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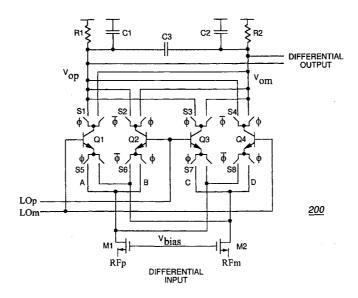
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**(54) Title:** METHOD AND APPARATUS PROVIDING IMPROVED INTERMODULATION DISTORTION PROTECTION

**(57) Abstract**

A radio frequency (RF) mixer circuit that receives local oscillator inputs (LOp) and (LOm) and RF inputs (RFp) and (RFm), where the output (Vop) and (Vom) is a product of the RF input and local oscillator signal. The mixer circuit, is intended to be used where second order intermodulation can become a problem. Second order intermodulation distortion (IM2) occurs when two interfacing signals mix with each other through a second order nonlinearity to produce an intermodulation product at the sum and difference frequencies of the two interferers. To reduce the amount of intermodulation distortion, dynamic matching is employed. In practice, dynamic matching operates to transform coefficients of IM2 distortion from constant values into functions of time where they may be handled by known rejection techniques.

# METHOD AND APPARATUS PROVIDING
# IMPROVED INTERMODULATION DISTORTION PROTECTION

5                                    TECHNICAL FIELD

This invention relates in general to wireless or
wireline communication devices and the systems upon which they
operate.  More generally, the present invention relates to a
method and apparatus providing second order intermodulation

10      distortion (IM2) protection for receivers and particularly
direct conversion and/or Zero-IF receivers.

BACKGROUND

In direct conversion and Zero-IF receivers, it is

15      necessary to maintain the spectral purity of the channel used
for reception.  Because of limited narrow band selectivity,
second order intermodulation distortion (IM2) presents an
undesired spectral component within the signal band of
interest.  This occurs when two or more interfering signals,

20      whose difference in frequency is less than the IF bandwidth of
the desired signal, mix with one another due to some second
order nonlinearity and produce a baseband spectral component.
To minimize the effects of second order intermodulation within
critical circuit blocks in the signal path, it is known in the

25      art to use differential circuits.  In theory, differential
circuits have infinite attenuation to second order
intermodulation distortion.  In reality, this is far from the

truth; due, in no small part, to device mismatches, parametric

imbalance, imperfect layout, and other device characteristic

inequalities that cause imbalances and provides a lower than

desired second order input intercept point (IIP2). As will be

5    appreciated by those skilled in the art, the best IIP2

achieved to date in the integrated mixer art is somewhere in

the neighborhood of +67 dBm. For several high performance

applications, this rejection rate falls nearly 13 dB short of

system requirements.

10        It would be extremely advantageous, therefore, to

provide a method and apparatus providing improved second order

intermodulation distortion performance. It would be of

greater advantage to apply this methodology to wireless and

wireline communications, devices that employ mixer circuits,

15   switches, and other components that exhibit parametric

mismatch or imbalance.


                    BRIEF DESCRIPTION OF THE DRAWINGS

         The features of the present invention, which are

20   believed to be novel, are set forth with particularly in the

appended claims. The invention, together with further objects

and advantages thereof, may best be understood by reference to

the following description, taken in conjunction with the

accompanying drawings, in the several figures in which like

25   reference numerals identify like elements, and in which:

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FIG. 1 is a differential RF mixer circuit as known in the art;

FIG. 2 is a first embodiment of a differential RF mixer circuit employing dynamic matching in accordance with the present invention;

FIG. 3 is a graph comparing the IM2 performance of the mixers of FIGs. 1 and 2;

FIG. 4 is a second embodiment of a differential RF mixer circuit employing dynamic matching in accordance with the present invention;

FIG. 5 is an embodiment of an RF mixer circuit employing spreading to achieve dynamic matching in accordance with the present invention;

FIG. 6 is a timing diagram for use in association with the device of FIG. 5;

FIG. 7 is an active harmonic mixer employing dynamic matching in accordance with the present invention;

FIG. 8 is a single-balanced mixer employing dynamic matching in accordance with the present invention;

FIG. 9 is a first embodiment of a CMOS down conversion mixer employing dynamic matching in accordance with the present invention;

FIG. 10 is a second embodiment of a CMOS down conversion mixer employing dynamic matching; and

FIG. 11 is a timing diagram for use in association with the devices of FIGs. 9 and 10.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

While the specification concludes with claims defining

the features of the invention that are regarded as novel, it

5   is believed that the invention will be better understood from

a consideration of the following description in conjunction

with the drawing figures, in which like reference numerals are

carried forward.

The present invention has applications for both wireless

10  and wireline communication devices, such as, for example,

modems, cellular and PCS phones, two-way radios, pagers and

the like.  By way of example and not by way of limitation, the

following description is applied primarily to mixer circuits

and particularly to radio frequency (RF) mixer circuits.

