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(54) **MULTICODE CDMA TRANSMITTER WITH IMPROVED SIGNAL PROCESSING**

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(63) Continuation of application No. 09/007,509, filed on Jan. 15, 1998, now patented.

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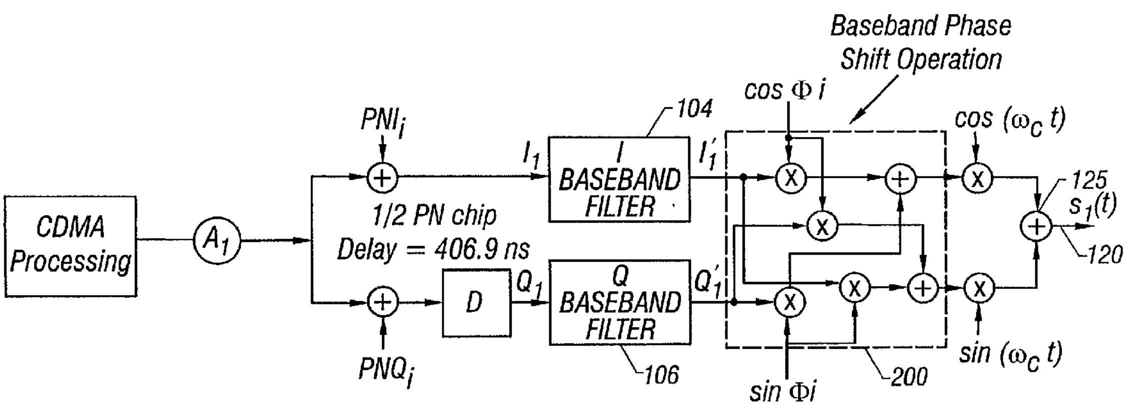
(52) **U.S. Cl.** **370/335**; 370/342

(57) **ABSTRACT**

CDMA communication over multiple channels by phase shifting at baseband and then RF modulating without a phase shift. Total number of baseband filters is reduced by summing channel components prior to baseband filtering.



