Application Report

SNWA002A–April 2005–Revised April 2013

AN-1375 Linear-In-dB RF Power Detector in W-CDMA User Equipment

ABSTRACT

Since most of the deployed W-CDMA networks use FDD mode only and the W-CDMA FDD has fast closed-loop power control in both uplink and downlink, hardware implementation for RF power detection in downlink from user equipment to base station is needed in order to meet the required air interface standard. This application report suggests application subsystem circuits for use in closed-loop power control in a handset or other user equipment.

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1 Introduction

Since 1997, Wideband Code Division Multiple Access technology has been adopted as the third generation cellular phone standard by 3GPP in Europe, China and Japan. W-CDMA employs Direct-Sequence Code Division Multiple Access (DS_CDMA) with a modulation chip rate of 3.84 Mcps. Quadrature Phase Shift Keying (QPSK) Modulation scheme is used in the downlink so that the User Equipment (UE) can possibly transfer a 2 × 3.84 = 7.68 Mbps raw data. In High Speed Data Downlink Packet Access (HSDPA) mode, 16 Quadrature Amplitude Modulation (QAM) scheme will be used and it leads to 4 × 3.84 = 15.36 Mbps raw data rate in a good radio condition. Either scheme is still limited to a RF carrier bandwidth of about 5 MHz as seen in Figure 1.

The W-CDMA standard has two modes: Frequency Division Duplex (FDD) and Time Division Duplex (TDD). Most of the deployed W-CDMA networks in the world use FDD mode as duplex technique. The TDD mode was added into the W-CDMA standard because some of the allocated spectrums in some countries were not symmetric for uplink and downlink. The advantage of TDD mode over FDD mode is the ease of power control. In the TDD mode, both the uplink and downlink transmissions use the same frequency; thus, the fast fading characteristics are very similar in both links. Henceforth the TDD transmission can do a better prediction on the fast fading conditions of the assigned frequency channel if the prediction or estimation is based on the received signals from the corresponding base station. This means that closed-loop power control is no longer needed, but only open loop will be sufficient in TDD mode in theory.

