Application Note 91

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Low Cost Coupling Methods for RF Power Detectors Replace Directional Couplers

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INTRODUCTION

Minimizing size and cost is crucial in wireless applications such as cellular telephones. The key components in a typical GSM cellular telephone RF transmit channel consist of an RF power amplifier, power controller, directional coupler and diplexer. Some of the more recent RF power amplifiers incorporate a directional coupler in their module, reducing component count and board area. Most power amplifiers, however, require an external directional coupler. Unfortunately, directional couplers come at a price and sometimes a performance loss. While cost is an issue, long lead-time and wide variations in coupling loss are other concerns facing cell phone designers.

The directional coupler commonly used (Murata LDC21897M190-078) is unidirectional (forward) and dual band. One input is for low frequency signals (897.6MHz ±17.5MHz) and has a coupling factor of 19dB ±1dB. The second input is for higher frequency signals (1747.5MHz ±37.5MHz) and has a coupling factor of 14dB ±1.5dB. The Murata LDC21897M190-078 directional coupler is housed in a 0805 package and requires an external 50Ω termination resistor.

When a signal is passed through one of the inputs, a small portion of RF signal, equal to the difference between P_{OUT} and the coupling factor, appears at the coupling output. The remainder of the signal goes to the corresponding signal output. In typical RF feedback configurations, the coupled RF output is passed through a 33pF coupling capacitor and 68Ω shunt resistor (Figure 1a).

Linear Technology has developed a coupling scheme for LTC RF power controllers and RF power detectors which is lower cost, more readily available and features tighter tolerance. This coupling method eliminates the 50Ω termination resistor, 68Ω shunt resistor and 33pF coupling capacitor used in traditional coupling schemes. Instead, a 0.4pF capacitor and 50Ω series resistor replace the directional coupler and its external components (Figure 1b)[1] .

Alternate Coupling Solutions for use with an LTC Power Controller

Method 1

The DC401B demo board was designed to demonstrate the performance of the tapped capacitor coupling method (Figure 2). RF signal is coupled back to the LTC4401-1 RF input through a 0.4pF capacitor and 50Ω series resistor as shown in Figure 1b. The RF signal is fed directly to the diplexer from the power amplifier. The component count is reduced by two.

The 0.4pF series capacitor must have a tolerance of ±0.05pF or less. The tolerance directly affects how much RF signal is coupled back to the power controller RF input. ATC has ultralow ESR, high Q microwave capacitors with the tight tolerances desired. The ATC 600S0R4AW250XT is a 0.4pF capacitor with ±0.05pF tolerance. This capacitor comes in a small 0603 package. The series resistor is 49.9Ω (AAC CR16-49R9FM) with 1% tolerance.

Method 2

The second solution implements a 4.7nH shunt inductor. The inductor compensates for the parasitic shunt capacitance associated with the RF input on the power controller. Consequently, it improves the power control voltage range and sensitivity. In dual-band applications, the inductor value is chosen to increase the sensitivity of one frequency band over the other. Using an inductor requires that a capacitor be placed between the RF input pin and the

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Note 1: This method has been tested with the LTC4401-1 and the following Hitachi power amplifiers: PF08107B, PF08122B, PF08123B.

inductor. This capacitor provides a low impedance path for the RF signal. A 33pF capacitor is used as shown in Figure 1c. At each of the frequencies tested, the reactance of the 33pF capacitor is lower than the inductor's.

This method uses the same 0.4pF capacitor and 50Ω resistor implemented in Method 1. The Murata film type inductor, LQP15MN4N7B00D, comes in a 0402 package and has ±1nH tolerance. The 33pF capacitor is an AVX 06035A330JAT1A, comes in a 0603 package and has 5% tolerance. Tight tolerance for the shunt inductor and 33pF capacitor is not critical.

