A NOVEL SUB-HARMONIC PUMPING DIRECT CONVERSION RECEIVER WITH HIGH INSTANTANEOUS DYNAMIC RANGE

Mitsuhiro SHIMOZAWA, Kenji KAWAKAMI, Kenji ITOH, Akio IIDA and Osami ISHIDA

Information Technology R&D Center
Mitsubishi Electric Corp.
5-1-1 Ofuna, Kamakura-city, Kanagawa 247,JAPAN

ABSTRACT

A novel sub-harmonic pumping direct conversion receiver (SHP-DCR) employing antiparallel diode pair (APDP) is proposed for high instantaneous dynamic range receivers used in mobile communications. The proposed SHP-DCR can suppress even harmonic mixing products, such as second order intermodulation (IM2) and LO noise that interfere a desired baseband signal. Moreover, the design condition of load resistance is indicated by analytical and experimental approaches for improving diode mixer disadvantages of lower conversion gain and higher LO power. A developed L-band SHP-DCR without a low noise amplifier achieves NF of 18.5dB, IP3 at input port of 3dBm and IM2 is below -90dB in the actual input range.

INTRODUCTION

A direct conversion receiver that converts RF signal to baseband signal directly is suitable for small sized terminals especially used in mobile communications[1][2]. But instantaneous dynamic range of conventional direct conversion receivers is extremely small compared with heterodyne receivers, because there are undesired baseband components produced by second order mixing. This second order mixing products in baseband are as follows:

(a)IM2 by large two signals in RF,

(b)baseband noise by self-mixing between LO and LO noise.

So there are less direct conversion receivers in actual mobile communications, except VHF pager receivers[3][4].

In this paper, we propose a novel SHP-DCR with APDP to reduce second order mixing products and achieve high instantaneous dynamic range. Noise and distortion characteristics of SHP-DCR are also described in analytical and experimental approaches. In addition, conversion gain of SHP-DCR can be improved by high load resistance R_L for low noise characteristics.

CONFIGURATION OF SUB-HARMONIC PUMPING DIRECT CONVERSION RECEIVER

Fig.1 shows the configuration of proposed SHP-DCR consisting of sub-harmonic pumping mixers, 90degree hybrid power divider for RF, in-phase power divider for LO and baseband amplifiers (BB-AMP). RF signal(f_{rf}) and LO(f_p) are mixed by APDP[5], then baseband output signal ($|f_{rf}-2f_p|$) is produced at load resistance R_L, and is amplified by BB-AMP. This R_L is designed higher than 50Ω for improving conversion gain and reducing LO power.

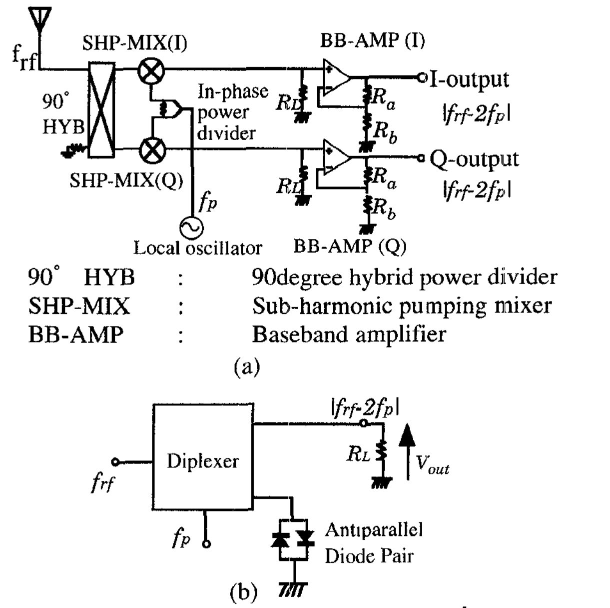

Fig.1 The configuration of proposed sub-harmonic pumping direct conversion receiver : (a) sub-harmonic pumping direct conversion receiver, and (b) sub-harmonic pumping mixer with antiparallel diode pair.

