A Feedforward Power Amplifier with Loops that can reduce RX Band Noises as well as Intermodulation Distortion Signals

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Abstract

In this paper, a new power amplifier is proposed for reduction of amplified RX band noise signals as well as TX band intermodulation distortion signals using feedforward technique. The proposed power amplifier, which contains two loops, TX band intermodulation distortion signals cancellation loop and RX band noise signals cancellation loop, can provide duplexer with low TX path insertion loss for various wireless communication systems due to choice of loose RX attenuation characteristic. The operation of the proposed amplifier is described graphically based on the conceptual schematic diagram. This power amplifier is implemented for IMT-2000 base-station frequency band. A two-tone test for power amplifier is done at 2.14GHz with frequency spacing of 5MHz, 31dB reduction of intermodulation distortion signals is obtained. Experimental loop test shows that the cancellation performance of TX band intermodulation distortion signals and RX band noise signals are more than 26dB and 30dB overall TX and RX band, respectively.

Ⅰ. Introduction

In various communication systems, it is important to isolate undesired signals from desired signals for good transmission voices and data. In code division multiplexing access (CDMA) system, amplified TX path signals must be transmitted through antenna and not be transmitted to RX path. Because amplified TX path signals are operated as noises to RX signals. So, the price of RF front-end section is influenced by the isolation characteristic between TX and RX path signals mainly.

On amplifying TX band signals, RX band noise signals, as shown in Fig. 1, are also amplified and transferred to duplexer without reduction and some of them are induced into RX path. Thus, RX band signal to noise ratio (SNR) is decreased. Also, to improve the isolation characteristic to RX path, the RX band attenuation of TX band pass filter should be increased. It increases the TX path insertion loss naturally. Thus, to compensate for the increased TX path insertion loss, output power of TX amplifier should be increased. As the output power increases, the cost for implementing the power amplifier is also increased with the same rate. Finally, to improve the isolation characteristic, it should be followed significant rising of the system prices.

In case of TX power amplifier, intermodulation distortion signals are present additionally when TX signals are amplified. As a result of efforts on cancellation of intermodulation distortion signals, several methods are introduced[1]-[9]. Feedforward linearization method has been a popular technique for reducing distortion at the output of multi-carrier cellular base-station. Ideally, distortion signals would be cancelled by an infinite amount over unlimited bandwidth. However the practical difficulties of accurately matching phase, amplitude, and delay impose limits. Especially since input and output impedance values for matching optimum high power in high power transistors are very small, so impedance matching to characteristic impedance (e.g. 50Ω) can be realized only narrow band. So it is very difficult to realized feedforward type wideband linear power amplifier in high power level[10].

In this paper, I propose a new feedforward power amplifier with two loops, TX band intermodulation distortion signals cancellation loop and RX band noise signals cancellation loop, to reduce the intermodulation distortion signals and to improve the RX rejection characteristic. The RX band noise signals cancellation loop, which has RX band pass filter to reject the TX signals, is very similar to second loop configuration of feedforward technique. By employing the RX band cancellation loop additionally, even though TX band intermodulation distortion signals cancellation loop has narrow bandwidth property, RX band noise signals can be reduced in TX output significantly.