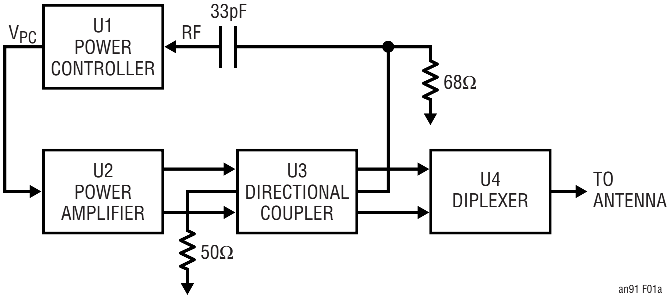

Figure 1a. Typical Cellular Phone Coupling Solution

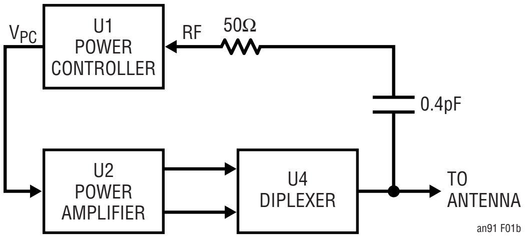

Figure 1b. Capacitive Coupling Method 1

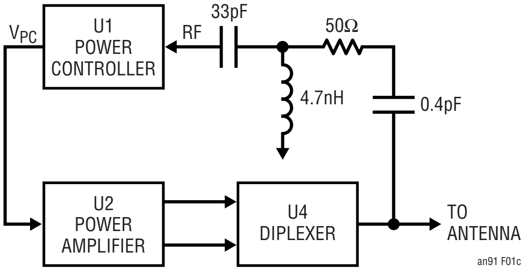

Figure 1c. Capacitive Coupling Method 2

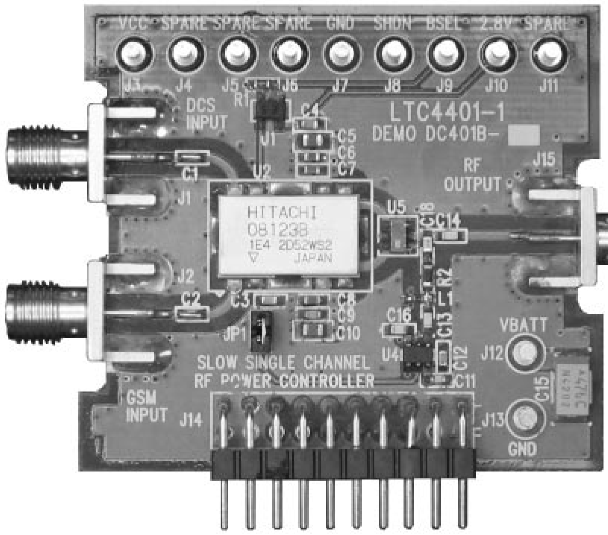

Figure 2. DC401B Demo Board

Theory of Operation

The 0.4pF capacitor and 50Ω resistor form a voltage divider with the input impedance of the LTC power controller. The voltage divider ratio varies over frequency. Reactance for capacitors is inversely proportional to frequency. Thus, as frequency increases, the reactance decreases for a fixed capacitance. Similarly, reactance increases as capacitance decreases. A tenth of a picofarad greatly impacts the reactance because the value of the coupling capacitor is so small. This is why tight tolerance is absolutely crucial. Small changes in capacitance will change the reactance and consequently, the voltage divider ratio. Table 1 shows the reactance of various components at 900MHz, 1800MHz and 1900MHz.

Table 1. Reactance Variations over Frequency

	Frequency (MHz)	900	1800	1900
Component Value	0.3pF	590Ω	295Ω	279Ω
	0.4pF	442Ω	221Ω	210Ω
	0.5pF	354Ω	177Ω	167Ω
	33pF	5.4Ω	2.7Ω	2.5Ω
	4.7nH	27Ω	53Ω	55Ω

The resistor value is determined by the series capacitor value and additional shunt and placement parasitics. When a shunt inductor is utilized, a smaller capacitor can be used, yielding less loss in the main line. The shunt inductor method is tuned to a particular frequency band at the expense of other frequency bands. The second coupling method, for example, is tuned to DCS band frequencies. The coupling loss for this method closely resembles the coupling loss of the directional coupler (Figure 3b).

