A BIPOLAR UPCONVERSION MODULATION LOOP TRANSMITTER FOR DUAL-BAND MOBILE COMMUNICATIONS

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ABSTRACT

This paper presents design considerations and measurement results of an upconversion modulation loop transmitter IC (PMB 2255) implemented in Siemens 26GHz Si bipolar technology B6HF. The device consists of a vector modulator, a downconversion mixer, a modulation phase-locked loop (PLL) and a three-wire programming bus. Besides power-down and standby modes, added values of switchable filter cutoff frequency and precharge function are also realized for dual- and multi-band digital mobile communication systems such as GSM900, GSM1800 and GSM1900. Based on measurements the device provides an excellent performance in designed intermediate frequency range from 300 to 550MHz with supply voltage from 2.7 to 4.5V, ambient temperature from -30 to 85°C, and local and RF frequencies up to 2.0GHz.

INTRODUCTION

In RF transmitters for mobile communication systems, where RF carriers are usually needed to be modulated using phase and frequency modulations, a very low level of phase noise and disturbing signals in transmitted signals is required [1]-[3]. For example, the transmitters should provide a maximum noise level of -162dBc/Hz at 20MHz offset from the carrier based on the GSM regulation. In a conventional direct modulation transmitter, the RF carrier generated by a PLL frequency synthesiser is modulated directly within a vector modulator using single-sideband modulation. As phase noise of the vector modulator is typically –130dBc/Hz, highly selective filtering such as ceramic duplexer filter is needed between modulator output and antenna. In an indirect modulation transmitter, the modulation is firstly performed at an intermediate frequency and then translated to the final transmission frequency by an upconversion mixer. Because the modulator noise is filtered at a lower frequency, overall filter cost could be lower than one in the direct modulation transmitter, depending on mixer noise performance and image rejection requirement.

This paper describes a transmitter IC using an upconversion modulation loop [4] for dual-band digital mobile communications, which was implemented in Siemens 26GHz Si bipolar technology. This transmitter IC is shown to lower filter requirement, system cost and current consumption, in contrast to the transmitters using conventional configurations.

DESIGN CONSIDERATION

In the upconversion modulation loop transmitter (UML-TX), as shown in Fig. 1, where the transmitter voltage-controlled oscillator (TX-VCO), low-pass filter (LPF), band-pass filter (BPF) and loop filter (LF) are external components, a vector modulator and a downconversion mixer (loop mixer) are inserted in the feedback path of the PLL. The phase/frequency detector (PFD) compares divided signals from the N- and R-counters whose divide ratios can be programmed from 1 to 8, and its outputs *Up* and *Dn* will control the current source and current sink of the charge pump, respectively. The charge pump current can be programmed at *Icp*=0.5, 1.0, 2.0 and 4.0mA, which can be used to compensate frequency gain of the TX-VCO in the loop, especially for dual-band applications. The charge pump can be connected with a separate supply voltage higher than supply voltage for other functional blocks. A high PFD frequency over 100MHz is desirable for a low divide ratio of the counters, and consequently, the phase noise and harmonic spurious related to the PFD frequency will be decreased.

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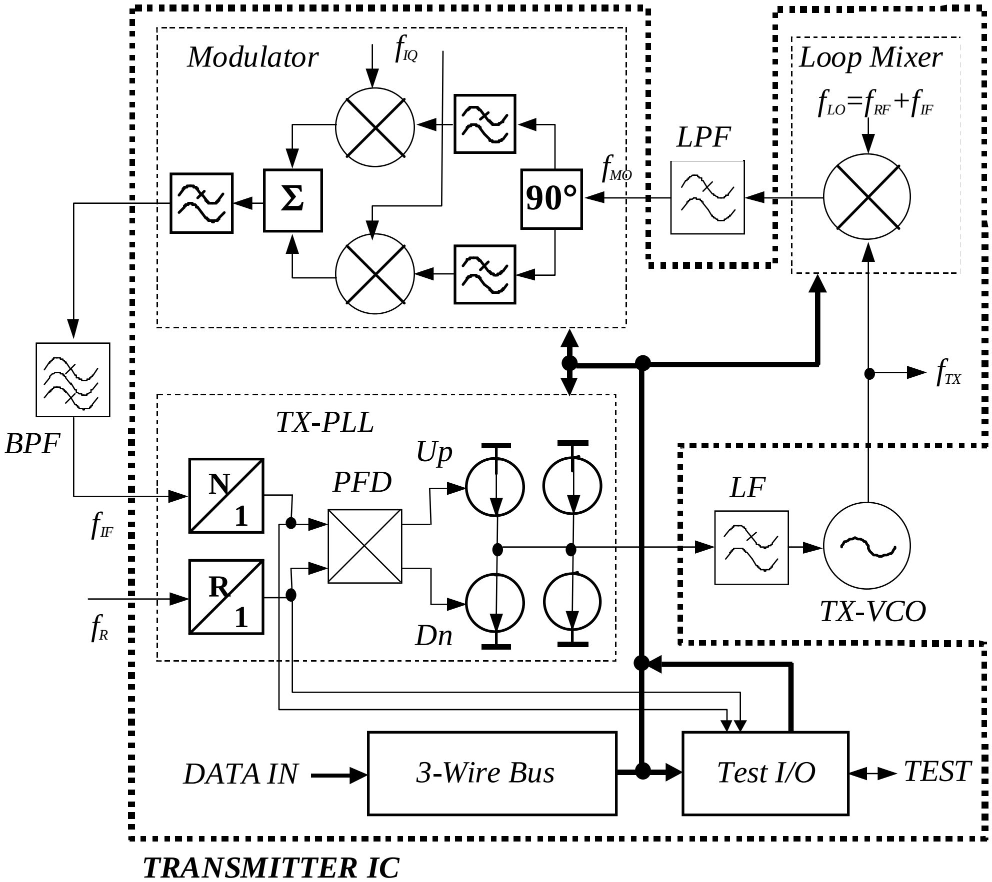