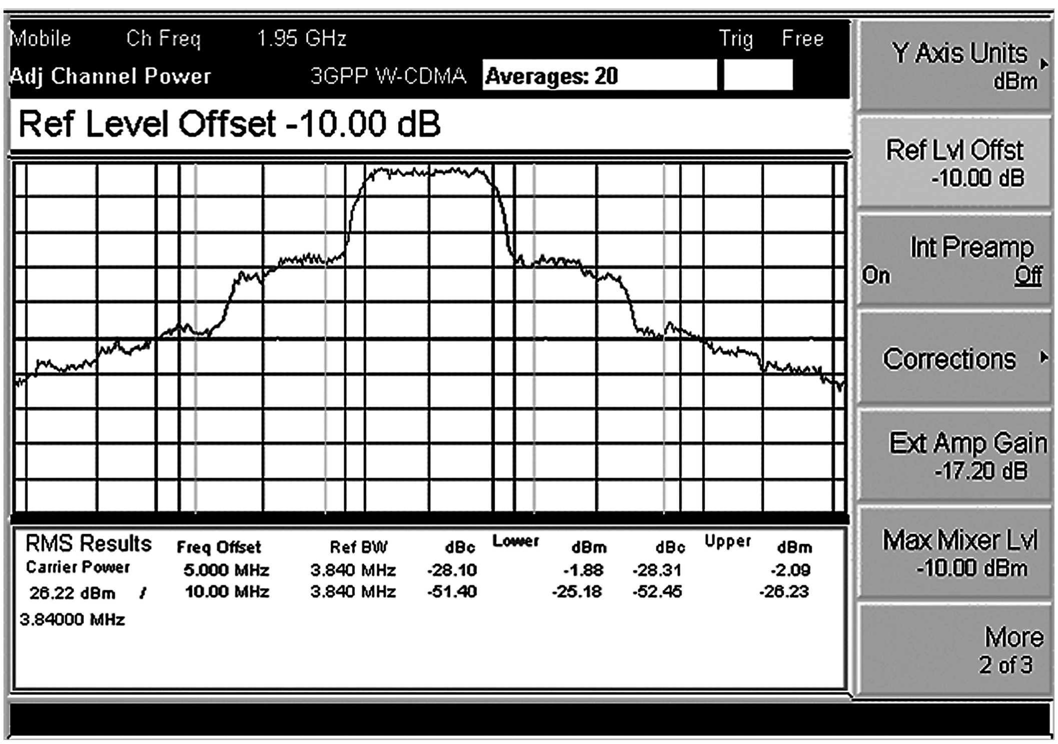

Figure 1. Typical W-CDMA Spectrum

2 Frequency Planning in FDD Mode W-CDMA

Table 1 shows frequency bands allocated in different regions of the world andTable 2 shows the transmit power requirements for each User Equipment (UE). Mobile handset is a kind of User Equipment as defined in W-CDMA document. Other popular UE is PCMCIA modem card for notebook personal computer or wireless PDA.

Table 1. FDD Mode W-CDMA Frequency Band Allocation

Region	Transmission Link	Frequency	Notes
1	Uplink	1920 to 1980 MHz	Africa, Europe, and North Asia
	Downlink	2110 to 2170 MHz	
2	Uplink	1850 to 1910 MHz	North and South America
	Downlink	1930 to 1990 MHz	
3	Uplink	1710 to 1785 MHz	Southern Asia, Australia, and Pacific Islands
	Downlink	1805 to 1880 MHz	

Table 2. User Equipment Power Classes

Power Class	Maximum User Equipment's Output Power
1	+33 dBm
2	+27 dBm
3	+24 dBm
4	+21 dBm

Most of the handsets sold in the market today are power-class-2 user equipment and the maximum RF power output of a typical W-CDMA power amplifier in the market is about +29 dBm. User Equipment with HSDPA feature is proliferating.

3 Hardware Implementation of Fast Closed-Loop Power Control in W-CDMA User Equipment

In summary, the FDD mode W-CDMA air interface requires a UE to adjust transmit power level in a ±1.0 dB per step every 667 µsec with accuracy of ±0.5 dB. Anyway circuit design for RF power control should meet this specification.

4 Generic Automatic Gain Control in Linear Amplification

Figure 2 shows a generic output power control for linear signal amplification in a handheld device. Since high linearity is required for W-CDMA signal because of the high crest factor and zero crossing nature of QPSK and 16QAM signal, the output power amplifier is usually biased at fixed gain with a fixed supply voltage V_{CC} directly from the battery's output. As the amplification gain is fixed, the output power level has to be adjusted by changing the input signal level of the power amplifier. This could be accomplished by adding a gain control driver amplifier at the input of PA. Currently, this Automatic Gain Control (AGC) Amplifier is usually integrated in the RF transmitter chip in a W-CDMA chipset.

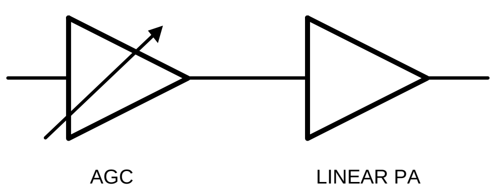

Figure 2. Generic RF Power Control Diagram

5 Transmit Radio Architecture with LMV228

Figure 3 is the recommended circuit diagram for LMV228 in a W-CDMA handset. A directional coupler is used to couple RF energy from the PA's output to input of LMV228. The maximum input RF power for LMV228 is +15 dBm in a 50Ω system. This level is set by the input ESD protection diodes inside the chip. A dc blocking capacitor is put between the directional coupler and LMV228 for blocking the dc enable high-level voltage to the 50Ω termination of coupler. Without this dc blocking capacitor, dc current will flow through the 50Ω resistor and then consume unnecessary power.