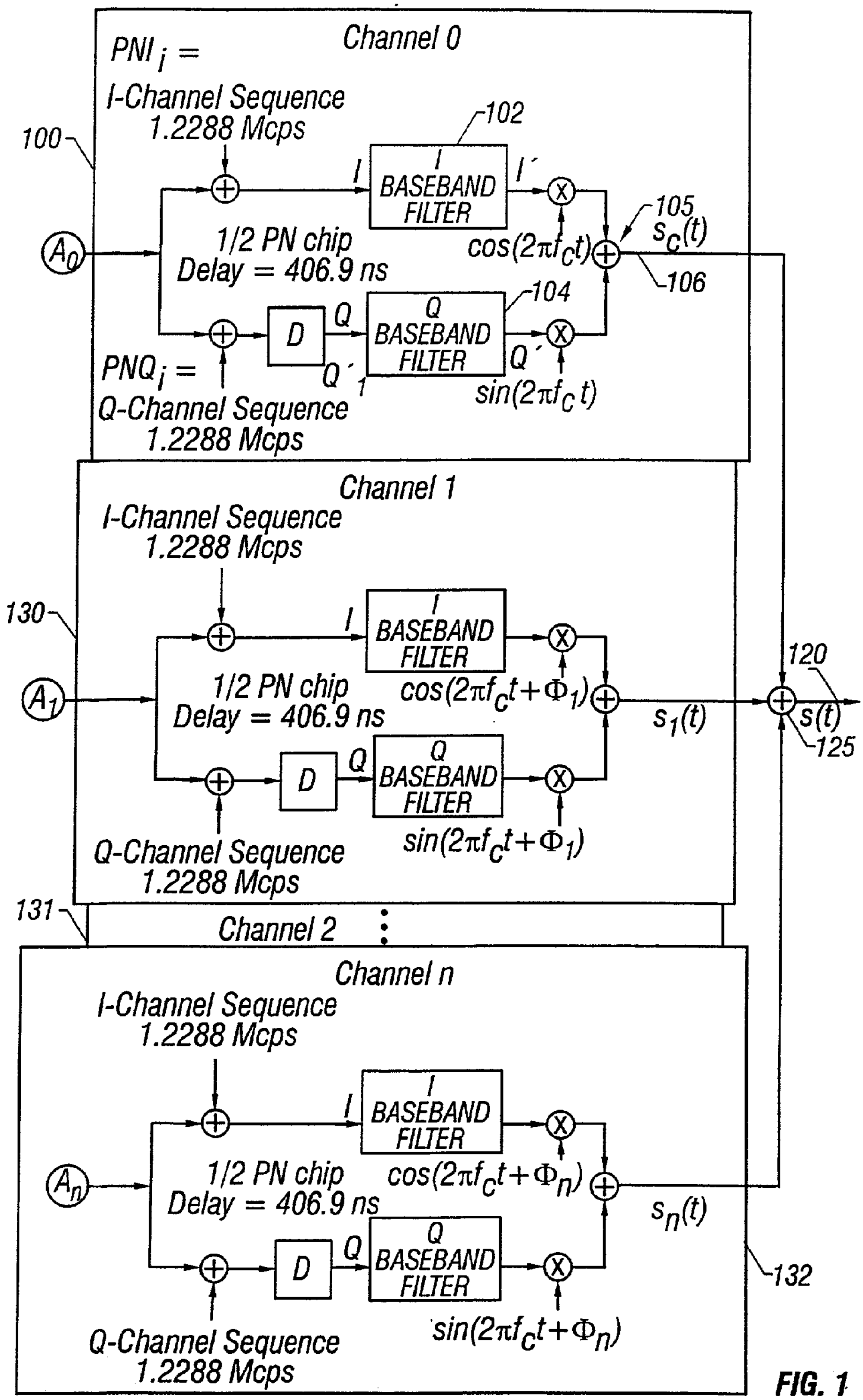

Channel 0
$PNI_i =$
I-Channel Sequence
1.2288 Mcps
100
102
I
BASEBAND
FILTER
I
I´
105
$s_c(t)$
A_0
1/2 PN chip
Delay = 406.9 ns
$cos(2\pi f_c t)$
106
104
D
Q
Q
BASEBAND
FILTER
Q´
Q'_1
$PNQ_i =$
$sin(2\pi f_c t)$
Q-Channel Sequence
1.2288 Mcps
Channel 1
I-Channel Sequence
1.2288 Mcps
130
I
BASEBAND
FILTER
120
A_1
1/2 PN chip
Delay = 406.9 ns
$cos(2\pi f_c t+\Phi_1)$
$s_1(t)$
$s(t)$
125
D
Q
Q
BASEBAND
FILTER
$sin(2\pi f_c t+\Phi_1)$
Q-Channel Sequence
1.2288 Mcps
131
Channel 2
Channel n
I-Channel Sequence
1.2288 Mcps
I
BASEBAND
FILTER
A_n
1/2 PN chip
Delay = 406.9 ns
$cos(2\pi f_c t+\Phi_n)$
$s_n(t)$
D
Q
Q
BASEBAND
FILTER
132
$sin(2\pi f_c t+\Phi_n)$
Q-Channel Sequence
1.2288 Mcps

