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# (54) SYSTEM AND METHOD FOR MULTIPLE-INPUT MULTIPLE-OUTPUT (MIMO) RADIO COMMUNICATION

SYSTEM UND VERFAHREN ZUR FUNKKOMMUNIKATION MIT MEHREREN EINGÄNGEN UND MEHREREN AUSGÄNGEN (MIMO)

SYSTEME ET PROCEDE DE COMMUNICATION RADIO A ENTREES ET SORTIES MULTIPLES (MIMO)

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## Description

**[0001]** This application claims priority to U.S. Provisional Application No. 60/319,437, filed July 30, 2002, to U.S. Provisional Application No. 60/461,672, filed April 10, 2003, and to U.S. Provisional Application No. 60/479,945, filed June 19, 2003.

## BACKGROUND OF THE INVENTION

**[0002]** The present invention is directed to a system and method to maximize capacity and/or range of a wireless radio communication link between two radio communication devices.

**[0003]** Multiple-input multiple-output (MIMO) radio communication techniques are known to enhance the received SNR for signals transmitted by one device to another. Research in MIMO radio algorithms has been conducted in which multiple signal streams are transmitted simultaneously from multiple antennas at one device to another device, thereby greatly enhancing the data rate of the wireless radio channel between two devices. One prior approach for transmitting multiple signals streams simultaneously by a plurality of antennas uses a power constraint on the total power transmitted by the plurality of antennas combined and a waterfilling solution. The waterfilling solution requires multiple full-power power amplifiers at the transmitting device since, for some channels, it is possible that all or nearly all the transmit power may be transmitted from one power amplifier.

**[0004]** As an example, document US6,377,631 discloses a method and a transmitter system incorporating spatio-temporal processing for transmitting signals via a channel having multiple inputs and multiple outputs. The transmitter system operates according to a substantially orthogonalizing procedure to decompose the time-domain space time channel into a set of parallel space-frequency bins and uses a spatial processing procedure to transmit the bins along various directions. In particular, document US6,377,631 teaches to transmit the signals on a subset of the possible channels taking into account variation of signal to noise ratio and information capacity among the channels.

**[0005]** There is room for improving the design of devices capable of MIMO radio communication, particularly where it is desirable to fabricate the radio transceiver of the device in an integrated circuit.

## SUMMARY OF THE INVENTION

**[0006]** Briefly, a system, method and device are provided for simultaneous radio communication of multiple signals (signal streams) between a first device having N plurality of antennas and a second device having M plurality of antennas. Unlike prior approaches, the approach taken herein is to impose a power constraint on each transmit antenna path at the transmitting device.

**[0007]** At the first device, a vector s representing L plurality of signals $[s_1 \ldots s_L]$ to be transmitted are processed with a transmit matrix A to maximize capacity of the channel between the first device and the second device subject to a power constraint that the power emitted by each of the N antennas is less than or equal to a maximum power. The power constraint for each antenna may be the same for all antennas or specific or different for each antenna. For example, the power constraint for each antenna may be equal to a total maximum power emitted by all of the N antennas combined divided by N. The transmit matrix A distributes the L plurality of signals $[s_1 \ldots s_L]$ among the N plurality of antennas for simultaneous transmission to the second device. At the second device, the signals received by the M plurality of antennas are processed with receive weights and the resulting signals are combined to recover the L plurality of signals. Solutions are provided for the cases when $N > M$ and when $N \leq M$.

**[0008]** The performance of a system in which the communication devices are designed around a power constraint at each antenna is nearly as good as the optimal waterfilling solution, yet provides significant implementation advantages. The radio transmitter can be implemented with power amplifiers that require lower power output capability, and thus less silicon area. Consequently, there is lower DC current drain by the transmitter, and lower on-chip interference caused by the power amplifiers.

**[0009]** The above and other objects and advantages will become more readily apparent when reference is made to the following description taken in conjunction with the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0010]**

FIG. 1 is a system diagram showing two multiple-antenna radio communication devices, where multiple signal streams are simultaneously transmitted from a first device to a second device.

FIG. 2 is a flow chart depicting the mapping and multiplexing of signals to multiple antenna paths for simultaneous transmission.

FIG. 3 is a block diagram of a radio communication device capable of performing the MIMO radio communication techniques shown in FIG. 1.

FIG. 4 is a block diagram of an exemplary transmitter section of a modem forming part of the device shown in FIG. 3.

FIG. 5 is a block diagram of an exemplary receiver section of the modem.

FIG. 6 is a graphical plot that illustrates the relative performance of the MIMO radio techniques described herein.

## DETAILED DESCRIPTION OF THE DRAWINGS

**[0011]** Referring to FIGs. 1 and 2, a system 10 is shown in which a first radio communication device 100 having N antennas 110(1) to 110(N) communicates by a wireless radio link with a second communication device 200 having M antennas 210(1) to 210(M). In the explanation that follows, the first communication device transmits to the second communication device, but the same analysis applies to a transmission from the second communication device to the first. The multiple-input multiple-output (MIMO) channel response from the N antennas of the first communication device to the M antennas of the second communication device is described by the channel response matrix **H.** The channel matrix in the opposite direction is $\mathbf{H}^T$.

**[0012]** Device 100 will simultaneously transmit L plurality of signals $s_1, s_2, ..., s_L$ by antennas 110(1) to 110(N). A vector **s** is defined that represents the L plurality of signals $[s_1 ... s_L]$ (at baseband) to be transmitted such that $\mathbf{s} = [s_1 ... s_L]^T$. The number (L) of signals that can be simultaneously transmitted depends on the channel **H** between device 100 and device 200, and in particular $L \leq$ Rank of $\mathbf{H}^H\mathbf{H} \leq \min(N,M)$. For example, ifN = 4, and M = 2, then $L \leq$ Rank of $\mathbf{H}^H\mathbf{H} \leq 2$.

**[0013]** The device 100 has knowledge of the channel state (e.g., using training sequences, feedback, etc.), i.e., device 100 knows **H.** Techniques to obtain and update knowledge of the channel **H** at the transmitting device (between the transmitting device and a receiving device) are known in the art and therefore are not described herein. For example, training and feedback techniques are described in U.S. Patent No. 6,144,711 to Raleigh et al.

**[0014]** Two matrices are introduced: **V** is the eignenvector matrix for $\mathbf{H}^H\mathbf{H}$ and **A** is the eigenvalue matrix for $\mathbf{H}^H\mathbf{H}$. Device 100 transmits the product As, where the matrix **A** is the spatial multiplexing transmit matrix, where **A** = **VD.** The matrix **D** = diag($d_1,...,d_L$) where $|d_p|^2$ is the transmit power in p^th^ mode, or in other words, the power of the p^th^ one of the L signals. Device 200 receives **HAs** + n, and after maximal ratio combining for each of the modes, device 200 computes $c = \mathbf{A}^H{}_H{}^H\mathbf{HA}_\mathbf{s} + \mathbf{A}^H\mathbf{H}^H\mathbf{n} = \mathbf{D}^H\mathbf{DAs} + \mathbf{D}^H\mathbf{V}^H\mathbf{H}^H\mathbf{n}$.

**[0015]** As shown in FIG. 2, at the first device 100, blocks of bits from a bit stream {b} are mapped onto a vector s with a mapping technique. The mapping technique may optionally include coded modulation to improve link margin. The bit stream {b} may be a file or collection of bits, representing any type of data, such as voice, video, audio, computer data, etc., that is divided or otherwise separated into discrete frames or blocks (generally referred to as signals) to be spatially multiplexed and simultaneously transmitted. One example is the simultaneous transmission of multiple IEEE 802.11x frames (each $s_i$ may be a different frame) from the first device 100 to the second device 200, where, for example, the first device 100 is an IEEE 802.11 access point (AP) and the second device is a client station (STA). The product of the transmit matrix A and the vector s is a vector **x.** This matrix multiplication step effectively weights each element of the vector s across each of the N antennas, thereby distributing the plurality of signals among the plurality of antennas for simultaneous transmission. Components $x_1$ through $x_N$ of the vector **x** resulting from the matrix multiplication block are then coupled to a corresponding antenna of the first communication device. For example, component $x_1$ is the sum of all of the weighted elements of the vector s for antenna 1, component $x_2$ is the sum of all of the weighted elements of the vector s for antenna 2, etc.

**[0016]** The transmit matrix **A** is a complex matrix comprised of transmit weights $w_{T,ij}$, for i = 1 to L and j = 1 to N. Each antenna weight may depend on frequency to account for a frequency-dependent channel **H.** For example, for a multi-carrier modulation system, such as an orthogonal frequency division multiplexed (OFDM) system, there is a matrix **A** for each sub-carrier frequency k. In other words, each transmit weight $w_{T,ij}$ is a function of sub-carrier frequency k. For a time-domain (single-carrier) modulation system, each transmit weight $w_{T,ij}$ may be a tapped-delay line filter.

