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(54) **COMPRESSED GAS MANAGEMENT SYSTEM**

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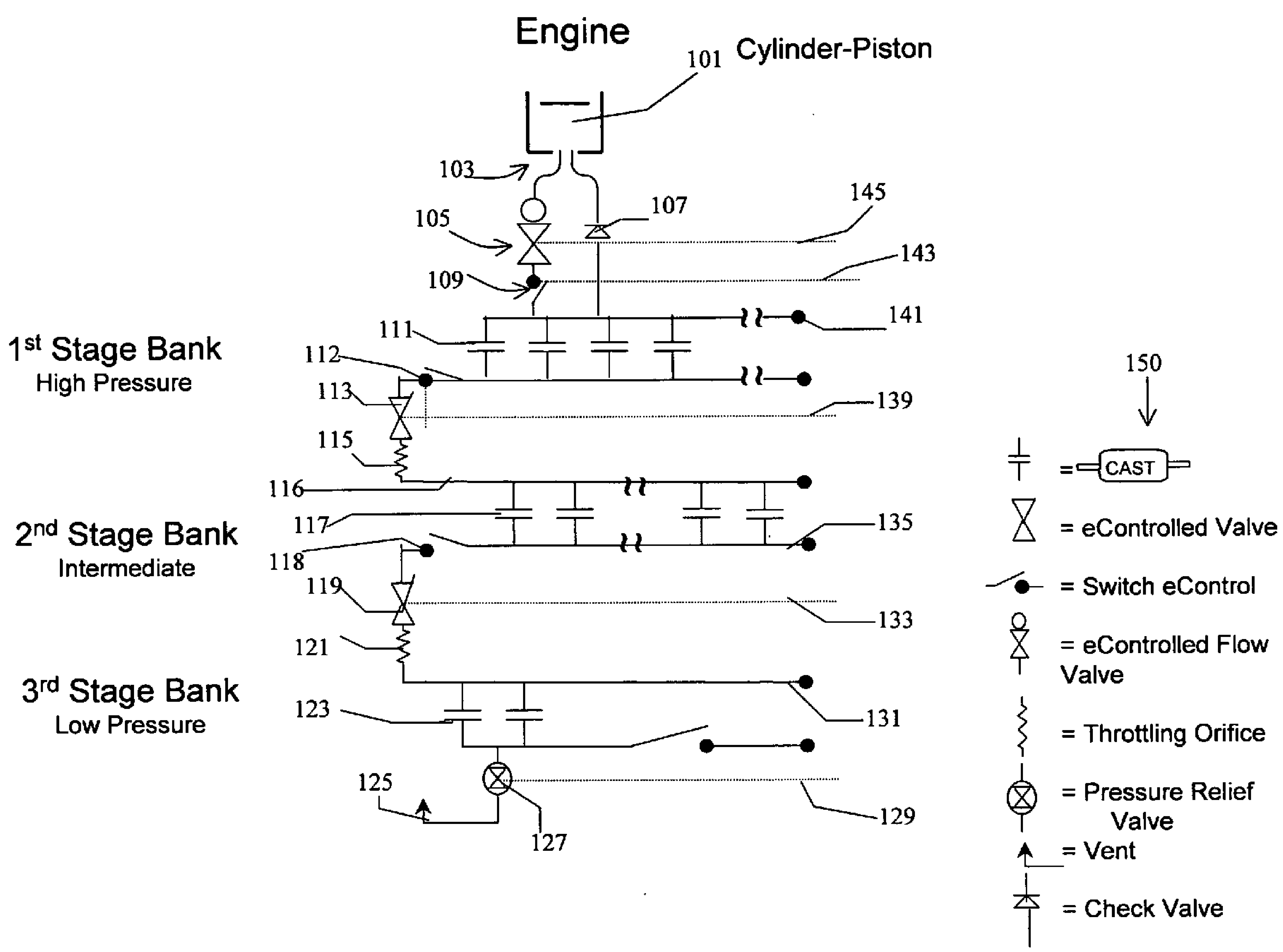
(57) **ABSTRACT**

The present invention is a system and method for managing compressed gas as an energy storage medium for providing power to vehicle uses. Compressed air has many pneumatic uses both inside and outside of vehicles and an Air Hybrid engine a source of compressed air energy for storage. This source of compressed air energy is stored, managed, and used in many methods and devices. The gas storage system presented is distributed over multiple storage units coupled to a gas flow network for control storage and use of the compressed gas.