15      As will be appreciated by those skilled in the art, a

mixer is essentially a nonlinear circuit and may be

characterized by the following equation:

$$V_{out} = a_1 \cdot (V_{lo} \cdot V_{rf}) + a_2 \cdot (V_{lo} \cdot V_{rf})^2 + a_3 \cdot (V_{lo} \cdot V_{rf})^3 \qquad (1)$$

20

Second order intermodulation originates from the second

term in Equation 1, when two interfering signals mix with each

other through a second order nonlinearity to produce an

intermodulation product at the sum and difference frequencies

25  of the two interferers.  In an ideal differential mixer,

coefficient $a_2$ is zero, resulting in no intermodulation
distortion. In reality, however, imbalances within a
differential mixer, typically caused by mismatches in mixer
device characteristics, imperfect layout, and other static
5  imbalances, causes coefficient $a_2$ to be a small, fixed
constant. This results in a finite amount of intermodulation
distortion. To reduce the amount of intermodulation
distortion, dynamic matching is utilized. In accordance with
the present invention, dynamic matching transforms coefficient
10 $a_2$ from a fixed constant into a function of time.

$$a_2 \rightarrow f(t)$$

Depending on the choice of $f(t)$, the IM2 distortion
15 generated by the second term in Equation 1 can be:
   1) translated up in frequency where it can be
attenuated by filtering, or
   2) spread over a range of frequencies such that the
contribution of IM2 within the signal band of interest is
20 insignificant.
   To fully understand the mechanism by which dynamic
matching works, the following mathematical description is

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given where $f(t)$ is chosen to be a tone signal defined as

$\cos\omega_x t$, thereby letting

$$V_{rf} = E_1 \cdot \cos\omega_1 t + E_1 \cdot \cos\omega_2 t \qquad (2)$$

$$V_{lo} = E_2 \cdot \cos\omega_{lo} t \qquad (3)$$

and substituting into the second term of Equation 1 yields the
following second order intermodulation terms

$$a_2 \cdot \frac{(E_1 \cdot E_2)^2}{2} \cdot [\cos(\omega_1 + \omega_2)t + \cos(\omega_1 - \omega_2)t] \qquad (4)$$

Choosing $a_2 = \cos\omega_x t$, substituting it into Equation 4 yields:

IM2 Distortion Components:

$$\cos\omega_x t \cdot \frac{(E_1 \cdot E_2)^2}{2} \cdot \cos(\omega_1 + \omega_2)t = \frac{(E_1 \cdot E_2)^2}{4} \cdot [\cos(\omega_x - \omega_1 - \omega_2)t + \cos(\omega_x + \omega_1 + \omega_2)t] \qquad (5)$$
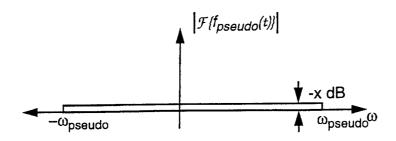
$$\cos\omega_x t \cdot \frac{(E_1 \cdot E_2)^2}{2} \cdot \cos(\omega_1 - \omega_2)t = \frac{(E_1 \cdot E_2)^2}{4} \cdot [\cos(\omega_x - \omega_1 + \omega_2)t + \cos(\omega_x + \omega_1 - \omega_2)t] \qquad (6)$$

It will be appreciated by those skilled in the art upon
review of equations 5 and 6, that the IM2 distortion
components have been translated up in frequency by $\omega_x$. By

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carefully selecting $\omega_x$, one can place the IM2 distortion

components outside the frequency band of interest where they

can be attenuated by filtering.  An added benefit of dynamic

matching is that it also translates any DC component generated

5   from a second order nonlinearity up in frequency by $\omega_x$ where

it too can be filtered.  This can be seen by substitution of

Equations 2 and 3 into the second term of Equation 1 thereby

yielding the following DC term:

10
$$a_2 \cdot \frac{(E_1 \cdot E_2)^2}{2} \tag{7}$$

To understand how IM2 distortion components are spread

over frequency, consider a pseudo-random sequence function,

$f_{pseudo}(t)$, which has the following spectrum in the frequency

15  domain:

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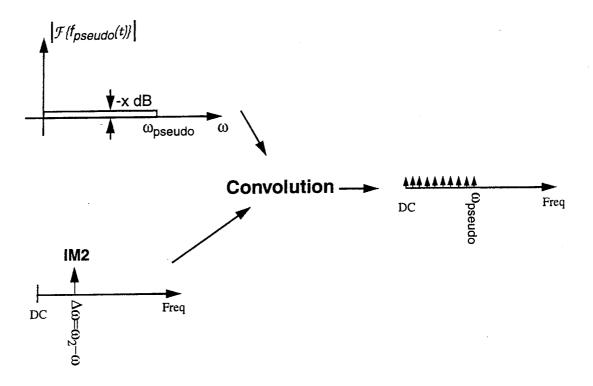
Now using the fact that multiplication in the time domain is

convolution in the frequency domain, the composite response of

$$a_2 \cdot (V_{lo} \cdot V_{rf})^2 \quad \blacktriangleright \quad f_{pseudo}(t) \cdot (V_{lo} \cdot V_{rf})^2 \quad \blacktriangleleft\blacktriangleright \quad \mathcal{F}\{f_{pseudo}(t)\} \circledast \mathcal{F}\{(V_{lo}(t) \, V_{rf}(t))^2\}$$

5    is graphically shown below:



10        By choosing $f_{pseudo}(t)$ to have insignificant magnitude, $-x$

dB, in the frequency domain, the IM2 distortion component will

be scaled by $-x$ dB and spread over a wider frequency range

than the desired frequency band.

As previously stated, the basic problem of second order

15   intermodulation distortion within an integrated, fully

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differential mixer arises from mismatches or imbalances between like devices within the circuit (hereinafter referred to as a parametric mismatch). For the differential mixer 100 shown in FIG. 1, the main source of IM2 distortion originates from mismatches in the quadrature switching devices (Q1, Q2, Q3, Q4). Improved balance in the differential mixer 100 of FIG. 1 can be achieved by dynamically matching these devices.