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SECOND ORDER MIXING CHARACTERISTICS OF APDP

Fig.2 shows desired signal and interference by second order mixing products in conventional direct conversion receivers. Fig.2(a) shows IM2 by large two signals in RF, and fig.2(b) shows baseband noise by self-mixing between LO and LO noise. In the SHP-MIX, mixing products $f_{out}(m,n)$ are

$$f_{out}(m,n) = \left| m \cdot f_p \pm \sum_{i=1}^{nc} (\pm n_i \cdot f_i) \right| \qquad m \geq 0, n_i \geq 0 \tag{1}$$

where $f_i(i=1,2,\cdots nc)$ are desired and undesired input signals. The current $i_{out}(t)$ of f_{out} is

$$i_{out}(t) \approx 4 I_s \cdot \mathrm{I_m}(\alpha \cdot \mathrm{V_P}) \cdot \prod_{i=1}^{nc} \mathrm{I_{ni}}(\alpha \cdot \mathrm{V_i}) \cos(2\pi \cdot f_{out}(m,n)) \quad \left(m \pm \sum_i^{nc} (\pm n_i) = odd \right)$$

$$= 2(1-\varepsilon) \cdot I_s \cdot \mathrm{I_m}(\alpha \cdot \mathrm{V_P}) \cdot \prod_{i=1}^{nc} \mathrm{I_{ni}}(\alpha \cdot \mathrm{V_i}) \cos(2\pi \cdot f_{out}(m,n)) \quad \left(m \pm \sum_i^{nc} (\pm n_i) = even \right) \tag{2}$$

where $I_n(\bullet)$ is the nth order modified Bessel function of second order and ε indicates balance factor between two diode currents. In case of a complete matched APDP that ε is equal to 1, mixing products that have even order harmonic numbers are never produced. By employing monolithic APDP with superior matching characteristics, interferences by second order harmonic mixing products can be extremely suppressed.

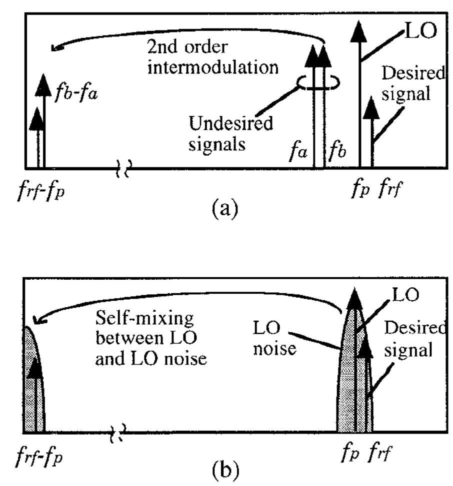

Fig. 2 Desired signal and interference by second order mixing products : (a) 2nd order intermodulation | f_b-f_a | by large two signals f_a and f_b, and (b) baseband noise by self-mixing between LO and LO noise.

NOISE CHARACTERISTICS OF SUB-HARMONIC PUMPING DIRECT CONVERSION RECEIVER

The noise figure of the proposed SHP-DCR as shown in Fig.1 is:

$$F_t = L_{div}^2 \left(F_{mix} + \frac{F_{bb} - 1}{G_{mix}^2} \right)$$

$$F_{bb} = 1 + \frac{\overline{V_{nbb}^2}}{2kTR_0}, \quad \overline{V_{nbb}^2} = 4kTR_i + E_n^2 + (I_n R_i)^2$$

$$R_i = \frac{R_{out} \cdot R_L}{R_{out} + R_L} + \frac{R_a \cdot R_b}{R_a + R_b} \tag{3}$$

where F_{mix} and G_{mix} are noise figure and voltage gain of the SHP-MIX, respectively, and L_{div} is voltage loss of the 90degree hybrid power divider, k is the Boltzman's constant, T is the absolute temperature, R_0 is the internal impedance of a generator, E_n and I_n are noise voltage and current density of the BB-AMP, R_{out} is the baseband impedance of the SHP-MIX, R_a and R_b are resistances shown in Fig.1. From equation (3), higher G_{mix} is required for reducing NF degradation by BB-AMP noise $\overline{V_{nbb}^2}$. Fig.3 shows a linear analysis model for G_{mix} of SHP-MIX. In the analysis, we consider f_{rf}, f_{rf}-$2f_p$, and f_{rf}+$2f_p$ for the frequency conversion matrix. The RF matching circuit is represented by an ideal transformer. G_{mix} of SHP-MIX is derived as follows:

$$G_{mix} = \frac{-Y_{12}}{\sqrt{\left(Y_{11}Y_{22} - Y_{12}^2 + \frac{Y_{11}}{R_L}\right)\left(Y_{22} + \frac{1}{R_L}\right)R_0}}$$

$$Y_{11} = 2g_0 - \frac{4g_2^2}{y_d + 2g_0}, \quad Y_{12} = 2g_2 - \frac{4g_2 g_4}{y_d + 2g_0}$$

$$Y_{22} = 2g_0 - \frac{4g_4^2}{y_d + 2g_0}, \quad g_n = \alpha\, I_s I_n(\alpha V_p) \tag{4}$$

where y_d is the terminal admittance of f_{rf}+$2f_p$ port, α is the constant, I_s is the saturation current of diode and V_p is the LO voltage. From equation (4), higher R_L can achieve a higher (absolute) G_{mix}, and G_{max} as maximized G_{mix} can be expressed in case of the infinite R_L

$$G_{max} = \frac{-Y_{12}}{\sqrt{Y_{22}(Y_{11}Y_{22} - Y_{12}^2)R_O}} \tag{5}$$

Fig.4 shows a noise analysis model of SHP-MIX. In this model, we consider noise components in the upper sideband of f_{rf}, in the lower sideband of f_{rf} and at f_{rf}-$2f_p$. Noise figure F_{mix} of SHP-MIX can be approximated in low series resistance of APDP and an infinite R_L as follows:

$$F_{mix} = \frac{1}{kTR_0} \cdot \frac{\overline{V_{nout}^2}}{G_{mix}^2}$$

$$\cong 2 + \frac{1}{kT} \cdot \frac{Y_{22}}{Y_{11}Y_{22} - Y_{12}^2} \left\{ 1 + \frac{1}{2} \left(\frac{2Y_{11}Y_{22} - Y_{12}^2}{Y_{12}Y_{22}} \right)^2 \right\} \overline{I_e^2} \tag{6}$$

where $\overline{V_{nout}^2}$ is the noise voltage produced at load resistance R_L

and $\overline{I_e^2}$ is shot noise of diode.

Fig.5 shows calculated G_{mix} and F_t by equations (3), (4) and (6). α of 33.1, I_s of 0.128pA, F_{bb} of 15dB and L_{div}=4dB are used in the calculation. This calculation reveals the following:

(1) G_{mix} becomes higher than 1. SHP-MIX cannot have power gain, but has voltage gain.

(2) APDP can be matched with higher R_L in case of lower LO power P_p. In addition shot noise $\overline{I_e^2}$ can be made lower by low local current.

(3) From (1) and (2), noise figure of SHP-DCR can be improved in case of a higher load resistance R_L.

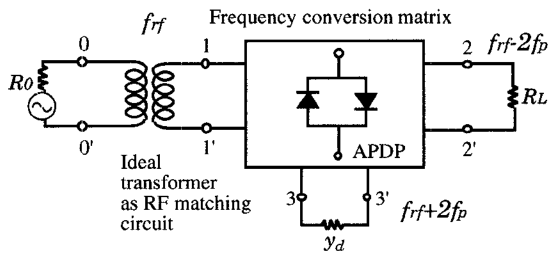

Fig. 3 Linear analysis model for voltage gain G_{mix} of SHP-MIX.