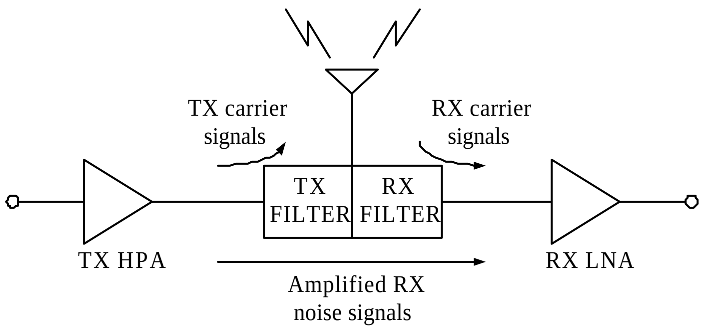


Fig. 1. Signals flow in full duplexing communication system

Ⅱ. BLOCK DIAGRAM AND OPERATION OF THE PROPOSED POWER AMPLIFIER

The block diagram of the proposed power amplifier is shown in Fig. 2(a). The operation of the proposed amplifier is well illustrated with four-tones spectra that are represented in Fig. 2(b)~(h). Input signals, as shown in Fig. 2(b), consist of two-tone TX signals and RX noise signals, these signals are divided by coupler 1 into main path and sub-path. When signals injected into main path go through the main amplifier, intermodulation distortion signals are generated at output of the main amplifier (point A shown in Fig. 2(a)). It is directional coupler that parts of signals are extracted at output section of the main amplifier. Extracted signals are injected into subtracter in TX intermodulation distortion signals cancellation loop and RX band pass filter in RX noises cancellation loop through Wilkinson divider, respectively. Other signals injected into subtracter are shown in Fig. 2(d), and only intermodulation distortion signals are present at subtracter output (point B), as shown in Fig. 2(e). Intermodulation distortion signals in subtracter output are adjusted to satisfy conditions (1) and (2) by variable attenuator(A_2), phase shifter(ϕ_2) and error amplifier 1.

(1)The magnitude of the signals which injected into coupler 3 via TX intermodulation distortion signals cancellation loop must have the same magnitude as intermodulation distortion signals which injected through delay line.

(2)The phase difference between signals which are injected into coupler 3 via TX distortion signals cancellation loop and intermodulation distortion signals which are injected through delay line is 180°.

Under the situation to satisfy conditions (1) and (2), intermodulation distortion signals are eliminated at output section of the coupler 3(point C), as shown in Fig. 2(f). Cancellation limitations are given by function of phase error and amplitude error as follows, respectively [3].