FIG. 2 shows a differential RF mixer circuit 200 employing dynamic matching in accordance with the present invention. In accordance with this embodiment, a switching network comprising switches $S_1$-$S_8$ has been added to rotate the effective positions of transistor pairs Q1 and Q4 between positions A and D and the positions of transistor pairs Q2 and Q3 between positions B and C at a commutating frequency. The result of cyclically changing the position of each transistor pair is that the imbalance in the circuit elements may be modulated. By choosing the modulating frequency to be well beyond the corner frequency of the single pole filter formed by R1, C1, C3, C2, and R2, the IM2 distortion component may be eliminated by translating the IM2 distortion components to a frequency different from the desired frequency and attenuating the IM2 distortion via the single pole filter. The IM2 performance of the mixer 200 of FIG. 2 is illustrated in FIG. 3. Of note, the IM2 distortion 302 as exhibited by the mixer 200 is 24 decibels (dB) below that exhibited by the mixer 100 of FIG. 1.

10

During operation, the mixer circuit 200 receives an RF

signal as an input for application to the emitters of

transistors $Q_1$-$Q_4$. Likewise, the mixer receives a local

oscillator (LO) reference signal as an input for application

5    to the bases of transistors $Q_1$-$Q_4$. As is known, the

application of these signals to devices $Q_1$-$Q_4$ will cause them

to be mixed and provide an output which is the product of the

RF signal and the local oscillator signal.

In accordance with the present embodiment, switches $S_1$-$S_8$

10   are located at the input and the output of transistor $Q_1$-$Q_4$,

respectively. Under the operation of a control or mitigation

signal ($\phi,\bar{\phi}$), switches $S_1$-$S_8$ are operated at a frequency $f_{comm}$

different than the frequency of the desired output in order to

modulate the imbalance exhibited by transistors $Q_1$-$Q_4$. As

15   previously stated, the mitigation signal frequency can be

selected so as to promote the attenuation of the undesired IM2

distortion components. This is accomplished by frequency

translating the desired signal components twice. Once, by

switches $S_5$-$S_8$, to translate the desired signal to a frequency

20   different than the desired frequency and again by switches $S_1$-

$S_4$ to recover the desired signal. The undesired signal

components are translated once by the switches $S_1$-$S_4$ at the

output of devices $Q_1$-$Q_4$ to translate the undesired signal

components to a frequency different from the desired frequency

25   prior to filtering.

11

Of note, the mitigation signal $(\phi,\bar{\phi})$ anticipated by the

present embodiment is a square wave. Notwithstanding, it will

be appreciated by those skilled in the art that the mitigation

signal may comprise any periodic wave form such as, for

5    example, sinusoidal waves or saw tooth waves. In the

alternative, frequency translation may be achieved by

switching the polarity of the inputs and outputs of the

elements exhibiting imbalance, for example, transistors $Q_1-Q_4$

at the frequency of $\omega_{comm}$.

10       One concern regarding this approach is the introduction

of undesirable spurs. Specifically, the spurs of concern are

those originating from the mixing of the mitigation signal at

frequency $f_{comm}$ and any signal in the frequency range of local

oscillatory frequency $\pm\Delta f + f_{comm}$ ($\Delta f <=$ IF bandwidth) which are

15   then down converted to baseband by mixing with the LO.

Notwithstanding this concern, experimentation and empirical

data show that such spurs can be controlled by the choice of

$f_{comm}$.

A second concern regarding this approach is the overall

20   device noise figure. Since several switching devices $S_1-S_8$

have been added to the mixer 200, the noise figure of the new

mixer might potentially be higher. Fortunately, devices $S_1-S_8$

act as ON-OFF switches with a very low ON resistance of 10 to

20 Ohms.  Their noise figure contribution of these devices is

not significant.

    As will be appreciated, there are a number of ways in

which this switching technique can be applied to the

5    conventional Gilbert Cell mixer topology of FIG. 2.  One such

alternative is shown in FIG. 4.

    FIG. 4, like FIG. 2, depicts a Gilbert Cell mixer

circuit employing dynamic matching to overcome the effects of

parametric mismatch between devices $Q_1$, $Q_2$, $Q_3$, $Q_4$.  As will be

10    appreciated upon closer inspection, the primary different

between FIG. 4 and FIG. 2 is the location and number of

commutating switches required to perform dynamic matching.

    With reference to FIG. 4, the commutating switches $S_1$-$S_4$

are located at the inputs and the outputs, respectively, of

15    the mixer circuit 400 as opposed to the inputs and outputs of

the devices $Q_1$-$Q_4$ as shown in FIG. 2.  This modification

reduces the required number of commutating switches and yet

exhibits similar performance as the mixer 200 shown in FIG. 2.

    It will be appreciated by those skilled in the art that

20    the switching network of the present invention may be diodes,

field-effect transistors (FET), transmission gates, bipolar

junction transistors (BJT) or any other switching devices

and/or technology.  FIG. 4 is presented to articulate the

point that there are numerous ways to deploy commutating

25    switches within the topology of a mixer circuit to improve the

IM2 distortion caused by device imbalance; such devices or

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elements to include transistors, resistors, diodes, inductors, capacitors, transformers, active baluns, and the like, without departing from the spirit of the present invention.

In addition to frequency translation, spreading is an

5    alternative method of achieving dynamic matching. With reference to FIG. 5, a differential RF mixer circuit 500 employing spreading techniques to achieve dynamic matching of elements exhibiting parametric mismatch is shown. FIG. 6 is a timing diagram showing the operation thereof.