As of today, most of the W-CDMA power amplifiers in the market have a maximum linear RF output at about +29 dBm. With a 20 dB coupler, input RF power to LMV228 will be 29 – 20 = 9 dBm. Depending on the transmission channel being used in the UE, the instantaneous input RF power to LMV228 should take into the consideration of crest factor of the modulation scheme.

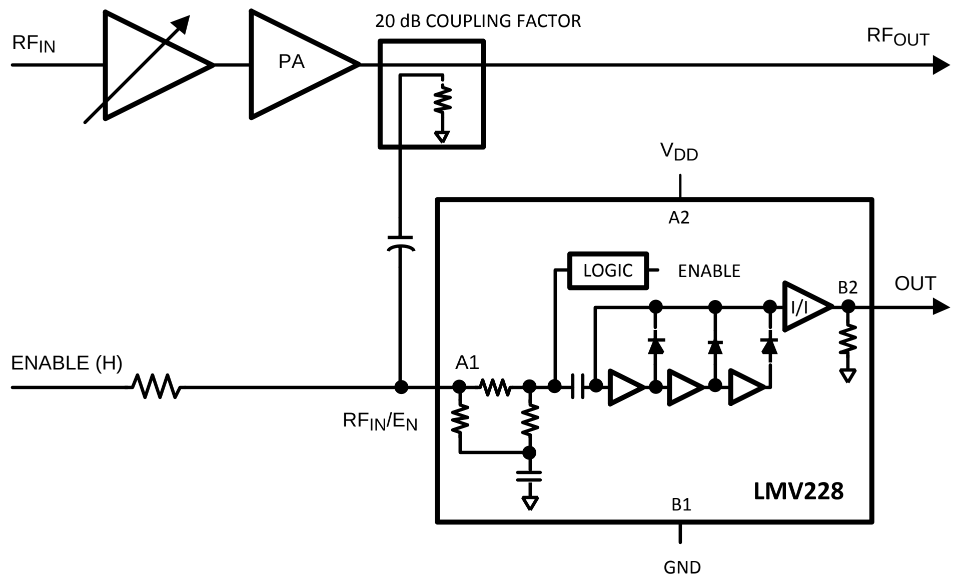

Figure 3. LMV228 Typical Applications Block Diagram

6 20 dB Direction Coupler

The use of directional coupler in Figure 3 has the advantage of using less layout area in a printed circuit board comparing to the use of isolator. The physical size of directional coupler is determined by operating frequency, dielectric constant of substrate and the needed coupling factor and isolation. Currently, package size of 0603 directional coupler fabricated by Low Temperature Co-fired Ceramic (LTCC) substrate can achieve up to 20 dB coupling factor in the W-CDMA band frequency. Any coupling factor higher than 20 dB requires either a much bigger substrate size or use of a much higher dielectric material as substrate or different technology and henceforth they are not available in the market today; however, 0603 package coupler with 20 dB coupling factor in W-CDMA band can be easily available from more than two vendors in the market today.

Typical performance of directional coupler is shown in Figure 4. Because of the isolation is 10 dB more than that of coupling factor, reflected power from antenna is then attenuated 10 dB more in comparison to the transmit power. Because of this directivity, power detected by the LMV228 is mostly coming from the output of transmit power amplifier. Reflection power due to antenna mismatches will be highly attenuated before reaching the input of LMV228.

