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APPLICATION NOTE

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The Advantages of Using a Quadrature Digital Upconverter (QDUC) in Point-to-Point Microwave Transmit Systems

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INTRODUCTION

Direct conversion and super heterodyne transmitter architectures are commonly used in wireless systems. This application note briefly reviews the pros and cons of each approach (additional resources are listed in the References section) and also offers an architectural option (direct real IF) that is well suited for IF generation in the indoor unit (IDU) section of a microwave point-to-point radio.

DIRECT CONVERSION

A direct conversion transmitter is shown in Figure 1. This architecture is favored for its simplicity and low cost relative to the super heterodyne approach. The key architectural blocks include an AD9779 dual baseband digital-to-analog converter (DAC), associated reconstruction filters, an AD8349 or ADL537x analog quadrature modulator, band filter, and power amplifier (PA) circuitry. An RF PLL produces the local oscillator (LO) signal that drives the modulator.

The dual DAC outputs generate in-phase and quadrature (I/Q) components of a complex baseband signal resulting from modulation mapping, pulse shaping, and upsampling (via interpolation filters) to the DAC sample clock frequency. The DAC reconstruction filters are usually implemented with inexpensive discrete inductors and capacitors. Care must be taken to avoid introducing any group delay variation between the reconstruction filter because this introduces modulation distortion resulting in EVM degradation.

The filtered baseband I/Q signals along with the LO signal drive the corresponding I/Q and LO inputs of an analog quadrature modulator. The quadrature modulator produces a modulated RF waveform at a carrier frequency that is equal to the LO frequency. This modulated output signal is band filtered (to remove out-of-band spurs) and amplified by the PA circuitry.

A common problem associated with this approach is referred to as LO leakage: the presence of the LO signal within the modulated signal bandwidth. Since this distortion term is in-band, it cannot be filtered out. The origin of this error is related to parasitic coupling as well as mismatches in the dc components of the signals at the modulator inputs. This includes DAC offsets as well as input offset voltages associated with the analog quadrature modulator. It is possible to cancel this effect by applying a compensating offset signal from the DAC. For a robust solution, however, this correction signal must track errors due to temperature and supply voltage variations.

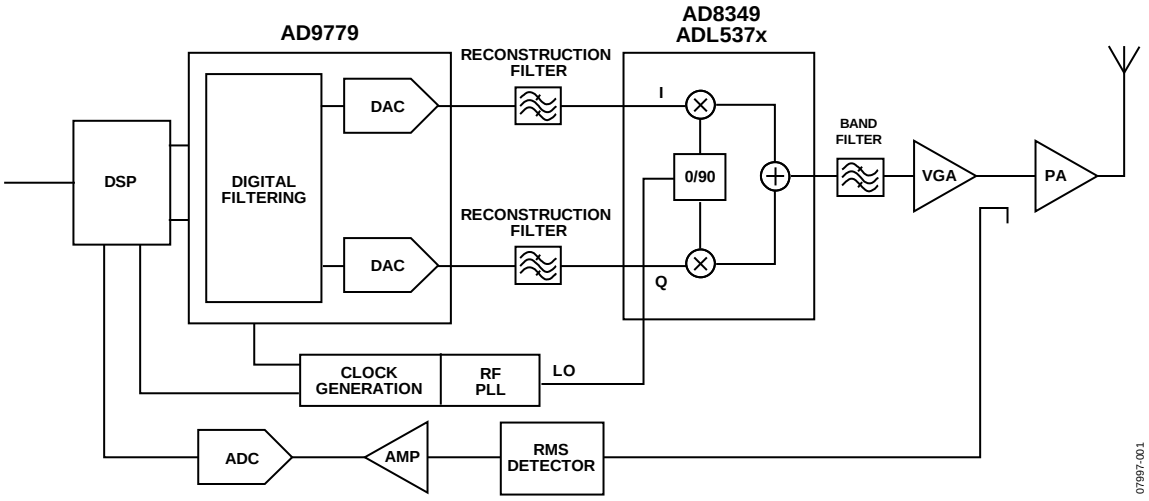

Figure 1. Block Diagram of Direct Conversion Tx Architecture

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Another problem encountered with this architecture relates to the impact of I/Q imbalance. Sources include DAC output power and/or reconstruction filter mismatches as well as phase and/or magnitude errors contributed by the analog quadrature modulator. It is possible to compensate for these errors by adding compensating amplitude and phase adjustments onto the DAC output signal. These compensating signals also need to track the error terms across supply voltage and temperature variations. Furthermore, the compensation algorithm introduces additional complexity into the linearization scheme.

