

Wavedancer 400 - A new ultra low power ISM band transceiver RFIC

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1.0) Abstract

Roke Manor Research has developed Wavedancer 400, an ultra low power transceiver RFIC for the 433MHz ISM band. Wavedancer 400 utilises a direct conversion architecture with class leading power consumption and receiver sensitivity and is aimed at low cost applications. The device offers two selectable bandwidths in both transmit and receive modes allowing either high data rates or maximum receiver sensitivity. These features mean it is ideally placed for use in a variety of applications such as telemetry, remote location deployment and ranged tagging.

2.0) Introduction

This paper describes the development of the Wavedancer 400 RFIC at Roke Manor Research. Roke Manor Research has considerable RFIC design expertise experience within the RFIC group particularly for highly integrated RF transceiver chips. This new Roke designed RFIC has been used as part of a prototype transceiver to both showcase its capabilities as well as serve as well as to serve as a test vehicle for further development and testing for performance improvements.

The main points of the design and some of the development challenges and design issues tackled will be described in this paper. A photo of the Wavedancer 400 RFIC die is shown in Fig 1:-

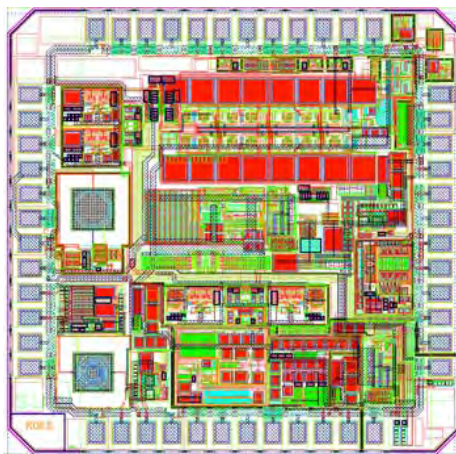


Figure 1 Picture showing the Wavedancer 400 RFIC design.

3.0) Wavedancer Capabilities

Wavedancer is a microprocessor controlled RF transceiver RFIC manufactured using an IBM 0.18um 7WL SiGe BiCMOS process with the following capabilities:-

- **Highly sensitive and selective receiver.** – Integrated receiver is a direct conversion design with a digitally sampled IF. A SAW filter is used to define the front end selectivity.
- **Efficient transmit power amplifier ($\eta=58\%$) with selectable PA output power (+10dBm or 0dBm).**

- **PLL Tuned synthesizer.** The RFIC contains a phase locked loop frequency synthesizer which can be controlled via a serial programming interface.
- **Multi Channel compatible** - The RFIC is capable of supporting a two way data link in the 433MHz ISM band. It is possible that the RFIC may be tuned and optimised for use at other UHF frequencies.
- **Wide/Narrow bandwidth modes.** The transceiver bandwidth is software selectable. This allows the device to be tailored for either maximum sensitivity or maximum data rate.
- **Wide data rate capability.** Data rates of between 10kbps and 2Mbps are possible depending on the bandwidth setting, coding and modulation method used.
- **Suitable for adaptive modulation techniques.** The design is suitable for implementing adaptive modulation techniques to tailor the data rate depending on the received carrier to noise ratio.
- **Flexible hardware architecture.** Uses a flexible hardware architecture where the demodulator can be defined externally from the RFIC. This allows it to be used as the basis to support a variety of data modes. The design is intended to be capable of supporting GFSK, GMSK and FSK modulation.
- **SPI Programming bus.** The RFIC can be fully controlled via a serial programming interface (SPI). This gives complete control over the RFIC and it can be used to set parameters such as the operating frequency, bandwidth, bias levels etc.
- **Separate Power Rails.** Separate power rails on the device for the PA, PLL and receive/transmit chains within the device enables unused circuitry blocks to be turned off to save power. The circuit blocks within the RFIC have been designed for class leading current consumption performance.

4.0) Reasons for developing Wavedancer 400

The capability displayed by the Wavedancer 400 RFIC is currently unsupported within the market place. The market place for low power UHF ISM band transceivers shows a gap for a lower power and more flexible model such as Wavedancer. The flexibility and range of capabilities help to broaden its appeal to prospective customers and make this RFIC suitable for a multitude of applications. The chart in Figure 2 below shows how Wavedancer compares to other competing ISM band transceiver products.

