A Microwave Communication Link with Self-Heterodyne Direct Down Conversion and System Predistortion

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Abstract — **A novel design of a microwave communications link operating at 5.8 GHz is presented based on self-heterodyne direct downconversion (SHDDC) and system predistortion. With the SHDDC scheme, the need of any local oscillators at the receive ends is eliminated, and the spectrum usage is minimized; however, the transmitter power efficiency is low, and there exists high mixer intermodulation levels in the receiver. To overcome these drawbacks, a system predistortion approach is proposed. A two-tone measurement is performed to validate the idea. It shows 6.83 dBc overall improvement in the signal-to-intermodulation ratio (SIMR) by applying a simple second-order predistortion technique. Further, successful transmission of a digitally modulated signal is also demonstrated.**

I. Introduction

Current microwave data transmission predominately utilizes the super-heterodyne scheme, in which a devoted local oscillator (LO) is required at the receiver end to pump the mixer and downconvert the RF signal. The LO power is usually much greater than the RF signal power, thus minimizing the distortion caused by the self-product terms of the RF signal in the mixer output. One alternative to the super-heterodyne method is the self-heterodyne scheme [1]. In this scheme, the transmitter sends out the local carrier as well as the modulated RF signal. The received signal is demodulated by passing it through a self-mixer. The self-heterodyne scheme significantly reduces the circuit complexity at the receiver, eliminating the need to supply a local oscillator circuit and the related carrier recovery circuit. Such a system is especially suited for broadcasting applications where the number of receive terminals is large and the size and complexity of each terminal is limited. This has been applied in millimeter wave communication systems [1] where the implementation of a local oscillator with low phase noise is technically difficult.

One drawback of the self-heterodyne system is that extra intermodulation distortion is introduced. Due to the limited carrier power received, the self-product terms of RF signal can no longer be neglected when compared to the IF output. One has to compromise between the transmitter power efficiency and the intermodulation level of the mixer output. One approach to overcome this problem is to carefully choose an IF frequency which is much higher than the signal bandwidth, allowing the intermodulation term to be filtered out. However, this approach has low spectrum efficiency and requires extra IF demodulators.

In this paper, a self-heterodyne direct down conversion (SHDDC) microwave communication link is proposed with the system predistortion technique. The essential idea of system predistortion is to predistort the baseband signal in the transmitter to compensate the intermodulation at the receiver mixer output caused by the proximity of the LO and RF power levels. Hence, the simplicity of the self-heterodyne scheme and the high spectrum efficiency of the direct down conversion receiver are both maintained.

This paper is organized as follows. In section II, the system predistortion concepts and the basic operation principles are introduced based on nonlinear power series analysis. In section III, a testbed with 5.8 GHz carrier frequency is set up, measured results for a two-tone signal are found to validate the proposed idea, and successful transmission of digital data modulated in 4-ary amplitude-shift keying (ASK) format [2] is demonstrated.

II. SHDDC System Overview

A. Nonlinear System Analysis

Theoretical validity of the SHDDC system is accomplished by applying power series nonlinear circuit analysis [3]. Fig. 1 shows the block diagram of the communications system. For a general nonlinear circuit, the excitation can be expressed as:

$$v_i(t) = \frac{1}{2} \sum_{\substack{q=-Q \\ q \neq 0}}^{Q} V_q e^{j\omega_q t} \qquad (1)$$

The resulting power series expression for the circuit output is:

$$v_o(t) = \sum_{n=1}^{N} a_n \left[\frac{1}{2} \sum_{q=-Q}^{Q} V_q H(\omega_q) e^{j\omega_q t} \right]^n \qquad (2)$$

In (1) and (2), $V_{-q}=V_q^*$, $\omega_{-q}=-\omega_q$, and $H(\omega_{-q})=H^*(\omega_q)$. Assuming for simplicity a memoryless, non-dispersive propagation channel such that $H(\omega_q)=1$ for all q, the output expression simplifies to:

$$v_o(t) = \sum_{n=1}^{N} a_n \left[v_i(t) \right]^n \qquad (3)$$

Letting the system excitation $s_i(t)=v_i(t)$ and ignoring the amplifiers before the transmit antenna and after the receive antenna, the expression at the input of the self-mixer is:

$$s_i'(t) = \left[A s_i^2(t) + B s_i(t) \right] s_{LO}(t) + C s_{LO}(t) \qquad (4)$$