The third key drawback of the direct conversion approach relates to a phenomenon called injection pulling of the LO by the output of the PA. This arises because the output frequency of the PA is the same as that of the LO, but contains other nearby frequencies associated with the modulation process. These frequencies couple back onto the LO as the PA output is modulated and effectively pulls the frequency slightly off the desired LO frequency, thereby contributing to EVM error.

Various isolation techniques can minimize this effect, such as shielding and best practice PCB layout. Another technique uses an offset VCO to produce a carrier frequency that is offset just enough from the LO frequency to prevent injection pulling. This technique obviously adds the cost of another VCO and the associated PLL circuitry.

Despite these drawbacks, the direct conversion approach is an increasingly popular option due to improvements in the performance characteristics of the analog quadrate modulator, enhanced techniques for using compensation signals from the DAC to cancel error terms, and its relative simplicity and competitive cost.

SUPER HETERODYNE

Figure 2 shows the super heterodyne architecture, which, like the direct conversion architecture, contains dual baseband DACs and their associated reconstruction filters. These operate in a manner similar to direct conversion, except that the analog quadrature modulator and first LO (IF LO) modulate the complex baseband signal onto a lower frequency IF carrier signal, rather than directly onto the final RF carrier signal. This improves the modulator dynamic performance relative to the direct conversion approach because the modulator operates at a lower frequency (IF instead of RF).

Typically, a surface acoustic wave (SAW) filter band limits the signal at the output of the IF stage, which effectively filters the undesired spurious signals at this point in the signal chain. A single mixer and RF LO then translate the IF signal up to the RF carrier frequency. Another band filter is needed at the RF output to reject the image produced by the mixing process as well as any RF LO leakage that might be present. Employing a high IF helps because it places the desired signal further from the LO leakage term, making the filtering task easier.

The super heterodyne approach has problems similar to the direct conversion approach due to the IF stage, which is susceptible to LO leakage and I/Q imbalance. The key disadvantage with this approach is the higher component count and associated cost.

The key advantages are the absence of LO injection and the removal of unwanted spurious content from the transmitted spectrum by the IF and RF band filters.

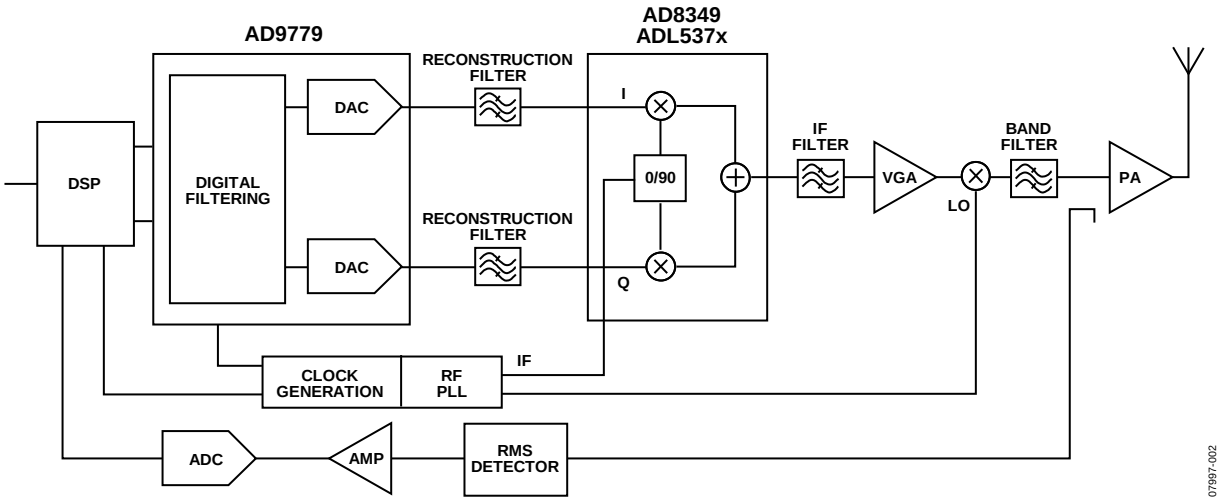

Figure 2. Block Diagram of Super Heterodyne Tx Architecture

DIRECT REAL IF

Figure 3 shows the direct real IF architecture. This implementation is similar to the super heterodyne approach shown in Figure 2, except that the IF signal comes from a quadrature digital upconverter (QDUC). Figure 4 shows an example of a QDUC (the AD9957) in block diagram form.

