A NIGHTMARE FOR CDMA RF RECEIVER: THE CROSS MODULATION

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Abstract

This paper presents an quantitative analysis on the cross modulation between transmitter CDMA leakage signal and single tone jammer signal, and some design guide lines for overcoming it in receiver design. The analysis shows that duplexer isolation and LNA IIP3 are responsible for the cross modulation. It also shows that LNA IIP3 required for meeting J-STD-018 PCS specification is about 4-5dBm with duplexer isolation of 50dB.

I. INTRODUCTION

The CDMA (Code Division Multiple Access) is becoming the popular worldwide wireless technology, due to the higher subscriber capacity and immunity for interference. So, there is a great demand on high performance CDMA MPs (Mobile Phone).

In designing CDMA MPs, one of the stringent requirements is the single tone desensitization test [1] as shown in Fig. 1, which is inherently aimed at giving VCO (Voltage Controlled Oscillator) phase noise specification. But, in the real world, when doing the single tone desensitization test, FER (Frame Error Rate) is degraded considerably even if the VCO phase noise is quite good and overall receiver IIP3 (two-tone 3rd order Input Intermodulation Product intercept point) is sufficiently high.

This FER degradation was experimentally turned out to be due to the interference occurred by the leakage CDMA signal from the power amplifier of Tx (transmitter) path because of the finite isolation of duplexer. Fig. 2 (a) and (b) show the single tone signal at the output of LNA (Low Noise Amplifier), of which IIP3 is -5dBm, without and with Tx CDMA leakage signal, respectively. Note that there occurs a significant increase of interference around single tone signal. This transfer of amplitude modulated CDMA signal to the unmodulated single tone jammer signal, affecting a signal one channel away from the single tone jammer signal, which is called the cross modulation, is inherent in CDMA MPs, because both the receiver and transmitter are on simultaneously in the active mode and there is no duplexer that has infinite isolation. Both NADC (North America Digital Cellular) and GSM (Global System for Mobile communication) systems avoid this challenging issue by offsetting the transmit and receive time slots.

So, there comes a great need for how to analyze the cross modulation quantitatively and what design guidelines can be given and what the solutions are available in the real CDMA MP world. To the authors' knowledge, this paper is the first one that quantitatively deals with the cross modulation in CDMA MPs and applies it to the design of a 1.8GHz LNA design. The published reports [2]-[4] on transceivers for wireless PCS (Personal Communication System) applications could not take care of the cross modulation problem occurred in the real MPs. We will deal with the cross modulation, which includes which blocks are responsible and what design guidelines can be given.

II. ANALYSIS

The amount of cross modulation depends on the leakage Tx CDMA signal power (this depends on duplexer isolation), the single tone jammer signal power and LNA IIP3. Interestingly, mixer IIP3 does not have a significant relationship with cross modulation even though it determines the overall receiver intermodulation performance, that is, overall IIP3 of receiver. That mixer has a negligible effect on cross modulation interference is because of the image rejection RF filter in front of the mixer. Fig. 3 shows the Pcmod (cross modulation power that is soaked into in-band and that is referred to input of receiver) contributed by LNA and mixer, respectively. Note that Pcmod generated by mixer is 30-40dB lower than that of LNA.

What value of LNA IIP3 is sufficient or what value of duplexer isolation is required for meeting the single tone desensitization specification?

The cross modulation is the third order distortion, which means that when the output of an amplifier is expressed in the following form, the cross modulation comes from the cubic term.

$$V_{out} = a_1 V_{in} + a_2 V_{in}^2 + a_3 V_{in}^3 + \cdots,$$

where Vout is the output voltage and Vin is the input voltage. In a case of two input signals, when one of them is a pure sinusoid and the other a sinusoidally modulated signal, the transfer of the modulation of one signal to the unmodulated occurs due to the cubic term of the nonlinearity.

Assuming that CDMA signal is one form of the sinusoidally modulated signals, Pcmod can be described as following expression.

$$\begin{aligned} Pc\,mod = 2P_{TX} + P_{Jam} - 2IIP3_{LNA} + 20\log m(dB) \\ + 12(dB) + a(dB) \end{aligned},$$

where Pcmod expressed in dBm / 1.23MHz is the cross modulation power referred to input of receiver, which is soaked into channel 1.25MHz away for PCS application, P_{TX} expressed in dBm / 1.23MHz, the Tx CDMA signal leakage power at the input of receiver, P_{Jam} the single tone jammer signal at the input of receiver, and m the modulation index fitting parameter. Notice that the first three terms are the same as those of two tone intermodulation product.

