have been done up. The next step is that the operators of the production line want to connect this monitoring system to the PLC controlling the line, so that when all the bolts are done up, it moves on to the next engine.

Immediately it can be seen that the monitoring system needs to keep very accurate count of the tool operations.

The customer had built a first generation system using off the shelf radio modules. These were 433 MHz devices, with a SAW stabilised transmitter using amplitude modulation and a wideband receiver. The monitoring station used two receivers for diversity. As well as a message being sent for each tool activation, a running total was transmitted so software at the monitoring station could keep track of the count.

Experience with this first system was generally positive but highlighted the need for improved performance from the radio link. If it were to be used to control the production line then it needed not just to keep count but to keep count in real time. It is no use, for instance, to miss one and catch up 30 seconds later. Clearly the underlying radio link needed a much lower MFR.

A project was therefore started to produce a second generation system. The customers stated requirement was to raise the reliability of the radio link, which was only 90% in some installations to 99.9%.

An analysis of the system, and particularly measurements on the receiver, showed that one key weakness was susceptibility to both in band and out of band interference. It is difficult to say what contribution interference had made to the observed statistics but it was clearly a potential problem that needed to be tackled. It is possible that interference could be the cause of a moderate MFR, but it was also found possible with the first generation equipment that either channel contention with inband signals or blocking by out of band signals could shut the system down completely.

Differences in second generation system

- 2 way, Ack/Nack
- Narrower channels
- Increased Blocking level
- Front end filtering
- Frequency agile
- Improved link budget
- Improved diversity

In particular the use of narrower channels and half duplex, with handshaking and repeats if necessary, and frequency agility, would solve the problems of dealing with other in band users. It should be noted that these other in band users also include other torque wrenches reporting to the same monitoring point, and indeed other systems in the same factory.

Two key design acceptance tests were set. One was that the system would successfully complete 50 consecutive transactions in the presence of other signals. With the use of repeat attempts and frequency agility, this actually proved easier than the other test, which was in a benign environment. This test was to send 500 consecutive messages, each successful the first time, with no need for repeats. It was this test that really exposed the raw MFR of the radio circuitry

In fact a first attempt, using commercial off the shelf radio modules, proved disastrous and uncovered a new failure mode that is not in the list above. It was found that communication would suddenly fail after 20 or so operations. The crucial difference between this and previous bench tests of the modules was that they were now being powered down and back up between operations, as they would in the field.

It turned out that the internal processor in the module suffered a brown out problem and, if this occurred at the wrong time, would re-write the internal EPROM settings. No solution to this was found and it was decided to develop a proprietary design.