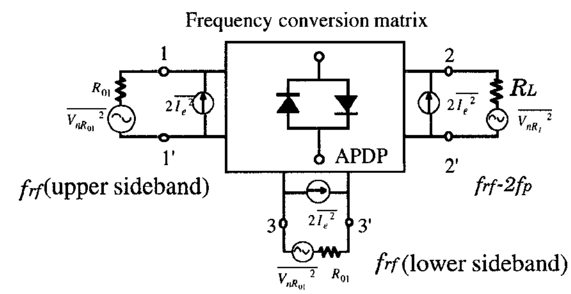

Fig.4 Noise analysis model of SHP-MIX.

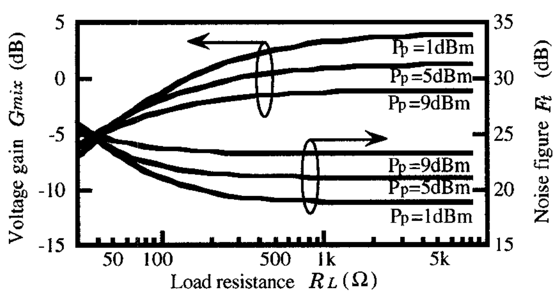

Fig.5 Calculated voltage gain of SHP-MIX and noise figure of SHP-DCR.

EXPERIMENTAL RESULTS

An L-band SHP-DCR has been developed. The SHP-MIX consists of an APDP, an open and a short circuited stubs[6]. Fig.6 shows intermodulation characteristics of the SHP-MIX at P_p=1dBm. IM2 is lower than -90dB in actual input power region. IP3 at input port of 3dBm is obtained.

Fig.7 shows a measurement system for baseband noise voltage density by self-mixing between LO and LO noise, and Fig.8 shows measurement result. Compared with a conventional diode double balanced mixer, the baseband noise voltage density of SHP-MIX is lower than -30dB.

Fig.9 shows voltage gain G_t and noise figure F_t of SHP-DCR with load resistance 1kΩ, R_a=1kΩ, R_b=10Ω, E_n=1.0nV/Hz$^{0.5}$ and I_n=2.0pA/Hz$^{0.5}$. F_t of 18.5dB and G_t of 39dB that includes L_{div} of 4dB, G_{mix} of 3dB and G_{bb} of 40dB is achieved at P_p=1dBm. Calculated results agree with well experimental ones.

Fig.10 shows a concept of instantaneous dynamic range of mobile communications. Under this concept of Japanese digital cordless phone named PHS (bit rate=384kHz, band width=288kHz), predicted minimum RF level that satisfies required bit error rate 0.01 is -90dBm including modem degradation of 3dB. Under the same condition, maximum undesired 2 tone RF input signals with a level of -31dBm/tone is allowed. So instantaneous dynamic range of 59dB can be achieved and this value satisfies PHS requirement of 50dB. Table 1 indicates instantaneous dynamic ranges of the SHP-MIX for direct conversion receiver and a dual gate FET mixer for heterodyne receiver[7]. The SHP-MIX has the same instantaneous dynamic range with heterodyne receiver.

Fig.11 shows output locus of the SHP-DCR. Between I and Q channel baseband signals, amplitude error of 0.5dB and phase error of 5degrees are obtained.

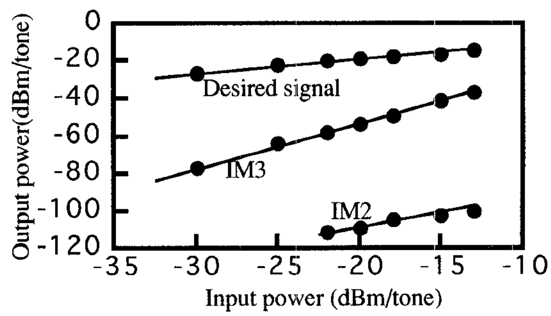

Fig.6 Measurement result of intermodulation of SHP-MIX.

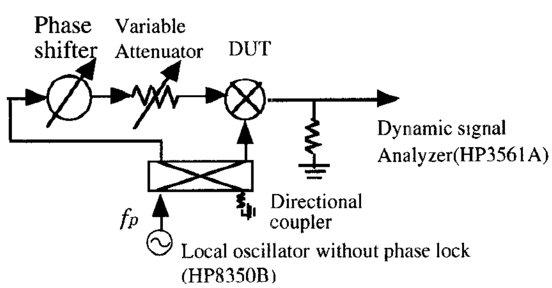

Fig.7 Measurement system for baseband noise voltage density by self-mixing between LO and LO noise.