Utilizing the transfer function assumption of before, the resulting power series expression for the final output of the system is:

$$s_o(t) = \sum_{n=1}^{N} a_n \left[s_i'(t) \right]^n \qquad (5)$$

Expanding (5) with N=2 yields:

$$\begin{aligned} s_o(t) = s_{LO}(t) \times \left[a_1 A s_i^2(t) + a_1 B s_i(t) + a_1 C \right] + \\ s_{LO}^2(t) \times \begin{bmatrix} a_2 A^2 s_i^4(t) + a_2 2AB s_i^3(t) + \\ a_2 B^2 s_i^2(t) + a_2 2AC s_i^2(t) + \\ a_2 2BC s_i(t) + a_2 C^2 \end{bmatrix} \end{aligned} \qquad (6)$$

The final baseband components are embedded in the $s^2_{LO}(t)$ term of (6). One now recognizes that cancellation of 2nd order terms occurs when:

$$2AC = -B^2 \qquad (7)$$

The 3rd and 4th order terms are less significant with regard to final intermodulation distortion. This development shows that 2nd order system predistortion is validated theoretically.

B. System Operation

Second order predistortion is performed via Agilent's HP34811A Benchlink software application. This software interfaces conveniently with the HP33120A arbitrary waveform generator used during measurement. In general, the predistortion coefficients A and B are complex. For this paper, scalar predistortion is examined to verify the validity of the system concept. Further, only A is varied during measurement; B is held constant and made equal to one. The case in which B=1 and A=0 represents the reference case in which there is no predistortion. Note that C is constant and positive during operation. From (7), one realizes that to achieve cancellation, scalar manipulation of A requires A to be negative.

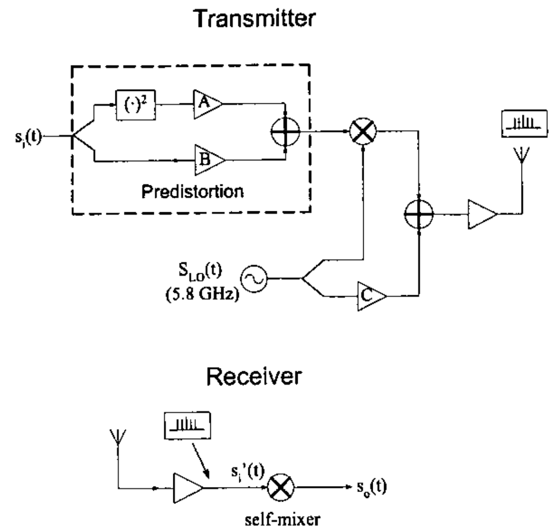

Fig. 1. Transmitter and receiver block diagrams.

The baseband signal is upconverted via analog amplitude modulation. Sufficient LO leakage exists to produce the desired carrier in the self-heterodyne scheme. After power amplification, the RF signal is transmitted and received using quasi-yagi antennas [4]. These antennas are characterized by endfire radiation, broad operating bandwidth, and moderate gain.

Direct downconversion is achieved with an active self-mixer, which is shown in Fig. 2. Desired downconversion is accomplished by adding open stubs at the self-mixer's output that effectively look like short circuits at the first two harmonics of the carrier frequency, namely 5.8 GHz and 11.6 GHz. This requires one stub to be $\lambda/4$ long (5.8 GHz short) and the other to be $\lambda/8$ in length (11.6 GHz short). A circuit optimizer (Agilent's Advanced Design System 2001) is used to find an acceptable input matching circuit. The circuit uses NEC's NE76038 as the active device, and fabrication is done on RT/Duroid 5880 with dielectric constant of 2.33 and 31 mil substrate thickness.