FIG. 1

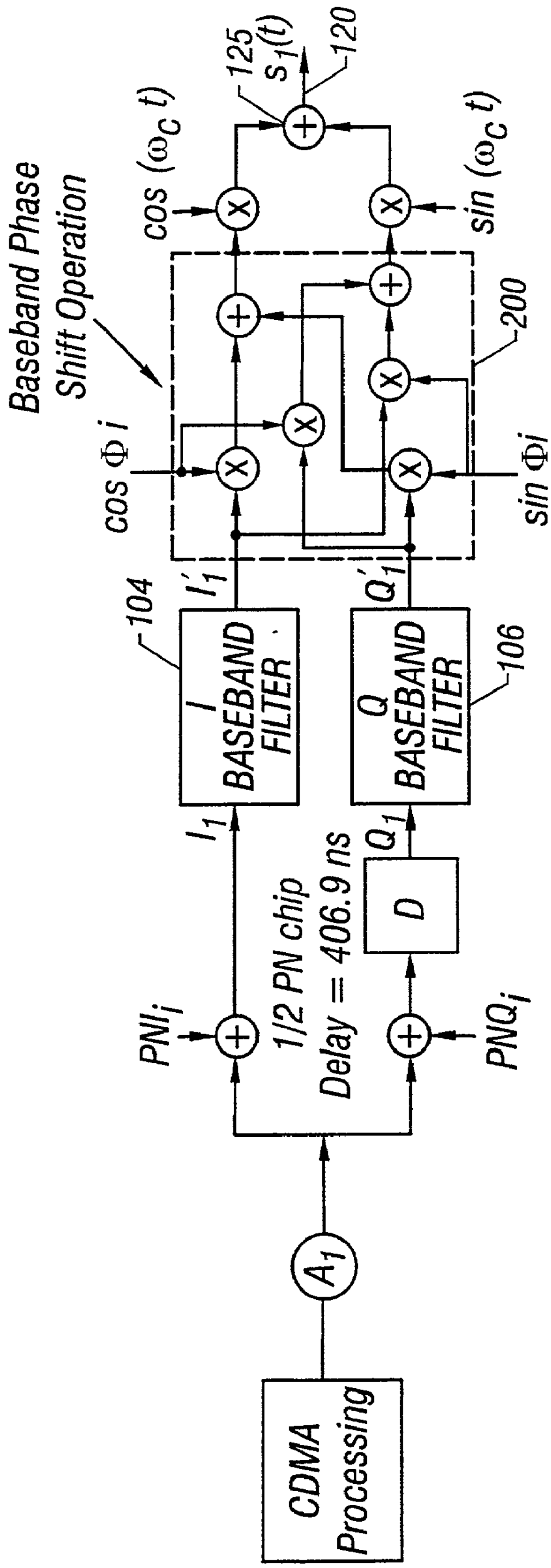

CDMA Processing
A1
PNIi
PNQi
1/2 PN chip
Delay = 406.9 ns
D
I1
Q1
I BASEBAND FILTER
104
Q BASEBAND FILTER
106
I1'
Q1'
Baseband Phase Shift Operation
cos Φ i
sin Φi
200
cos (ωc t)
sin (ωc t)
125
s1(t)
120