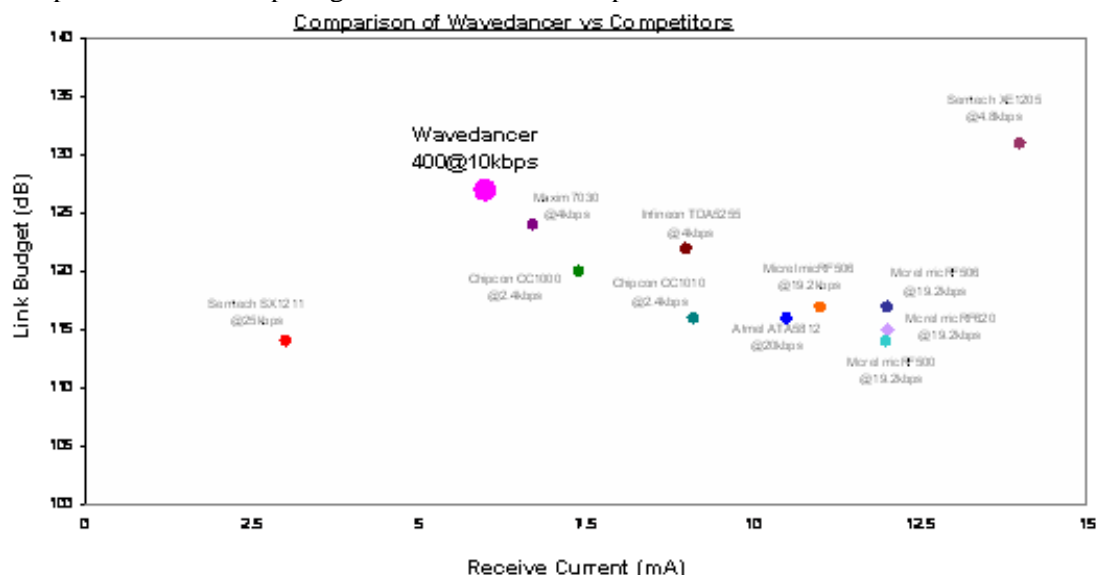


Figure 2 - Chart of Wavedancer vs. competing devices.

This chart clearly shows the desirable combination of a high link budget capability combined with low current consumption possessed by the Wavedancer 400 RFIC. This compares favourably to other similar competing devices.

The RFIC design group at Roke has had extensive expertise in designing RFIC's and has the capability to produce an RFIC that can support this particular application. By developing Wavedancer 400, Roke is able to build a technology base that could be exploited by future Roke customers.

4.1) Potential Applications

Wavedancer was primarily designed to operate in low power sensor networks for production applications. However the flexible architecture of the Wavedancer 400 RFIC makes it suitable for use in a wide variety of other applications, including :-

- Low data rate power telemetry/control for tagging/logging applications.
- Ranged RF Tagging.
- Remote location deployment for telemetry and communications.
- Low power custom communications links such as Wireless CCTV and it also has possible applications in the Medical sector.

Other suggested areas of use for this RFIC include Building/Factory Management, Consumer Electronics, Defence and National Security sectors.

5.0) Wavedancer 400 RFIC Specification

A brief summary of the Specifications and capabilities of the Wavedancer 400 RFIC are shown below in Fig 3:-

Preliminary Specification	
Frequency Band	400-450MHz
Supply Voltage	2.5-3.6V
Supply Current	6mA – Receive 15mA – Transmit at 10dBm
Modulation (constant envelope)	GFSK, GMSK, FSK
Bandwidth (user definable)	12.5-100kHz – narrowband 1MHz – wideband
Sensitivity	-115dBm – in 12.5kHz bandwidth
Programmable Output Power	0dBm – minimum 10dBm – maximum
Package	QFN-32 – 5mm × 5mm
Additional Features	
<ul style="list-style-type: none"> • Multi-channel compatible • RSSI (<i>future enhancement</i>) • Bit Synchronisation – S/H circuit • Internal Filters for Transmit and Receive • Compliant FCC Part 15 	

Figure 3 - Brief RFIC specification.