**[0017]** Prior approaches involve selecting the weights $d_p$ to maximize capacity

$$C = \sum_{p=1}^{L} \log(1 + SNR_p), \quad SNR_p = |d_p|^2 \lambda_p \frac{E(|s_p|^2)}{E(|n_p|^2)}$$

subject to a *total* power constraint emitted by the plurality of transmit antennas combined on the transmit matrix **A,** i.e.,

$$P_{TOT} = \mathrm{Tr}(\mathbf{AA^H}) * \mathbf{E}|\mathbf{s_p}|^2 = \mathrm{Tr}(\mathbf{VDD^HV^H}) * \mathbf{E}|\mathbf{s_p}|^2$$
$$= \mathrm{Tr}(\mathbf{VDD^HV^H}) < P_{max} \ \ (\text{assuming } \mathbf{E}|\mathbf{s_p}|^2 = 1)$$

The optimum solution to this problem is to use waterfilling to select the weights $d_p$ (i.e., use waterfilling to put more power in eigenchannels with higher SNR $\lambda_p$).

**[0018]** The waterfilling approach requires N full-power capable power amplifiers at the transmitting device since, for some channels, it is possible for the optimal solution to require all or nearly all the transmit power to be sent from one antenna path. To reiterate, the prior approaches constrain the total power emitted from all of the antenna paths combined, simply $\Sigma P_i = P_{TOT} < P_{max}$ (for i = 1 to N antennas) where $P_{max}$ is a total power constraint and $P_i$ is the power from transmit antenna path i.

**[0019]** A better approach is to use a power constraint for each individual transmit antenna path. On such constraint is that the power transmitted from each antenna is less that the total power transmitted from all N antennas combined ($P_{max}$) divided by N, e.g., $P_i \leq P_{max}/N$ for all i. Using the approach, referred to as the "antenna power constraint" approach, each power amplifier cans be designed to output (no more than) $P_{max}/N$ average power, where $P_{max}$ is a maximum power of the transmission from all of the N antennas combined. A significant benefit of this approach is that the power amplifiers can be designed to have lower maximum output power capability, thus requiring less silicon area. The use of smaller and lower-output power amplifiers has the benefit of lower on-chip power amplifier interference and lower DC current drain.

**[0020]** Using a $P_{max}/N$ power constraint for *each* antenna, the problem becomes:
Maximize capacity C subject to

$$(\mathbf{AA^H})_{ii} < P_{max}/N, \ i = 1,\ldots,N.$$

This is a difficult problem to solve for $d_p$, since it involves finding the roots of a non-linear function using N Lagrange multipliers (one for each of the above N constraints). However, there is a simple non-optimal solution for each of two cases.

<u>Case 1: N ≤ M:</u>

**[0021]** In this case, the transmitting device (having N plurality of antennas) multiplies the vector s representing the L signals $[s_1 \ldots s_L]^T$ to be transmitted with the transmit matrix **A** (i.e., computes **As),** where the transmit matrix A is computed with **D** set equal to ($P_{max}$/N) (where **I** is the identity matrix) enforcing equal power in each mode. As a result, $\mathbf{H^HH}$ is Hermitian and (with probability 1) is full-rank, which means that V is orthonormal. Consequently, $(\mathbf{AA}^H)_{ii} = (\mathbf{VDD}^H\mathbf{V}^H)_{ii} = (\mathbf{VV}^H)_{ii}P_{max}/N = P_{max}/N$, which means that equal power $P_{max}/N$ is transmitted at each antenna by a corresponding power amplifier of device 100, and the total transmit power is equal to $P_{max}$.

<u>Case 2: N > M:</u>

**[0022]** In this case, $\mathbf{H^HH}$ is not full-rank. Let $\mathbf{v}_1,\ldots,\mathbf{v}_L$ denote the L eigenvectors for $\mathbf{H^HH}$ having nonzero eigenvalues. Let V = $[\mathbf{v}_1 \ldots \mathbf{v}_L]$, and let **D** = sqrt (d × $P_{max}$/N) × **I**, where the power for each mode is the same and $d_p$ = d for p = 1 to L. The power in antenna path i is given by (d × $P_{max}$/N) × $(\mathbf{VV}^H)_{ii}$. Thus, the power emitted from each of the i antenna paths may be different. The transmitting device (having the N antennas) multiplies the vector s representing the L signals $[s_1 \ldots s_L]^T$ to be transmitted with the transmit matrix A (i.e., computes **As**), where the transmit matrix **A** is computed with D set equal to sqrt (d × $P_{max}$/N) × **I**, where the power for each mode is the same and $d_p$ = d for p = 1 to L.

**[0023]** Approach 1: Set d =1/z, where $z = \max_i \{(\mathbf{VV^H})_{ii}\}$. Then the maximum power from any antenna path is $P_{max}/N$. The total power from all antenna paths can be shown to be at least $P_{max}/M$ and no greater than $P_{max}$.

**[0024]** Approach 2: Set d = 1. In this case, the total power emitted by the N plurality of antennas is $P_{max}/M$ and the power emitted by antenna i for i = 1 to N is ($P_{max}$/N) × $(VV^H)_{ii}$.

**[0025]** Assuming the power amplifiers at devices on both sides of the link have the same peak output power, then for Case 1 and Case 2/Approach 2, the total power transmitted from the N antenna device will be equal to the total power transmitted from the M antenna device. Hence, the link between the two devices is symmetric in these situations. Case 2/Approach 1 is slightly more complicated (since it requires a normalization step) but has more transmitted power than Approach 2.

**[0026]** The solutions described above are capable of performing within 1 dB of the Shannon limit for a symmetric system (same number of antennas on both sides of the link), but facilitate use of smaller and more efficient power amplifiers in the radio transceiver, and as a result, achieve lower on-chip interference between radio paths (caused by the power amplifiers) than the waterfilling solution.

**[0027]** The antenna power constraint need not be the same for each of the transmit antennas and may be specific to or different for each antenna. Moreover, even if a different antenna power constraint is used for each antenna, each of the antenna-specific power constraints may be less than or equal to $P_{max}/N$.

**[0028]** The device 200 with M plurality of antennas will transmit to device 100 subject to the same type of power constraint at each of the M plurality of antennas. The cases described above are applied where M is compared relative to N, and the appropriate solution is used for transmitting signals to device 100.

**[0029]** FIG. 3 shows a block diagram of a radio communication device suitable for devices 100 and 200. Device 100 comprises a modem 120, a plurality of digital-to-analog converters (DACs) 130, a plurality of analog-to-digital converters (ADCs) 140, a MIMO radio transceiver 150 coupled to antennas 110(1) to 110(N) and a control processor 160. The modem 120, also referred to as a baseband signal processor, performs the baseband modulation of signals to be transmitted (vector s) and the baseband demodulation of received signals. In so doing, the modem 120 multiplies the vector s representing the L signals $[s_1 \ldots s_L]^T$ to be transmitted by the transmit matrix **A.** The DACs 130 are complex DACs that convert the digital baseband modulated signals representing As to corresponding analog signals coupled to transmit paths in the MIMO radio transceiver 150. The ADCs 140 convert the received analog signals from corresponding receive paths in the MIMO radio transceiver 150 to digital signals for baseband demodulation by the modem 120. In the baseband demodulation process, the modem 120 will apply appropriate receive weights to the received signals to recover the L signals $[s_1 \ldots s_L]^T$. The MIMO radio transceiver 150 comprises a plurality of radio transceivers each comprising a transmitter 152(i) and a receiver 154(i) associated with and coupled to a corresponding antenna by a corresponding switch 156(i). Each transmitter includes a power amplifier (not shown). The MIMO radio transceiver 150 may be a single integrated circuit or two or more separate integrated circuits. An example of a single-integrated MIMO radio transceiver is disclosed in co-pending and commonly assigned U.S. Patent Application No. 10/065,388, filed October 11, 2002.

**[0030]** There are many ways to implement the modem 120. FIGs. 4 and 5 show block diagrams of examples of the transmitter section 120A and receiver sections 120B, respectively, of the modem 120, for a multi-carrier, e.g., orthogonal frequency division multiplexed (OFDM) application. Generally, matrix multiplication of the type described above is performed independently on each OFDM subcarrier to optimize performance for indoor frequency-selective fading channels. With reference to FIG. 4, the transmitter section 120A of the modem comprises a scrambler block 310, a block 315 of convolutional encoders, a block 320 of interleavers, a spatial multiplexer block 325 that performs the matrix multiplication with the transmit matrix A that is different at each of the OFDM sub-carriers k (i.e., **A** = **A**(k)), a subcarrier modulator 330, a block 335 of inverse Fast Fourier Transforms (IFFTs) and a block 340 of low pass filters. The output of the low pass filters block 340 is coupled to the DACs 130 (FIG. 3). A preamble generator 350 is also provided and is coupled to the DACs **130**. As shown in FIG. 4, assuming the modem is in an N antenna device, there are L instances of blocks 315, 320 and 325 to perform processing on each baseband transmit signal stream and N instances of blocks 335, 340 and 130 for processing signals associated with each transmit antenna path.