$$Cancellation(dB) = 10\log\left[\sin^2 f_e + (1-\cos f_e)^2\right] \qquad (1)$$

$$Cancellation(dB) = 20\log\left[\left|10^{E/20} - 1\right|\right] \qquad (2)$$

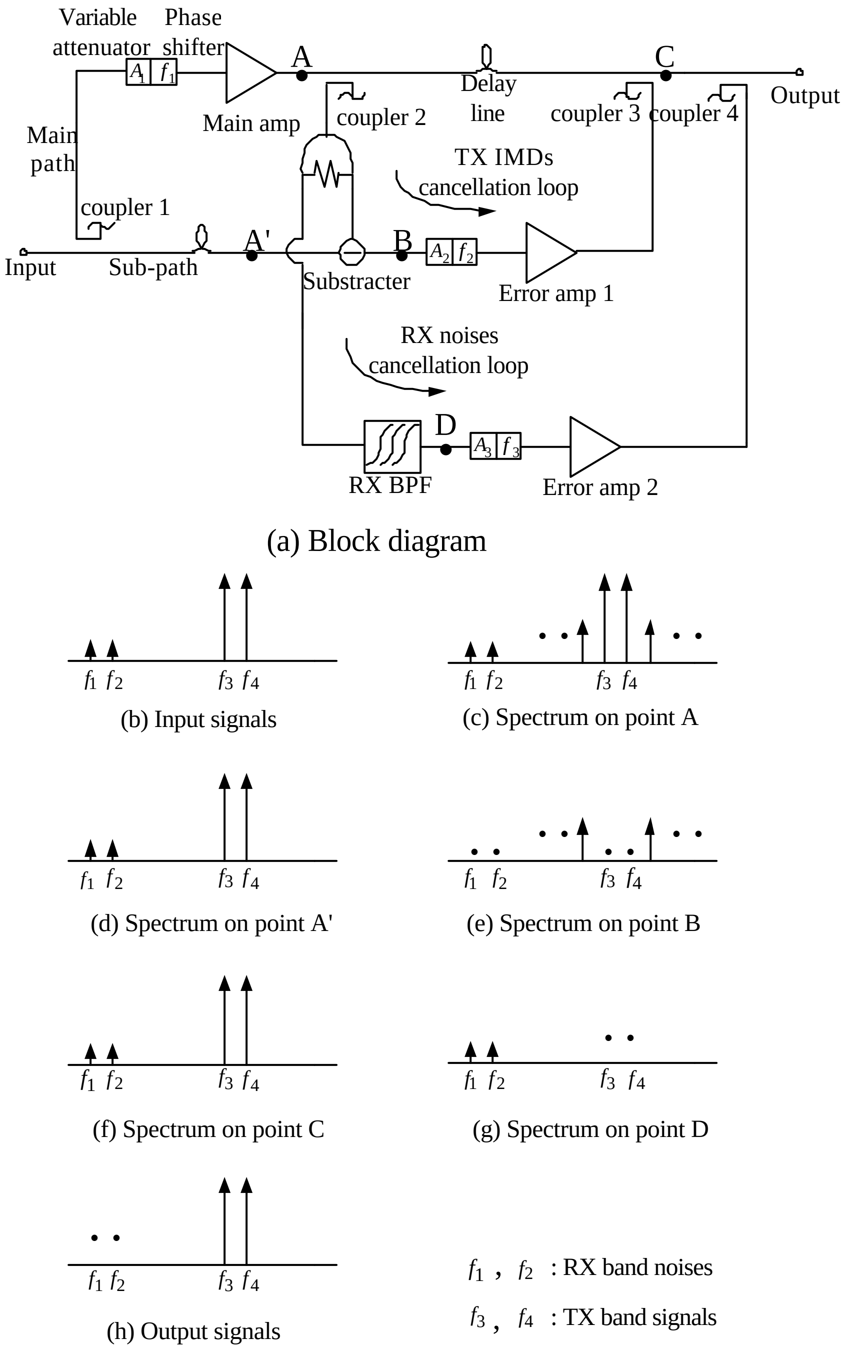


Fig. 2. (a) The block diagram of the proposed power amplifier
(b) Input signals, (c) Spectrum on point A, (d) Spectrum on point A', (e) Spectrum on point B, (f) Spectrum on point C, (g) Spectrum on point D, (h) Output signals

In above equation, ϕ_e and E mean the phase error and the amplitude error in dB between the two paths, respectively. However, RX noise signals are not still eliminated. These phenomena are caused by limited frequency property of circuits in TX intermodulation distortion cancellation loop. These results were obtained with conventional feedforward type power amplifier. Thus, amplified RX noise signals are transferred to duplexer without reduction, these signals decrease the system performance.

In this paper, I employed additional cancellation loop to eliminate RX noise signals. RX band pass filter is contained to extract the only RX noise signals in this loop, and spectrum at the RX band pass filter output (point D) is shown in Fig. 2(g). RX band pass filter can be exchanged to TX band rejection filter. Similarly operation of TX intermodulation distortion signals cancellation loop, RX noise signals through RX band pass filter are adjusted by variable attenuator(A_3), phase shifter(ϕ_3) and error amplifier 2. Fig. 2(h) shows final output signals that are eliminated RX band noise signals. The delay time of RX band noise signals in passing through RX band pass filter, variable attenuator (A_3), phase shifter (ϕ_3) and error amplifier 2 is compensated with main path delay line. Main delay line that is connected at main amplifier output port is not only used as delay line to compensate delay time of TX intermodulation cancellation loop but also used to compensate delay time of RX noises cancellation loop. Since noise signals level is very low, error amplifier 2 is realized with very small power amplifier. And when coupler 4 has loosing coupling coefficient, reduction of TX signals can be ignored.

Ⅲ. DETAILED CIRCUIT DESIGN

The implemented main amplifier consists of an ERA-5SM manufactured by Mini-Circuit and a XHL-21336 and a MRF-19030 manufactured by Motorola, it has 57dB gain and 0.24dB flatness over IMT-2000 base-station TX band. But this main amplifier has also 56.3±0.5dB gain in RX band, so noise signals are also amplified. The output characteristic of main amplifier is shown in Fig. 3. Error amplifier 1 in TX intermodulation distortion signals cancellation loop consists of two ERA-5SMs and a XHL-21336, error amplifier 2 in RX noises cancellation loop consists of four ERA-5SMs. Total gains of error amplifier 1 and 2 are 64dB and 68dB, respectively.