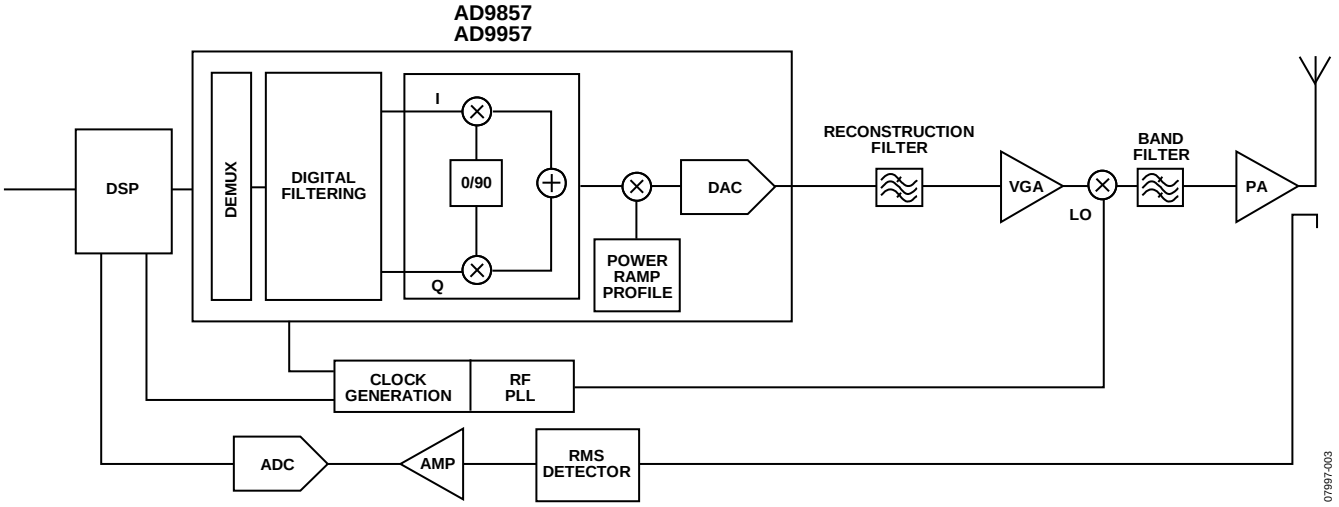

Figure 3. Block Diagram of Direct IF Tx Architecture

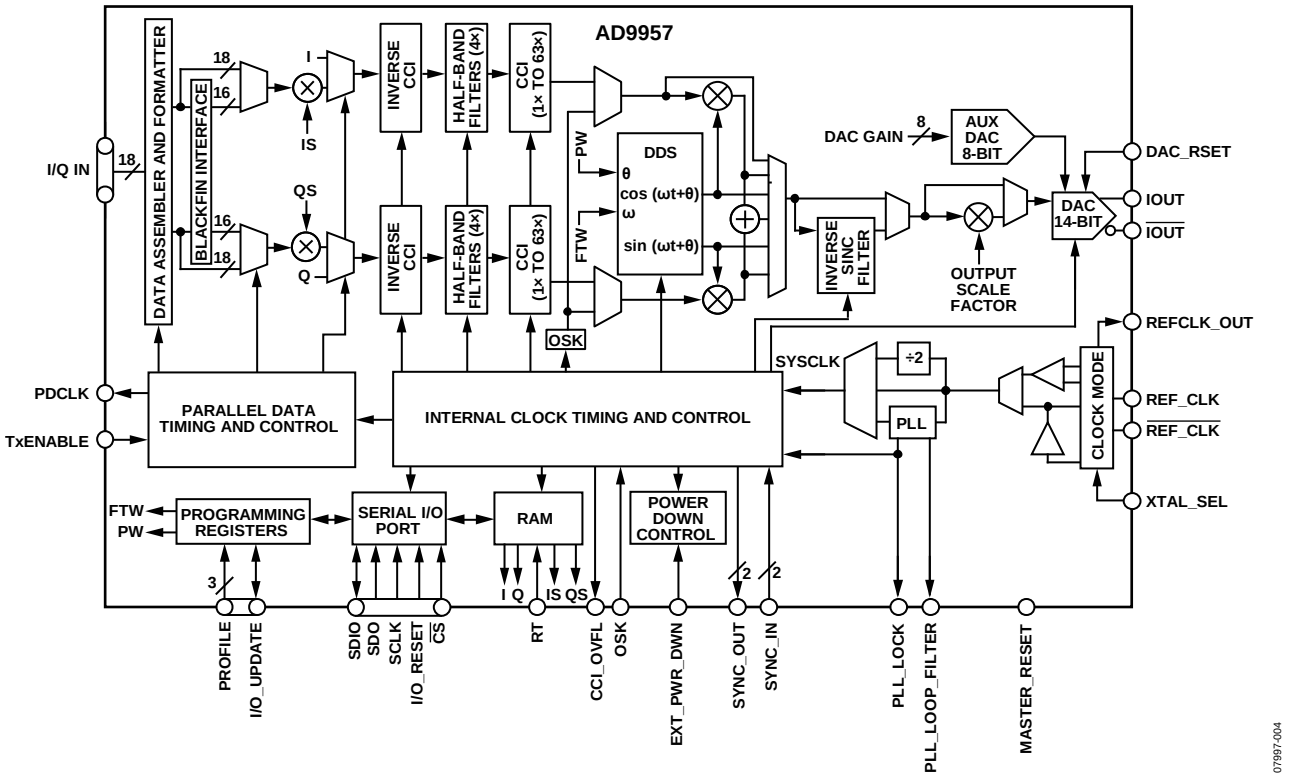

Figure 4. Detailed Block Diagram of AD9957 QDUC

A QDUC takes in the digital baseband I and Q data, which is modulation mapped and pulse shaped. In the case of the AD9957, I and Q data-words are delivered in time-interleaved fashion (I word, Q word, I word, and so on) at a rate of up to 250 megawords per second. This enables the AD9957 to upconvert very wide bandwidth signals, such as those required for point-to-point microwave systems. This digital baseband data is upsampled in the QDUC by a chain of half-band interpolation filters followed by a CCI filter. The upsampled digital baseband signal feeds a digital quadrature modulator. The LO signal for the digital modulator comes from a quadrature NCO with a 32-bit frequency tuning word.

The output of the digital modulator is a modulated digital carrier at the frequency set by the NCO. The digital modulator feeds an optional inverse sinc filter, which compensates for the sin(x)/x frequency response characteristic of the DAC. The inverse sinc filter provides gain flatness across the Nyquist bandwidth of the DAC, which is required for wideband modulated signals to preserve EVM performance. A digital amplitude scaling circuit at the DAC input provides digital gain control of the digital modulation signal. Note, however, that using digital scaling to attenuate the output signal causes a reduction in the dynamic range. The high speed DAC converts the digital IF signal to an analog IF signal. The DAC has a separate gain adjustment mechanism. It allows control of the peak DAC output current, which sets the RF power level at the DAC output. The AD9957 can support a system clock and DAC sampling rate of up to 1 GHz.