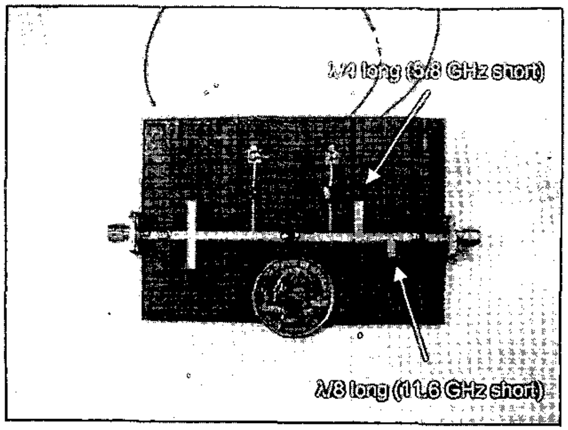

Fig. 2. Self-mixer circuit.

III. MEASUREMENT SETUP AND RESULTS

A. Experimental Setup

Fig. 3 shows the measurement setup for the predistortion system. Agilent's HP33120A arbitrary waveform generator and HP34811A Benchlink software package are consolidated to generate the desired baseband waveform. Agilent's HP8340A synthesized sweeper generates the 5.8 GHz oscillator to pump Mini-Circuits' SKY-60MH 4-diode bridge mixer. This upconverter yields sufficient LO leakage to generate the local carrier required with the self-heterodyne scheme. Before wireless transmission, Agilent's HP8349B microwave amplifier offering high output power (~20dBm) is used to boost the RF signal. The transmission distance between transmit and receive antennas is about 8 cm, which is greater than the far-field distance associated with the antennas being used. Because the microwave amplifier provides high output power and the transmission distance is relatively short, a gain block preceding the receiver self-mixer is not necessary.

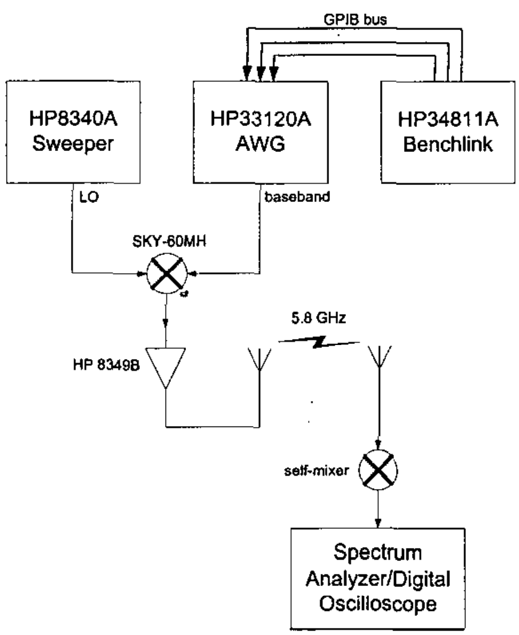

Fig. 3. Predistortion system measurement setup.

B. Two-Tone Measurement

In this section, the effect of applying various values of the predistortion coefficient A to a two-tone signal with 2 MHz and 3 MHz components is examined, thus validating the system predistortion idea. This kind of signal represents a simplified form of a realistic digital signal, extracting only two of the many frequency components present in a digital signal. The coefficient A provides second order predistortion and has a negative value. It is important in the SHDDC scheme to consider the carrier power relative to the RF power. For acceptable transmission efficiency, the carrier power should approximately equal the total RF power. Measured results show carrier power of -3.17 dBm and RF power of -8.25 dBm just preceding the receiver self-mixer stage. Fig. 4 shows the signal-to-intermodulation ratio (SIMR) at the system output for various values of A. SIMR is defined as the power ratio of the final baseband signal to the highest intermodulation tone. The highest intermodulation invariably occurs at 1 MHz. The normalized parameter in the measurement is the final signal power level at the two original tones (2,3 MHz). This power level is determined to be -3.75 dBm. The SIMR for the reference case (A=0) is 5.17 dBc. From Fig. 4, using A=-1 yields the best SIMR result. This optimized SIMR is 12.00 dBc, which is 6.83 dBc higher than the reference SIMR.

