Application Report

SNWA001A–April 2005–Revised April 2013

AN-1374 Use of LMV225 Linear-In-dB RF Power Detector in CDMA2000 1X and EV_DO Mobile Station and Access Terminal

ABSTRACT

This application report discusses the use of LMV225 Linear-In-dB RF Power Detector In a CDMA2000 1X and EV_DO mobile station and access terminal.

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1 Introduction

Since the commercialization of CDMA IS-95 cellular network started in 1996, Code Division Multiple Access (CDMA) technology has been proven to be the best wireless technology for the advancing cellular and personal communications industry. All the prevailing 3G standards, CDMA2000, W-CDMA, and TD_SCDMA, have adopted CDMA as their access method. The CDMA method is based on spread spectrum modulation techniques and spread spectrum principle is based on the Shannon information theory. The Shannon capacity law states that the channel capacity in an Additive White Gaussian Noise is:

$$C_{sh} = B_{RF} \cdot (1 + SNR) \quad (1)$$

Where:

C_{sh} = Channel Transmission Capacity In bps

B_{RF} = Channel Bandwidth In Hz

SNR = Signal-to-Noise Ratio

Systems with a wider bandwidth, a bigger B_{RF}, require a lower SNR comparing to that of narrowband system, a smaller B_{RF}, in order to achieve the same capacity C_{sh}. On the other hand, a high SNR will have a higher transmission capacity in the channel for a given bandwidth B_{RF}. This means you can have more users if all the users transmit the same amount of data.

2 Why Power Control Is Important In CDMA Reverse Link?

Since any Mobile Station is considered to be an interferer to other users within the same base station coverage area and to all users on neighbor cells, transmit power control of the MS becomes extremely important for good performance and higher system capacity in CDMA operation. Therefore, the greater the number of active MS, the higher the interference level within the system. Thus, the lower the MS transmission power, the lower the total interference, that is, a higher SNR, within the RF carrier bandwidth B_{RF} and the higher the system capacity C_{sh}.

The main idea of power control schemes is to set MS' transmission power to a minimum level so that the base station receives signals from all MS with a similar level. Under this condition, the signal to noise ratio at the base station input is:

$$SNR = \frac{1}{M - 1} \quad (2)$$

and M is the total number of users for this base station.

In summary, the main benefits of power control in the CDMA system are:

- Increase of System Capacity
- Minimization of Near-Far Effect
- Reduce MS' battery power consumption

3 IS-95 And CDMA2000 Power Control For The Mobile Station Or Access Terminal

The power control feature controls interference level in the reverse link by estimating the best transmission power level and reacting to power control directions sent by network or base station.

In CDMA IS-95 and CDMA2000 1X, base station determines the power control, whereas, in CDMA2000 EV-DO, access terminal executes power control. Overall, the power control schemes in both standards are very similar. It employs two power control methods, that is, open-loop control and closed-loop control.

4 Open-Loop Power Control

The open-loop method uses power level at the MS receiver P_{RX} to estimate the forward-link path loss and then specifies the initial transmit power P_{TX} of the MS such that the sum of forward and reverse link powers is kept constant by the user terminal's choice, that is, P_{TX} + P_{RX} = Constant in cellular or PCS or 3G. The P_{RX} is calculated from Eb/Io, which is measured by MS's DSP. Eb/Io is the ratio of Energy Per Bit, Eb, over Power Spectral Density Of Noise And Interference, Io.

After the initial P_{TX} is obtained, both MS and base station will start closed-loop control. And base station transmits an error signal to the MS for instructing it to increase or decrease power by a step depending on which CDMA standard is implemented.

5 Closed Loop Power Control

The closed loop power control consists of two processes: outer loop (only base station) and inner (MS and base station simultaneously), which achieve up to 800 Hz of power control rates in IS-95 and CDMA 1X.

The closed-loop power control's main purpose is to minimize fast-fading effects caused by signal multi-path propagation losses, based on measurements made at the base station.

