UMTS Picocell Front End Module

INTRODUCTION

The wireless market is expanding with significant growth likely to be in Wideband CDMA. Universal Mobile Telecommunications System (UMTS) is the third-generation (3G) wireless communications standard that is capable of delivering voice and high-speed data using WCDMA. The UMTS system offers a layered approach to coverage by utilizing macrocells (towers), microcells, picocells and femtocells. Picocells are essentially mini-basestations that deliver ~24 dBm power at the antenna. These products fill in coverage gaps and add capacity in high-traffic, high data rate areas. Described herein is a new front end module for the UMTS/ WCDMA picocell market. The term "front end" module refers to the portion of an RF transceiver that extends from the antenna to the mixers or local oscillator section. In addition, these front end modules can also be utilized for UMTS repeaters.

The module essentially consists of a transmit (Tx) bandpass filter, a Tx power amplifier (PA), a duplexer, a receive (Rx) low noise amplifier (LNA), and an Rx bandpass filter. The effort of bringing these elements together for this market segment in one compact, surface mount design was quite challenging.

UMTS uses FDD (frequency division duplexing). This means that there is a separate Tx frequency band, 2110-2170 MHz, and a separate Rx band, 1920-1980 MHz. Therefore, a ceramic duplexer is required at the antenna port so that the picocell can receive and transmit simultaneously. By using a distributed filtering scheme consisting of a duplexer, and Tx and Rx bandpass filters, we can provide UMTS attenuation requirements normally seen in much larger solutions. The flexible design allows for a suitable PA and LNA to be added to meet UMTS picocell power and Rx noise figure requirements. In the transmit path, the module can deliver 24 dBm WCDMA power at the antenna port, while achieving a typical ACLR (Adjacent Channel Leakage power Ratio) of -57 dB with a PAR (peak to average ratio) of 8 dB. The 3GPP (Third Generation Partnership Project) specification dictates that a minimum ACLR of -45 dB be achieved under worst case conditions.

The Model VFM1004A, which has U.S. and foreign patents pending, is designed to meet 3GPP Release 6 specifications. Its size is 31.0 mm x 25.1 mm x 6.75 mm. It can replace all of the RF components that would be typically used in a UMTS basestation (or "Node B") local area front end. The front end module is shown in Fig. 1.

Fig. 1

The front end module simplified block diagram is shown in Fig. 2. The receive section is under the metal lid. The transmit section is mainly exposed to minimize heat accumulation.