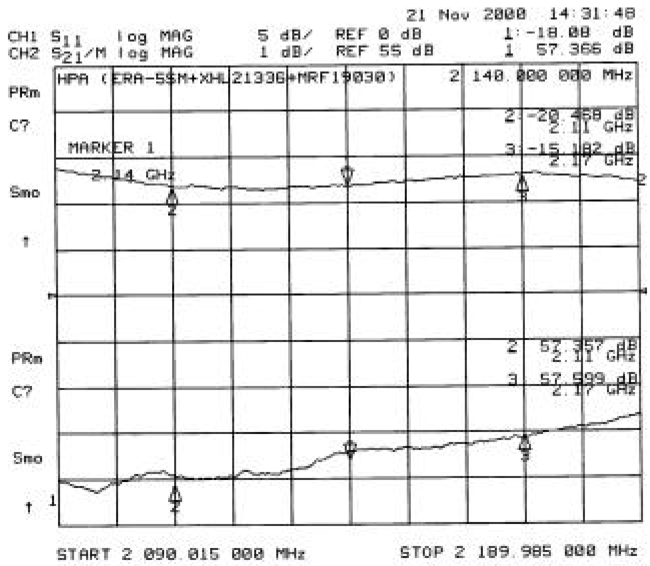


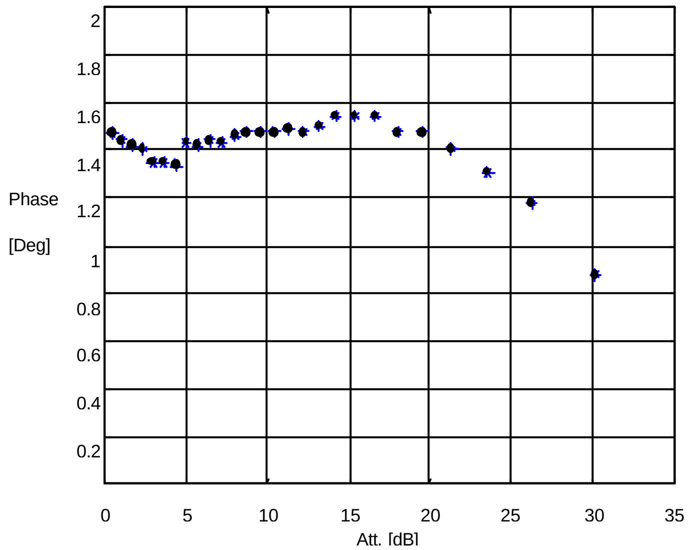
Fig. 3. The output characteristic of main amplifier

The 30dB microstrip directional coupler manufactured by KMW (KDCNRW30-32-01) and the 10dB directional coupler manufactured by Anaren(1A1305-10) are used for linearization loop. For subtraction circuit, Wilkinson coupler is implemented. Variable phase shifter is a reflection type hybrid phase shifter using varactor diode [11]. The phase shifter has about 120 degrees of the adjustable phase control range.

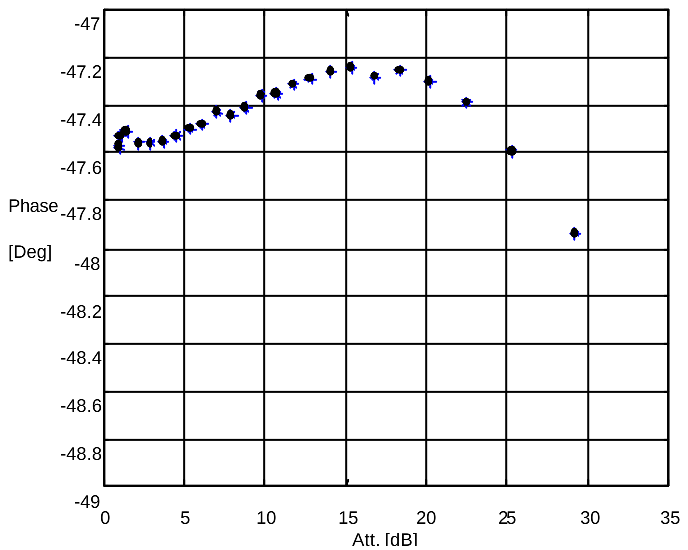
The variable attenuator is a low phase shifting attenuator using PIN diode [12]. Because PIN diode has parasitic components besides junction resistance, phase shifting phenomenon on attenuation is occurred. Series inductance component is operated dominantly. If external capacitance is connected and resonated with series inductance component, phase shifting phenomenon can be minimized. So open stub is connected PIN diode to resonate inductance component of PIN diode. Phase variations are less than 0.8^{o} in IMT-2000 base-station TX/RX band for 30dB attenuation range. Fig. 4 is phase variation characteristic to attenuation of implemented attenuator in IMT-2000 base-station TX and RX band.