10   The circuit 500 works as follows. With reference to FIG. 6, during period 1, the collector of $Q_1$ is connected to Vop, the emitter of $Q_1$ is connected to node A, and the base of $Q_1$ is connected to $LO_p$. During period 2, the collector of Q1 is connected to Vom, the emitter is connected to node A, and

15   the base is connected to $LO_M$. At this point, Q1 has effectively been switched into the position of Q2 as shown in period 1. During period 3, the collector of Q1 is connected to Vop, the emitter is connected to node B, and the base is connected to $LO_M$. Here, Q1 has been switched into the

20   location of Q3 as shown in period 1. Finally, during period 4, the collector of Q1 is connected to Vom, the emitter is connected to node B, and the base is connected to $LO_p$. Q1 has now effectively been switched into the position of Q4 as shown in period 1. This is the end of the cycle and during period

25   5, transistor Q1 will return to its original position. By manipulating the switching network ($S_1$-$S_{12}$) connections, to and

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from transistors Q1, Q2, Q3, and Q4 can be altered to

effectively rotatge transistors $Q_1$-$Q_4$ through different

physical positions within the mixer circuit 500 and, hence,

randomize or spread the second order distortion term.

5    Simulations performed with this topology show a greater than

20 dB improvement as compared to the conventional mixer

topology 100 of FIG. 1.  While the preferred embodiments of

the invention have been illustrated and described, it will be

clear that the invention is not so limited.  Numerous

10   modifications, changes, variations, substitutions and

equivalents will occur to those skilled in the art without

departing from the spirit and scope of the present invention

as defined by the appended claims.  For example, dynamic

matching as described herein can be applied to any RF

15   component exhibiting parametric mismatch; such components to

include resistors, capacitors, inductors, diodes, transistors,

transformers, active baluns, such as single-ended to

differential converter, and the like. These techniques can

likewise be applied to any mixer topology and may be further

20   employed within a wireless or wireline communication system.

    With reference to FIGs. 7-11, the application of

switching networks to provide dynamic matching within other

mixer topologies is specifically shown.  For example, FIG. 7

depicts an active harmonic mixer 700 employing dynamic

25   matching in accordance with the present invention.  During

operation, when the mitigation signal amplitude is high, ($\phi$),

15

Q1's collector is tied to Vop and its emitter is tied to node
A, Q2's collector is tied to Vom and its emitter is tied to
node A, Q3's collector is tied to Vop and its emitter is tied
to node B, and Q4's collector is tied to Vom and its emitter
5    is tied to node B.  During this period, the IM2 distortion
component has a defined amplitude, $A_1$, that is unique to the
above-defined set of switching network connections.  When the
mitigation signal goes low, ($\bar{\phi}$), Q1's collector is tied to Vom
and its emitter is tied to node B, Q2's collector is tied to
10   Vop and its emitter is tied to node B, Q3's collector is tied
to Vom and its emitter is tied to node A, and Q4's collector
is tied to Vom and its emitter is tied to node A.  During this
period, the IM2 distortion component has a second defined
amplitude, $A_2$ that is unique to the set of switching network
15   connections associated with the mitigation signal being in the
low state.  If the mitigation signal toggles at a frequency
$f_{sw}$, then the IM2 distortion component amplitude will change
from A1 to A2 and back to A1 at the same frequency.  By
choosing $f_{sw}$ appropriately, the IM2 distortion component can be
20   easily filter by filter stage at the output of the mixer 700.

       Following this same technique, FIG. 8 depicts a single-
balanced RF mixer 800 employing dynamic matching in accordance
with the present invention.

       FIG. 9 is a first embodiment of a CMOS down conversion
25   mixer 900 employing dynamic matching in accordance with the

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present invention.  FIG. 10 is a second embodiment of a CMOS

down conversion mixer 1000 employing dynamic matching.  FIG.

11 is a timing diagram for use in association with the devices

900 and 1000 of FIGs. 9 and 10.  The primary difference

between FIGs. 9 and 10 is the application of the input signal

to the gates of devices M1-M4 as shown in FIG. 9 as opposed to

application of the input signal to the drains of devices M1-M4

as shown in FIG. 10.  As will be appreciated by those skilled

in the art, the devices M1-M4 operate in saturation in FIG. 10

while they operate in the linear region in FIG. 9.

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CLAIMS

1. A method for improving the second order intermodulation distortion exhibited by a radio frequency (RF) component, comprising the steps of:

providing a switching network capable of altering electrical connections to and from a plurality of elements exhibiting parametric mismatch;

applying a desired signal to inputs of the plurality of elements to generate output signals comprising desired and undesired signal components;

manipulating the switching network under control of a periodic mitigation signal to alter electrical connections to and from the plurality of elements at a rate established by the mitigation signal;

frequency translating the desired signal components to a first frequency;

frequency translating the undesired signal components to a second frequency; and

filtering the undesired signal components.


2. The method of claim 1, wherein the RF component is a device selected from the group consisting of RF amplifiers, RF mixers and baluns.

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3. The method of claim 1, wherein the plurality of elements exhibiting parametric mismatch are selected from the group consisting of capacitors, inductors, transformers, transistors, resistors, and diodes.

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4. The method of claim 1, wherein the desired signal is frequency modulated before the step of applying the desired signal to the inputs of the plurality of elements.

10          5. The method of claim 2, wherein the periodic mitigation signal is a signal selected from the group consisting of:  sinusoidal wave, square wave, and saw tooth waves.

6. A method for improving the second order
intermodulation distortion of a radio frequency (RF)
component, comprising the steps of:

applying a desired signal to inputs of a plurality of

5    elements exhibiting parametric mismatch to generate output

signals comprising desired and undesired signal components;

and

spreading the undesired signal across a range of

frequencies by application of a spreading sequence at the

10   inputs and outputs of the plurality of elements exhibiting

parametric mismatch.