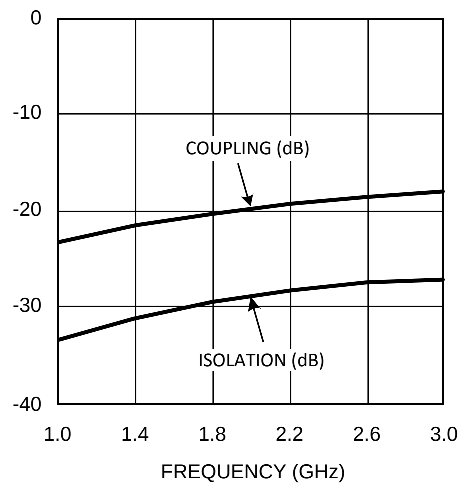

Figure 4. Directional Coupler Performance

7 Highlight of LMV228

The LMV228 is designed and optimized to provide the best RF power detection range in the W-CDMA User Equipment. Its detection range is more than 40 dB from +15 dBm and down to –25 dBm as shown in Figure 5 and Figure 6. Its frequency response spans from 60 MHz to more than 2 GHz depending on the specified detection range. The internal architecture of LMV228 provides accurate temperature compensation and supply voltage variation compensation, output voltage relates linearly to the RF input signal level in dBm. We usually call this feature as “Linear-in-dB”. The LMV228 can operate from 2.7V to 5.5V single power supply. Characteristic test data shows that its RF performance is almost the same through out the whole supply voltage.

At the output of LMV228, there is an integrated filter for low-ripple average power detection of spread spectrum signal. Additional filtering can be applied using a single capacitor. This external capacitor C_{OUT} is shunt from the output of LMV228 to ground. Since the output resistance of LMV228 is R_{OUT} = 19.8 kΩ, the cutoff frequency of this additional filtering would be $f_C = 1/2\pi C_{OUT} R_{OUT}$.

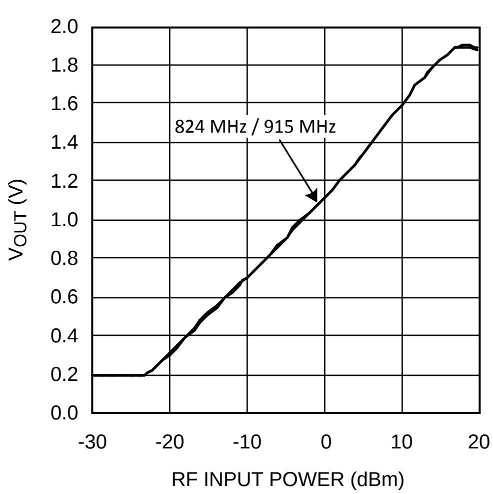

Figure 5. LMV228 in Cellular Bands

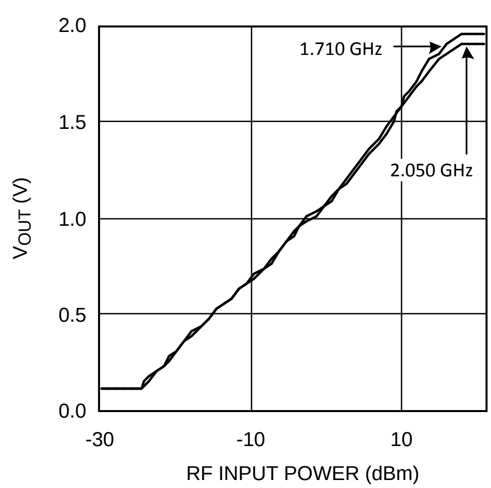

Figure 6. LMV228 in DCS/PCS/UMTS Bands

8 Production Calibration of User Equipment

As can be seen from Figure 5, LMV228 has 30 dB linear-in-dB detection range. This characteristic has reduced complexity in production calibration process. The power amplifier calibration procedure is a critical part of W-CDMA UE manufacturing process. Expensive automatic test equipment is used to collect information regarding “output power of UE vs. control code/signal “ from small signal to strong signal. This information is then stored in UE’s memory for actual phone operation. Anytime a output power level is requested by the base station, DSP or MCU of the UE will go to the memory and find out what control code should be used to make the PA to achieve the requested output power level.