In addition to the basic specification given in Fig. 3, the RFIC also has these capabilities:-

- **An SPI programming bus** - This allows the operating parameters such as the PLL frequency, Bias levels, PA o/p power and the bandwidth to be controlled by an external microprocessor.
- **Quadrature I-Q low phase-noise PLL Synthesizer** – Generates a local oscillator signal allowing >200MHz frequency coverage.

- **Digitally Sampled IF** – The IF signal is digitally sampled by an internal quantiser using an externally supplied clock signal. This allows complete external control of the sampling frequency.
- **Programmable variable bandwidth digital IF filters** – Used in narrowband mode to allow the link budget to be tailored for different path loss conditions.
- **Highly efficient transmitter power amplifier** – Optimised for high efficiency (58%) to minimise power consumption.

6.0) Wavedancer 400 RFIC Architecture

The block diagram in Figure 4 below shows the internal architecture of the RFIC and shows the architecture of the chip:-

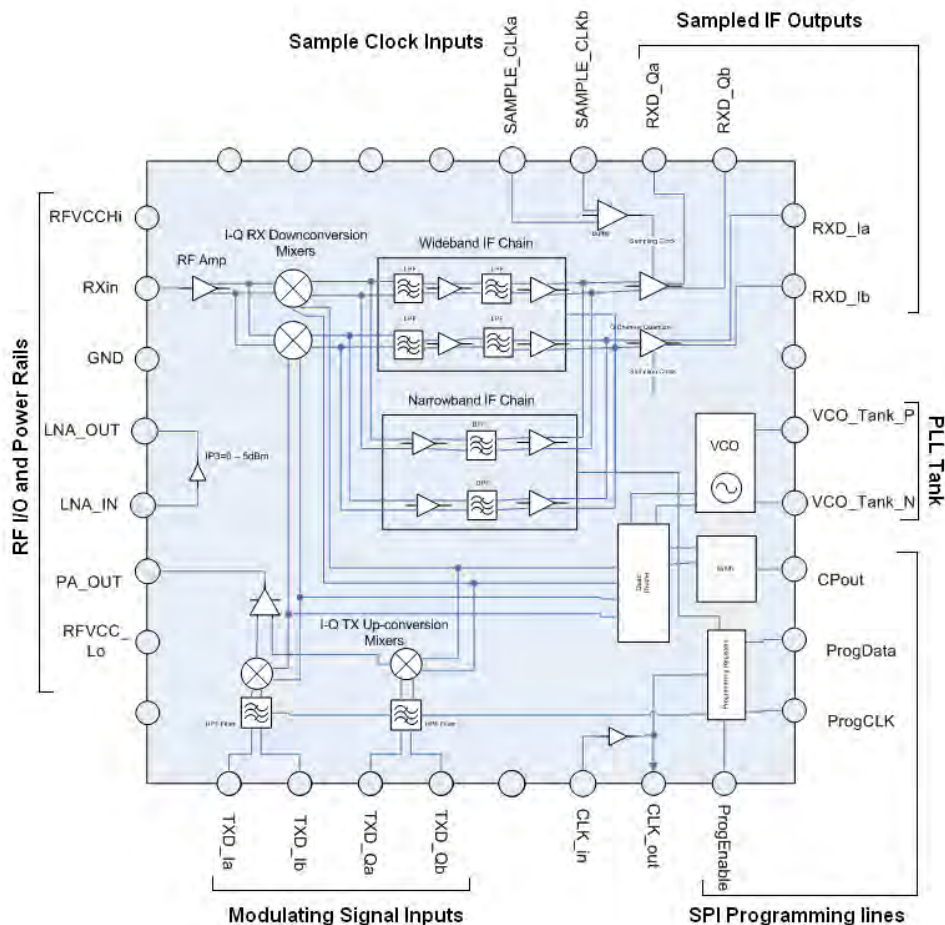


Figure 4 - Block diagram of the Wavedancer 400 RFIC

The diagram above in Figure 4 shows the Wide and Narrowband IF chains, the architecture of the PLL and the mixers used in the receiver for down converting the received signal to a low IF. It also shows the mixers used for up converting the modulating signal to 433MHz in the transmit chain.