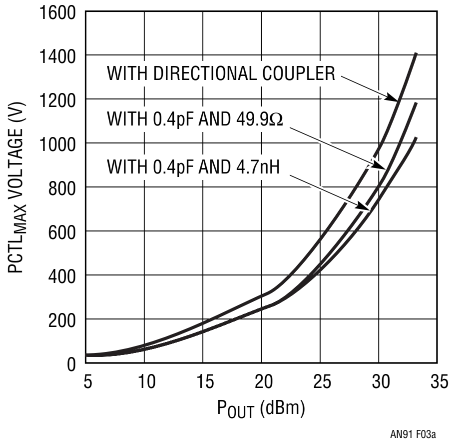

Figure 3a. GSM900 PCTL vs P_{OUT}

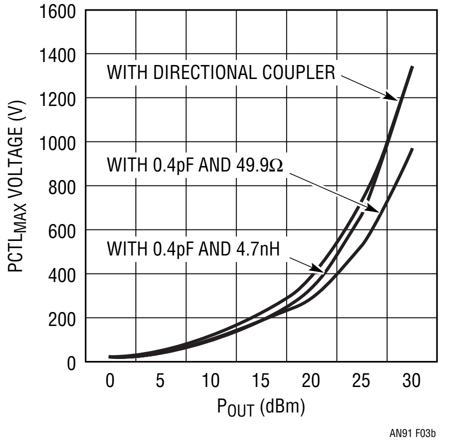

Figure 3b. DCS1800 PCTL vs P_{OUT}

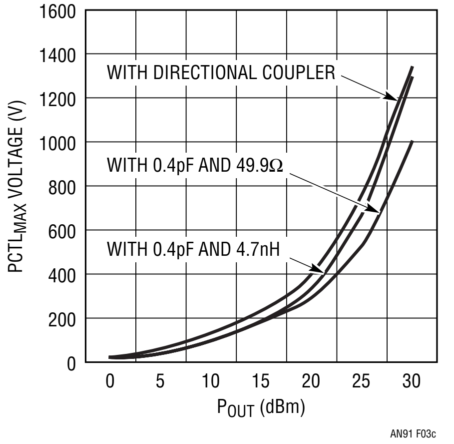

Figure 3c. PCS1900 PCTL vs P_{OUT}

Considerations

There are several factors to consider when using either coupling method, such as board layout and loading in the main line. Conservative parts placement is necessary in order to minimize the distance between the TX output 50Ω line and the RF input pin on the power controller. Parasitic effects can also greatly alter the feedback network characteristics. With good layout techniques and use of tight tolerance components, this directional coupler substitute can be used over GSM, DCS and PCS band frequencies.

Test Setup and Measurement

Three different coupling methods were tested using the DC401A and the DC401B demo boards. The DC401A RF demo board has a triple-band directional coupler and served as the control board. The coupling factor is 19dB at 900MHz and 14dB at 1800MHz and 1900MHz. The DC401B was used to test the two capacitive coupling methods described earlier (Figure 8).

Each of these demo boards contains an LTC4401-1 power controller and a Hitachi PF08123B triple-band power amplifier. The component layout of the two boards is identical, except for the components that make up the coupling scheme.

A key measurement of interest is coupling loss. One method of measuring coupled RF signal is to select an RF output power level and compare the PCTL voltages applied in each of the three coupling methods. Figure 4 shows what a typical PCTL waveform looks like. Only the maximum level amplitude (maximum PCTL voltage) is adjusted for each measurement. The PCTL waveform is generated by Linear Technology's ramp shaping program, LTRSv2.vxe and is programmed onto the DC314A demo board. The DC314A digital demo board provides regulated power supplies, control logic and a 10-bit DAC to generate the $\overline{\text{SHDN}}$ signal and the power control PCTL signal. Input power applied to each power amplifier channel is 0dBm. A nominal battery voltage of 3.6V is used. Figure 7 illustrates the test setup.