FIG. 2

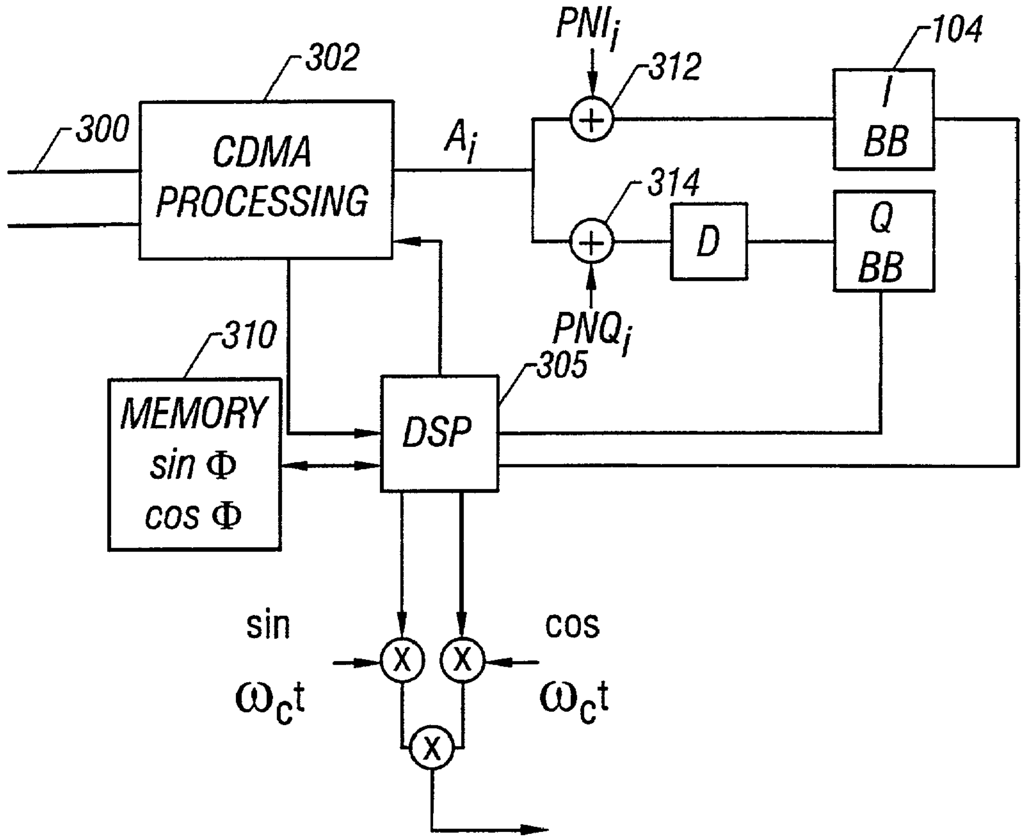
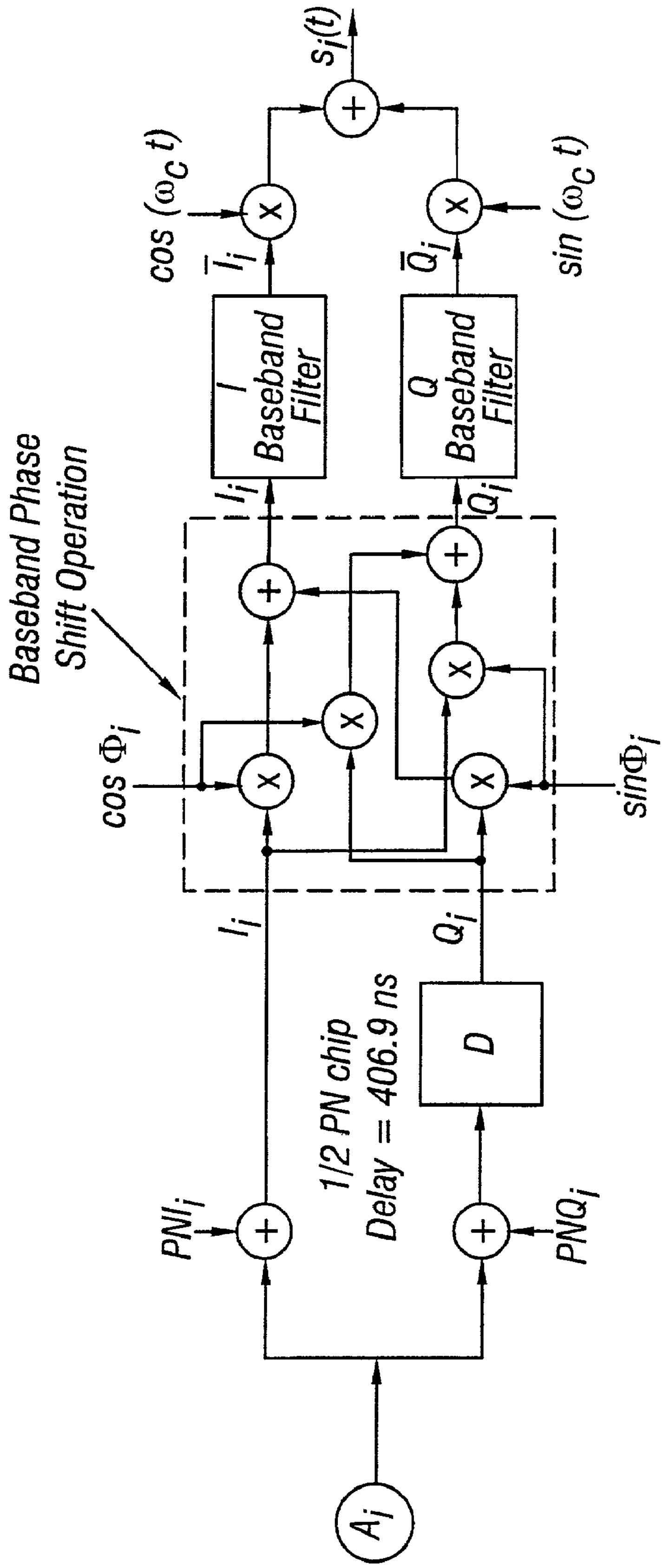
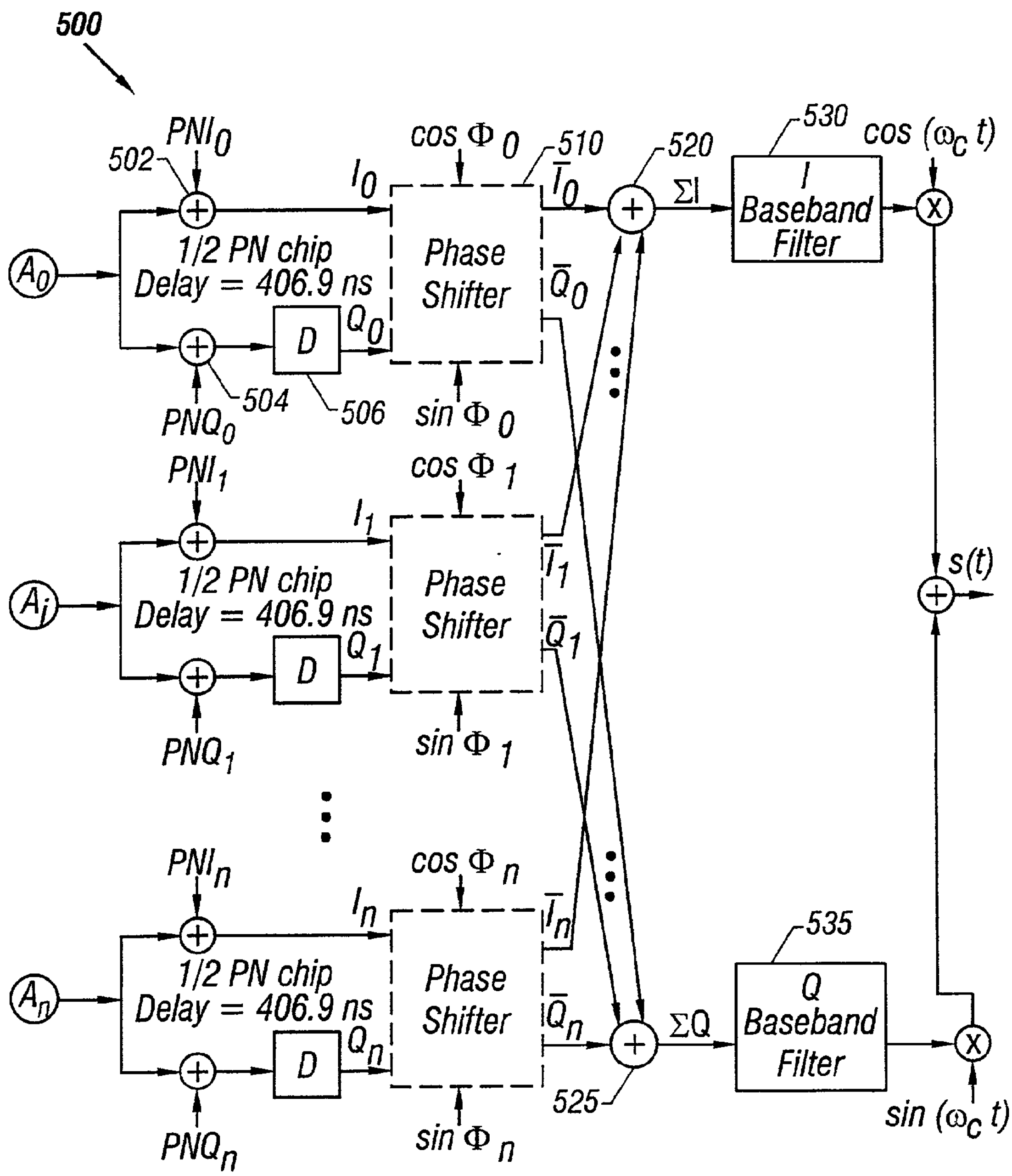