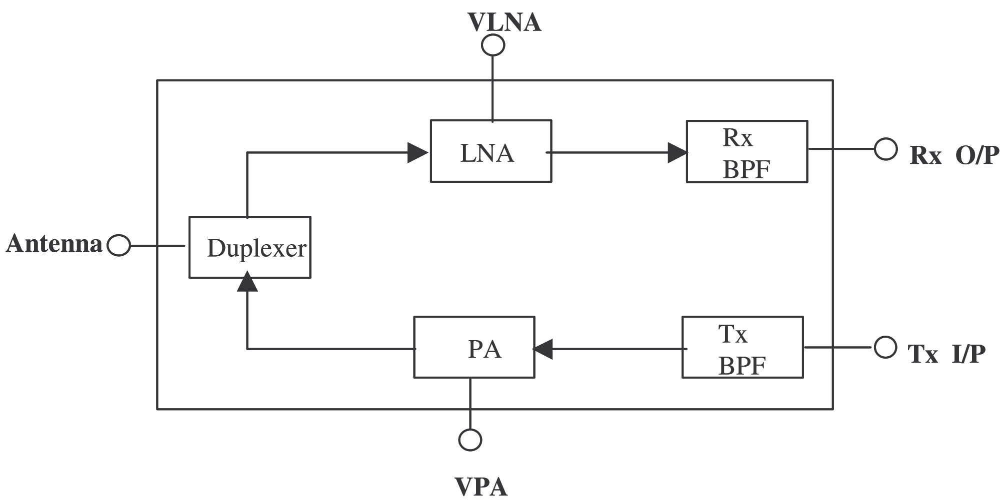

Fig. 2

CIRCUIT ELEMENT DISCUSSION

At the antenna port, the duplexer is of a ceramic monoblock construction. Its insertion loss is typically 1.3 dB on the receive side and 1.5 dB on the transmit side (1). In the transmit path, the GaAs power amplifier is capable of delivering the full UMTS local area requirements. It dissipates ~6W while delivering 24 dBm at the antenna port (Test model 1 64DPCH clipped to 8dB PAR). The Tx bandpass filter, in conjunction with the duplexer, attenuates transmit spurious and prevents Rx de-sensitization.

In the receive path, the low noise amplifier has a noise figure of 1.3 dB and a typical gain of 13 dB. The LNA is very linear and is designed to work within the distributed architecture. The receive monoblock bandpass filter works in conjunction with the duplexer to provide in excess of 65 dB "transmit to receive" isolation.

BLOCKING

The Rx bandpass filter also provides the close-in blocking needed in order to be compliant with the UMTS standard. With respect to receiver design, one of the most difficult aspects of the standard is a blocking requirement that leads to a front end attenuation of 15 dB to 20 dB at 1.9 GHz and 2 GHz (2). Table 1 is an extract of the TS25.104-630 standards document.

Table 1: Blocking Performance Requirement for Local Area BS

Operating Band	Center Frequency of Interfering Signal	Interfering Signal mean power	Wanted Signal mean power	Minimum Offset of Interfering Signal	Type of Interfering Signal
I	1920 - 1980 MHz	-30 dBm	-101 dBm	10 MHz	WCDMA signal
	1900 - 1920 MHz 1980 - 2000 MHz	-30 dBm	-101 dBm	10 MHz	WCDMA signal
	1 MHz -1900 MHz 2000 MHz - 12750 MHz	-15 dBm	-101 dBm	—	CW carrier

In a typical radio system design, the radio is protected from these blockers by the duplexer. Often, the requirement of the duplexer is that it has an out-of-band attenuation of 30 dB or better with a minimum attenuation of 20 dB at 0 Hz to 1.9 GHz, and 2 GHz to 12.75 GHz. For a 60 MHz wide filter with a low insertion loss, this is difficult. Duplexers that provide this performance can be as large as 28 cm x 23 cm x 7.6 cm. In order to achieve the required close-in rejection, the front end module uses a distributed filter approach. As a result, a similar performance can be achieved within the form factor of this module.

RECEIVER SENSITIVITY

The receiver sensitivity of a radio is the minimum power required at the antenna port to achieve a specific BER (bit error rate) or SNR (signal to noise ratio) at the output. The receiver sensitivity of the radio is related to noise figure and gain.

The worst case noise figure for the front end module receive section is 5 dB. Keep in mind that linear multiplication is equivalent to logarithmic addition. The noise figure in dBs is equal to 10 log(F), where F is the noise factor, i.e., SNR_{in} / SNR_{out}.

With an LNA gain of 12 dB, for example, the noise figure equation is as follows:

$F1 = 5$ dB = 3.16 (for the front end module)
$F2 = 15$ dB = 31.60 (for the remainder of the radio Rx section)
$G1 = 12$ dB = 15.84 (gain of the LNA)

The "cascaded noise figure" equation is as follows:
$Fin = F1 + (F2 - 1)/G1 = 3.16 + (31.60 - 1)/15.84 = 5.09$

Converting to decibels, $Fin = 10 \log (5.09) = 7.1$ dB

Therefore, the worst case noise figure for the receive section is 7.1 dB. This translates to "a maximum input signal level at the minimum sensitivity" of -120 dBm. This is using a UMTS processing gain of 25 dB, and a signal of 6 dB above the noise floor. The following equation shows how this was derived.