The RX band pass filter using $\lambda/4$ coupling line technique of insertion loss method is implemented for extraction of RX noise signals [13][14]. The characteristic of implemented RX band pass filter is shown in Fig. 5, it has

1.8dB insertion loss over RX frequency band and 24dB attenuation characteristic over TX frequency band.



(a) Phase variation characteristic of TX band attenuator



(b) Characteristic of RX band attenuator

Fig. 4. Phase variation characteristic to attenuation of implemented attenuator in IMT-2000 base-station TX/RX band

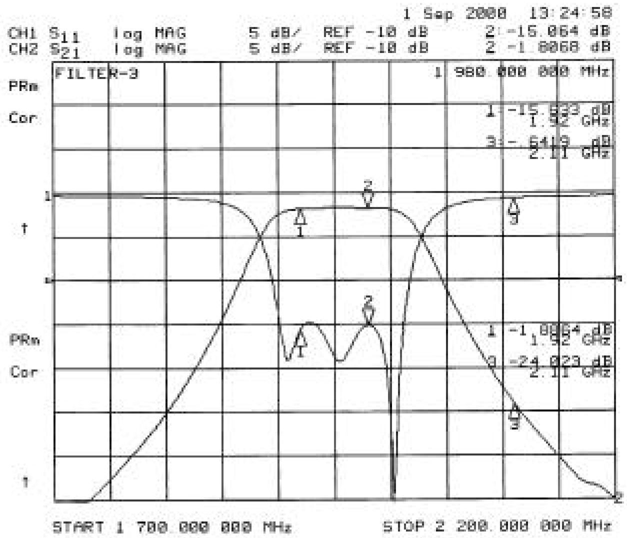


Fig. 5. Characteristic of RX band pass filter

Ⅳ. EXPERIMENTAL RESULTS

When output power of main amplifier is 36.4dBm/tone, two-tone intermodulation distortion characteristic of main amplifier is shown in Fig. 6. Fig. 6 shows that the intermodulation distortion characteristic of main amplifier is 33.5dBc. The spectrum of subtracter output is shown in Fig. 7, it

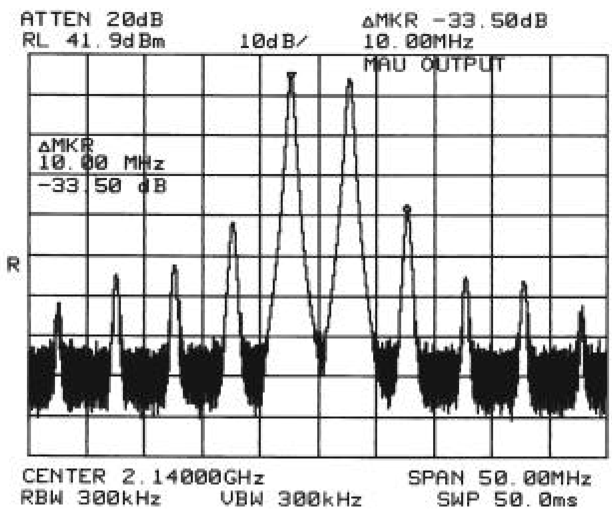


Fig. 6. 2-tones intermodulation characteristic of the main amplifier before linearization

shows that rejection characteristic of main carrier signals is 50.7dBc. The cancellation performance of intermodulation distortion signals, shown in Fig. 8, is more than 31dB.