The parameter m depends on the degree of the amplitude modulation of CDMA signal, which is empirically found to range from 0.6 to 0.7.

The parameter α called the soaking factor denotes the amount of cross modulation power that penetrates into the in-band as shown in Fig. 4. The soaking factor mainly depends on the channel spacing and channel bandwidth. In the case of 1.8GHz PCS applications, the soaking factor is experimentally found to range from 12 to 15dB.

Note that Pcmod increases by 2dB as the Tx leakage power increases by 1dB, while Pcmod increases by 1dB as the single tone jammer power increases by 1dB.

III. DISCUSSION

Fig. 5 shows Pcmod vs. LNA IIP3, where Pref denotes the tolerable Pcmod level obtained from the consideration that Pcmod should be lower than thermal noise floor. The required LNA IIP3 is approximately 4-5dBm with duplexer isolation of 50dB. Fig. 6 depicts the required duplexer isolation with given LNA IIP3, which gives the design guide line for duplexer. Thus, from Figs. 5 and 6, we can decide the LNA IIP3 and duplexer isolation specifications to overcome the the cross modulation interference in CDMA MPs.

As a measurement result, a LNA with IIP3 of about +5dBm has been designed and fabricated using 0.5um BiCMOS technology. Chip photography is given in Fig. 7, and its cross modulation interference is measured as in Fig. 8. Note that there is a significant decrease of the interference compared to Fig. 2(b).

IV. SUMMARY

This paper quantitatively analyzes the cross modulation phenomenon inherent in CDMA MPs and gives the design guide lines of LNA and duplexer for overcoming it. The required LNA IIP3 is about 4-5dBm with duplexer isolation of 50dB.

References

[1] TIA / EIA / J-STD-018, “Recommended ~”.

[2] John R. Long, et al., “A Low Voltage ~ ”, IEEE ISSCC 1995.

[3] F. McGrath, et al., “A 1.9GHz GaAs ~ “, IEEE Trans. on MTT, July, 1995.

[4] P. Landy, et al., “IS-95A ~ “, 1998 Annual Wireless Symposium.

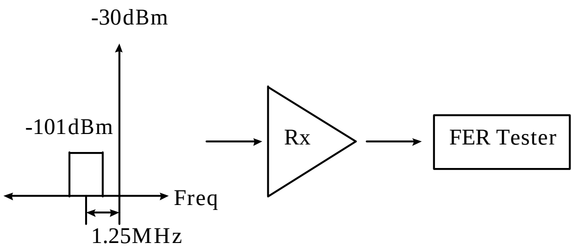
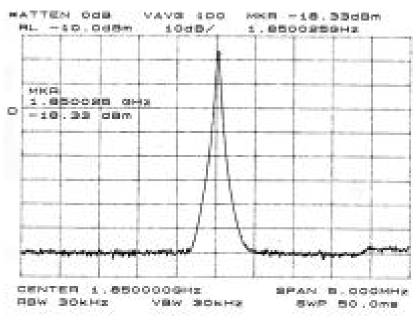
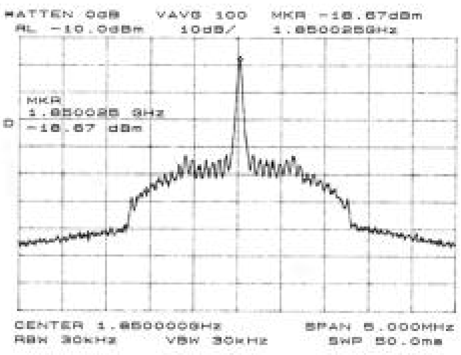


Fig. 1 Single tone desensitization test in J-STD-018



(a)



(b)

Fig. 2 Measured Pcmod at the output of LNA (IIP3=-5dBm) (a) without and (b) with Tx leakage