Receiver sensitivity equation: Sin (dBm) = NF (dB) + KTB (dBm) + Eb/No (dB) – PG (dB)

,where Sin = input signal power, i.e., Rx sensitivity
NF = noise figure of receiver
KTB = thermal noise power [-174 dBm/Hz + 10 log (3.84 MHz)]
Eb/No = energy-to-noise ratio (S/N above the noise floor to insure successful demodulation)
PG = UMTS processing gain [10 log(3.84 MHz/12.2 kHz)]

This assumes a UMTS channel bandwidth of 3.84 MHz, and a digital voice data rate of 12.2 kbps.

Therefore…

Sin = 7.1 dB –108 dBm + 6 dB – 25 dB = -120 dBm. This is the maximum input signal level at the required sensitivity for the radio.

MODULE DATA

The Tx and Rx gain at the antenna for the front end module are shown in Fig. 3. The typical gain of the LNA in the Rx path is 13 dB. The gain of the PA in the Tx path is 15 dB. A two-stage power amplifier configuration (Model VFM1019C) could yield a gain of 28 dB.

Tx, Rx Gain

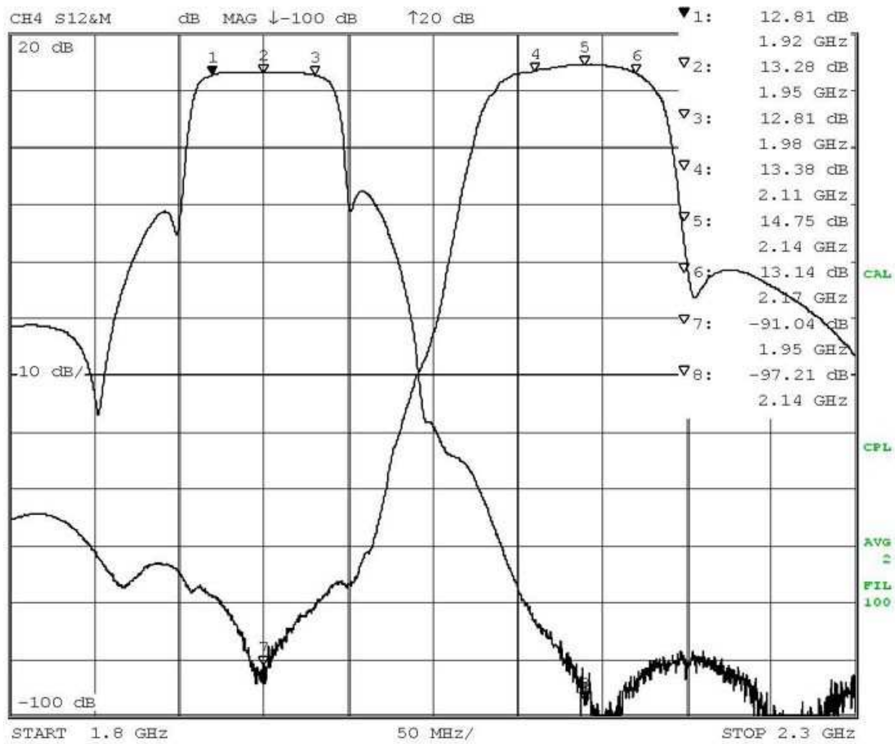

Fig. 3

The graph of Fig. 4 shows the ACLR of the transmit section of the module. The Adjacent Channel Leakage power Ratio measures the amount of power in an adjacent channel due to intermodulation distortion generated by a digitally modulated signal in the main channel passing through a non-linear device, such as a power amplifier. This parameter is a good figure of merit for the transmit path in a UMTS radio. The ACLR has a bandwidth of 3.84 MHz with a spacing from the carrier of 5 MHz. This shows an ACLR of -57 dB. The alternate channel power (ACP) has a spacing of 10 MHz from the carrier and the typical value is -67 dB for this module.