6.1) Wavedancer 400 Receiver Architecture.

The receiver is a direct conversion design with a 90 kHz IF with the I and Q outputs typically digitally sampled by an external quantizer. A sampling rate below the nyquist rate was used in the prototype to allow the IF to be down converted to DC and demodulated using the same circuit block. Other sampling frequencies may easily be used as the sampling clock is an

external input to the RFIC. A block diagram showing the receiver architecture is shown in Figure 5.

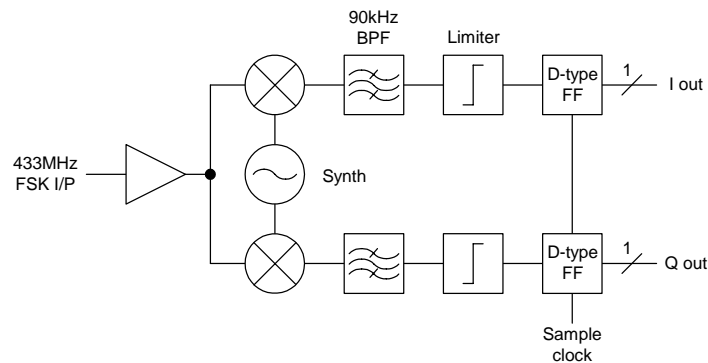


Figure 5 - Diagram of the Wavedancer 400 RFIC receiver architecture

In the example prototype, the incoming modulated signal at 433.92MHz is mixed with a local oscillator signal at 433.83MHz to frequency translate the signal down to provide I and Q IF signals at 90kHz. The signals are band pass filtered by a pair of 3rd order Butterworth filters with a 3dB bandwidth of 16 kHz. In the current design, cross coupled filters are used to shift the centre frequency up from 0Hz to an IF, providing some rejection of the negative frequency image. This is useful because it moves the carrier away from flicker noise (to optimising the noise figure) and it also makes the design immune to DC offsets as the signal can be AC coupled.

The filtered I and Q signals are then hard-limited and sampled using D-type flip-flops to give 1-bit outputs. The RFIC has a pin for the clock signal to be fed into the RFIC as an external input. This gives the user complete external control over the sampling frequency.

Two IF strips are included inside the RFIC design as shown in Fig 4 so that either a wideband IF or a narrowband IF can be used. Only one IF chain is shown in Fig. 6 for clarity. The filters in the narrowband IF are programmable transconductance – capacitor (GmC types). These allow the IF bandwidth is to be varied from 12.5 kHz to 100 kHz to be tailored for user-specific applications.

The sampled IF outputs from the RFIC can then be used to drive a digitally implemented external FM demodulator to recover the original modulation.

6.2) Wavedancer 400 Transmitter Architecture.

The FSK modulator shown in block diagram in Fig. 6 is implemented within the RFIC is modulated by incoming data stream fed into the RFIC as an external input.

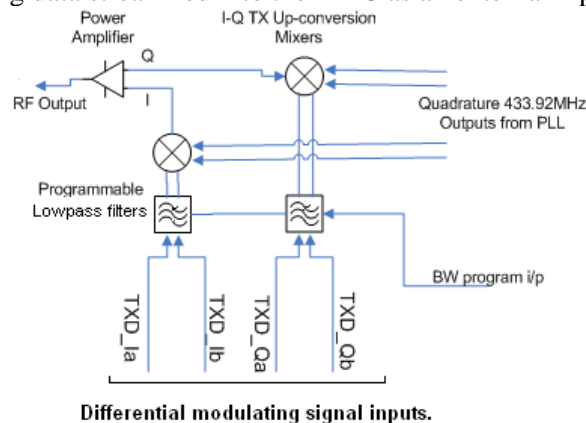


Figure 6 - Wavedancer 400 Modulator Architecture

The externally applied modulating signals are filtered by a pair of programmable low pass filters on the RFIC. The filtered are used to smooth the square wave differential input signals.