**[0031]** The receiver section 120B shown in FIG. 5 comprises a block 415 of resamplers, a block of lowpass filters 420, a block 425 of numerically controlled oscillators (NCOs), a block 430 of FFTs, a block of equalizers 435 in which the receive weights are applied to the receive signals, a block of de-interleavers 440 and a block of convolutional decoders 445. A preamble processing and automatic gain control (AGC) block 450 and a channel estimator block 455 are also provided for channel estimation computations and other functions. The preamble and AGC block 450 recovers a preamble in the received signal and the channel estimator 455 generates knowledge about the channel H, which knowledge is supplied to the equalizer 435 to compute and apply receive weights to the signals output by the FFT block 430. Assuming the modem is in an N antenna device, there are N instances of blocks 415, 420, 425 and 430 to perform processing on each received signal stream and L instances of blocks 435, 440 and 445 to recover the L signals.

**[0032]** As suggested in the description above of FIGs. 4 and 5, a first device passes channel response information to a second device by sending a known OFDM training sequence once through each antenna in, for example, a packet preamble. For a frequency domain implementation, the second device performs a space-frequency decomposition (SED) given this channel information, and uses the SFD data to process received signals from that device, and to transmit signals back to the other device. This assumes reciprocity in the link, and therefore MIMO phase calibration at each device needs to be performed. Techniques for MIMO phase calibration are disclosed in commonly assigned and co-pending U.S. Patent Application No.10/457,293, filed June 9, 2003.

**[0033]** Information regarding constellation order as a function of subcarrier index and eigenchannel may also be included in preamble. Each subcarrier has an associated constellation order for each eigenchannel. In the transmitter section 120A, a multi-dimensional vector trellis encoder (VTE) may be used to map input bits from the scrambler onto OFDM constellation symbols. Examples of multi-dimensional VTE's are known in the art. Other techniques for obtaining channel state information are known in the art as suggested above.

**[0034]** A modem may be built that applies the power constraint principles described above to a time-domain system implementation where tapped delay-line filters are used.

**[0035]** FIG. 6 illustrates how the more efficient antenna power constraint described herein compares to the optimal waterfilling approach.

**[0036]** In sum, a system and method are provided for MIMO radio communication between a first device having N plurality of antennas and a second device having M plurality of antennas. At the first device, a vector s representing L signals [$s_1$ ... $s_L$] to be transmitted is processed with a transmit matrix **A** to maximize capacity of the channel between the first device and the second device subject to a power constraint that the power emitted by each of the N antennas is less than a maximum power, whereby the transmit matrix **A** distributes the L signals [$s_1$ ... $s_L$] among the N plurality of antennas for simultaneous transmission to the second device. Similarly, a radio communication device is provided comprising N plurality of antennas, N plurality of radio transmitters each coupled to a corresponding one of the plurality of antennas, and a baseband signal processor coupled to the N plurality of radio transmitters to process a vector s representing L signals [$s_1$ ... $s_L$] to be transmitted with a transmit matrix **A** to maximize capacity of the channel between the first device and the second device subject to a power constraint that the power emitted by each of the N antennas is less than a maximum power, whereby the transmit matrix **A** distributes the L signals [$s_1$ ... $s_L$] for simultaneous transmission to the second device by the N plurality of antennas. The transmit matrix **A** is computed subject to the power constraint being different for one or more of the N antennas or being the same for each of the N plurality of antennas. For example, in the latter case, the transmit matrix **A** may be computed subject to the power constraint for each of the N plurality of antennas being equal to a total maximum power emitted by all of the N plurality of antennas combined divided by N.

**[0037]** The above description is intended by way of example only.

## Claims

1. A method for radio communication between a first device (100) having N plurality of antennas (110(1)-110(N)) and a second device (200) having M plurality of antennas (210(1)-210(M)) comprising: processing a vectors representing L signals [$s_1$ ...$s_L$] with a transmit matrix A that is computed to maximize capacity of the channel between the first device and the second device, whereby the transmit matrix A distributes the L signals [$s_1$ ... $s_L$] among the N plurality of antennas for simultaneous transmission to the second device, **characterized in that** each of the N antennas is subject to a specific power constraint which is less than or equal to a power corresponding to a total maximum power $P_{max}$ emitted by all of the N plurality of antennas combined divided by N.

2. The method of claim 1, wherein the transmit matrix A is computed subject to the power constraint being different for one or more of the N plurality of antennas.

3. The method of claim 1, wherein the transmit matrix A is computed subject to the power constraint being the same for each of the N plurality of antennas.

4. The method of claim 3, wherein the transmit matrix A is computed subject to the power constraint for each of the N plurality of antennas being equal to said total maximum power emitted by all of the N plurality of antennas combined divided by N.

5. The method of claim 4, wherein the vector s is multiplied with the transmit matrix A, where the transmit matrix A is equal to VD, where V is the eigenvector matrix for $H^H H$, H is the channel response from the first device to the second device, D= diag($d_1$,...,$d_L$) and $|d_p|^2$ is the power of the $p^{th}$ one of the L signals.

6. The method of claim 5, wherein when N ≤M, the processing comprises multiplying the vector s with the transmit matrix **A,** where D = I × sqrt ($P_{max}$/N), and I is the identity matrix, such that the power transmitted by each of the N plurality of antennas is the same and equal to $P_{max}$/N.

7. The method of claim 5, wherein when N > M, D = sqrt (d × $P_{max}/N_{Tx}$) × I, such that the power transmitted by antenna i for i = 1 to N is (d × $P_{max}$/N) × $(VV^H)_{ii}$, and $d_p$ = d for p = 1 to L.

8. The method of claim 7, wherein d = 1/z and $z = \max_i \{(VV^H)_{ii}\}$, such that the maximum power from any of the N plurality of antennas is $P_{max}$/N and the total power emitted from the N plurality of antennas combined is between $P_{max}$/M and $P_{max}$.

**9.** The method of claim 7, wherein d =1, such that the power emitted by antenna i for i = 1 to N is $(P_{max}/N) \times (VV^H)_{ii}$ and the total power emitted from the N plurality of antennas combined is $P_{max}/M$.

**10.** The method of claim 1, and further comprising the steps at the second device of receiving at the M plurality of antennas signals transmitted by the first device, and processing signals received at each of the plurality of M antennas with receive weights and combining the resulting signals to recover the L signals.

**11.** The method of claim 1, wherein each of the L signals is baseband modulated using a multi-carrier modulation process, and wherein the step of processing comprises multiplying the vector s with a transmit matrix **A**(k) at each of a plurality of sub-carriers k.

**12.** A radio communication device (100), comprising: N plurality of antennas (110(1)-110(N)); N plurality of radio transmitters (152(1)-152(N)) each coupled to a corresponding one of the plurality of antennas; and a baseband signal processor (120) coupled to the N plurality of radio transmitters to process a vector s representing L signals $[s_1,\ldots s_L]$ with a transmit matrix A that is computed to maximize capacity of the channel between said device and a second device (200), whereby the transmit matrix A distributes the L signals $[s_1\ldots s_L]$ for simultaneous transmission to the second device by the N plurality of antennas,**characterized in that** each of the N antennas is subject to a specific power constraint which is less than or equal to a power corresponding to a total maximum power $P_{max}$ emitted by all of the N plurality of antennas combined divided by N.

**13.** The device of claim 12, wherein the transmit matrix **A** is computed subject to the power constraint being different for one more of the N plurality of antennas.

**14.** The device of claim 12, wherein the transmit matrix **A** is computed subject to the power constraint being the same for each of the N plurality of antennas.

**15.** The device of claim 14, wherein the transmit matrix **A** is computed subject to the power constraint for each of the N plurality of antennas being equal to said total maximum power emitted by all of the N plurality of antennas combined divided by N.

**16.** The device of claim 15, wherein the baseband signal processor multiplies the vector s with the transmit matrix **A**, where the transmit matrix **A** is equal to **VD**, where **V** is the eigenvector matrix for $\mathbf{H}^\mathbf{H}\mathbf{H}$, **H** is the channel response from the device to said second device having M plurality of antennas (210(1)-210(M)), $\mathbf{D} = \text{diag}(d_1,\ldots,d_L)$ and $|d_p{}^2|$ is the power of the p^th^ one of the L signals.

**17.** The device of claim 16, wherein when $N \leq M$, $D = I \times \text{sqrt}\,(P_{max}/N)$, and **I** is the identity matrix, such that the power transmitted by each of the N plurality of antennas is the same and equal to $P_{max}/N$.

**18.** The device of claim 16, wherein when N>M, the baseband signal processor multiplies the vector s with the transmit matrix A that is computed where $D = \text{sqrt}\,(d \times P_{max}/N_{Tx}) \times I$ such that the power emitted by antenna i for i = 1 to N is $(d \times P_{max}/N) \times (VV^H)_{ii}$, and $d_p = d$ for p = 1 to L.

**19.** The device of claim 18, wherein d = 1/z and $z = \max_i \{(VV^H)_{ii}\}$ such that the maximum power from any antenna of the N plurality of antennas is $P_{max}/N$ and the total power emitted from the N plurality of antennas combined is between $P_{max}/M$ and $P_{max}$.

**20.** The device of claim 18, wherein d=1, such that the power emitted by antenna i for i = 1 to N is $(P_{max}/N) \times (VV^H)_{ii}$, and the total power emitted from the N plurality of antennas combined is $P_{max}/M$.

**21.** The device of claim 12, wherein each of the L signals is baseband modulated using a multi-carrier modulation process, and the baseband signal processor multiplies the vector s with a transmit matrix A(k) at each of a plurality of sub-carriers k.