7. The method of claim 6, wherein the RF component is a

device selected from the group consisting of RF amplifiers, RF

15   mixers and baluns.


8. The method of claim 6, wherein the plurality of

elements exhibiting parametric mismatch are selected from the

group consisting of capacitors, inductors, transformers,

20   transistors, resistors, and diodes.


9. The method of claim 6, wherein the spreading signal

is a pseudo-random code.

10. A radio frequency (RF) mixer circuit having a plurality of elements exhibiting parametric mismatch, said elements generating desired and undesired signal components during mixing, said mixer comprising:

5      inputs for receiving a desired signal and a local oscillator signal;

an output for providing an output signal comprising a product of the desired signal and the local oscillator signal; and

10     a mitigation signal applied to the input and the output to frequency translate or spread the undesired signal components generated by the plurality of elements exhibiting parametric mismatch.

15     11. The mixer of claim 10, further comprising at least one switching network.

12. The mixer circuit of claim 10, wherein the mitigation signal is applied to switching network switches at

20  the input and the output of the RF mixer.

13. The mixer of claim 10, wherein the mitigation signal is applied to switching network switches disposed within the mixer circuit to randomize or spread the undesired signal

25  components over a band of frequencies.

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14. The mixer circuit of claim 10, wherein the plurality of elements exhibiting parametric mismatch are selected from the group consisting of transistors, resistors, inductors, diodes, and transformers.

5

15. The mixer circuit of claim 10, wherein a switching network switch is a device selected from the group consisting of diodes, field effect transistors (FET), transmission gates, and bipolar junction transistors (BJT).

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16. A wireless or wireline communication device having a mixer circuit comprising a plurality of elements exhibiting parametric mismatch, said elements generating desired and undesired signal components during mixing, said mixer

5    comprising:

inputs for receiving a desired signal and a reference signal;

an output coupled to the plurality of elements exhibiting parametric mismatch for providing an output signal

10   comprising a product of the desired signal and the reference signal; and

a mitigation signal applied to the input and the output to frequency translate or spread the undesired signal components generated by the plurality of elements exhibiting

15   parametric mismatch.


17. The device of claim 16, further comprising at least one switching network.


20   18. The device of claim 16, wherein the mitigation signal is applied to switching elements at the input and the output of the mixer circuit.


19. The device of claim 16, wherein the mitigation

25   signal is applied to switching network elements disposed within the mixer circuit.

20. The device of claim 16, wherein the plurality of elements exhibiting parametric mismatch are selected from the group consisting of transistors, diodes, resistors, inductors, and transformers.

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21.   A method for improving the second order
intermodulation distortion exhibited by components having
parametric mismatch, comprising the steps of:

        receiving a desired signal;

5       frequency translating the desired signal by a
translating frequency to generate a translated signal;

        applying the translated signal to inputs of a plurality
of elements exhibiting parametric mismatch to generate outputs
comprising translated desired and undesired signal components;

10      frequency translating the translated desired signal
components by the translating frequency to recover the desired
signal;

        frequency translating the undesired signal by the
translating frequency to translate the undesired signal