The use of both closed-loop power control processes, outer and inner loop, in combination may lead to fading compensations of 20 to 35 dB within a 20 msec frame-by-frame interval, within a dynamic range of up to 80 dB.

6 Outer Closed-Loop Power Control

In the outer loop, base station specifies a target Eb/Io (from MS to base station) at the receiver for each frame every 20 msec. This Eb/Io automatically reduces in steps of 0.2 to 0.3 dB or rises up to 3 to 5 dB if frame error occurs.

The entire Outer Closed-Loop process only involves the base station.

7 Inner Closed-Loop Power Control

In the inner loop, the base station compares the Eb/Io of the reverse traffic channel with the target Eb/Io every 1.25 msec and then instructs the MS to reduce or increase transmit power so that the targeted Eb/Io would be achieved. Power steps vary from ±0.25 dB to ±0.5 dB for CDMA2000 and ±1.0 dB for CDMA IS-95. Its update rate is 800 bps.

8 Hardware Implementation Of Power Control In CDMA Mobile Station

In summary, the CDMA IS-95 requires the MS to adjust transmit power level in a ±1.0 dB per step every 1.25 msec while the step size for CDMA2000 could be either ±0.25 dB to ±0.5 dB.

Figure 1 shows a generic output power control for linear power amplifier signal chain for a handheld device. Since high linearity is required for CDMA signal, the output power amplifier is usually biased at fixed gain and then the output power level has to be adjusted through a gain control linear driver amplifier, usually called Automatic Gain Control Amplifier in CDMA MS.

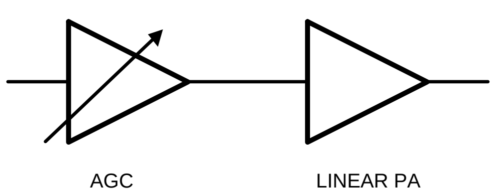

Figure 1. Output Power Control for Linear Application

It was found that the transmit radio architecture in Figure 2 can reduce DC power consumption of the power amplifier thanks to the use of isolator, like Murata CE04 or

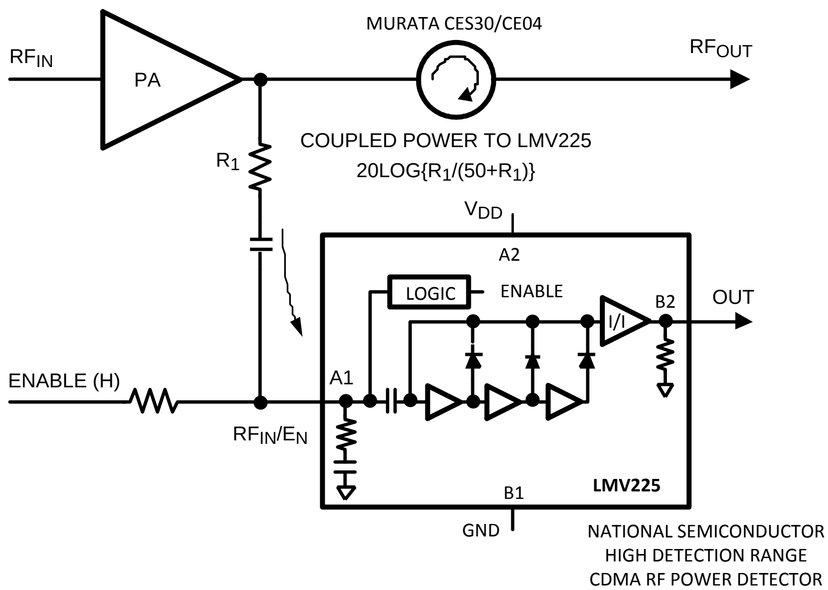

Figure 2. Transmit Radio Architecture

CES30, and accurate RF power detector LMV225. The isolator provides close-to-perfect 50Ω load for PA's output while LMV225 detects accurate transmit power level and then the MS' DSP can smartly set its output power just to the right level as required by base station. In this application circuit, a resistor is used to divert RF signal from the main signal path to the input of LMV225. An about 100 pF capacitor is needed to DC block the enable control signal from entering the main signal path. This dc blocking capacitor is necessary since we don't want the dc voltage go into the output of PA nor the input of isolator. Since an isolator has been in place, it is very safe to say that most of the diverted RF energy is from the transmit PA. Reflection energy from the antenna will be diverted to a built-in 50Ω load inside the isolator and then seldom reach the PA's output or LMV225. Therefore, the coupled power to LMV225 can be estimated by $20\log[R_1/(R_1 + 50)]$.