Since it is time-consuming and expensive to take automatic bench test data of “control-code vs. output-power-level” for each UE, statistical estimation method together with the linear-in-dB characteristic of LMV228 could be used to reduce testing points and time. If we consider the detection range from −15 dBm to +15 dBm is linear in relationship (P_{IN} vs. V_{OUT}), we can use a linear equation, $V_{OUT} = m' \cdot P_{IN} + b'$, to represent it. Slope m′ and intercept b′ can be found from two-point testing in the production process. If test points are (P_{IN1} ,V_{OUT1}) and (P_{IN2} ,V_{OUT2}), then we can get $m' = (V_{OUT2} - V_{OUT1})/(P_{IN2} - P_{IN1})$ and $b' = V_{OUT1} - m' \cdot P_{IN1}$ from basic operation of algebra. Once m′ and b′ are found, any output power can be estimated by: Power = $(V_{OUT} - b')/m'$.

9 LMV228 in Dual-Band W-CDMA User Equipment

Figure 7 is a recommended block diagram for use in a dual-band W-CDMA User Equipment. Each transmit band uses its own directional coupler since the transmit path layout of each band is usually far apart in the PCB. Three 17Ω resistors are used to make a resistive RF power combiner to collect output signal from either the cellular band or the W-CDMA band. The 17Ω resistors are used because of 50Ω matching for all ports in the RF frequency. The resistive power divider has an intrinsic loss of 6 dB on each signal path.