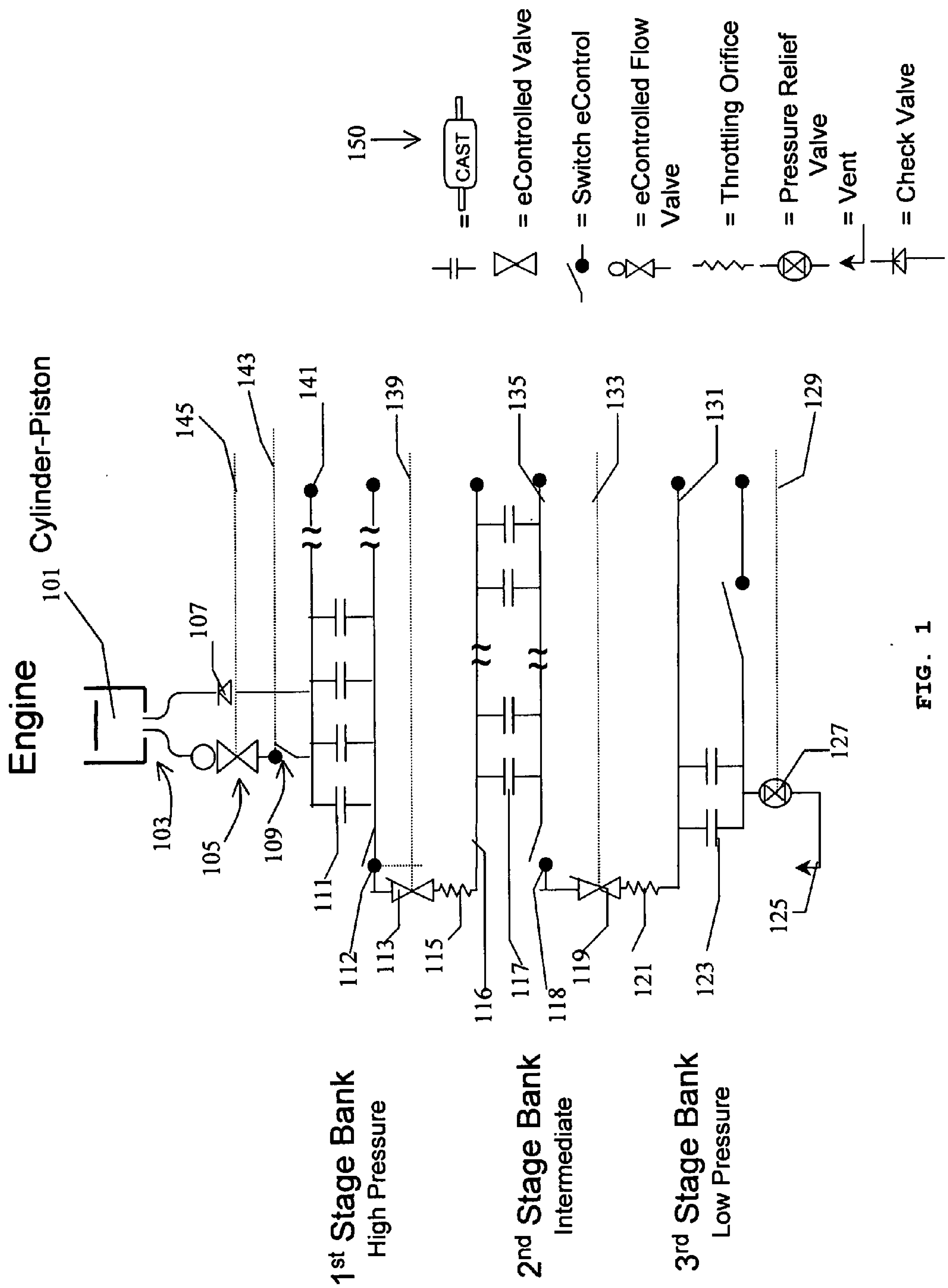

Engine
Cylinder-Piston
101
103
105
107
109
111
112
113
115
116
117
118
119
121
123
125
127
129
131
133
135
139
141
143
145
150
1st Stage Bank
High Pressure
2nd Stage Bank
Intermediate
3rd Stage Bank
Low Pressure
= CAST
= eControlled Valve
= Switch eControl
= eControlled Flow Valve
= Throttling Orifice
= Pressure Relief Valve
= Vent
= Check Valve