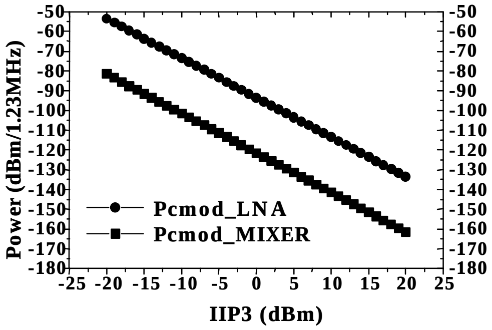


Fig. 3 Pcmod contributed by LNA and mixer

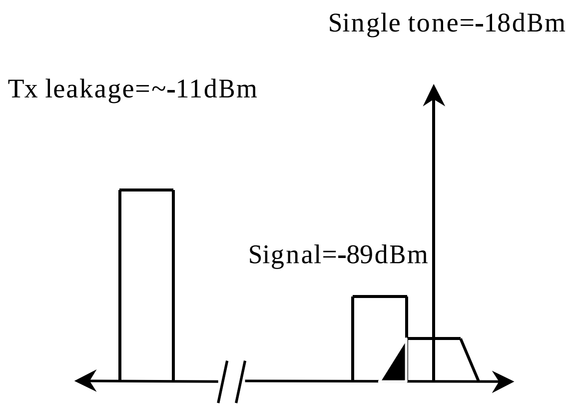


Fig. 4 Pcmod at the output of LNA. Dark area denotes soaking factor α.

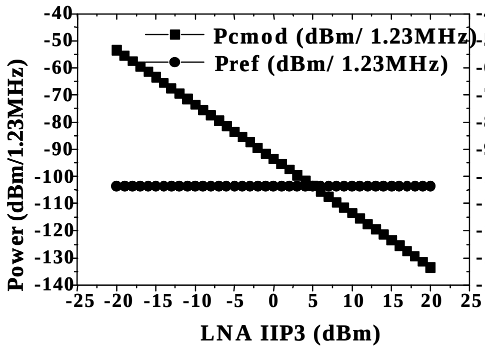


Fig. 5 Pcmod vs. LNA IIP3

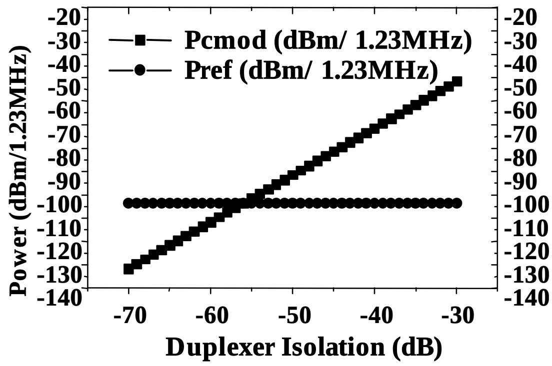


Fig. 6 Pcmod vs. duplexer isolation

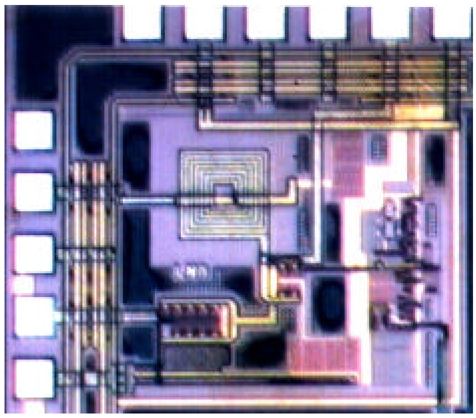


Fig. 7 Chip micro-photography of LNA with IIP3 of +5dBm

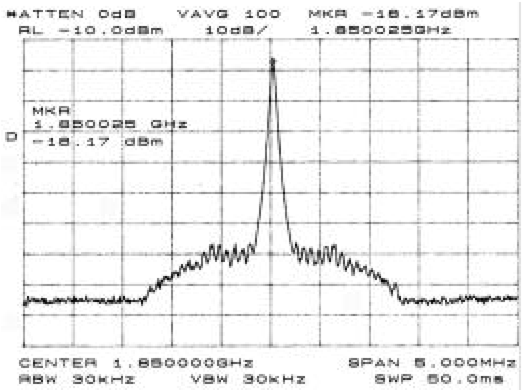


Fig. 8 Measured Pcmd at the output of LNA (IIP5=+5dBm)