A reconstruction filter at the AD9957 output removes the Nyquist images associated with the DAC output. The filtered signal feeds a mixer for conversion up to the final RF carrier. The reconstruction filter can be implemented as a discrete low-pass filter, typically fifth to seventh order elliptical design. The cutoff frequency for these filters is typically set at 40% to 45% of the DAC sampling rate. The AD9957 can, therefore, generate IF signals approaching 400 MHz. A SAW filter is often substituted for a low-pass reconstruction filter with this architecture. As is the case with the super heterodyne, a high IF eases filtering of the RF image.

This architecture is well suited for microwave point-to-point systems because the final carrier frequencies for these systems can range from 6 GHz to 11 GHz for medium to long paths and up to 23 GHz for shorter paths. These carrier frequencies require an additional upconversion even for the currently realizable direct conversion approaches.

A key advantage of the direct real RF approach is that extremely accurate I and Q matching is achievable because the quadrature modulation function occurs completely within the digital domain. Similarly, due to the digital implementation, LO or carrier leakage at the IF stage is very low, about −75 dBc.

Another advantage of the direct real RF architecture is the extremely fine tuning resolution at the IF due to the NCO. This adds increased flexibility to transmitter frequency planning. Depending on the application, the actual RF channel tuning can be done by tuning the carrier at IF (via the NCO) as opposed to tuning the RF LO. This provides very fine frequency and phase control as well as extremely fast frequency hopping, if required.

Figure 5, Figure 6, and Figure 7 show measurements taken at the output of the AD9957, which include, respectively, a spectral plot of a 56 MHz wide 256-QAM signal centered at 350 MHz, the resulting constellation plot, and the accompanying modulation results (such as EVM). The EVM of only 0.9% is a measure of excellent I/Q matching. The constellation is well centered, indicating low I/Q offset and minimal LO leakage. A direct measure of LO leakage uses a single-sideband suppressed carrier (SSB-SC) signal as the input to the AD9957. The LO leakage measurement appears in the plot of Figure 8, which shows the SSB-SC spectrum centered at 350 MHz and LO leakage of −76 dBc.