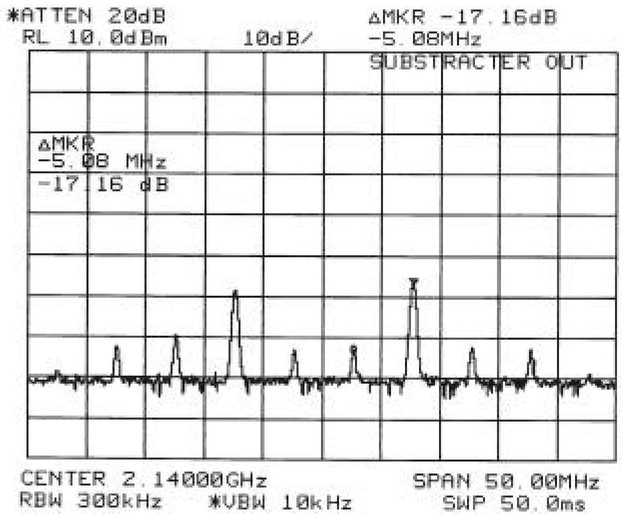


Fig. 7. Subtracter output spectrum

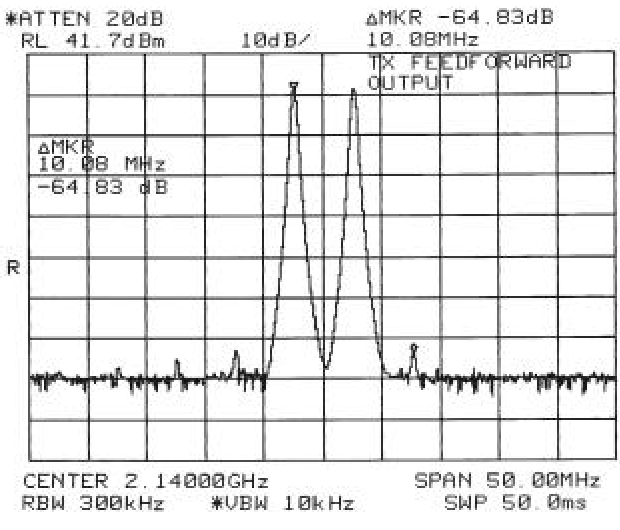


Fig. 8. 2-tones intermodulation characteristic of the feedforward amplifier after linearization

To show the rejection characteristic of RX band noise signals effectively, TX band intermodulation distortion signals cancellation loop and RX band noise signals cancellation loop were individually measured and tuned to have the best signal cancellation over TX and RX band by adjusting the variable attenuators and phase shifters. For the measurement of TX band intermodulation distortion signals cancellation loop, RX band noise signals cancellation loop was disconnected and replaced by 50-Ω termination. Also, for the measurement of RX band noise signals cancellation loop, TX band intermodulation distortion signals cancellation loop was disconnected and replaced by 50-Ω termination. Fig. 9 and Fig. 10 were shown TX band intermodulation distortion signals cancellation loop characteristic and RX band noise signals cancellation loop characteristic, respectively. Rejection characteristics of intermodulation distortion signals and noise signals are more than 24.2dB and 21.8dB over operating bands. In RX band noise signals cancellation loop, there is a group delay deviation due to RX band pass filter. This delay deviation gives serious limitation of cancellation from equation (1). Thus, more excellent rejection for RX band noise signals cancellation loop can be expected by decreasing the delay deviation characteristic of RX band pass filter, which means improvement of phase balance between main path and RX noises cancellation path.

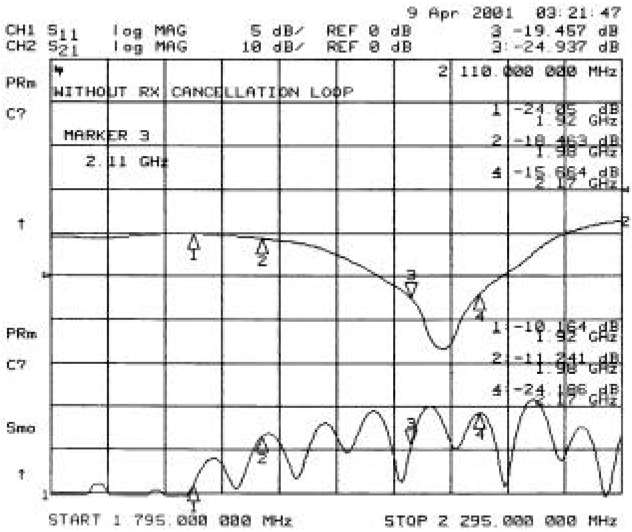


Fig. 9 TX band intermodulation distortion signals cancellation loop characteristic