Figure 3 briefly shows and explains the test results. PA's distortion performance with −40 dBc ACPR, Adjacent Channel Power Rejection, at 500 mA supply current can be improved to −50 dBc ACPR at 450 mA supply current. The current reduction in this case is 10% and distortion improvement is about 10 dB. Figure 4 shows a typical test circuit boards used in this kind of experiment.

Now we have shown that LMV225 together with a CES30 isolator can deliver better performance in linear CDMA PA applications, in term of dc power consumption and RF distortion, for IS-95, W-CDMA, CDMA2000 and TD-SCDMA air interfaces. In fact, it is necessary for a CDMA2000 mobile station or access terminal to have LMV225 as a transmit power detector in order to implement the stringent inner closed-loop power control because of variations and uncertainties in performance of the transmit signal path components, namely AGC, PA's gain, loss of passive parts. We are going to explain it in more detail in the next section.

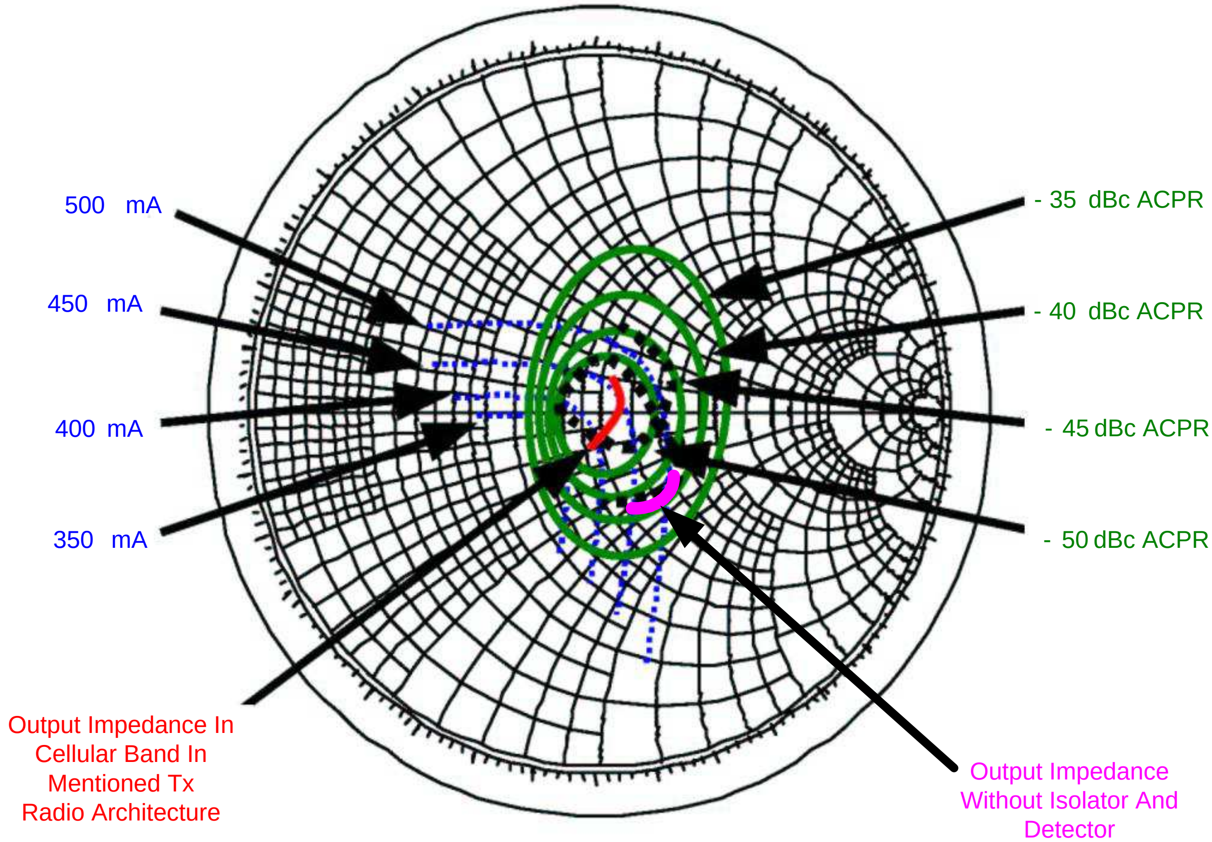

Figure 3. Output Impedance Smith Chart

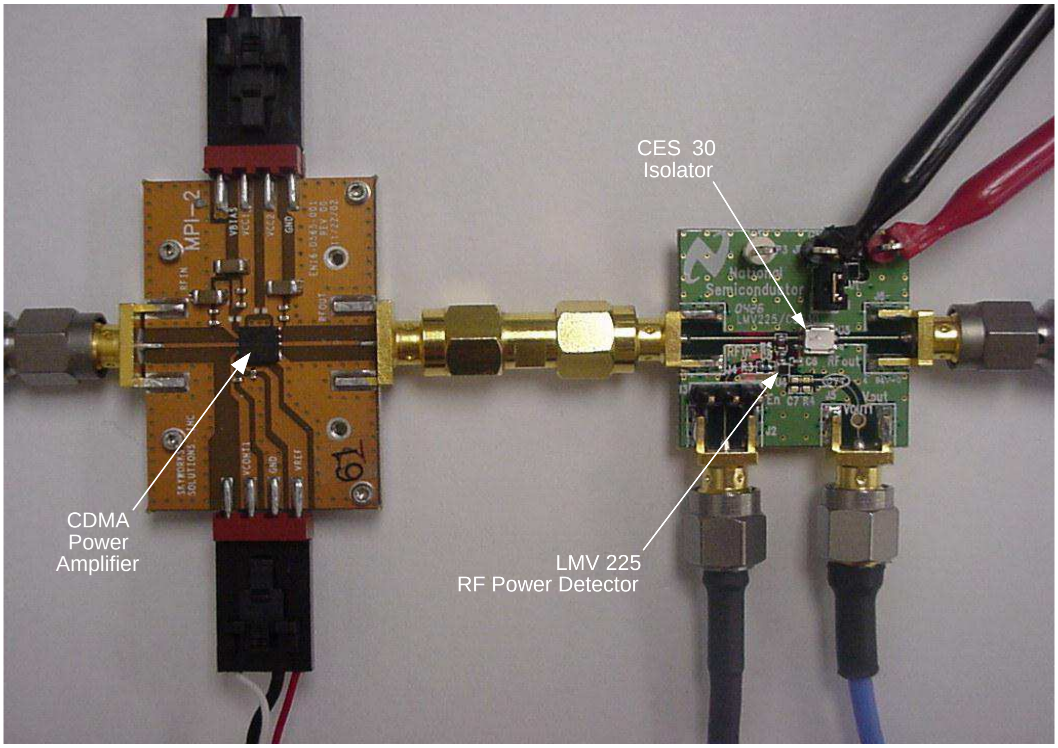

Figure 4. LMV225 Eval Board + CDMA PA's Module

9 Mobile Station Transmit Signal Path and Radio

The transmit radio architecture on Figure 2 can be used for many different kinds of CDMA chipset. One of the very best and popular solutions is MSM6500™/RFT6120™ from Qual Comm Inc. in San Diego, California, USA. Figure 5 depicts a recommended LMV225 application block diagram for transmit power detection in CDMA2000 1X or EV-DO single band handheld devices. In this transmitter architecture, the output power to antenna is found to be:

$$RF_{OUT} = P_{RFT} - L_{SAW} + G_{PA} - L_{ISOLATOR} - L_{DUPLEXER} \quad (3)$$

Where:

RF_{OUT} = RF power to antenna (assume 50Ω matched)

P_{RFT} = Output power from R_{FT} transmit chip

L_{SAW} = Insertion loss of SAW filter

G_{PA} = Fixed gain of CDMA PA

$L_{ISOLATOR}$ = Insertion loss of isolator

$L_{DUPLEXER}$ = Insertion loss of duplexer

Here the insertion loss of the resistive power divider formed by R_1 and LMV225 is negligible since both R_1 and LMV225 have formed a high impedance shunt load to the signal path. We can see that L_{SAW}, G_{PA}, $L_{ISOLATOR}$, $L_{DUPLEXER}$ can be considered to be constant in room temperature. And then the RF power to antenna RF_{OUT} will be adjusted by P_{RFT}, which is controlled by the AGC in transmit chip. In fact, the AGC amplifier typically supports about 80 dB dynamic range as per requirements from IS-95 or CDMA2000. It was also discovered that CDMA MS work in a medium output power most of the time and then the power control accuracy is more important from medium power level to high output power. For inaccurate high output power level will reduce MS' talk time and generate more interferences to other network users.

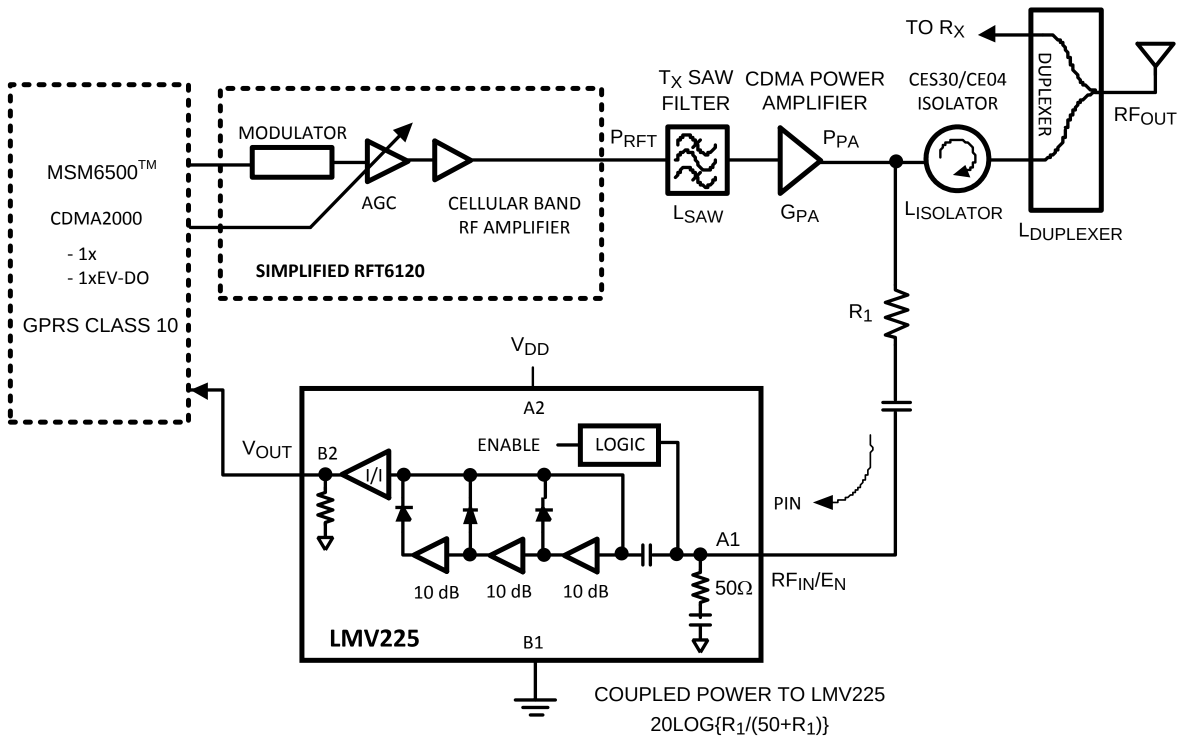

Figure 5. Single-Band CDMA2000 T_X Architecture

10 Highlight of LMV225

The LMV225 is designed and optimized to provide the best power detection range in a CDMA handheld device. Its detection range is shown in Figure 6 and Figure 7. As we mentioned above, it is more crucial to have accurate power control from medium output power level to high output power level. The coupling resistor R_1 should be chosen so that LMV225 can see RF signal representing that critical range. Suppose the AGC is trying to set at the highest gain level so that maximum output level from the CDMA PA can be achieved, say 28 dBm. If crest factor of the sent RF signal at this time is 3 dB, then instantaneous peak power level from the CDMA PA will be 28 + 3 = 31 dBm. If we choose this as the maximum reference point in which LMV225 should see and detect, that is, 0 dBm to RF_{IN}/Enable of LMV225 when PA's instantaneous output power is 31 dBm, a 31 dBm coupling factor should be used. It is fount that a 1.8 kΩ resistor for R_1 could make a 31 dB coupling factor in this circuit.