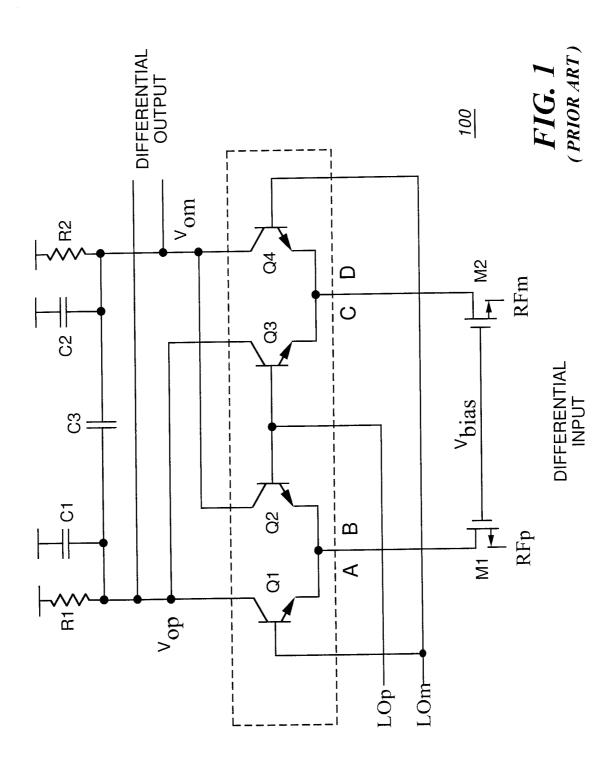15   components; and

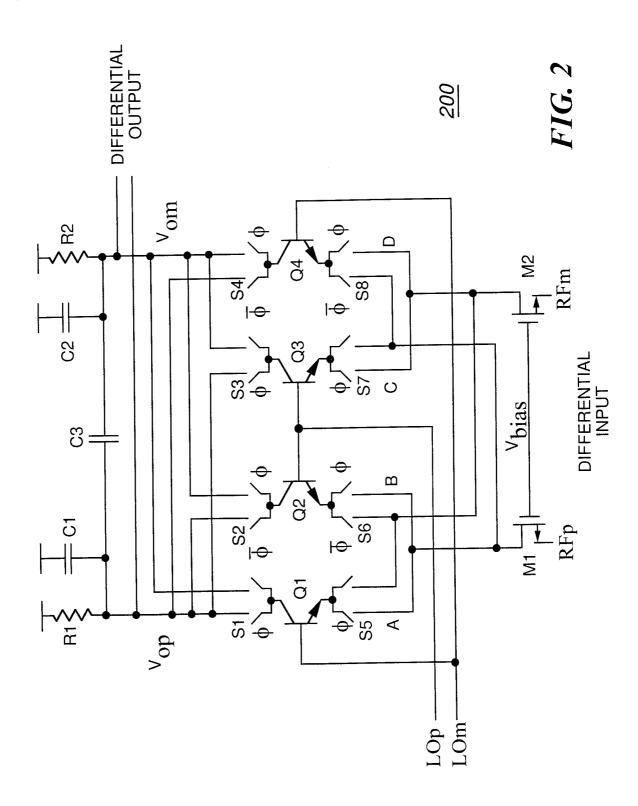        filtering the translated and undesired signal
components.


        22.   The method of claim 21, wherein the component is a
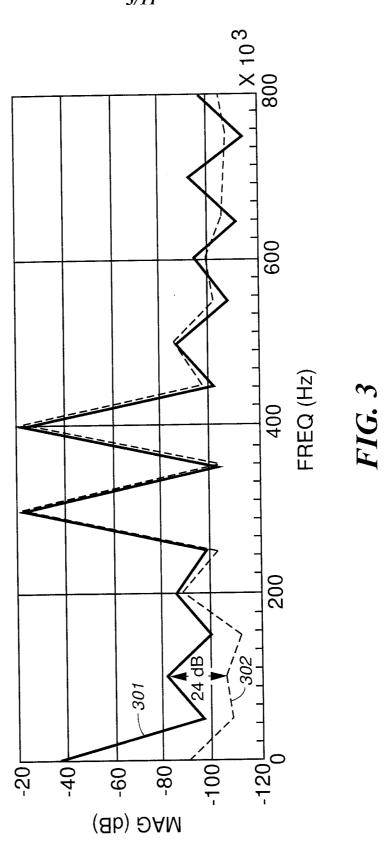20   device selected from the group consisting of mixers and
baluns.

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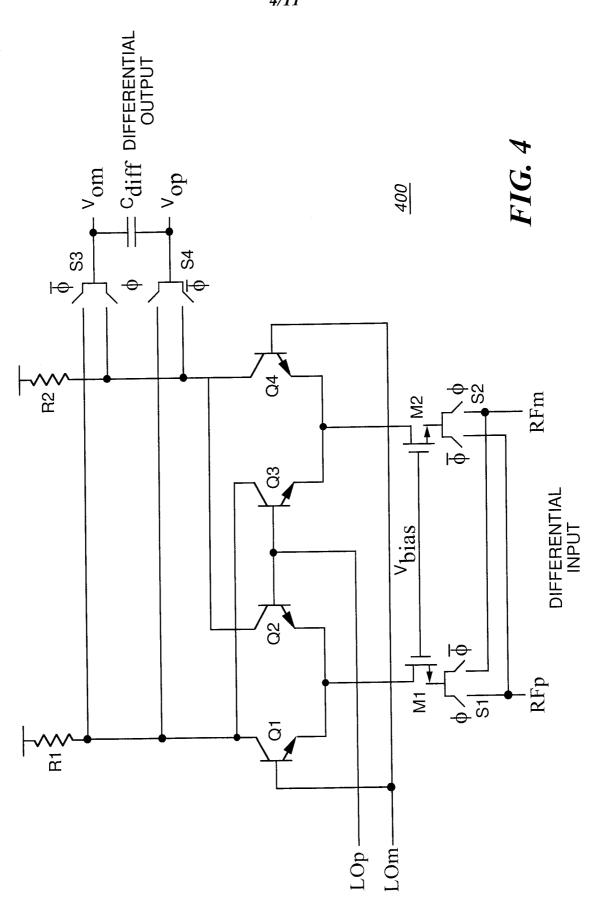23.  The method of claim 21, further comprising the step

of:

    providing a switching network capable of altering

electrical connections to and from the plurality of elements

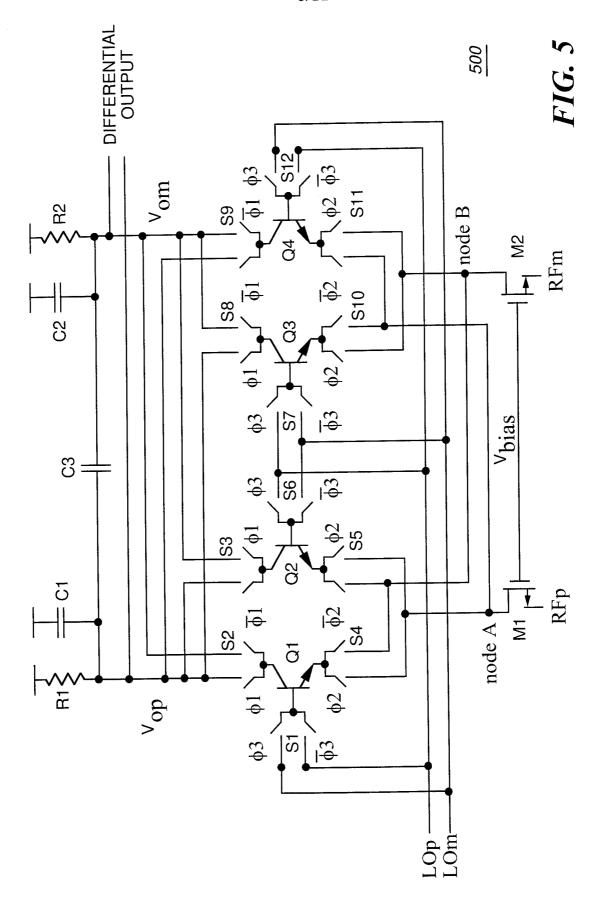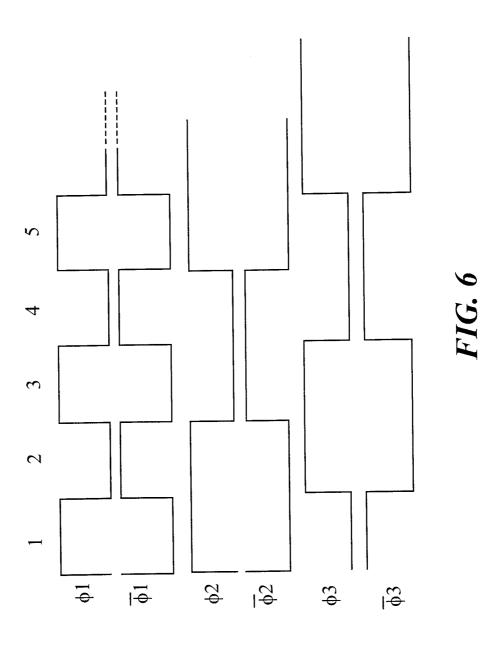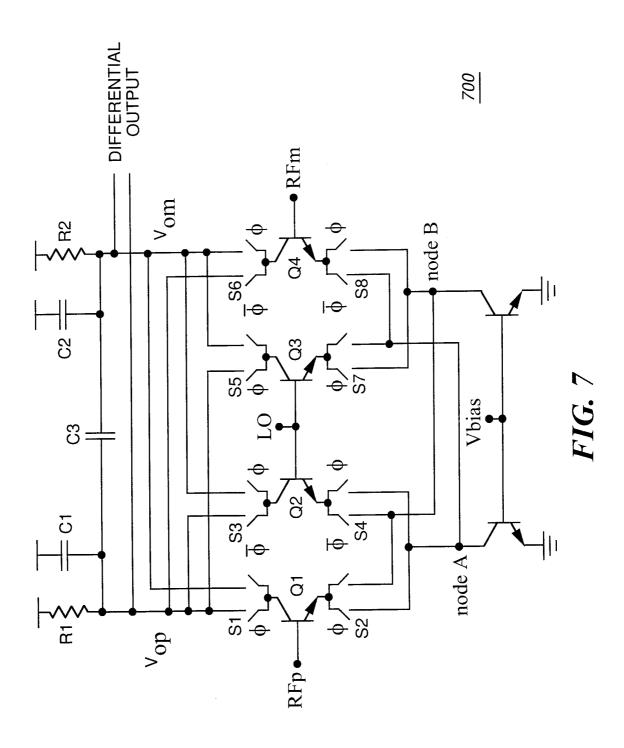5  to physically change element positioning within a circuit.
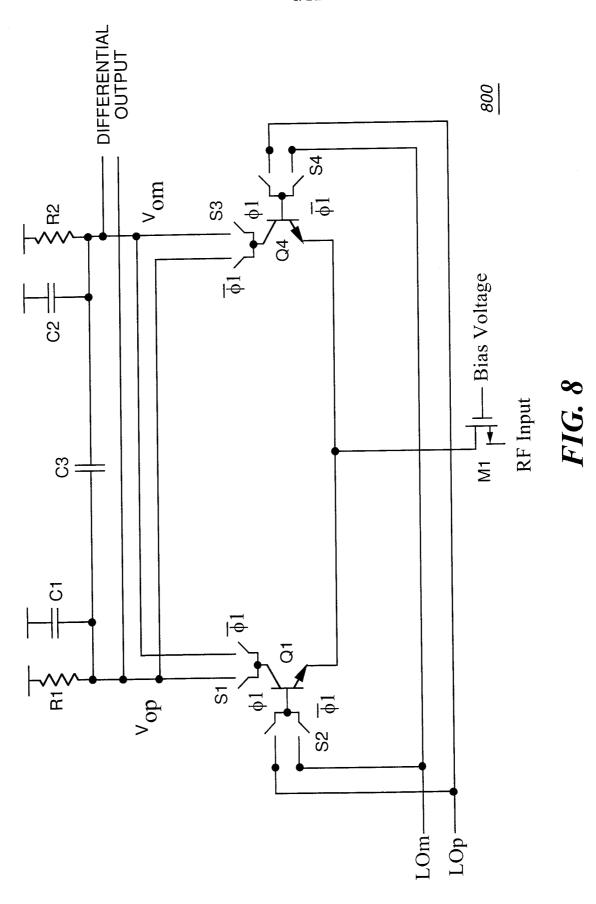
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DIFFERENTIAL
OUTPUT