ACLR @ 2140 MHz

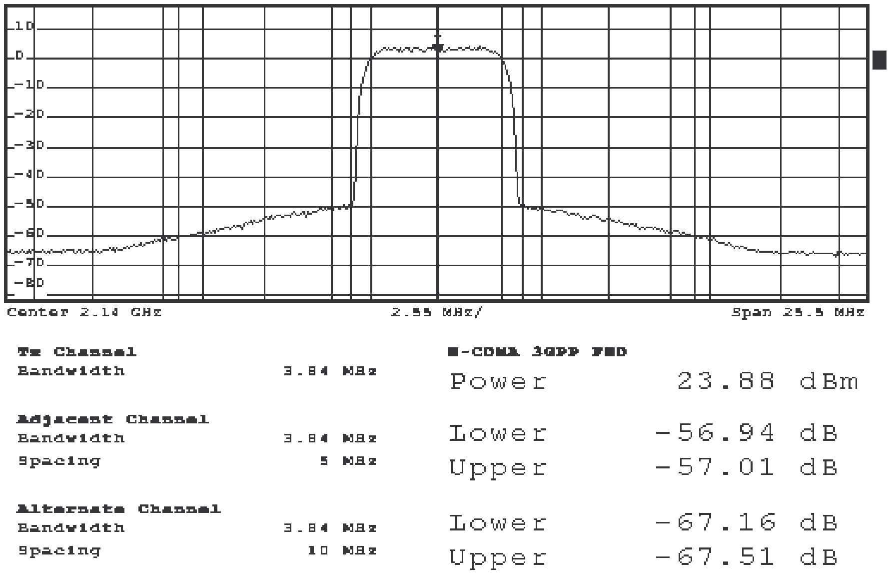

Fig. 4

The graph of Fig. 5 shows the attenuation to 12.75 GHz in the transmit path of the module. This shows a far out attenuation, with respect to the carrier signal, of > 60 dB.

Tx Wideband Sweep

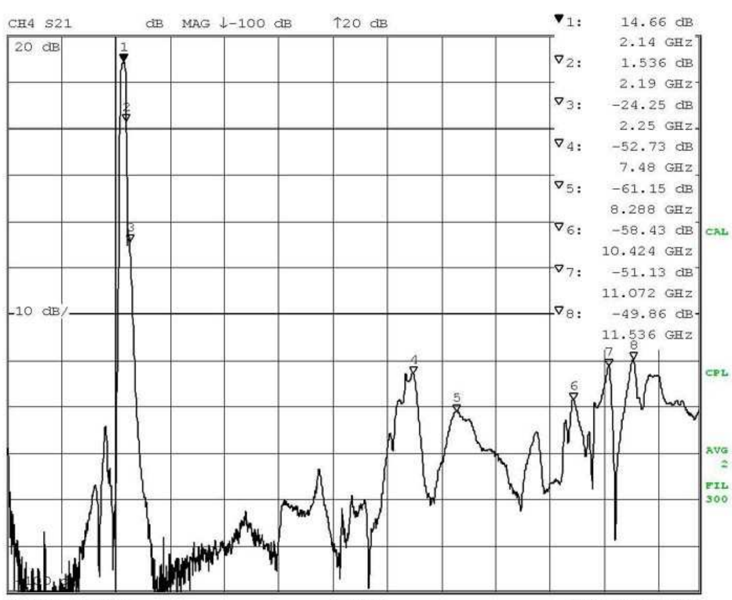

Fig. 5

The graph of Fig. 6 shows the attenuation to 12.75 GHz in the receive path. This has an attenuation of > 33 dB, again with respect to the carrier signal.