In microwave point-to-point transmitters, the IDU typically generates an IF of about 350 MHz. This is connected to the outdoor unit via a cable that can be up to 100 feet in length. A high IF or RF signal in the gigahertz range, such as is attained from the direct conversion transmitter, can be used, but this requires a more expensive cable connection to the ODU to prevent excessive signal attenuation. The added cable cost can be significant, as much as three times the cost of the cable for the IF at 350 MHz. Direct IF generation via the AD9957 provides the benefits of excellent quadrature matching, low carrier leakage, and frequency flexibility with little additional hardware and minimal cost impact.

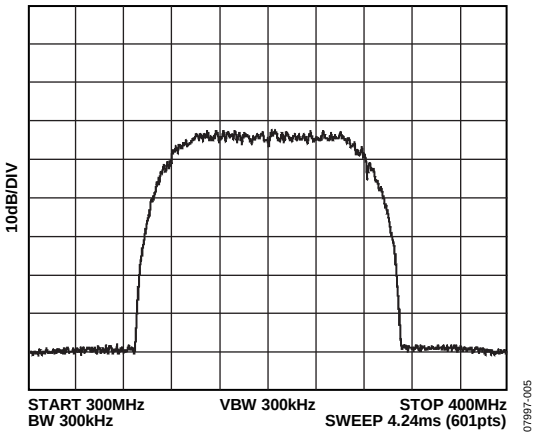

Figure 5. Spectrum for 256-QAM 56 MHz Bandwidth Signal

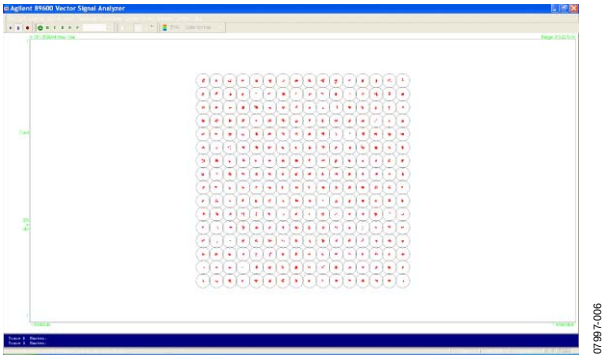

Figure 6. Constellation for 256-QAM 56 MHz Bandwidth Signal

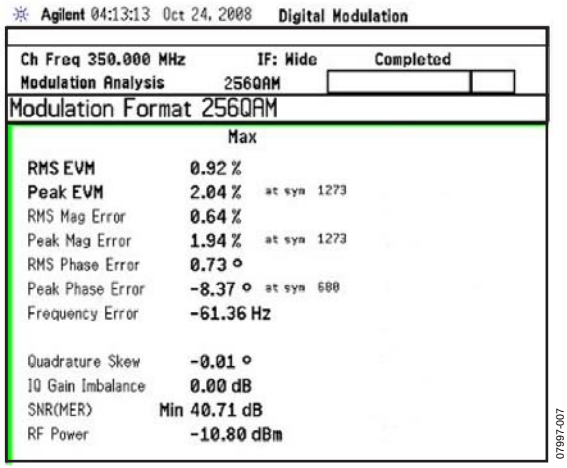

Figure 7. Measured Results 256-QAM 56 MHz Bandwidth Signal

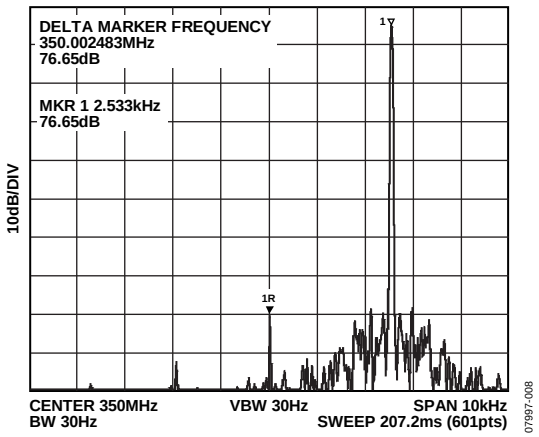

Figure 8. LO leakage in Single-Side Band Suppressed Carrier at 350 MHz

REFERENCES

For further information on the pros and cons of the direct conversion and super heterodyne architectures, refer to the technical articles listed below, available at www.analog.com.

DeSimone, Anthony and Eamon Nash. 2002. "Simplifying Direct-Conversion Tx Paths in Wireless Designs." *Comms Design*.

Gentile, Ken. 2007. "Digital Pulse-Shaping Filter Basics." Application Note AN-922. Analog Devices, Inc. (September).

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NOTES

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