A higher PCTL voltage indicates less coupling loss (i.e., more RF signal is being coupled back). Having too little coupling loss can be a problem at higher power levels because the PCTL value may exceed the maximum voltage that the DAC can output. Having too much coupling loss can make achieving lower output power levels difficult. Using a PCTL voltage less than 18mV is not recommended, since the RF output will be unstable. Thus, the minimum output power, P_{OUT}, is limited by PCTL = 18mV.

At 900MHz (GSM900), PCTL voltage measurements were taken at the following output power levels: 5dBm, 10dBm, 13dBm, 20dBm, 23dBm, 30dBm and 33dBm. At 1800MHz (DCS1800) and 1900MHz (PCS1900), PCTL measurements were recorded for the following output powers: 0dBm, 5dBm, 10dBm, 15dBm, 20dBm, 25dBm and 30dBm. Figures 3a, 3b and 3c relate the output power to the applied PCTL voltage for each coupling method. In general, the capacitive coupling solutions have more coupling loss than the directional coupler. The full output range was achieved using both coupling methods.

Coupling Solution for LTC5505 Power Detector [2]

The tapped capacitor method can also be utilized in systems using the LTC5505 power detector. For example, in the circuit in Figure 5, a shunt inductor is implemented at the RF input pin to tune out the parasitic shunt capacitance of the power detector package (5-pin ThinSOT™) and the PCB at the actual operating frequency. Using a shunt inductor improves the sensitivity of the LTC5505-2 by a factor of 2dB to 4dB. If operating between 3GHz to 3.5GHz, the shunt inductor is not recommended because the bond wire inductance compensates for the input parasitic capacitance. A DC blocking capacitor (C4) is needed, because Pin 1 of the LTC5505-2 is internally DC biased.

Figure 6 illustrates an example of dual band mobile phone transmitter power control with an LTC5505-2 and a capacitive tap instead of a directional coupler. A 0.3pF capacitor (C1) followed by a 100Ω resistor (R1) forms a tapping circuit with about 20dB loss at cellular band (900MHz) and 18dB loss at PCS (1900MHz) band referenced to the LTC5505-2 RF input pin. For best coupling accuracy, C1 should have tight tolerance (±0.05 pF).

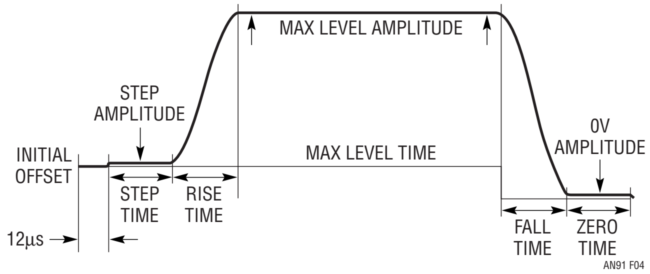

Figure 4. Typical PCTL Ramp Waveform

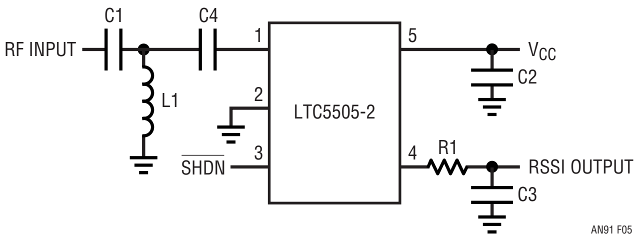

Figure 5. LTC5505-2 Application Diagram with a Shunt Inductor

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ThinSOT is a trademark of Linear Technology Corporation.

Note 2: Consult factory for more applications information on LTC power detectors.