**22.** A radio communication system comprising a first device (100) and a second device (200), said first device comprising: N plurality of antennas (110(1)-110(N)).
N plurality of radio transmitters (152(1)-152(N) each coupled to a corresponding one of the plurality of antennas; and a baseband signal processor (120) coupled to the N plurality of radio transmitters to process a vector s representing

L signals $[s_1 \dots s_L]$ with a transmit matrix A that is computed to maximize capacity of the channel between the first device and the second device, whereby the transmit matrix A distributes the L signals $[s_1 \dots s_L]$ for simultaneous transmission to the second device by the N plurality of antennas; said second device comprising:
M plurality of antennas (210(1)-210(M)).
M plurality of radio receivers each coupled to a corresponding one of the plurality of antennas; and
a baseband signal processor coupled to the M plurality of radio receivers to process signals output by the plurality of radio receivers with receive weights and combining the resulting signals to recover the L signals $[s_1 \dots s_L]$, **characterized in that** each of the N antennas is subject to a specific power constraint which is less than or equal to a power corresponding to a total maximum power $P_{max}$ emitted by all of the N plurality of antennas combined divided by N.

**23.** The system of claim 22, wherein the transmit matrix A is computed subject to the power constraint being different for one or more of the N antennas.

**24.** The system of claim 23, wherein the transmit matrix A is computed subject to the power constraint being the same for each of the N plurality of antennas.

**25.** The system of claim 24, wherein the transmit matrix A is computed subject to the power constraint for each of the N antennas being equal to said total maximum power emitted by all of the N antennas combined divided by N.

**26.** The system of claim 25, wherein the transmit matrix **A** is equal to **VD,** where **V** is the eigenvector matrix for $\mathbf{H^H H}$, **H** is the channel response from the device to another device having M plurality of antennas, $D=\mathrm{diag}(d_1,\dots,d_L)$ and $|d_p|^2$ is the power of the p^th^ one of the L signals.

## Patentansprüche

**1.** Verfahren zur Funkkommunikation zwischen einer ersten Vorrichtung (100) mit einer Vielzahl von N Antennen (110(1) - 110(N)) und einer zweiten Vorrichtung (200) mit einer Vielzahl M von Antennen (210(1) - 210 (M), das aufweist: Verarbeiten eines Vektors s, der L Signale $[s_1 \dots s_L]$ darstellt, mit einer Übertragungsmatrix A, die berechnet wird, um die Kapazität des Kanals zwischen der ersten Vorrichtung und der zweiten Vorrichtung zu maximieren, wobei die Übertragungsmatrix A die L Signale $[s_1 \dots s_L]$ zwischen der Vielzahl N von Antennen für die gleichzeitige Übertragung an die zweite Vorrichtung verteilt, **dadurch gekennzeichnet, daß** jede der N Antennen einer spezifischen Leistungsrandbedingung unterworfen ist, die weniger oder gleich einer Leistung ist, die einer von allen der Vielzahl N von Antennen emittierten maximalen kombinierten Gesamtleistung $P_{max}$ geteilt durch N entspricht.

**2.** Verfahren nach Anspruch 1, wobei die Übertragungsmatrix A berechnet wird, wobei sie der Leistungsrandbedingung unterworfen wird, die für eine oder mehr der Vielzahl N von Antennen unterschiedlich ist.

**3.** Verfahren nach Anspruch 1, wobei die Übertragungsmatrix berechnet wird, wobei sie der Leistungsrandbedingung unterworfen wird, die für jede der Vielzahl N von Antennen gleich ist.

**4.** Verfahren nach Anspruch 3, wobei die Übertragungsmatrix A berechnet wird, wobei sie der Leistungsrandbedingung unterworfen wird, dass sie für jede der Vielzahl N von Antennen gleich der von allen der Vielzahl N von Antennen emittierten maximalen kombinierten Gesamtleistung $P_{max}$ geteilt durch N ist.

**5.** Verfahren nach Anspruch 4, wobei der Vektor s mit der Übertragungsmatrix A multipliziert wird, wobei die Übertragungsmatrix A gleich VD ist, wobei V die Eigenvektormatrix für $H^H H$ ist, H die Kanalantwort von der ersten Vorrichtung an die zweite Vorrichtung ist, $D = \mathrm{diag}\,(d_1 \dots d_L)$ und $|d_p|^2$ die Leistung des p-ten der L Signale ist.

**6.** Verfahren nach Anspruch 5, wobei $N \le M$, der Verarbeitungsschritt das Multiplizieren des Vektors s mit der Übertragungsmatrix A aufweist, wobei $D = I \cdot \sqrt{P_{max} / N}$ und I die Einheitsmatrix ist, so daß die von jeder der Vielzahl N von Antennen übertragene Leistung die gleiche und gleich $P_{max}/N$ ist.

**7.** Verfahren nach Anspruch 5, wobei, wenn $N > M$, $D = \sqrt{d \cdot P_{max} / N_{Tx}} \cdot I$, so daß die von der Antenne i für i = 1 bis N übertragene Leistung $(d \cdot P_{max}/N) \cdot (VV^H)_{ii}$ ist und $d_p = d$ für p = 1 bis L.

**8.** Verfahren nach Anspruch 7, wobei d = 1/z und $z = \max_i \{(VV^H)_{ii}\}$, so daß die maximale Leistung von jeder der Vielzahl N von Antennen $P_{max}/N$ ist und die von der Vielzahl N von Antennen emittierte kombinierte Gesamtleistung zwischen $P_{max}/M$ und $P_{max}$ ist.

**9.** Verfahren nach Anspruch 7, wobei d = 1, so daß die von der Antenne i für i = 1 bis N emittierte Leistung $(P_{max}/N) \cdot (VV^H)_{ii}$ ist, und die von der Vielzahl N von Antennen emittierte kombinierte Gesamtleistung $P_{max}/M$ ist.

**10.** Verfahren nach Anspruch 1, das ferner die Schritte des Empfangens der Vielzahl M von Antennensignalen, die von der ersten Vorrichtung gesendet werden, an der zweiten Vorrichtung und des Verarbeitens der an jeder der Vielzahl M von Antennen empfangenen Signale mit Empfangsgewichten und des Kombinierens der sich ergebenden Signale aufweist, um die L Signale wiederzugewinnen.

**11.** Verfahren nach Anspruch 1, wobei jedes der L Signale unter Verwendung eines Mehrträger-Modulationsverfahrens basisbandmoduliert wird und wobei der Verarbeitungsschritt das Multiplizieren des Vektors s mit einer Übertragungsmatrix A(k) bei jedem der Vielzahl von Teilträgern k aufweist.

**12.** Funkkommunikationsvorrichtung (100), die aufweist:

eine Vielzahl N von Antennen (110(1) - 110(N)),
eine Vielzahl N von Funksendern (152(1) - 152(N)), die jeweils mit einer entsprechenden der Vielzahl von Antennen gekoppelt sind; und
einen Basisbandsignalprozessor (120), der mit der Vielzahl N von Funksendern gekoppelt ist, um einen Vektor s, der L Signale $[s_1 \ldots s_L]$ darstellt, mit einer Übertragungsmatrix A zu verarbeiten, die berechnet wird, um die Kapazität des Kanals zwischen der Vorrichtung und einer zweiten Vorrichtung (200) zu maximieren, wobei die Übertragungsmatrix A die L Signale $[s_1 \ldots s_L]$ für die gleichzeitige Übertragung an die zweite Vorrichtung durch die Vielzahl N von Antennen verteilt, **dadurch gekennzeichnet, daß** jede der N Antennen einer spezifischen Leistungsrandbedingung unterworfen ist, die weniger oder gleich einer Leistung ist, die einer von allen der Vielzahl N von Antennen emittierten maximalen kombinierten Gesamtleistung $P_{max}$ geteilt durch N entspricht.

**13.** Vorrichtung nach Anspruch 12, wobei die Übertragungsmatrix A berechnet wird, wobei sie der Leistungsrandbedingung unterworfen wird, die für eine oder mehr der Vielzahl N von Antennen unterschiedlich ist.

**14.** Vorrichtung nach Anspruch 12, wobei die Übertragungsmatrix A berechnet wird, wobei sie der Leistungsrandbedingung unterworfen wird, die für jede der Vielzahl N von Antennen gleich ist.

**15.** Vorrichtung nach Anspruch 14, wobei die Übertragungsmatrix A berechnet wird, wobei sie der Leistungsrandbedingung unterworfen wird, dass sie für jede der Vielzahl N von Antennen gleich der von allen der Vielzahl N von Antennen emittierten maximalen kombinierten Gesamtleistung $P_{max}$ geteilt durch N ist.

**16.** Vorrichtung nach Anspruch 15, wobei der Basisbandsignalprozessor den Vektor s mit der Übertragungsmatrix A multipliziert, wobei die Übertragungsmatrix A gleich VD ist, wobei V die Eigenvektormatrix für $H^H H$ ist, H die Kanalantwort von der Vorrichtung an die zweite Vorrichtung mit der Vielzahl M von Antennen (210(1) - 210(M)) ist, $D = \mathrm{diag}(d_1 \ldots d_L)$ und $|d_p|^2$ die Leistung des p-ten der L Signale ist.