PNI_i
312
104
302
I
BB
300
CDMA
PROCESSING
A_i
314
D
Q
BB
PNQ_i
310
305
MEMORY
sin Φ
cos Φ
DSP
sin
ωct
cos
ωct
X
X
X

FIG. 3



Baseband Phase
Shift Operation
cos Φi
sinΦi
I
Baseband
Filter
Q
Baseband
Filter
cos (ωc t)
sin (ωc t)
si(t)
1/2 PN chip
Delay = 406.9 ns
D
PNIi
PNQi
Ai
Ii
Qi

Fig.4



500
502
PNI0
I0
cos Φ 0
510
I0
520
ΣI
530
I Baseband Filter
cos (ωc t)
A0
1/2 PN chip
Delay = 406.9 ns
Phase Shifter
Q0
D
Q0
504
506
PNQ0
sin Φ 0
PNI1
I1
cos Φ 1
Ai
1/2 PN chip
Delay = 406.9 ns
Phase Shifter
I1
Q1
D
Q1
PNQ1
sin Φ 1
s(t)
PNIn
In
cos Φ n
In
535
Q Baseband Filter
An
1/2 PN chip
Delay = 406.9 ns
Phase Shifter
Qn
ΣQ
D
Qn
525
PNQn
sin Φ n
sin (ωc t)

FIG. 5

MULTICODE CDMA TRANSMITTER WITH IMPROVED SIGNAL PROCESSING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This is a continuation of U.S. patent application Ser. No. 09/007,509, filed Jan. 15, 1998 (allowed).