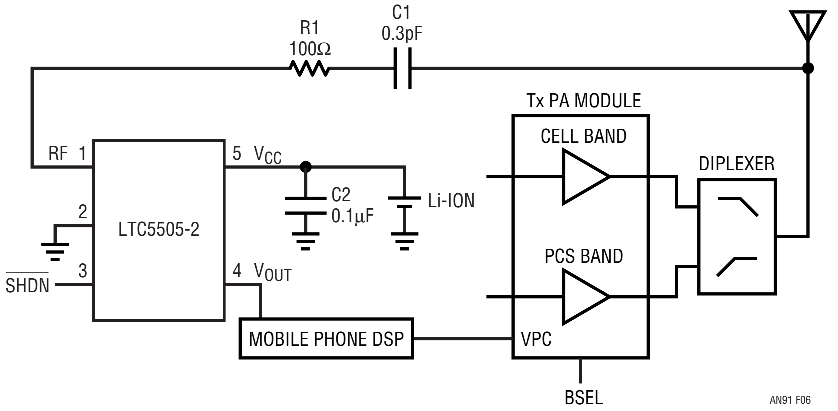

Figure 6. LTC5505-2 Tx Power Control Application Diagram with a Capacitive Tap

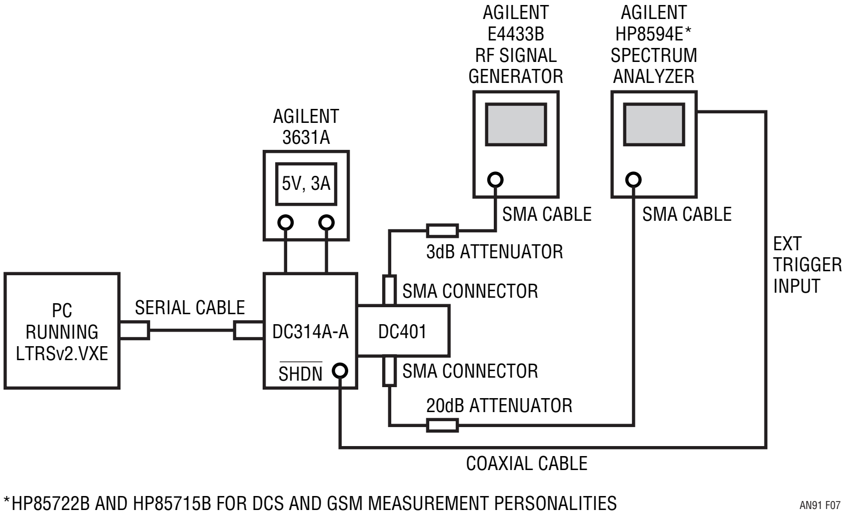

Figure 7. PCTL Measurement Test Setup

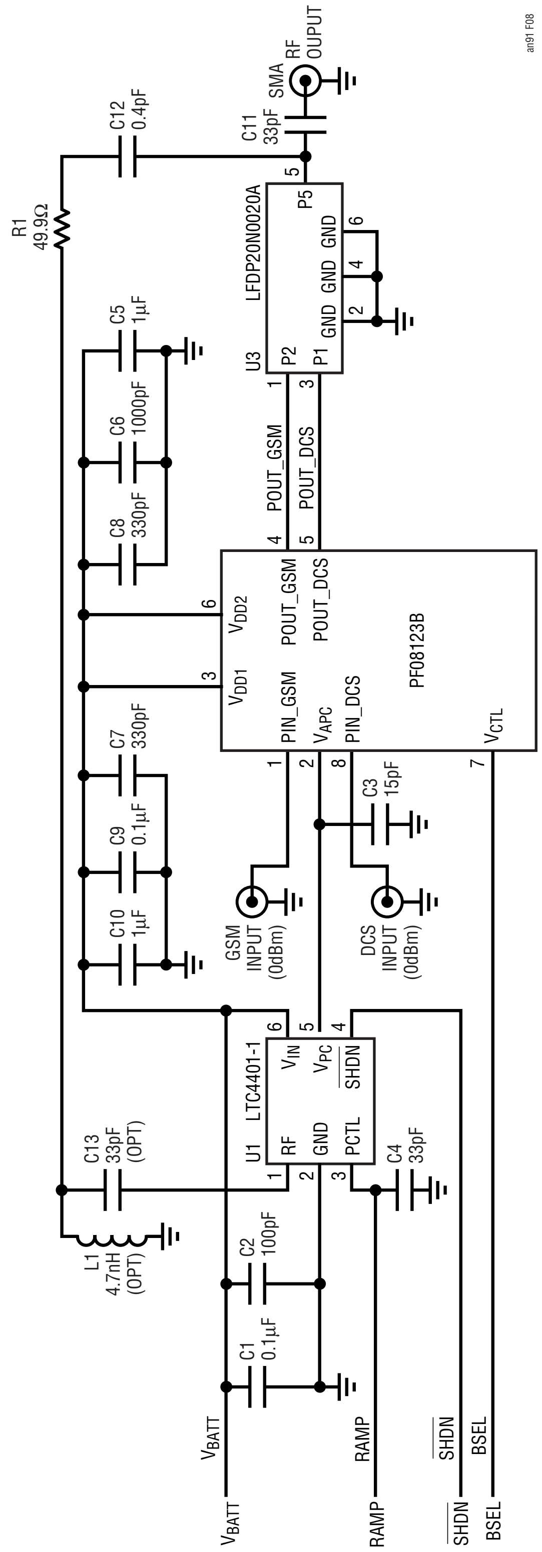

Figure 8. DC401B Schematic

Conclusion

Laboratory measurements have shown that the capacitive coupling method is an effective means of coupling the RF output signal. If coupling capacitors with tight tolerances are used, the coupling factor will be consistent. On the other hand, a directional coupler's coupling factor can vary up to 1.5dB. The total number of components decreases if the series resistor and capacitor are used. Cost will also be reduced.

The capacitive coupling scheme has been shown to work with the LTC4401-1 power controller and Hitachi PF08123B power amplifier. This scheme can be applied to all LTC power controllers (LTC1757A, LTC1758, LTC1957, LTC4400, LTC4401, LTC4402 and LTC4403) and supported power amplifiers, as well as LTC power detectors. When used with different power controller and power amplifier combinations, the capacitor and resistor