**17.** Vorrichtung nach Anspruch 16, wobei $N \leq M$, wobei $D = I \cdot \sqrt{P_{max}/N}$ und I die Einheitsmatrix ist, so daß die von jeder der Vielzahl N von Antennen übertragene Leistung die gleiche und gleich $P_{max}/N$ ist.

**18.** Vorrichtung nach Anspruch 16, wobei, wenn N > M, der Basisbandsignalprozessor den Vektor s mit der Übertragungsmatrix A multipliziert, die berechnet wird, so daß $D = \sqrt{d \cdot P_{max}/N_{Tx}} \cdot I$, so daß die von der Antenne i für i = 1 bis N übertragene Leistung $(d \cdot P_{max}/N) \cdot (VV^H)_{ii}$ ist und $d_p = d$ für p = 1 bis L.

**19.** Vorrichtung nach Anspruch 18, wobei d = 1/z und $z = \max_{i}\{(V V)_{ii}\}$, so daß die maximale Leistung von jeder der Vielzahl N von Antennen $P_{max}/N$ ist und die von der Vielzahl N von Antennen emittierte kombinierte Gesamtleistung zwischen $P_{max}/M$ und $P_{max}$ ist.

**20.** Vorrichtung nach Anspruch 18, wobei d = 1, so daß die von der Antenne i für i = 1 bis N emittierte Leistung $(P_{max}/N) \cdot (VV^H)_{ii}$ ist, und die von der Vielzahl N von Antennen emittierte kombinierte Gesamtleistung $P_{max}/M$ ist.

**21.** Vorrichtung nach Anspruch 12, wobei jedes der L Signale unter Verwendung eines Mehrträger-Modulationsverfahrens basisbandmoduliert wird und der Basisbandsignalprozessor den Vektor s mit einer Übertragungsmatrix A(k) bei jedem der Vielzahl von Teilträgern k multipliziert.

**22.** Funkkommunikationssystem, das aufweist:

eine erste Vorrichtung (100) und eine zweite Vorrichtung (200),

wobei die erste Vorrichtung aufweist:

eine Vielzahl N von Antennen (110(1) - 110(N)),
eine Vielzahl N von Funksendern (152(1) - 152(N)), die jeweils mit einer entsprechenden der Vielzahl von Antennen gekoppelt sind; und
einen Basisbandsignalprozessor (120), der mit der Vielzahl N von Funksendern gekoppelt ist, um einen Vektor s, der L Signale $[s_1 \ldots s_L]$ darstellt, mit einer Übertragungsmatrix A zu verarbeiten, die berechnet wird, um die Kapazität des Kanals zwischen der ersten Vorrichtung und der zweiten Vorrichtung zu maximieren, wobei die Übertragungsmatrix A die L Signale $[s_1 \ldots s_L]$ für die gleichzeitige Übertragung an die zweite Vorrichtung durch die Vielzahl N von Antennen verteilt,

wobei die zweite Vorrichtung aufweist:

eine Vielzahl M von Antennen (210 (1) - 210(N)),
eine Vielzahl M von Funkempfängern, die jeweils mit einer entsprechenden der Vielzahl von Antennen gekoppelt sind; und
einen Basisbandsignalprozessor, der mit der Vielzahl M von Funkempfängern gekoppelt ist, um Signale, die von der Vielzahl von Funkempfängern ausgegeben werden, mit Empfangsgewichten zu verarbeiten und die sich ergebenden Signale zu kombinieren, um die L Signale $[s_1 \ldots s_L]$ zurück zu gewinnen,

**dadurch gekennzeichnet, daß** jede der N Antennen einer spezifischen Leistungsrandbedingung unterworfen ist, die weniger oder gleich einer Leistung ist, die einer von allen der Vielzahl N von Antennen emittierten maximalen kombinierten Gesamtleistung $P_{max}$ geteilt durch N entspricht.

**23.** System nach Anspruch 22, wobei die Übertragungsmatrix A berechnet wird, wobei sie der Leistungsrandbedingung unterworfen wird, die für eine oder mehr der Vielzahl N von Antennen unterschiedlich ist.

**24.** System nach Anspruch 23, wobei die Übertragungsmatrix A berechnet wird, wobei sie der Leistungsrandbedingung unterworfen wird, die für jede der Vielzahl N von Antennen gleich ist.

**25.** System nach Anspruch 24, wobei die Übertragungsmatrix A berechnet wird, wobei sie der Leistungsrandbedingung unterworfen wird, dass sie für jede der Vielzahl N von Antennen gleich der von allen der Vielzahl N von Antennen emittierten maximalen kombinierten Gesamtleistung $P_{max}$ geteilt durch N ist.

**26.** System nach Anspruch 25, wobei die Übertragungsmatrix A gleich VD ist, wobei V die Eigenvektormatrix für $H^H H$ ist, H die Kanalantwort von der Vorrichtung an eine andere Vorrichtung mit der Vielzahl M von Antennen ist, D= diag($d_1 \ldots d_L$) und $|d_p|^2$ die Leistung des p-ten der L Signale ist.

## Revendications

1. Procédé de communication radio entre un premier dispositif (100) ayant une pluralité N d'antennes (110(1) - 110 (N)) et un second dispositif (200) ayant une pluralité M d'antennes (210(1) - 210(M)), comprenant : le traitement d'un vecteur s représentant L signaux [$s_1$ ... $s_L$] avec une matrice de transmission A qui est calculée pour optimiser la capacité du canal entre le premier dispositif et le deuxième dispositif de manière que la matrice de transmission A distribue les signaux L [$s_1$ ... $s_L$] parmi la pluralité N d'antennes pour la transmission simultanée au deuxième dispositif, **caractérisé en ce que** chacune des N antennes est soumise à une contrainte de puissance spécifique qui est inférieure ou égale à une puissance correspondant à une puissance maximale totale $P_{max}$ émise par toute la pluralité N d'antennes combinées divisée par N.

2. Procédé selon la revendication 1, dans lequel la matrice de transmission A est calculée soumise à la contrainte de puissance qui est différente pour une ou plus de la pluralité N d'antennes.

3. Procédé selon la revendication 1, dans lequel la matrice de transmission A est calculée soumise à la contrainte de puissance qui est la même pour chacune de la pluralité N d'antennes.

4. Procédé selon la revendication 3, dans lequel la matrice de transmission A est calculée soumise à la contrainte de puissance pour chacune de la pluralité N d'antennes qui est égale à ladite puissance maximale totale émise par toute la pluralité N d'antennes combinées divisée par N.

5. Procédé selon la revendication 4, dans lequel le vecteur s est multiplié par la matrice de transmission A, la matrice de transmission A étant égale à VD, V étant la matrice de vecteurs propres pour $H^H H$, H étant la réponse du canal du premier dispositif au deuxième dispositif, D = diag ($d_1$, ... , $d_L$) et $|d_p|^2$ est la puissance du $p^{ième}$ des L signaux.

6. Procédé selon la revendication 5, dans lequel quand N ≤ M, le traitement comprend la multiplication du vecteur s par la matrice de transmission A, D = I • sqrt($P_{max}$ /N) et I étant la matrice d'identité, de sorte que la puissance transmise par chacune de la pluralité N d'antennes soit la même et égale à $P_{max}$ /N.

7. Procédé selon la revendication 5, dans lequel quand N > M, D = sqrt (d • $P_{max}$ /$N_{Tx}$) • I, de sorte que la puissance transmise par l'antenne i pour i = 1 à N soit (d • $P_{max}$ /N) $(VV^H)_{ii}$ et $d_p$ = d pour p = 1 à L.

8. Procédé selon la revendication 7, dans lequel d = 1/z et $z = \max_i \{(VV^H)_{ii}\}$, de sorte que la puissance maximale de l'une quelconque de la pluralité N d'antennes soit $P_{max}$ /N et que la puissance totale émise à partir de la pluralité N d'antennes combinées soit entre $P_{max}$/M et $P_{max}$.

9. Procédé selon la revendication 7, dans lequel d = 1, de sorte que la puissance émise par l'antenne i pour i = 1 à N soit ($P_{max}$ /N) • $(VV^H)_{ii}$, et que la puissance totale émise à partir de la pluralité N d'antennes combinées soit $P_{max}$/M.

10. Procédé selon la revendication 1, et comprenant en outre les étapes au deuxième dispositif de réception, à la pluralité M d'antennes, de signaux transmis par le premier dispositif, et de traitement des signaux reçus à chacune de la pluralité M d'antennes avec des poids de réception et de combinaison des signaux résultants pour récupérer les L signaux.

11. Procédé selon la revendication 1, dans lequel chacun des L signaux est modulé en bande de base en utilisant un processus de modulation à porteuses multiples et dans lequel l'étape de traitement comprend la multiplication du vecteur s avec une matrice d'émission A(k) à chacune d'une pluralité de sous-porteuses k.