Fig. 1: Block diagram of the upconversion modulation loop transmitter (UML-TX)

The transmitter output signal f_{TX} will be downconverted into an intermediate frequency f_{IF} by the loop mixer and the modulator. The mixer local frequency, which can be generated by a RF frequency synthesiser, is $f_{LO}=f_{RF}\pm f_{IF}$, depending on frequencies at the mixer inputs. Between the mixer output and the modulator input a low-pass filter is required in order to suppress effectively unwanted high-sideband and other sideband spurious produced due to the frequency downconversion in the mixer. The use of the loop mixer allows fine frequency increments (channel spacings) in the modulation loop and it reduces the divide ratio of the N-counter. This results in a fast lock-in and low phase noise level of the modulation loop because a large loop bandwidth can be used. The modulated IF signal will be filtered by a band-pass filter to suppress unwanted frequency products and fed to the input of the N-counter. For unterstanding operation principle of the UML-TX, it is assumed that there is a single-sideband modulation applied to the vector modulator. The modulation loop forces the TX-VCO to shift its output frequency f_{TX} to $f_{RF}+f_{IQ}$ for a high-sideband modulation or to $f_{RF}-f_{IQ}$ for a low-sideband modulation to cancel the frequency difference introduced by the modulation frequency f_{IQ} in the PLL. Hence, the input signal of the N-counter has a constant frequency after the modulation loop is locked in. If the vector modulator performs additional phase modulation, such as GMSK modulated signals applied at the I- and Q-inputs for GSM mobile phone, the modulation loop modulates the output signal phase of the TX-VCO in such a way as to cancel the phase modulation induced in the modulator, so that the loop has a constant frequency at the modulator output and a nearly zero phase difference between the two inputs of the PFD. The reference frequency f_R at the input of the R-counter can be generated by an oscillator or a PLL frequency synthesiser, for example an IF frequency synthesiser. Because the modulator is in the loop, this configuration enables different divide ratios of the programmable N- and R-counters to be used, and as a result, allows more flexibility in frequency plans of the receiver and transmitter systems.

The most important advantage of the transmitter configuration is that the high-frequency noise in the signal path up to the TX-VCO input is strongly attenuated by the loop, so that the wideband phase noise of the transmitted signal is determined by the TX-VCO, but not by the modulator or the loop mixer. The loop filter LF of the TX-PLL can be realized by simple RC structure, and LC circuits can be used for the band-pass and low-pass filters at the modulator and mixer outputs. Comparing to conventional direct and indirect modulation transmitters, this configuration relaxes filter requirement, and thus, reduces system cost potentially. Moreover, as insertion loss of the duplexer filter, which is required between power amplifier and antenna in a conventional transmitter, is eliminated and output level of the power amplifier can be lowered. Therefore, low current consumption can be achieved in the upconversion modulation loop transmitter system.