$V_{om}$

$V_{op}$

R2

C2

C3

C1

R1

Q4

Q3

Q2

Q1

D

C

B

A

M2

RFm

M1

RFp

$V_{bias}$

DIFFERENTIAL
INPUT

LOp

LOm

100

*FIG. 1*
*( PRIOR ART )*

*FIG. 2*

3/11



*FIG. 3*

4/11



FIG. 4

400

FIG. 5

500

6/11



FIG. 6

*FIG. 7*

*FIG. 8*

9/11



*FIG. 9*

FIG. 10
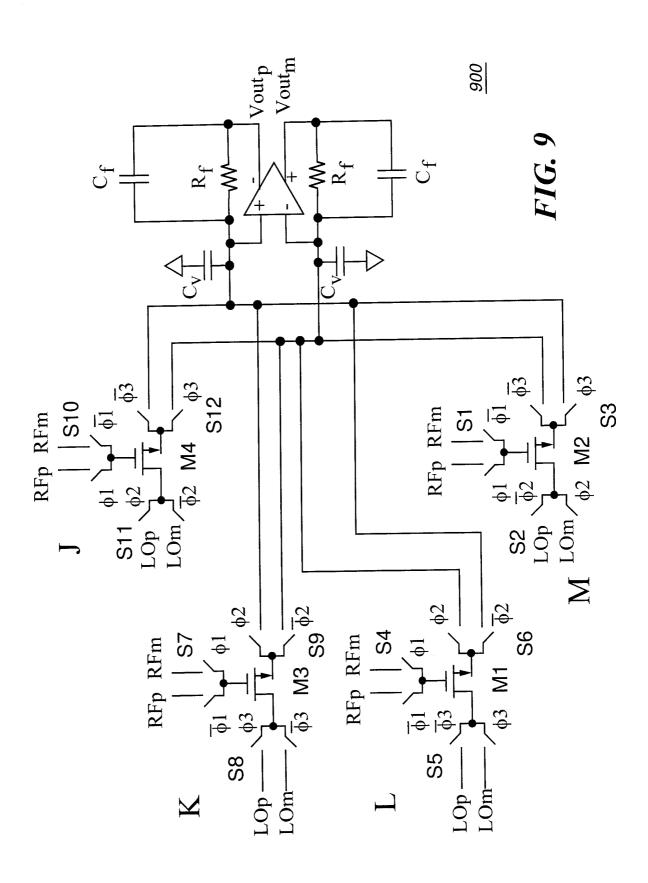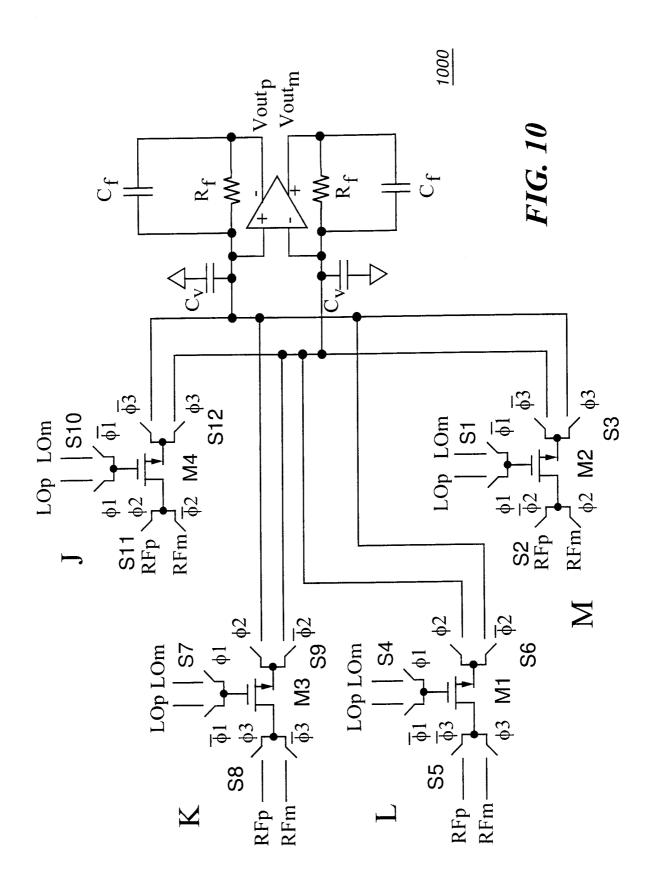
| DEVICE | PERIOD 1 | PERIOD 2 | PERIOD 3 | PERIOD 4 |
|--------|----------|----------|----------|----------|
| M1 | L | M | K | J |
| M2 | M | K | J | L |
| M3 | K | J | L | M |
| M4 | J | L | M | K |

*FIG. 11*

# INTERNATIONAL SEARCH REPORT

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04K 1/02; HO4B 1/04; H04L 23/02
US CL :455/126, 63

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/126, 63

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | US 5,732,333 A (COX et al.) 24 March 1998 col. 3, lines 65-67, col. 4, lines 1-14, col. 5, lines 1-9, col. 6, lines 5-29. | 1-23 |
| Y,P | US 5,854,811 A (SASAKI et al.) 29 December 1998, col. 1, lines 65-67, col. 2, lines 60-67, col. 3, lines 1-15, col. 3, lines 45-60, col. 4, lines 43. | 1-23 |
| Y | US 5,812,600 A (HESS et al.) 22 September 1998 col. 3, lines 47-62, col. 4, lines 15-21, col. 5 lines 10-30, col. 6, lines 7-27. | 1-23 |
| A,E | US 5,970,053 A (SCHICK et al.) 19 October 1999. | 1-23 |
| A | US 5,535,247 (GAILUS et al.) 09 July 1996. | 1-23 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

| | | | |
|---|---|---|---|
| * | Special categories of cited documents: | "T" | later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention |
| "A" | document defining the general state of the art which is not considered to be of particular relevance | | |
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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 23 NOVEMBER 1999 | 14 DEC 1999 |

| Name and mailing address of the ISA/US | Authorized officer |
|---|---|
| Commissioner of Patents and Trademarks<br>Box PCT<br>Washington, D.C. 20231<br>Facsimile No. (703) 305-3230 | NICK CORSAR *James R. Matthews*<br>Telephone No. (703) 305-4700 |

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