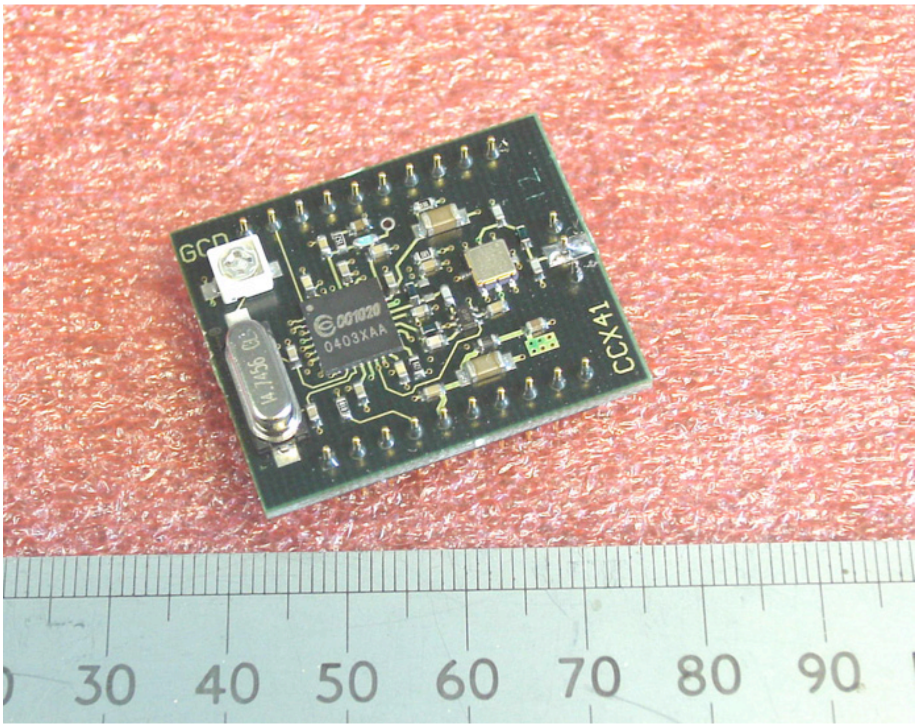
Driving down MFR – Clock Recovery

Figure 2 shows a small radio module daughter board using a compact transceiver IC, the Chipcon CC1020. The design is heavily based on the Chipcon application note and demo board, with the following differences:

- Reworking of the ground arrangement on the PCB
- Addition of a SAW filter in the RF path
- Changes to the transmit filtering.

In choosing these changes some useful clues were found by examining the revision history of the documents to see which areas had required attention.

The CC1020 is a complete transceiver and provides data clocking on transmit and clock recovery on receive. It uses 2FSK modulation and virtually every parameter, including data rate, deviation and receiver bandwidth can be controlled by



programmable registers. Chipcon supply a software program to set up the registers for given configurations.

Using the recommended settings gave good results, but unfortunately not quite good enough. With short data bursts there was a small but significant drop out rate. The message being sent consisted of a preamble, ie., a clock sequence of alternating 1s and 0s followed by a frame marker sequence. It was found that occasionally the receiver would not achieve clock lock before the frame marker. Interestingly, increasing the length of the clock sequence had little effect; it was observed that clock lock would either happen within a few bits or would otherwise take a very large number of bits. (The algorithm inside the chip is not known, but this behaviour is similar to that of a PLL without an initial frequency steer).

Receiver clock recovery appeared to be the crucial step in the whole process and it is, fortunately, possible to observe. A test system was set up with a pulse generator gating the output of a signal generator which was then routed by cable to the radio module at the other end of the lab which was in receive mode. The signal generator was set to sine wave FM, at a rate that equated to the clock lock 0101 sequence. This set up only simulated the first part of the message but it did give complete control over the “transmitter” parameters.

A scope display was set up to be triggered from the transmit bench but monitoring the receiver data clock. It proved possible to configure this so that there was an easy visual recognition of the time at which clock recovery happened. In this way it was possible to experiment with receiver parameters and to test the effect on lock time with variations in deviation and allow experiments with offsets in centre frequency and data rate.

Eventually a set of transmitter and receiver parameters were achieved that gave quick and reliable clock recovery and this could be shown to hold true over a range of frequency offsets and signal strengths. Interestingly this required that the expected deviation of the demodulator be set to a substantially different value than the actual transmitted signal.

The manufacturers data sheet claims a PER of 0.2% (or 1 in 500). Indeed with the revised settings and only a short preamble it was possible to demonstrate the 500 consecutive correct operations. These settings however were not the optimum for sensitivity and bandwidth. It seems that there is a trade off between sensitivity and MFR.

This information was fed back to the manufacturers and the response received was "this is in line with our experience; we have just issued a revised data sheet".

Figures 3 and 4 (above) show a torque wrench with the sending unit fitted and the monitoring station with two remote receiver units.

Conclusion

It is possible to make a highly reliable SRD link and still keep it low cost. One obvious requirement is to consider all the issues of interference and compatibility with other radio users. It is however also necessary to consider carefully every aspect of the circuitry.

Two clear messages come out of this story. One is the importance of setting up repetitive testing when looking for high reliability. The other is that, despite what people may claim, the use of bought in radio modules, demo kits and application notes does not remove the need for serious engineering expertise and effort.

Further Information

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