FIELD OF THE INVENTION

[0002] The present invention describes a multicode CDMA transmitter simplified hardware and signal processing.

BACKGROUND

[0003] The IS-95 standard describes a communication protocol to be carried out using code division multiple access ("CDMA") processing. Wireless communications standards, such as the IS-95 communications standard, will allow transmission at up to 64 kilobits per second ("KB/s") on forward and reverse links. This data transmission uses multiple code channels. Each code channel carries a specified data rate. The proposed system is shown in **FIG. 1**.

[0004] The ratio between the peak value and the average value of the transmitted signal in such a system should be kept as small as possible in order to minimize the peak power output of the transmitter chain. However, all of the multiple code channels **100**, **130**, **132** convey information which may be correlated to some extent. The information in those code channels are eventually added together by adder **125** to form a composite signal **120**. That signal would have a high peak to average power ratio in the transmitted signal.

[0005] The IS-95 standard suggests minimizing this problem by independently phase shifting each of the supplemental code channels $S_1(t)$ to $S_n(t)$ with respect to the fundamental channel. These phase shifts are fixed by the IS-95 standard as follows:

TABLE 1

PHASE SHIFT ANGLES FOR SUPPLEMENTAL CODE CHANNELS

Supplemental Code Channel I	Carrier phase offset ϕ_1 (radian)
1	$\pi/2$
2	$\pi/4$
3	$3\pi/4$
4	0
5	$\pi/2$
6	$\pi/4$
7	$3\pi/4$

[0006] This modification attempts to minimize the peak to average ratio. However, it does so at the expense of significant hardware/signal processing requirements.

[0007] A fundamental code channel **100** is combined with a plurality of supplemental code channels. The supplemental code channels **130**, **132** are shown. The total number of supplemental code channels can actually vary between n=1 and 7. The fundamental channel is used to transmit voice while the supplemental channels transmit coded information i.e., (data).

[0008] Channel **100** transmits its data "in phase" and "quadrature" modulated according to the component cosine or sin of $2\pi f_c t$. Each of the code channels are formed independently using distinct I and Q code sequences which are respectively modulated according to the cos and sin.

[0009] The I and Q code sequences are baseband-filtered by respective filters **102**, **104**. The baseband filters are offset-quadrature phase shift keying ("0-QPSK") modulators. These modulators operate as known in the art. The thus modulated signals are then added to form a composite signal **106**; also called $S_n(t)$, where n is the channel number. All of the composite signals from the various phase-shifted channels are finally added by an adder **125**, to form a final composite signal **120**. The mobile unit transmits that composite signal. The circuit shown in **FIG. 1** requires two of the baseband filters **102**, **104** for each of the channels. This circuit requires $2\cdot(n+1)$ baseband filters for the n+1 channels.

[0010] Moreover, this proposed circuit applies its phase shift as part of the modulation by the fundamental frequency, hence in the RF domain.

[0011] The inventor of the present invention realized that operations in the baseband domain can be carried out much more easily than operations at RF. For example, an integrated circuit which is optimized for arithmetic operations is often used in forming the coded signal. Most of the calculations at baseband can be done on such a device, e.g. a digital signal processor ("DSP") or other specialized processing device.

[0012] On the other hand, operations carried out at RF frequencies cannot be done this way. Such operations require specialized RF techniques including balancing lines and other known features.

SUMMARY

[0013] The inventor of the present invention, recognizing these drawbacks, has made certain recognitions about the overall circuit. These recognitions allow certain advantages, including implementation of the phase shift operation for each supplemental channel prior to RF modulation. This enables the operation to be done on an existing specialized processing device, e.g., a digital signal processor (DSP), hence allowing such operations to be done using the existing hardware.