FIG. 1

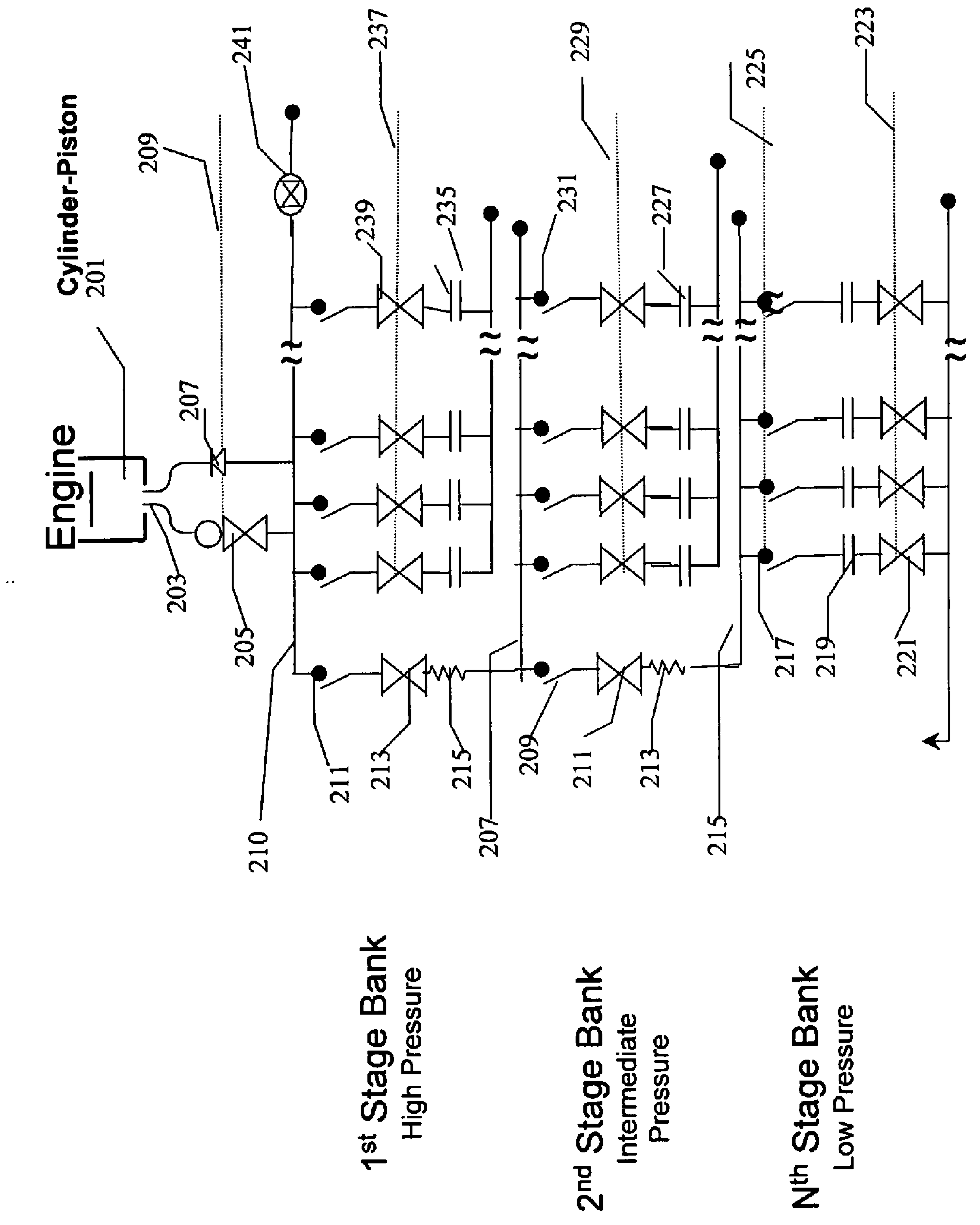