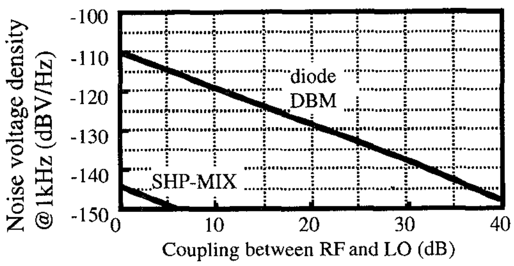

Fig.8 Measured baseband noise voltage density by self-mixing between LO and LO noise (SHP-MIX: Pp=3dBm, diode double balanced mixer: Pp=10dBm).

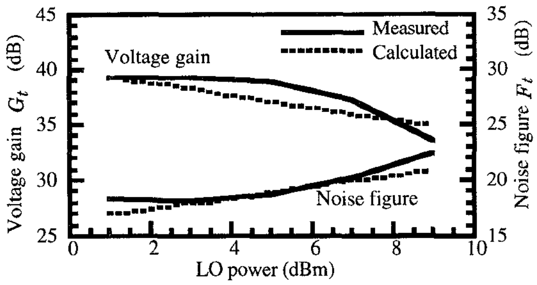

Fig.9 Measured and calculated voltage gain and noise figure of SHP-DCR(R_L =1kΩ).

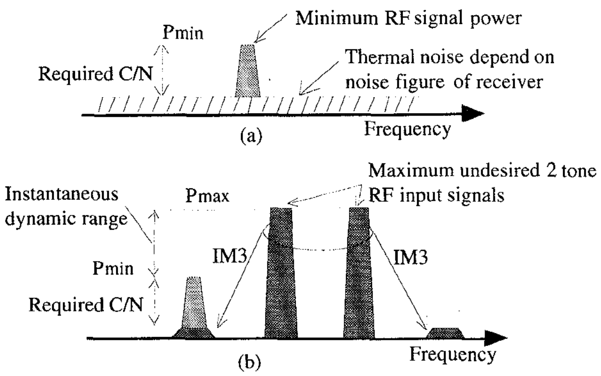

Fig.10 A concept of instantaneous dynamic range of mobile communications : (a) minimum RF signal power, and (b) maximum undesired 2 tone RF input signals power.

Table1 Instantaneous dynamic ranges of SHP-MIX for direct conversion receiver and dual gate FET mixer for heterodyne receiver.

	SHP-MIX for direct conversion receiver	Dual gate FET mixer for heterodyne receiver
LO power (dBm)	1	-10
NF as receiver (dB)	14.5	6
IP3 at input port (dBm)	-1	-10
Pmin (dBm)	-90	-102
Pmax (dBm/1tone)	-31	-44
Pmin-Pmax (dB)	59	58

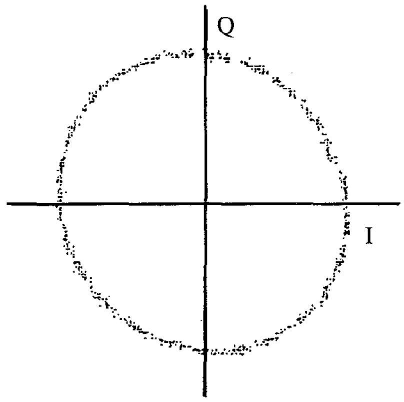

Fig.11 Output locus of SHP-DCR (Amplitude error=0.5dB, Phase error=5degrees).

CONCLUSION

A SHP-DCR employing APDP is proposed. Superior instantaneous dynamic range of the SHP-DCR has been demonstrated by analytical and experimental approaches. A developed L-band SHP-DCR without low noise amplifiers achieved NF of 18.5dB, IP3 at input port of 3dBm and IM2 is below -90dB in the actual input range.

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