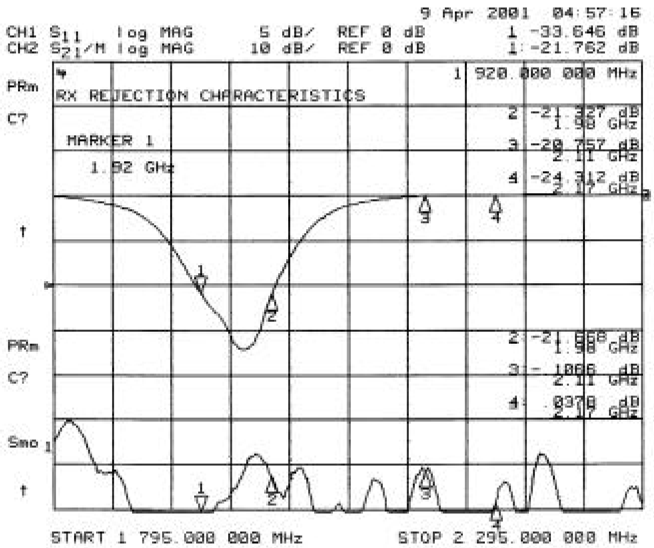


Fig. 10 RX band noise signals cancellation loop characteristic

To show the rejection characteristic of RX band noise signals as well as TX band distortion signals effectively, TX band intermodulation distortion signals cancellation loop and RX band noise signals cancellation loop were connected simultaneously and tuned to have the best signal cancellation over TX and RX band by adjusting the variable attenuators and phase shifters. With RX band noise signals cancellation loop, RX band noise signals are reduced more than 18dB which characteristics is worse than characteristics of RX band noise signals cancellation loop alone. Because combine coupler of RX band noise signals cancellation loop is attached behind of combine coupler of TX band intermodulation distortion signals cancellation loop, there is some unbalance between noise signals of RX band noise signals cancellation loop. Fig. 11 shows TX band intermodulation distortion signals cancellation and RX band noise signals cancellation characteristics in case of with/without RX band noise signals cancellation loop. With TX band intermodulation distortion signals cancellation and RX band noise signals cancellation loop, TX band intermodulation distortion signals can be reduced more than 26dB and RX band noise signals can be reduced more than 30dB.

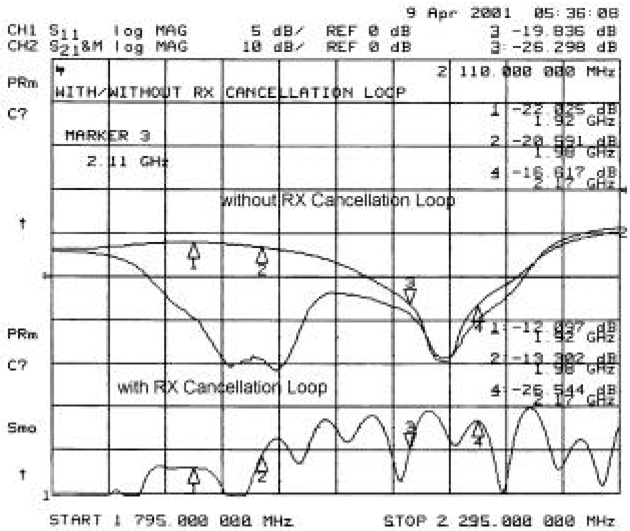


Fig. 11 TX band intermodulation distortion signals cancellation and RX band noise signals cancellation characteristics in case of with/without RX band noise signals cancellation loop

Ⅴ. CONCLUSIONS

To reduce the RX band noise signals, a new feedforward TX power amplifier with RX band noise signals cancellation loop is proposed. The power amplifier is implemented for IMT-2000 base-station frequency band. By employing the RX band noises cancellation loop, the rejection performance of RX band noise signals is improved more than 30dB for RX full band of IMT-2000. Also, TX intermodulation distortion signals are reduced more than 26dB due to feedforward linearization technique. Thus, RX noise signals that induced into RX path decrease and RX isolation characteristic toward TX for duplexer can be looser than the cases of conventional power amplifier. Therefore, it can be expected that the reduction of costs and occupied volume for implementing the duplexer with high TX to RX isolation characteristic. In addition, it can be reduced that the output power of the amplifier due to duplexer with low TX path insertion loss.

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