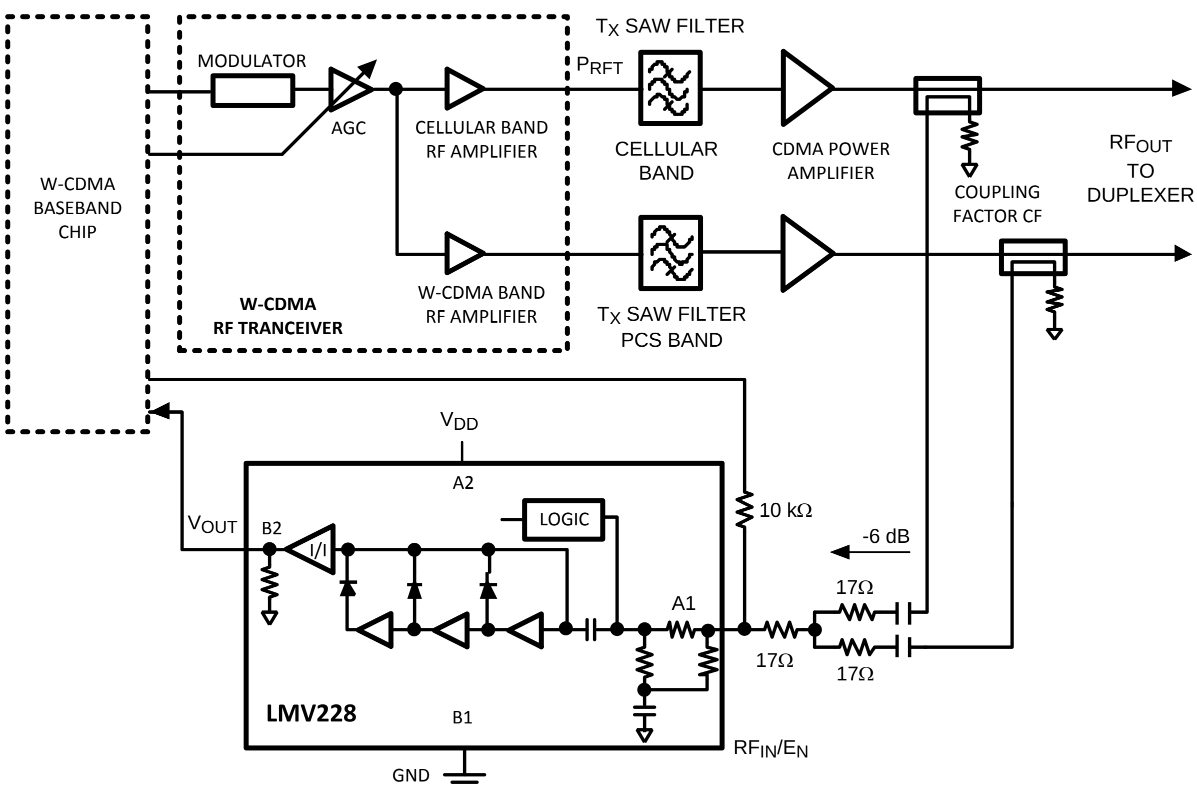

Figure 7. Dual-Band LMV228 Applications

Keep in mind that only one path will be on in actual application. If the directional coupler in this architecture has a 20 dB coupling factor, the actual coupled input signal level to LMV228 will become (P_{OUT} – 20 - 6)dBm since the loss of the combiner has to be accounted for in the signal path.

Two dc blocking capacitors needed to be used to eliminate unwanted DC current on the coupler's 50Ω termination.

Figure 8 is another circuit diagram of RF power combiner. Different attenuation levels for each signal path can be set independently in this circuit. Because of the flexibility of setting attenuation level, non-20 dB coupling factor directional coupler could be used.

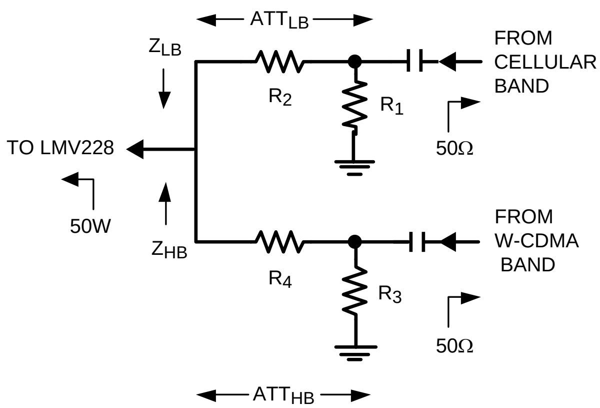

Figure 8. RF Power Combiner

In the cellular band, the additional attenuation is defined as:

$$ATT_{LB} = 20\log\left(\frac{Z_{LB}}{R_2 + Z_{LB}}\right) \quad (1)$$

Because of 50Ω matching requirement in the directional coupler side, the following relation could be obtained as:

$$\frac{1}{50} = \frac{1}{R_1} + \frac{1}{R_2 + Z_{LB}} \quad (2)$$

We also expect the Z_{LB} is matched to the parallel of 50Ω and Z_{HB}, and thus we obtain:

$$\frac{1}{Z_{LB}} = \frac{1}{50} + \frac{1}{R_4 + \frac{1}{1/R_3 + 1/50}} \quad (3)$$

In the W-CDMA band, the additional attenuation is defined as:

$$ATT_{HB} = 20\log\left(\frac{Z_{HB}}{R_4 + Z_{HB}}\right) \quad (4)$$

Because of 50Ω matching requirement in the directional coupler side, the following relation could be obtained as:

$$\frac{1}{50} = \frac{1}{R_3} + \frac{1}{R_4 + Z_{HB}} \quad (5)$$

We also expect the Z_{HB} is matched to the parallel of 50Ω and Z_{LB}, and thus we obtain:

$$\frac{1}{Z_{HB}} = \frac{1}{50} + \frac{1}{R_2 + \frac{1}{1/R_1 + 1/50}} \quad (6)$$

Solving the above six equations could find the values of each variable R_1, R_2, R_3, R_4, Z_{LB} and Z_{HB}.

10 Conclusion

Finally, a Logarithmic Amplifier RF Power Detector LMV228 has been presented as a critical component in FDD mode W-CDMA power control in the downlink. The LMV228 can detect RF power up to +15 dBm and meet power control requirements specified the W-CDMA air interface standard. This part can be available in either micro SMD or LLP package.

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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265