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A Single VCO Chipless RFID Nearfield Reader

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This letter demonstrates an extremely simple, low cost, chipless RFID reader. The reader consists of only a single Voltage Controlled Oscillator (VCO) as the detector front end. The information from the chipless RFID tag appears as a low frequency variation on the VCO DC bias supply which is readily detected and demodulated. Experimental results are shown for successful detection of a 10 bit RFID tag, operating over the frequency range 2.4-3.4 GHz. The results when compared to those taken from a vector network analyser (VNA) prove that the VCO detector can provide a similar level of performance to the more sophisticated VNA arrangement. The proposed solution provides a significant simplification of the chipless RFID reader.

Introduction: Research into Chipless RFID is already producing small credit card sized tags that are completely passive and require no active (Chip) devices. This leads to the possibility of ultra-low cost tags that could be inkjet printable, in a similar way to optical bar codes. Despite the simplicity of such tags, the hardware that is required to read them needs to be high performance, complicated and therefore expensive. This is because, in order to yield the information stored within them, chipless RFID tags usually produce small changes in resonance. These small changes in resonance are difficult to detect since the reflected signal from the tag is very low due to low amounts of backscatter from such small size tags, and the fact that these tags have no on-board active components to amplify the signals returned back to the reader.

Most experimental results reported for chipless RFID tags are measured using a vector network analyser (VNA), e.g. [1]. Here the differences in resonance that are required to be detected often result in a change in the S parameters of as little as 0.5 dB. Such small changes suggest that a high performance instrument, such as a VNA is needed for reliable detection. There has been work ongoing to produce stand alone chipless RFID reader hardware, that does not need the use of a VNA [2,3]. These readers still require reasonable performance and sophistication at the receiver front end. Consequently they contain most of the components that would be required for a high performance superheterodyne receiver.

In this letter, we present, for the first time, a high performance chipless RFID reader which uses only a single active component, a voltage controlled oscillator (VCO), as the receiver front end. The resonance information from the tag appears at the reader as a low frequency signal superimposed on the bias current of the VCO. This proposed solution has the potential for significant cost reduction of chipless RFID readers, which could allow them to deployed, in volume, on platforms such as hand held mobile devices.

Theory of Operation: The operation of the VCO based chipless RFID reader solution can be described using the simplified oscillator equivalent circuit [4], shown in Fig. 1. The active device impedance, Z_D, is dependent on the magnitude, A, and frequency, ω, of the RF current, *i(t)*. If the load impedance Z_L changes there will a corresponding change in *i(t)*. Consequently there will be a change in the current produced by the source *v(t)*. Since *v(t)* is produced by the active oscillating device, there will be subsequent change to the DC bias current of the active device. Therefore if the load impedance Z_L can be influenced by the RFID tag impedance, which contains the unique resonance signature of the tag, then this signature will manifest itself as a change in the DC bias current of the oscillator. In this letter a VCO is used, such that the impedance of the RFID tag can be measured over a wide frequency range. The VCO will change frequency as the frequency dependant parameter $Z_L(\omega)$varies. As parameter $Z_L(\omega)$ is a function of frequency this can lead to a change in bias current with frequency. However this change can be readily calibrated out, with no tag present, only allowing the change in bias current from the tag resonance signature to be measured.

Single VCO Chipless RFID Reader: The single VCO chipless RFID reader arrangement is shown in Fig. 2. The VCO output is connected to an antenna of suitable bandwidth for the VCO and the chipless RFID tag is placed in the near field of the antenna for detection. A ramp generator is connected to the tuning voltage of the VCO to allow the VCO frequency to be swept across the frequency range of the tag. The VCO DC supply is fed via a series resistor, allowing the VCO DC current to appear as a voltage which is made available to the decoder circuitry, in this case channel 1 of a digital storage oscilloscope.