Rx Wideband Sweep

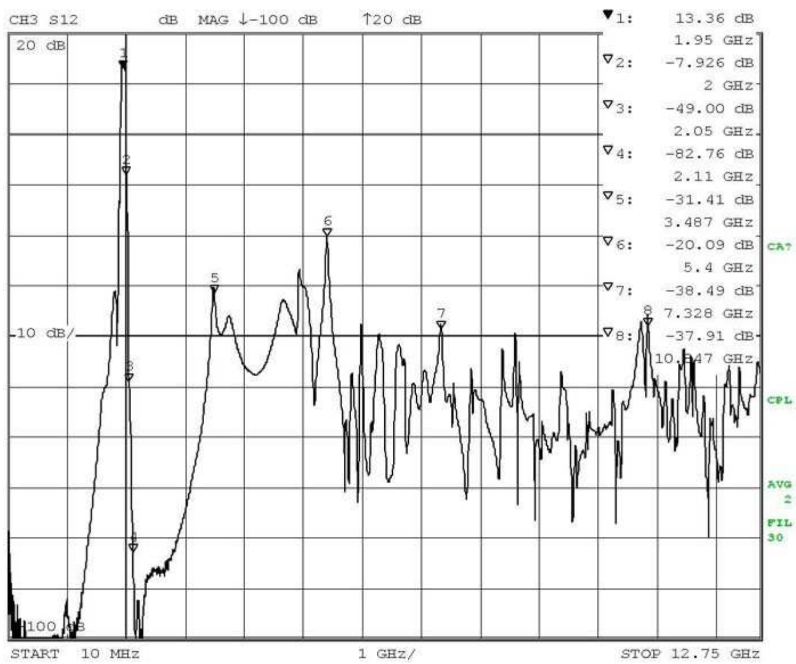

Fig. 6

THERMAL CONSIDERATIONS

Thermal management of the front end module is an important element in system reliability. The front end module PCB has many metallized vias under the power amplifier to drastically reduce its thermal resistance. The power amplifier has a junction-to-case thermal resistance (Θjc) of approximately 9.5°C/watt. At full power, the PA dissipates 6.84 watts of heat at ambient room temperature (3). At 85°C, the PA dissipates 5.96 watts. The maximum ΔT of the power amplifier junction-to-case at room temperature would be (6.84 watts)(9.5°C/watt) = 65°C.

The junction temperature, Tj, under worst case conditions is calculated as follows:

Ta = ambient temperature = 85°C
P @ 85°C = power dissipated = 5.96 watts
Θjc = thermal resistance, PA junction to case = 9.5°C/watt
$\Theta c\text{-}hs$ = thermal resistance, case to heatsink = 1.2°C/watt, assuming a screw is used to secure the module through the motherboard to the heatsink. The heatsink is directly contacting the motherboard.

At 85°C ambient, the calculated junction temperature is..

$$
\begin{aligned}
Tj &= Ta + P\,(\Theta jc + \Theta c\text{-}hs) \\
&= 85°C + 5.96W[(9.5 + 1.2)°C/watt\,] \\
&= 148.8°C
\end{aligned}
$$

Consequently, at 85°C ambient temperature, a $Tj < 150°C$ yields a very robust reliability situation.

MODULE TESTBOARD

The front end module mounted onto a testboard with a heatsink is shown in Fig. 7.

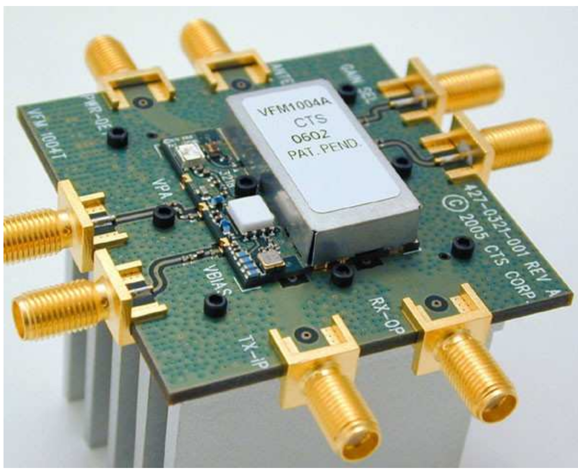

Fig. 7

In this photo, the RF paths are roughly top and bottom. The DC paths are left and right of the module.

CONCLUSION

A front end module for a UMTS picocell has been described. Along with the proper selection of amplifiers, the concept of distributed filtering has been utilized to achieve performance that is compliant with the stringent UMTS standards in a remarkably small size.

REFERENCES:

1. CTS datasheet VFM1004A, Rev. H
2. Conversation with Dr. Andrew Fox, Deltenna Ltd.
3. CTS application note “UMTS Picocell Front End Module” Rev. H