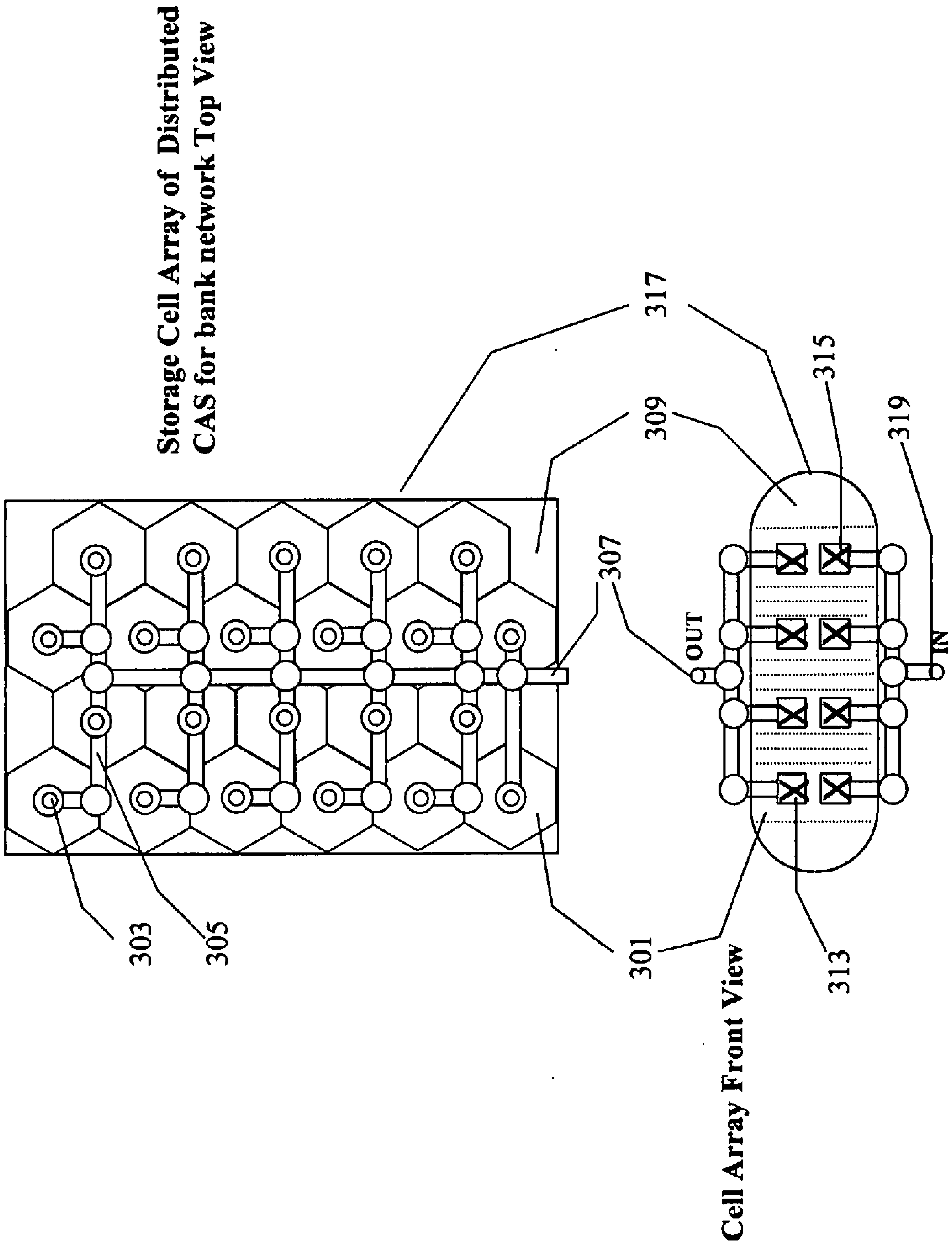