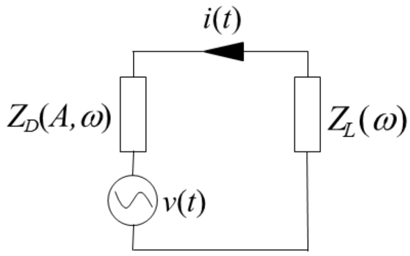


Fig. 1 *Simplified oscillator equivalent circuit*

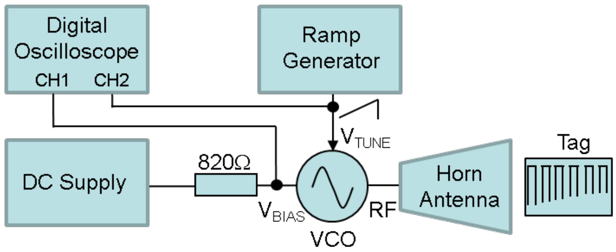


Fig. 2 *Single VCO Chipless RFID reader*

The VCO chosen was the Mini circuits ROS3000, this has a broad frequency range of 2-3.4 GHz, allowing it to be used with a variety of chipless RFID tags, and, to the best of our knowledge, is unbuffered. If you consider the equivalent circuit of Fig. 1, if a buffer amplifier was placed in the path of *i(t)* then any variation in the load impedance would not make any change to the active oscillating device, and no change in DC bias current would result. To prevent this, the VCO chosen had a high value of pullability, 13.5 MHz @12 dBr, indicating that small changes to the load impedance could provide reasonable change to the oscillating active device, and hence the DC bias current. Experimental measurement of tuning voltage versus frequency showed that the VCO also has a reasonably linear tuning range.

Regarding the choice of the chipless RFID tag, the tag from [1] was used. It was redesigned to offer a frequency range of 2.4 to 3.4 GHz with 10 resonances using U shaped resonators on an FR4 substrate (Fig. 3). Individual resonators can be readily shorted out by covering them with copper tape, to provide changes to the bit pattern of the tag, size (25x40mm).

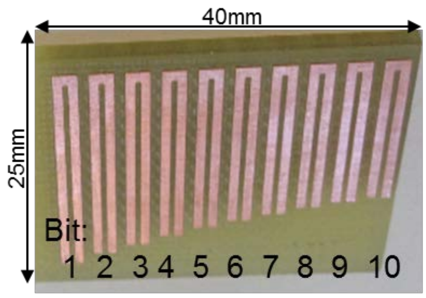


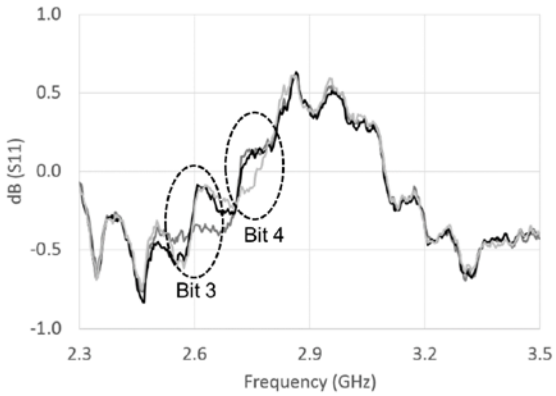
Fig. 3 *Chipless RFID Tag*

Experimental Results: The chipless RFID tag was first measured using an Agilent E8361A Performance Network Analyser (PNA). The PNA was setup provide a frequency sweep of 2.3-3.5 GHz, port power of -10dBm, and the IF bandwidth was reduced from its default setting of 35 KHz to 300 Hz, which was essential, otherwise the small changes in RFID tag resonance could not be distinguished from noise. Port 1 of the PNA was connected to a horn antenna (Sunol Sciences DRH-118, 1-18GHz). First the measurement was calibrated by measuring the S11 of the horn antenna in free space, and normalising the measured S11 to 0 dB. The chipless RFID tag was then placed across the near field of the antenna and the difference in the S11 from the free space calibration was obtained. The tag was mounted on expanded polystyrene directly across the aperture of the antenna (20cm from the feed point), to prevent any unwanted reflections from mounting structures. It had already been verified that the expanded polystyrene, with no RFID tag present, produced negligible change to the S11 free space result.