12. Dispositif de communication radio (100), comprenant :

    une pluralité N d'antennes (110(1) - 110(N));
    une pluralité N d'émetteurs radio (152(1) - 152(N)), chacun étant couplé à une correspondante de la pluralité d'antennes ; et un processeur de signaux de bande de base (120) couplé à la pluralité N d'émetteurs radio pour traiter un vecteur s représentant L signaux [$s_1$ ... $s_L$] avec une matrice de transmission A qui est calculée pour optimiser la capacité du canal entre ledit dispositif et
    un second dispositif (200), de manière que la matrice de transmission A distribue les L signaux [$s_1$ ... $s_L$] pour

une transmission simultanée au second dispositif par la pluralité N d'antennes,

**caractérisé en ce que** chacune des N antennes est soumise à une contrainte de puissance spécifique qui est inférieure ou égale à une puissance correspondant à une puissance maximale totale $P_{max}$ émise par toute la pluralité N d'antennes combinées divisée par N.

**13.** Dispositif selon la revendication 12, dans lequel la matrice de transmission A est calculée soumise à la contrainte de puissance qui est différente pour une ou plus de la pluralité N d'antennes.

**14.** Dispositif selon la revendication 12, dans lequel la matrice de transmission A est calculée soumise à la contrainte de puissance qui est la même pour chacune de la pluralité N d'antennes.

**15.** Dispositif selon la revendication 14, dans lequel la matrice de transmission A est calculée soumise à la contrainte de puissance pour chacune de la pluralité N d'antennes qui est égale à ladite puissance maximale totale émise par toute la pluralité N d'antennes combinées divisée par N.

**16.** Dispositif selon la revendication 15, dans lequel le processeur de signaux de bande de bande multiplie le vecteur s par la matrice de transmission A, où la matrice de transmission A est égale à VD, V étant la matrice de vecteurs propres pour $H^HH$, H étant la réponse du canal provenant du dispositif audit deuxième dispositif ayant une pluralité M d'antennes (210(1)-210(M)), D = diag $(d_1 \dots d_L)$ et $|d_p|^2$ est la puissance du $p^{ième}$ des L signaux.

**17.** Dispositif selon la revendication 16, dans lequel quand $N \leq M$, $D = I \bullet \text{sqrt}(P_{max} / N)$ et I étant la matrice d'identité, de sorte que la puissance transmise par chacune de la pluralité N d'antennes soit la même et égale à $P_{max} / N$.

**18.** Dispositif selon la revendication 16, dans lequel quand $N > M$, le processeur de signaux de bande de base multiplie le vecteur s par la matrice de transmission A qui est calculée où $D = \text{sqrt}(d \bullet P_{max} / N_{Tx}) \bullet I$, de sorte que la puissance émise par l'antenne i pour i = 1 à N est $(d \bullet P_{max} / N) \bullet (VV^H)_{ii}$ et $d_p = d$ pour p = 1 à L.

**19.** Dispositif selon la revendication 18, dans lequel $d = 1/z$ et $z = \max\{(VV^H)_{ii}\}$, de sorte que la puissance maximale de l'une quelconque de la pluralité N d'antennes est $P_{max} / N$ et la puissance totale émise de la pluralité N d'antennes combinées soit entre $P_{max}/M$ et $P_{max}$.

**20.** Dispositif selon la revendication 18, dans lequel d = 1, de sorte que la puissance émise par l'antenne i pour i = 1 à N soit $(P_{max} / N) \bullet (VV^H)_{ii}$, et la puissance totale émise de la pluralité N d'antennes combinées soit $P_{max}/M$.

**21.** Dispositif selon la revendication 12, dans lequel chacun des L signaux est modulé en bande de base en utilisant un processus de modulation à porteuses multiples, et le processeur de signaux de bande de base multiplie le vecteur s par une matrice de transmission A(k) à chacune d'une pluralité de sous-porteuses k.

**22.** Système de communication radio comprenant un premier dispositif (100) et un second dispositif (200), ledit premier dispositif comprenant :

une pluralité N d'antennes (110(1) - 110(N));
une pluralité N d'émetteurs radio (152(1) - 152(N)), chacun étant couplé à une correspondante de la pluralité d'antennes ; et
un processeur de signaux de bande de base (120) couplé à la pluralité N d'émetteurs radio pour traiter un vecteur s représentant L signaux $[s_1 \dots s_L]$ avec une matrice de transmission A qui est calculée pour optimiser la capacité du canal entre le premier dispositif et le second dispositif, de manière que la matrice de transmission A distribue les L signaux $[s_1 \dots s_L]$ pour une transmission simultanée au second dispositif par la pluralité N d'antennes,
ledit second dispositif comprenant :

une pluralité M d'antennes (210(1) - 210(M)) ;
une pluralité M de récepteurs radio, chacun étant couplé à une correspondante de la pluralité d'antennes ; et
un processeur de signaux de bande de base couplé à la pluralité M de récepteurs radio pour traiter les signaux envoyés en sortie par la pluralité de récepteurs radio avec des poids de réception et en combinant les signaux résultants pour récupérer les L signaux $[s_1 \dots s_L]$,

**caractérisé en ce que** chacune des N antennes est soumise à une contrainte de puissance spécifique qui est inférieure ou égale à une puissance correspondant à une puissance maximale totale $P_{max}$ émise par toute la pluralité N d'antennes combinées divisée par N.

**23.** Système selon la revendication 22, dans lequel la matrice de transmission A est calculée soumise à la contrainte de puissance qui est différente pour une ou plus des N antennes.

**24.** Système selon la revendication 23, dans lequel la matrice de transmission A est calculée soumise à la contrainte de puissance qui est la même pour chacune de la pluralité N d'antennes.

**25.** Système selon la revendication 24, dans lequel la matrice de transmission A est calculée soumise à la contrainte de puissance pour chacune des N antennes étant égale à ladite puissance maximale totale émise par toutes les N antennes combinées divisée par N.

**26.** Système selon la revendication 25, dans lequel la matrice de transmission A est égale à VD, V étant la matrice de vecteurs propres pour $H^H H$, H étant la réponse du canal du dispositif à un autre dispositif ayant une pluralité M d'antennes, $D = \mathrm{diag}(d_1 \ldots d_L)$ et $|d_p|^2$ est la puissance du $p^{ième}$ des L signaux.