values may need to be adjusted. Decreasing the coupling capacitor or increasing the series resistor will increase the coupling loss. Linear Technology currently supports Anadigics, Conexant, Hitachi, Philips and RFMD power amplifiers. DC401B demo boards are available upon request.

PARTS LIST (Demo Board DC401B)

REFERENCE	QUANTITY	PART NUMBER	DESCRIPTION	VENDOR
C1, C9	2	0603YC104MAT1A	0.1µF 16V 20% X7R Capacitor	AVX
C2	1	06035A101JAT1A	100pF 50V 5% NPO Capacitor	AVX
C3	1	06035A150JAT1A	15pF 50V 5% NPO Capacitor	AVX
C4, C11, C13 (OPT)	2	06035A330JAT1A	33pF 50V 5% NPO Capacitor	AVX
C5, C10	2	EMK212BJ105MG-T	1µF 16V 20% X5R Capacitor	Taiyo Yuden
C6	1	06033C102KAT1A	1000pF 25V 10% X7R Capacitor	AVX
C7, C8	2	06035A331JAT1A	330pF 50V 5% NPO Capacitor	AVX
C12	1	600S0R4AW 250 XT	0.4pF ±0.5pF NPO Capacitor	ATC
L1 (OPT)	1	LQP15MN4N7B00	4.7nH 0402 ±0.1nH Inductor	Murata
R1	1	CR16-49R9FM	49.9Ω 1/16W 1% Chip Resistor	AAC
U1	1	LTC4401-1	SOT-23-6 RF Power Control IC	LTC
U2	1	PF08123B	Power Amplifier SMT IC	Hitachi
U3	1	LFDP21920MDP1A048	Dual Wideband Diplexer SMT IC	Murata

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