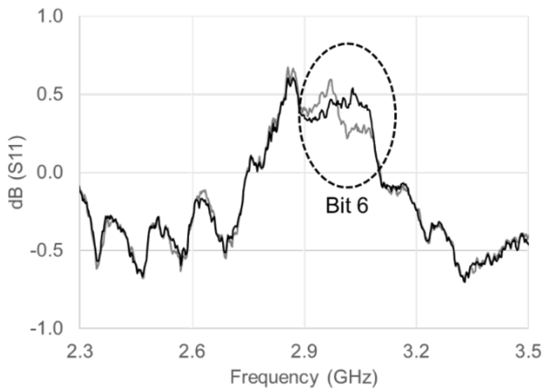
The results from the S11 measurements on the PNA are shown in Fig. 4, a-b. For each of these four measurements, one of the resonators on the tag was shorted using copper tape. The measurements were then compared with the tag with all resonators present. The frequency at which the difference in the S11 occurs, corresponds to the tag (or bit) that had been shorted out. Fig. 4 a-b clearly shows that the shorted resonators produce a difference in S11, of up to 0.3 dB, for the measured scenarios of shorting bits 3, 4 and 6.

The measurement was then carried out of the chipless RFID tag using the single VCO reader of Fig. 2. The antenna configuration was exactly the same as per the PNA measurement, except the antenna was now connected to the VCO output, Fig.2. The system was first calibrated in free space, by sweeping the VCO frequency with the ramp generator, and recording the DC bias voltage Vs tuning voltage on the digital storage oscilloscope (Agilent Infinium 54855). This trace was then normalised to 0 mV to provide the free space calibration. The ramp generator frequency used was 1 Hz, mainly for the reason that a higher ramp frequency would prevent changes in the DC bias voltage being detected, due to smoothing from the internal DC decoupling capacitors of the VCO. Faster sweep times would be possible if a custom designed VCO was used with minimal DC decoupling.

The results obtained from the single VCO reader are shown in Fig. 5a-b. The results clearly show that bits 3, 4 and 6 have been detected, producing a DC bias voltage change of up to 0.5 mV, compared to the tag with no shorted resonators. From these results it is seen that the single VCO detector is performing with a similar level of performance to the PNA measurement, despite it being significantly less complicated.

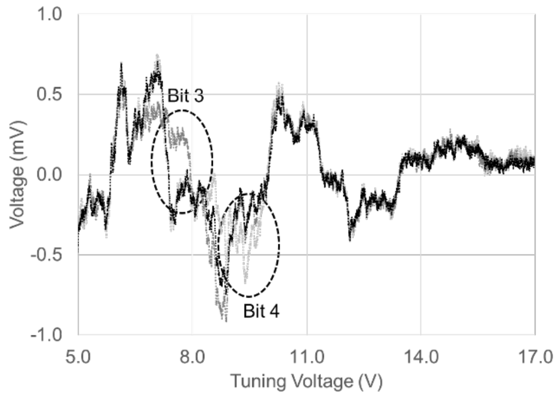


a



b

Fig. 4 *Chipless RFID tag Detection using PNA*
a Bits 3&4
b Bit 6



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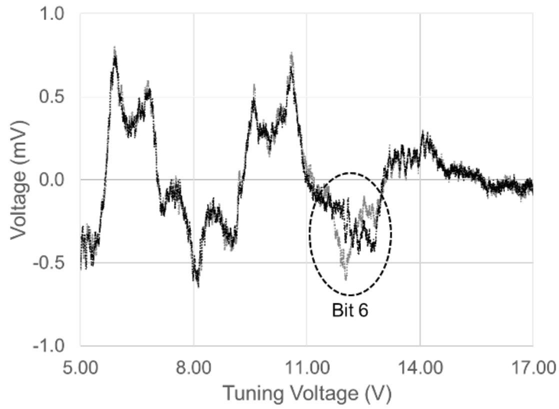

b

Fig. 5 *Chipless RFID tag Detection using Single VCO Reader*
a Bits 3&4
b Bit 6

Conclusion: This letter has shown how a significant reduction in complexity of a chipless RFID reader operating from 2.4-3.4 GHz can be achieved using just a single VCO. Experimental results showed that the change in resonance of an individual bit in a 10 bit resonant tag placed in the near field of the reader could be detected directly as a low frequency signal. The new reader shown in this letter performed with a level of performance similar to a vector network analyser, and was able to clearly show the changes in the resonator bits with a change of around 0.5 mV on the DC bias voltage. This reader could be easily incorporated with a low cost microcontroller to provide a very low cost, effective, chipless RFID reader.

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