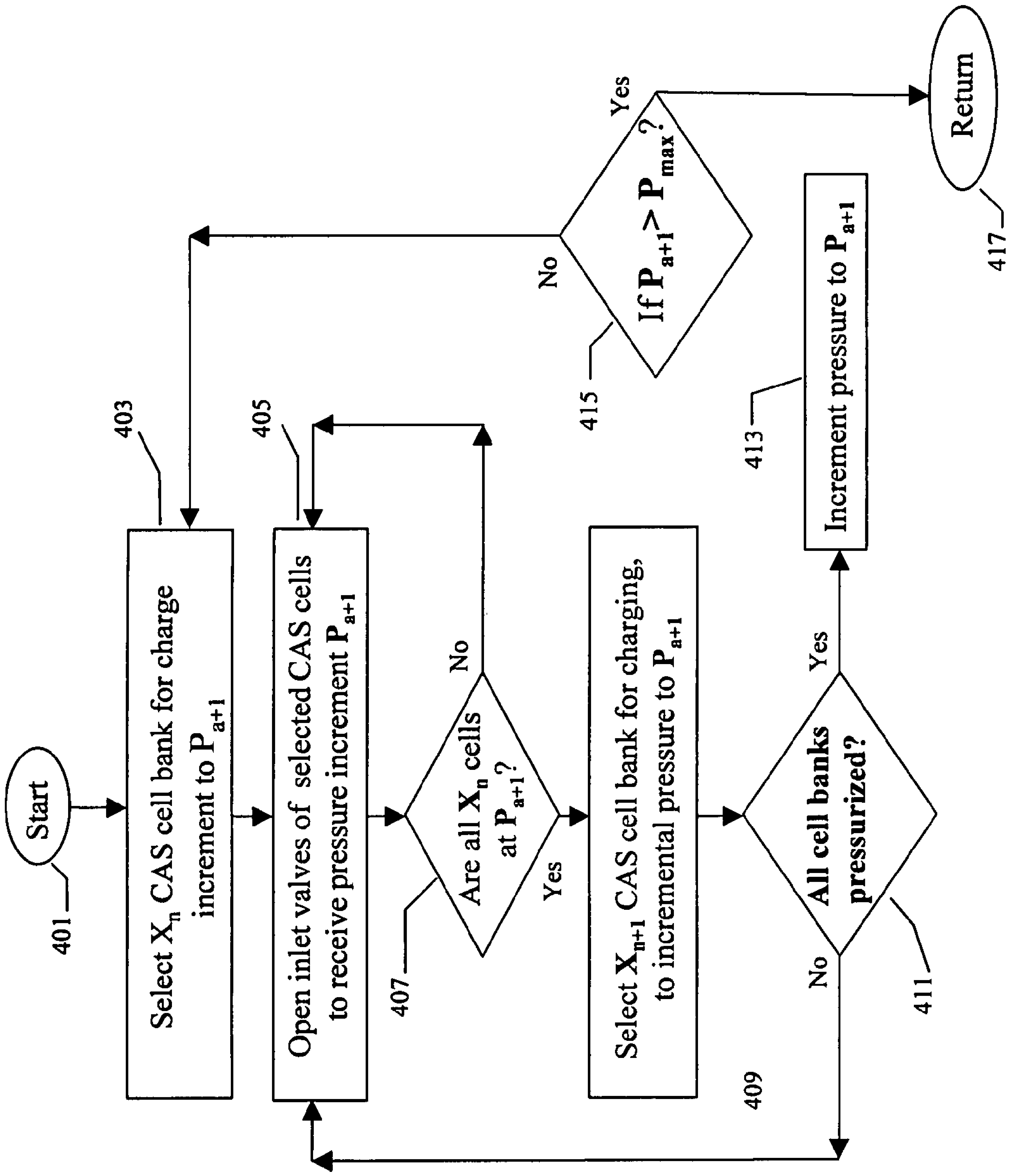