Filtering is important here to limit the spectral content to the fundamental reaching the mixers only. Any harmonics mixing with the LO signal cause unwanted spurious signals and intermodulation products reaching the input of the power amplifier where they will be amplified along with the wanted signal. The filtered modulating signals modulate the transmitter by switching between the I and Q channels to reverse the phase of the transmitted signal.

The harmonics which do reach the mixers cause intermodulation and this results in noise sidebands around the wanted signal (as shown in Figure 8 below). These are required to be suppressed as much as possible:-

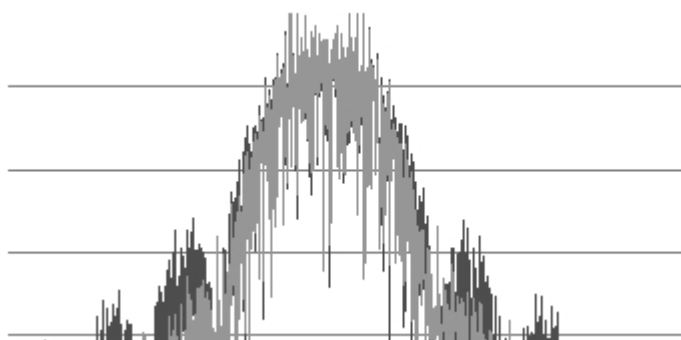


Figure 7 - Simulated TX spectrum showing noise sidebands.

The mixers mix the modulating signals with quadrature I and Q carriers generated by the PLL to generate an FSK modulated signal at 433.92 MHz.

The transmitter has the flexibility to be configured as a direct modulation loop, or using an I/Q up conversion loop. The direction of the phase changes during the transitions are used to distinguish between logic 0 and logic 1, i.e. the polarity of the transmit signal is fixed.

6.3) Modulation Schemes

The Wavedancer 400 RFIC is designed for use with FSK, GFSK and GMSK modulation schemes. FSK would provide the best BER performance for low C/No values and it can be easily generated with minimal external components. It is ideal for low data rate communications where received signals are close to the receiver noise floor.

6.4) RFIC Power

Wavedancer 400 RFIC operates from 2.5V and 3.3V power rails. These low voltage rails allow the chip to be operated from a single rechargeable 3.6V Lithium cell for battery operated applications. The RFIC was specifically designed for low power operation and the RFIC consumes only 6mA during receive and 15mA during transmit. The duty cycle between TX, RX sleep modes of the RFIC can be used to manage the power for lower average power consumption. Separate power rails for the PLL, PA and TX/RX chains on the Wavedancer 400 RFIC facilitate using power management techniques.

7.0) A Sample Wavedancer 400 RFIC Application

7.1) Wavedancer 400 Prototype application board

A prototype UHF transceiver application board using the Wavedancer 400 RFIC was developed to prove the RFIC design and for use as a development platform. A labelled photo of the application board showing the main parts of the design is shown below in Figure 8:-

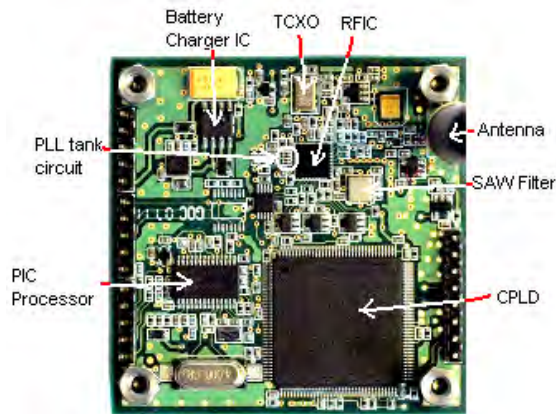


Figure 8 - Labelled diagram of the Wavedancer 400 RFIC application board.

7.2) A Wavedancer Network

A network consisting of 3 prototype transceivers was constructed for use as a demonstrator to show the capabilities of the Wavedancer 400 RFIC. Two transceivers are used as RF tags to report temperature readings periodically to a base unit as shown in Fig.9. The base unit was generally used in receive mode to demodulate and decode the incoming data.