FIG. 1

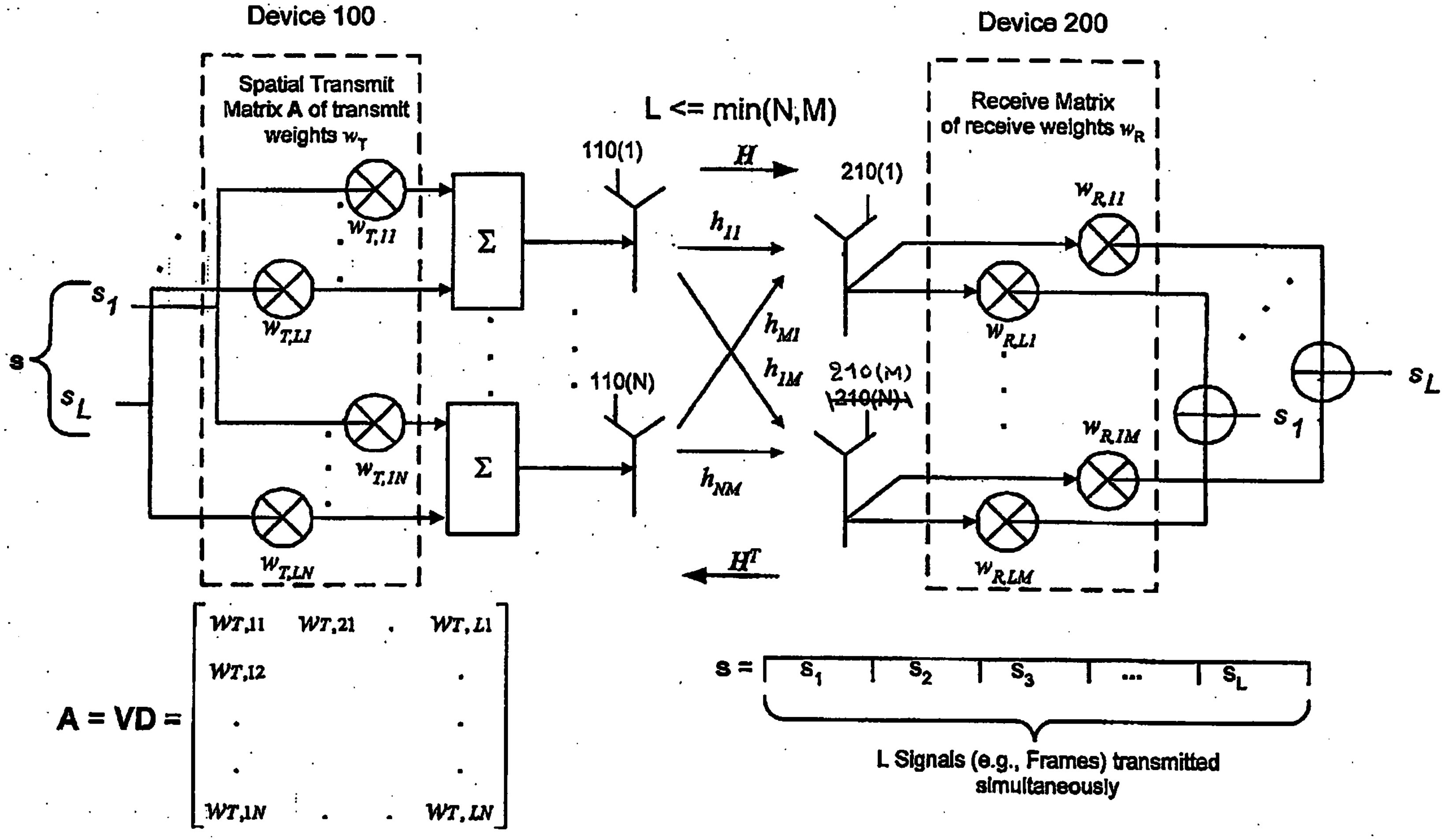

Device 100
Spatial Transmit Matrix A of transmit weights $w_T$
$w_{T,11}$
$w_{T,L1}$
$w_{T,1N}$
$w_{T,LN}$
s
$s_1$
$s_L$
Σ
Σ
110(1)
110(N)
L <= min(N,M)
$H$
$H^T$
$h_{11}$
$h_{M1}$
$h_{1M}$
$h_{NM}$
210(1)
210(M)
~~210(N)~~
Device 200
Receive Matrix of receive weights $w_R$
$w_{R,11}$
$w_{R,L1}$
$w_{R,1M}$
$w_{R,LM}$
$s_1$
$s_L$
A = VD =
$w_{T,11}$ $w_{T,21}$ . $w_{T,L1}$
$w_{T,12}$
$w_{T,1N}$ . . $w_{T,LN}$
s = $s_1$ $s_2$ $s_3$ ... $s_L$
L Signals (e.g., Frames) transmitted simultaneously

FIG. 2

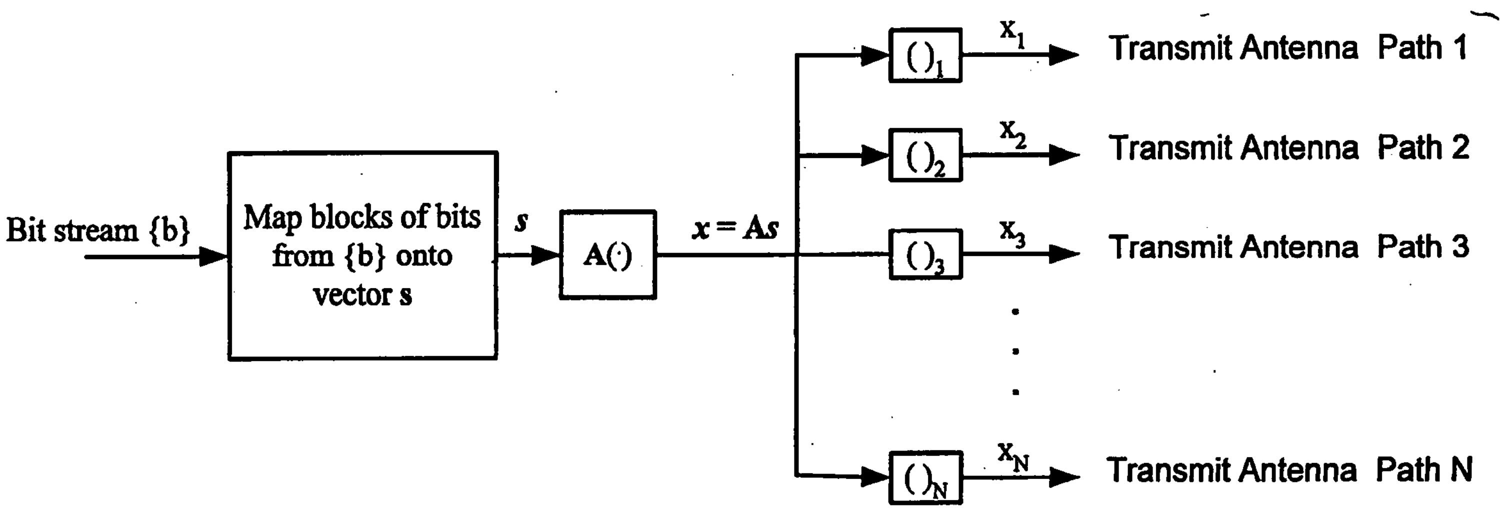

Bit stream {b}
Map blocks of bits from {b} onto vector s
$s$
$A(\cdot)$
$x = As$
$()_1$
$()_2$
$()_3$
$()_N$
$x_1$
$x_2$
$x_3$
$x_N$
Transmit Antenna Path 1
Transmit Antenna Path 2
Transmit Antenna Path 3
Transmit Antenna Path N

FIG. 3

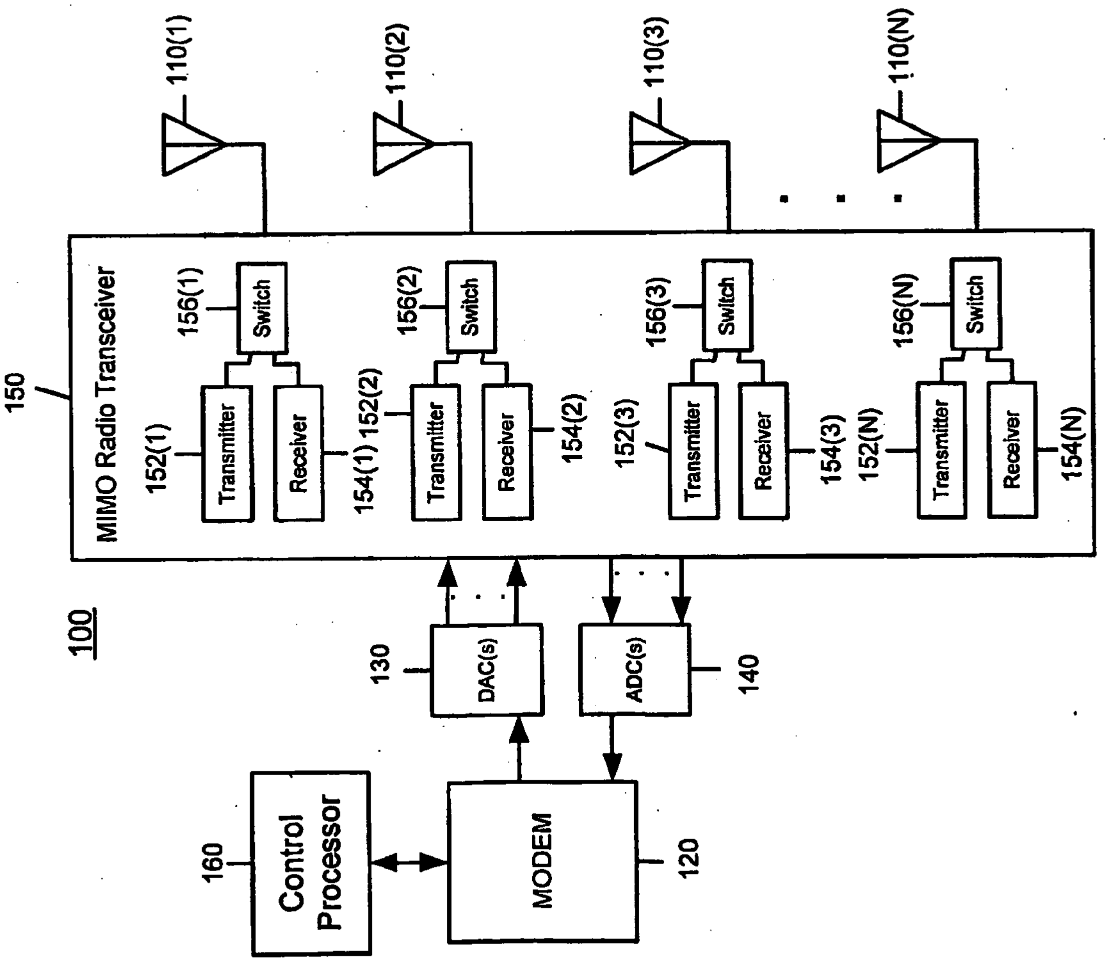

100
150
MIMO Radio Transceiver
110(1)
110(2)
110(3)
110(N)
156(1)
Switch
152(1)
Transmitter
Receiver
154(1)
156(2)
Switch
152(2)
Transmitter
Receiver
154(2)
156(3)
Switch
152(3)
Transmitter
Receiver
154(3)
156(N)
Switch
152(N)
Transmitter
Receiver
154(N)
130
DAC(s)
ADC(s)
140
160
Control Processor
MODEM
120