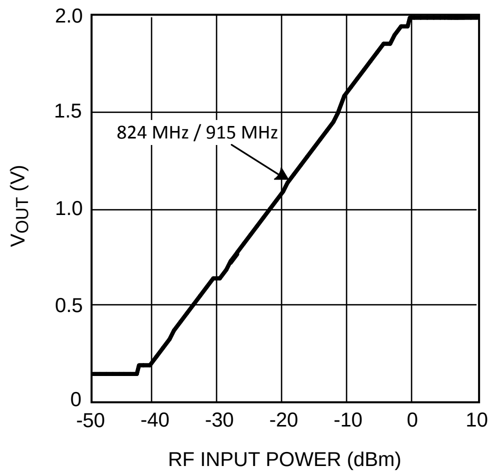

Figure 6. Typical Performance at Cellular Bands

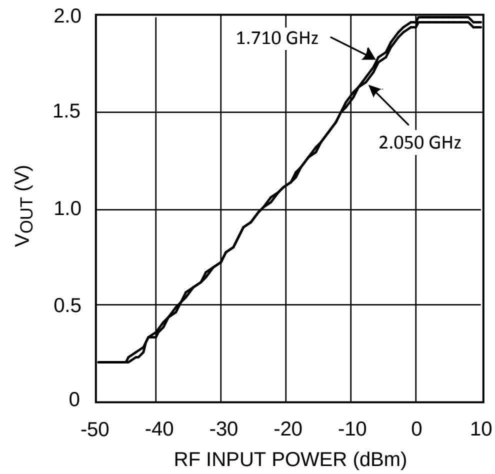

Figure 7. Typical Performance at DCS/PCS/W-DCMA Bands

11 Added-Values from the Linear-In-dB Characteristic of LMV225

As can be seen from Figure 6 and Figure 7, LMV225 has 30 dB linear-in-dB detection range. This characteristic has reduced complexity in production calibration process. The calibration process is a critical part of CDMA MS manufacturing process. Automatic test equipment is used to collect information regarding output power of MS vs. control code/signal from small signal to strong signal. This information is then stored in MS' memory for field uses. Anytime a output power level is requested by the base station, DSP of the MS will go to the memory and find out what control code/signal should be used in order to achieve the requested output power level. Some of AGC in the market may have exponential characteristic between control signal and output gain. If this is the kind of AGC used together with LMV225, the linear-in-dB characteristic will not make the original control curve more complicated as the original AGC characteristic curve comparing to other detection method, like diode detection, and so on. However, if the AGC has a linear control range, the linear-in-dB characteristic will reduce the calibration points from 20+ points to 2 points or so. This two-point calibration process is based on the principle that only two different points are needed to represent a 1st order linear equation in a two dimensional plane. If y = mx + b is the equation, the slope m and intercept b could be found out by two test coordinates (x1, y1) and (x2, y2).