[0014] In addition, the inventor recognized that use of linear baseband filtering enables a circuit which reduces the total number of baseband filters.

[0015] These and other operations will be described with reference to the following.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] These and other aspects will now be described in detail with reference to the accompanying drawings, wherein:

[0017] **FIG. 1** shows a reverse channel structure device;

[0018] **FIG. 2** shows a system of phase shifting at baseband;

[0019] **FIG. 3** shows a block diagram of the connection between the signal, the CDMA processing, and the DSP;

[0020] **FIG. 4** shows an alternative embodiment of the baseband shifting operation; and

[0021] **FIG. 5** shows yet another embodiment of phase shifting at baseband.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] A first embodiment performs the phase shifting operation at baseband instead of RF. The baseband operations can be carried out on a special purpose calculation device, e.g., a digital signal processor.

[0023] The inventor noted that the i-th signal (where i is between 0 and n=7 channels max) to the input of the final; adder **120** can be mathematically expressed as follows:

$$\begin{aligned} s_i(t) &= I_i'\cos(\omega_c t+\phi_i) + Q_i'\sin(\omega_c t+\phi_i) i 0 \le i \le 7 \qquad (1)\\ &= I_i'[\cos\omega_c t\cos\phi_i - \sin\omega_c t\sin\phi_i] + Q_i'[\sin\omega_c t\cos\phi_i + \cos\omega_c t\sin\phi_i]\\ &= \cos\omega_c t[I_i'\cos\phi_i + Q_i'\sin\phi_i] + \sin\omega_c t[Q_i'\cos\phi_i - I_i'\sin\phi_i] \end{aligned}$$

[0024] The first part of this equation represents the specific operation of **FIG. 1**. For each channel, the phase shifting is carried out at RF by multiplying the baseband signal by the cosine and sine, respectively of the fundamental $\omega_c t+\phi_i$. The first part of the equation simply represents the operations carried out by the prior art circuit of **FIG. 1**.

[0025] The second two portions of the equation show an equivalent mathematical representation of the signal to remove the phase shifting at Rf due to the fact that the angles ϕ_i as shown in Table 1 are constant. The final part of equation 1 requires multiplication only by cos ω_ct sin ω_ct without any phase shift being added in the RF domain. Instead the phase-shift is equivalently added via multiplication in the baseband domain.

[0026] **FIG. 2** shows a basic system whereby the phase shifting is carried out in the baseband domain, prior to multiplication by the fundamental frequency. The baseband shifter **120** carries out multiplication according to the equation (1) which effectively carries out the phase shift in the analog domain.

[0027] Therefore, this system effectively calculates two baseband coefficients,

$A=I'i\cos\phi_{i+Q'i}\sin\phi_i$, and

$B=Q'_i\cos\phi_i - I'_i\sin\phi_i$.

[0028] The circuit of **FIG. 2** includes a baseband phase shifter **200**, which multiplies the I and Q components by multiples of the phase shift. The multiplication occurs at baseband.

[0029] An important feature of the embodiment of **FIG. 2** is that no phase shifting at RF is required. All of the required mathematical operations, which here include only multiplications and additions can be easily performed in a DSP, which is used as part of the CDMA processing to output the coefficients A and B. Moreover, since the phase shift angles ϕ_i are constant, the values for the constants cos ϕ, and sin ϕ, can be stored in memory with the required precision to perform the above operations.

[0030] A block diagram of the circuit using a specialized processing device is shown in **FIG. 3**. The signal for transmission **300** is coded in the usual way in CDMA processing and encoding module **302** This module, for example, performs basic CDMA signal encoding. The way in which this coding is carried out is well known in the art, and described in many standards. As part of this coding, however, a specialized processing circuit, here a digital signal processor **305**, is used. The coding operation also uses a working memory **310**. The phase shift values are always sin or cos of the constant phase shifts ϕ. Hence, the working memory **310** stores values of various constants, including sin ϕ_i and cos ϕ_i, of the constant phase shift angles.

[0031] The output signal A_I forms the input signal to the code channels such as 100. The code channels are divided into I and Q channels. The I and Q channels are appropriately multiplied by the I and Q channel sequence at **312** and **314** respectively. Those values are baseband filtered by the respective baseband filters **104**, **106** to form the baseband-filtered signals I' and Q', respectively. The baseband-filtered signals I' and Q' are then fed back into the digital signal processor **305**. DSP multiplies these signals by the constant sin ϕ and cos ϕ coefficients to obtain the values A and B as described above. These values A and B are multiplied by the fundamental frequency to form the RF output signals.