FIG. 4

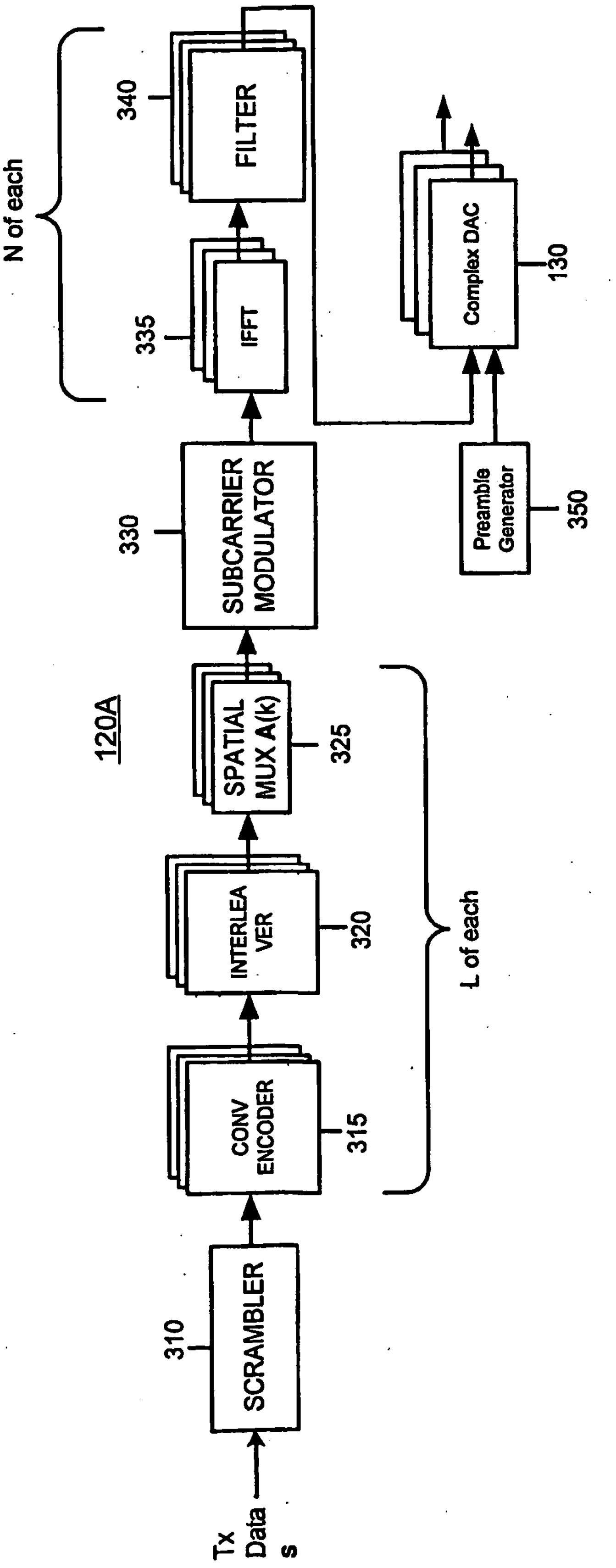

120A
Tx Data s
SCRAMBLER
310
CONV ENCODER
315
INTERLEAVER
320
SPATIAL MUX A(k)
325
L of each
SUBCARRIER MODULATOR
330
IFFT
335
FILTER
340
N of each
Preamble Generator
350
Complex DAC
130

FIG. 5

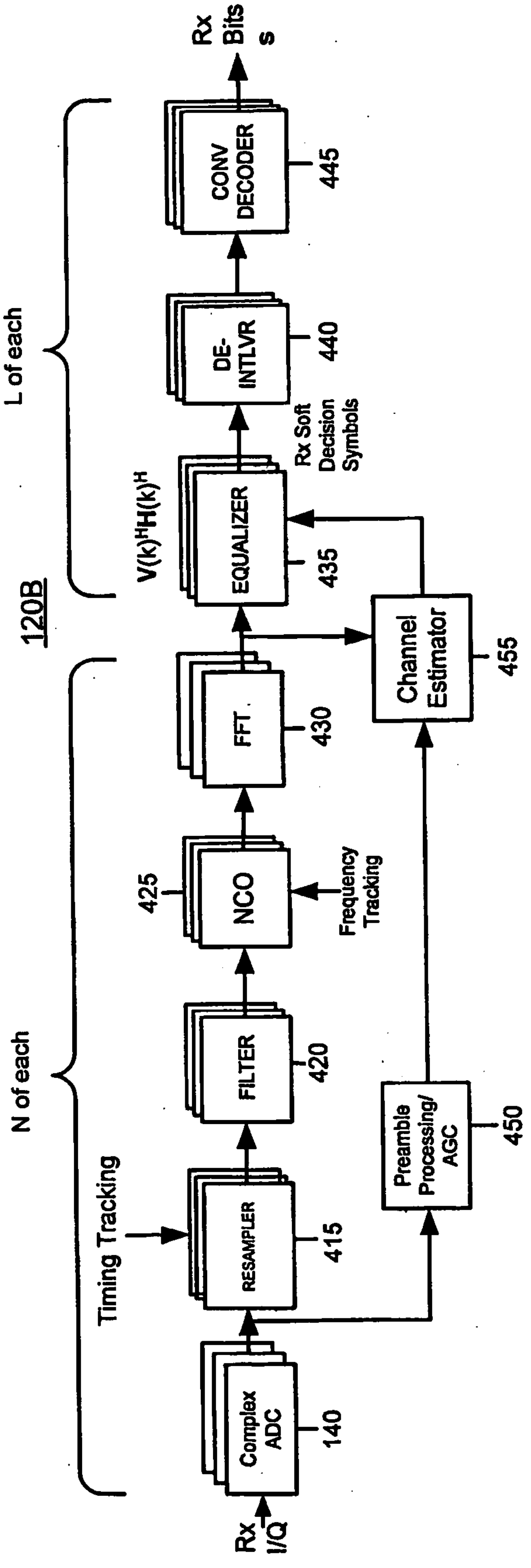
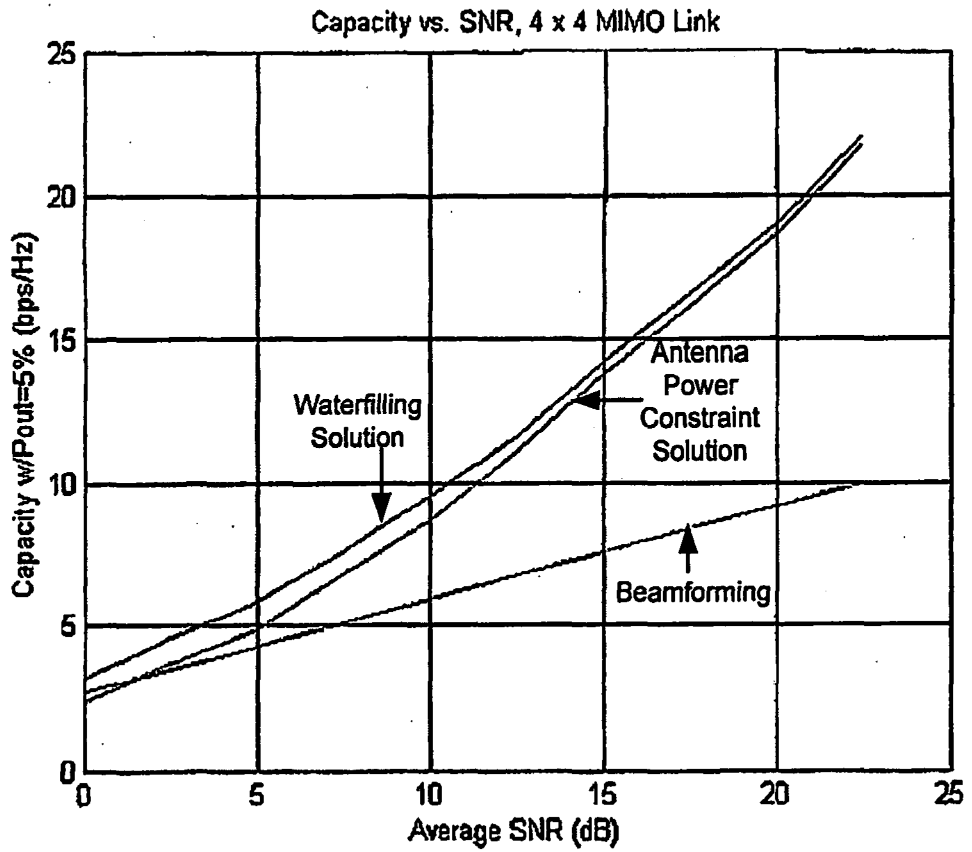

120B
N of each
L of each
Rx I/Q
Complex ADC
140
Timing Tracking
RESAMPLER
415
FILTER
420
NCO
425
Frequency Tracking
FFT
430
Preamble Processing/ AGC
450
Channel Estimator
455
V(k)^H H(k)^H
EQUALIZER
435
Rx Soft Decision Symbols
DE-INTLVR
440
CONV DECODER
445
Rx Bits

FIG. 6


Capacity vs. SNR, 4 x 4 MIMO Link
Capacity w/Pout=5% (bps/Hz)
0
5
10
15
20
25
Average SNR (dB)
0
5
10
15
20
25
Waterfilling Solution
Antenna Power Constraint Solution
Beamforming

## REFERENCES CITED IN THE DESCRIPTION

### Patent documents cited in the description

- US 31943702 P **[0001]**
- US 46167203 P **[0001]**
- US 47994503 P **[0001]**
- US 6377631 B **[0004] [0004]**
- US 6144711 A, Raleigh **[0013]**
- US 06538802 A **[0029]**
- US 45729303 A **[0032]**