12 LMV225 in Dual-Band CDMA2000 Mobile Station

Figure 8 is a recommended block diagram for use in CDMA2000 handheld devices. Although resistors R_1 and R_1' may not be the same, it is possible for the users to optimize both bands performance so that both R_1 and R_1' have the same value. On the other hand, isolation between low band and high band should be acceptable because only one of the power amplifiers is on in real application and the resistor (R_1 or R_1') will typically provide more than 30 dB isolation.

13 Conclusion

Finally, a Logarithmic Amplifier RF Power Detector LMV225 has been presented as critical component in CDMA2000 power control in the reverse link. It is found that the LMV225 not only delivers the fundamental requirements specified the CDMA2000 air interface standard, but also it can save DC power consumption, improve distortion in the transmit path like ACPR, save production calibration efforts and ease of use in R and D stage.

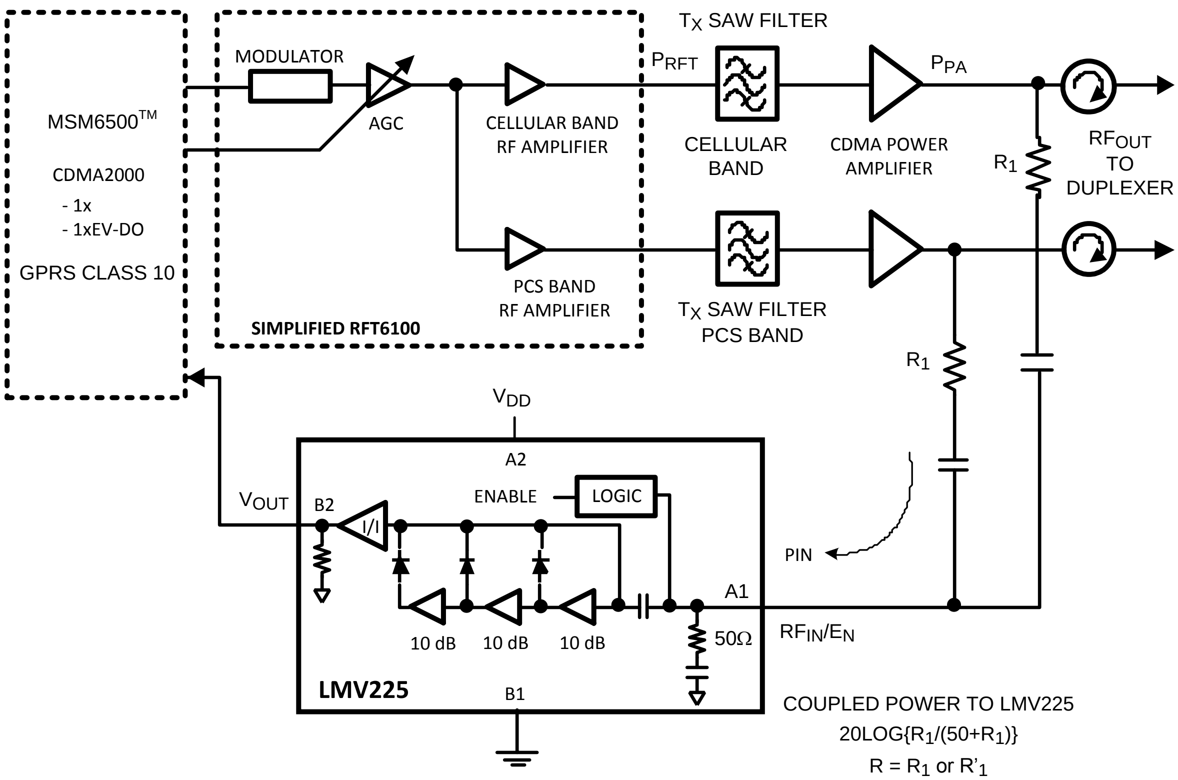

Figure 8. Dual-Band CDMA2000 Transmit Architecture

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