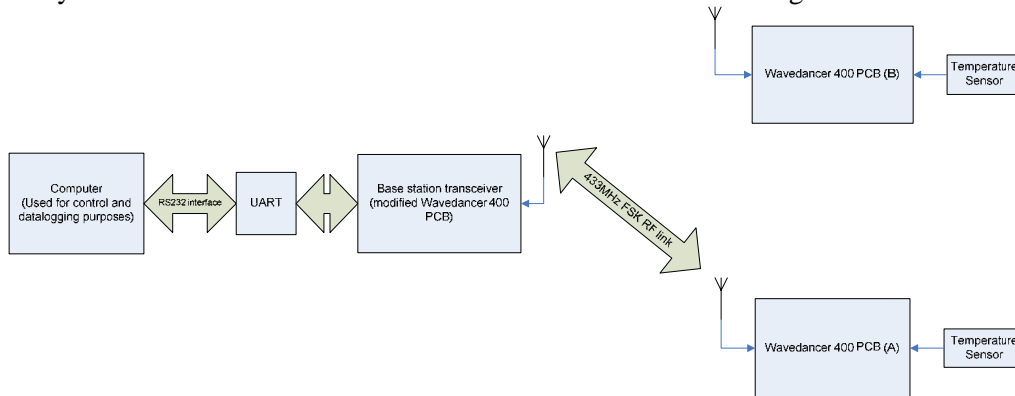


Figure 9 - Diagram showing a network of Wavedancer 400 transceivers

The prototype was used as a data logging wireless thermometer. The tag boards report temperature and battery voltage information periodically to a base unit.

The maximum achieved range of the prototype was approximately 20m in an indoor environment using shortened helical antennas and the wideband receiver setting. It is intended that reliable communications over a 100m LOS(line of sight) path will be achieved using this configuration.

Below is a plot showing an illustration of the scrolling graph logging temperature vs. time in Fig. 10.

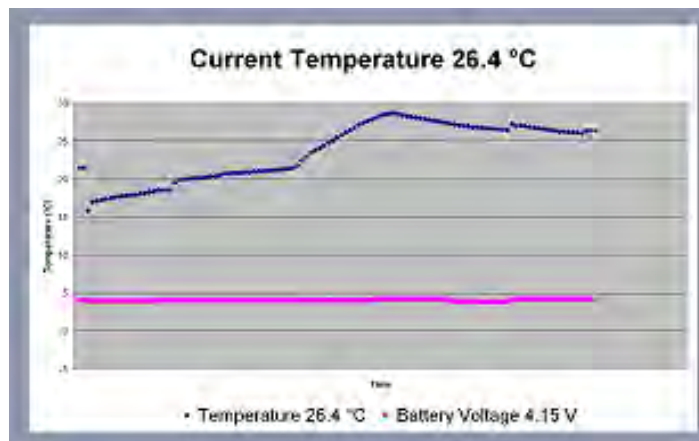


Figure 10 - Screenshot of the scrolling graph in the Excel GUI.

8.0) Wavedancer RFIC Future Developments

Roke has achieved positive test results from the first application of Wavedancer. Some future enhancements to the existing design have already been planned:-

- AC decoupled inputs to level comparators to reduce problems of DC offsets limiting the usable sensitivity.
- Improvements to the chip to improve the phase noise performance at 10kHz to 100kHz carrier offset.
- Ability to easily switch between narrowband and wideband settings.
- Developing a version of Wavedancer to function at 868MHz.
- Possibility of developing a dual band RFIC for the 433/868MHz ISM bands.
- Tape approval conformity for 2nd iteration device.

9.0) Conclusions

Roke has developed a low power RFIC which has been successfully used for the first time in a demo application after the first iteration to prove the design concept. Development is currently underway to enhance the design and this will be fabricated in a 2nd iteration.

The features and performance of this new RFIC from Roke place it in application areas which are currently unsupported. This allows Roke to provide its customers with a solution in this field.

10.0) Acknowledgements

The author would like to thank Roger Hopper, Mark Hickson and Richard Horn at Roke Manor Research for their help during the preparation this paper.

For further information, please see this website for the Wavedancer 400 datasheet:-

www.roke.co.uk/download/datasheets/056-wavedancer.pdf

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