[0032] A further simplification can be achieved by using a linear baseband filtering operation. This allows the phase shifting operation to be equivalently performed before baseband filtering as shown in **FIG. 4**. Note that the circuit of **FIG. 4** can also be done as part of the CDMA processing block as shown in **FIG. 3**.

[0033] To see the merits of the above simplification, note that the composite transmit signal S(t) can be expressed as

$$\begin{aligned} s(t) &= \sum_{i=0}^{7} s_i(t) = \sum_{i=0}^{7}\left(\tilde{I}_i\cos\omega_c t + \tilde{Q}_i\sin\omega_c t\right) \qquad (2)\\ &= \cos\omega_c t\sum_{i=0}^{7}\tilde{I}_i + \sin\omega_c t\sum_{i=0}^{7}\tilde{Q}_i. \end{aligned}$$

[0034] **FIG. 4** shows that note that $\tilde{I}_1=L[\hat{I}_i]$ and $\tilde{Q}_1=L[\hat{Q}_1]$, where L [•] denotes the linear baseband filtering operation. Using these relationships in (2) and noting the fundamental property of a linear operation (i.e., L[x]+L [y]**32** L [x+y]), the composite TX signal can be expressed as

$$s(t) = \cos\omega_c tL\left[\sum_{i=0}^{7}\hat{I}_i\right] + \sin\omega_c tL\left[\sum_{i=0}^{7}\hat{Q}_i\right]. \qquad (3)$$

[0035] Since this can be carried out as a summation of a number of coefficients, the inventor recognized that only a single baseband filter is required for each out of phase channel. Since there are two out of phase channel sequences I and Q, only two baseband filters are required. Summations of I and Q coefficients is carried out before the baseband filter.

[0036] The circuit of **FIG. 5** carries out this operation. Three channels are shown, A0, A1 and A_n, where in the preferred embodiment n=7. Channel **500** includes a first portion which is substantially identical to the operation in the left portion of **FIG. 4**. Each of the I and Q channels includes the PNI and PNQ injectors **502**, **504**, a delay line **506**, and a phase shifter element **510**. The phase shifter element **510** can be that shown using combinations of multiplications, or can use a specialized processing device as shown in **FIG. 3**.

[**0037**] All of the $\hat{I}_i$ outputs from the phase shifters are summed together in adder 520, and all of the $\hat{Q}_i$ outputs are summed together in adder 525. The resultant combined output of each adder corresponds to the summation of all $\hat{I}$ and $\hat{Q}$ channels. The $\hat{I}$ summation is baseband filtered by I baseband filter **530**. The $\hat{Q}$ summation is baseband filtered by Q baseband filter **535**. The resultant baseband outputs are then shifted to RF by multiplication by the sin and cos components $\omega_c t$.

[**0038**] This invention allows performing even more of the phase shifting operations at baseband. Only additions and multiplications are required. The constant values for cosines and sines of the phase shifts for the individual supplemental channels can be stored in memory.

[**0039**] All of these operations are ideally suited for implementation on a DSP or other specialized processing device.

[**0040**] Only two baseband filters are required. More generally, any number of channels can be summed together, accordingly reducing the number of baseband filters required.

[**0041**] Although only a few embodiments have been described above, other modifications are contemplated.

[**0042**] For example, any number of baseband filters be used. Other forms of modulation, including conventional QPSK could be used. This is also applicable to other forms of wireless communication that use the principle of adding multiple code channels.

What is claimed is:

1. A code division multiple access communication system for processing a communication and transmitting said communication using an RF carrier, comprising:

a plurality of individual code channels, each said code channel including part of said communication, said part being processed separately from other parts of said communication, at least one of said individual code channels being transmitted with a phase shift relative to another code channel;

said at least one code channel including:

a phase shifting circuit operating to phase shift said signal relative to said another code channel, said phase shifting circuit operating at a baseband frequency to produce a phase shifted signal; and

an RF modulator, modulating the phase shifted signal according to the RF carrier to produce a signal at said RF carrier that is phase shifted relative to said another code channel.

* * * * *