This device can be programmed via wire bus and/or hardware pins into different power-down and standby modes. Moreover, two additional functions, switchable cutoff frequency of low-pass filters integrated in the modulator and precharge function, are implemented for dual- and multi-band digital mobile communications. The harmonic frequency products can be coupled into the TX-PLL such as the input of the N-counter due to substrate and package parasitic couplings, and the coupled signals can be mixed down into the modulation frequency band because of nonlinear circuit behaviour in the TX-PLL. This can result in an increased unwanted frequency products such as 3rd- and 5th-order intermodulation products in the modulation frequency band. Although the external band-pass filter is employed, the harmonic products induced by the parasitic couplings in the device cannot be attenuated by the external filter. As shown in Fig. 1, therefore, internal 2nd-order low-pass filters are integrated in the modulator, and they are designed to be switchable between low and high cutoff frequencies in order to effectively suppress the harmonic products for the specified IF frequency range. The low and high cutoff frequencies can be switched via the bus for applications between two IF ranges from 300 to 400MHz and from 400 to 550MHz. As shown in Fig. 1, the precharge function is realized by a current source and sink which are connected parallel to the normal charge pump. In standby mode of the device, where the bus is powered up and ready to receive new programming data and other functional blocks are powered down, the precharge function is activated. If the current source is switched on, the loop filter capacitors are charged and the tuning voltage *Vcp* at the charge pump output will become a high level that is lower than supply voltage, otherwise, the capacitors are discharged and a low tuning voltage *Vcp* can be reached which is higher than ground level. The high and low tuning voltages will determine high and low starting frequencies of the TX-VCO after powered up. In dual-band systems such as GSM900/1800 or GSM900/1900, the LO and TX frequencies f_{LO} and f_{TX} are usually so selected that the frequency f_{LO} is higher than f_{TX} for one band and lower than f_{TX} for another band. Due to input sensitivity roll-off of the N-counter and the modulator and also increased attenuation of the filters at high frequencies, it can be difficult for the modulation loop to be locked in, because the output frequency of the loop mixer can start at the maximum value. Using the precharge function, it is guaranteed that the mixer begins to provide the minimum frequency at its output after the modulation loop is activated.

MEASUREMENT RESULTS

The device was implemented in the Siemens 26GHz Si bipolar technology B6HF [5] and it is assembled in a P-TSSOP-28 package. The device was measured in supply voltage range from 2.7 to 4.5V and ambient temperature from –30 and 90°C, and the charge pump can operate with a higher supply voltage up to 5.5V. It is shown that the device is fully functional and measured DC/AC characteristic parameters are within the specified limits. Table 1 gives a comparison between the measured and specified key parameters for the device. The device has also been applied successfully in a dual-band GSM900/1800 transmitter system.

CONCLUSION

The upconversion modulation loop transmitter IC is implemented in Siemens high-frequency bipolar technology B6HF. This device has different operation, power-down and standby modes which are programmable via 3-wire bus and hardware pins. Switchable cutoff frequency of the internal modulator filters and precharge function are also realized for dual- and multi-band digital mobile communication systems such as GSM900, GSM1800 and GSM1900. Comparing to conventional direct and indirect modulation transmitters, where the high-frequency noise from the modulator and mixer has to be attenuated by highly selective filters, this transmitter configuration relaxes filter requirement, and as a result, system cost and current consumption can be reduced potentially.

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Table 1: Comparison between measured and specified key parameters

DC/AC Parameters	**Measurement**	**Specification**	**Unit**
Supply voltage	2.7 to 4.5	2.7 to 4.5	
Supply voltage for charge pump	2.7 to 5.5	2.7 to 5.5	V
Ambient temperature	-30 to 90	-30 to 85	°C
Total supply current: at power down at standby at Icp=0.5mA at Icp=4.0mA	<0.01 0.87 48.3 65.9	<0.01 0.9 51.0 67.0	mA
IF frequency: locked-in not locked-in	300 to 550 100 to 650	300 to 550 300 to 650	MHz
Modulator input sensitivity	<-25.0	<-18.0	dBm
Modulator AC output current	0.98	1.0	mA_{rms}
Modulator carrier suppression	>39.0	32.0	dBc
Modulator single-sideband suppression	>38.0	35.0	dBc
Modulator intermodulation suppression (*IM3*)	>65.0	52.0	dBc
Modulator harmonic suppression (*H3)* at LIF (300-400MHz) at HIF (400-550MHz)	 >36.0 >36.0	 17.0 32.0	dBc
Modulator phase noise at 400kHz offset	-123.5	-120.0	dBc/Hz
Mixer input frequencies	800 to 2000	800 to 2000	MHz
Mixer output power at 50Ω	-10.2	-10.0	dBm
Mixer carrier suppression	30.0	20.0	dBc
Mixer input –1dB compression point	-13.2	13.0	dBm
Mixer phase noise at 400kHz offset	126.0	120.0	dBc/Hz
Counter input frequency	100 to 650	100 to 650	MHz
Counter input sensitivity	<-25.0	<-18.0	dBm
PFD input frequency	up to 180	up to 150	MHz
Charge pump source and sink currents	0.51 1.06 2.08 4.12	0.5 1.0 2.0 4.0	mA
Precharge source and sink currents	94.0	100.0	µA
Precharge output voltage: with source current with sink current	 Vcc-0.2 0.1	 Vcc-0.4 0.2	V