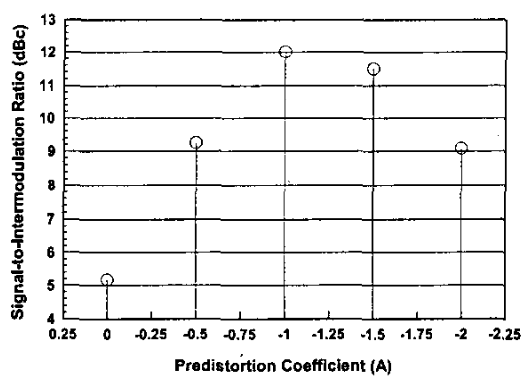

Fig. 4. SIMR ratio for various A.

Fig. 5 shows the corresponding output baseband spectrum of the system using the optimized A value. The largest intermodulation components are of 2nd order, with the 1 MHz term contributing the most intermodulation. One can further suppress higher frequency components with implementation of a low-pass filter.

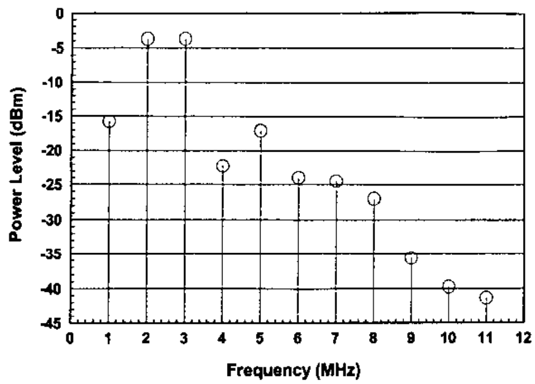

Fig. 5. Baseband power spectrum at system output using optimized predistortion coefficient A=-1.

C. 4-ary ASK Measurement

After validating the system predistortion idea via two-tone measurement analysis, successful recovery of a digital signal should be demonstrated. Digital data with 2 Mb/s data rate modulated in 4-ary amplitude-shift keying (ASK) format is considered for this measurement. Fig. 6 shows the original undistorted digital signal, the demodulated signal without predistortion, and the demodulated signal with predistortion. From Fig. 6(b), one can observe the errors in the signal recovery without using predistortion. Conversely, Fig. 6(c) shows successful demodulation of the original digital signal utilizing predistortion.

IV. Conclusion

A novel design of a microwave communications link operating at 5.8 GHz using self-heterodyne direct downconversion (SHDDC) and system predistortion is proposed. Implementation of a SHDDC scheme removes the necessity of local oscillators in the receiver, thus considerably simplifying the receiver circuit complexity. This is desirable for applications with many receiving terminals with restrictions on circuit size and complexity. Because SHDDC inherently has high intermodulation levels, system predistortion is proposed to lessen such effects. Two-tone measurement is executed to validate the proposed system concept, and successful demodulation of a 4-ary ASK signal is demonstrated.

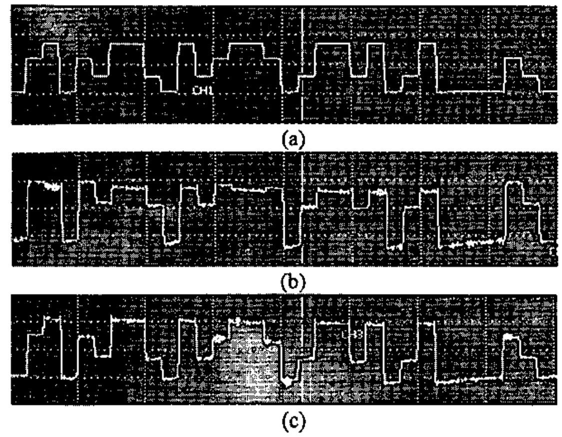

Fig. 6. (a) Original 2 Mb/s 4-ary ASK signal, (b) demodulated signal without predistortion, (c) demodulated signal with predistortion.

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