Engine
Cylinder-Piston
201
203
205
207
209
210
211
213
215
217
219
221
223
225
227
229
231
235
237
239
241
1st Stage Bank
High Pressure
2nd Stage Bank
Intermediate
Pressure
Nth Stage Bank
Low Pressure

FIG. 2



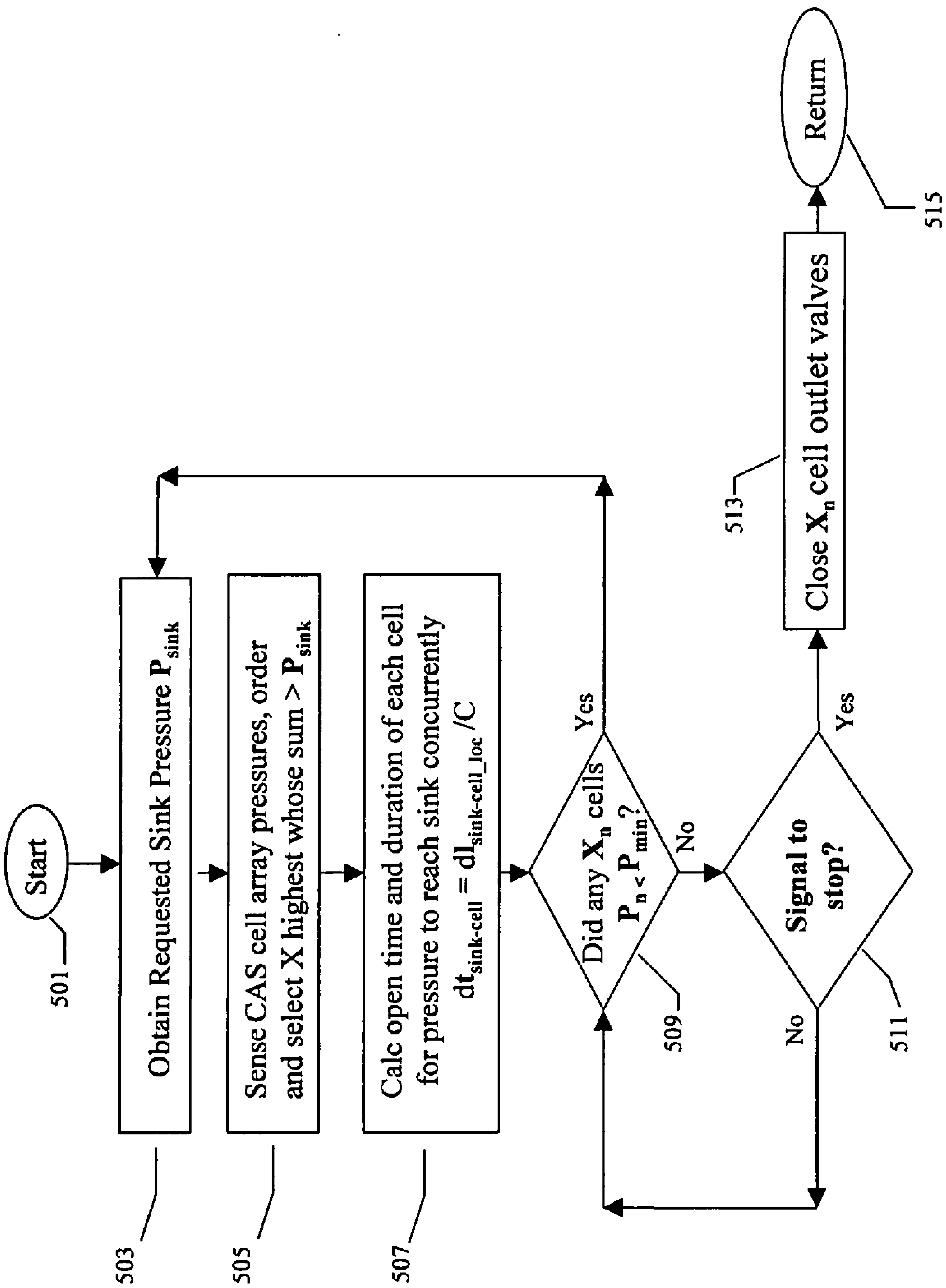
Storage Cell Array of Distributed CAS for bank network Top View
Cell Array Front View
301
303
305
307
309
313
315
317
319
OUT
IN

FIG. 3



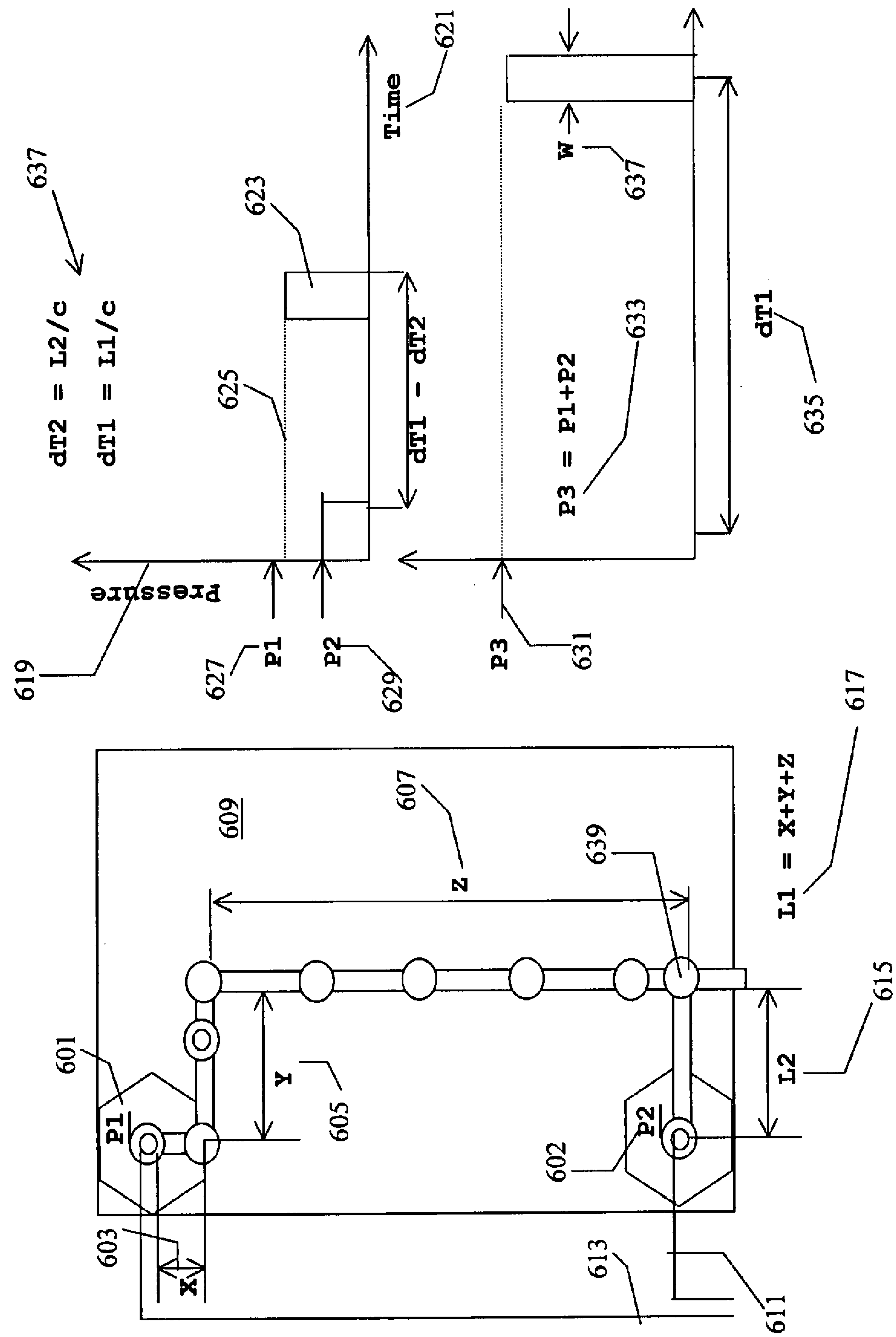
CHARGE of Distributed CAS

FIG. 4



DISCHARGE of Distributed CAS

FIG. 5



637
dT2 = L2/c
dT1 = L1/c
623
625
621
Time
dT1 - dT2
Pressure
619
P1
627
P2
629
P3
631
P3 = P1+P2
633
W
637
dT1
635
609
607
Z
639
L1 = X+Y+Z
617
601
P1
Y
605
L2
615
P2
602
603
X
613
611

FIG. 6

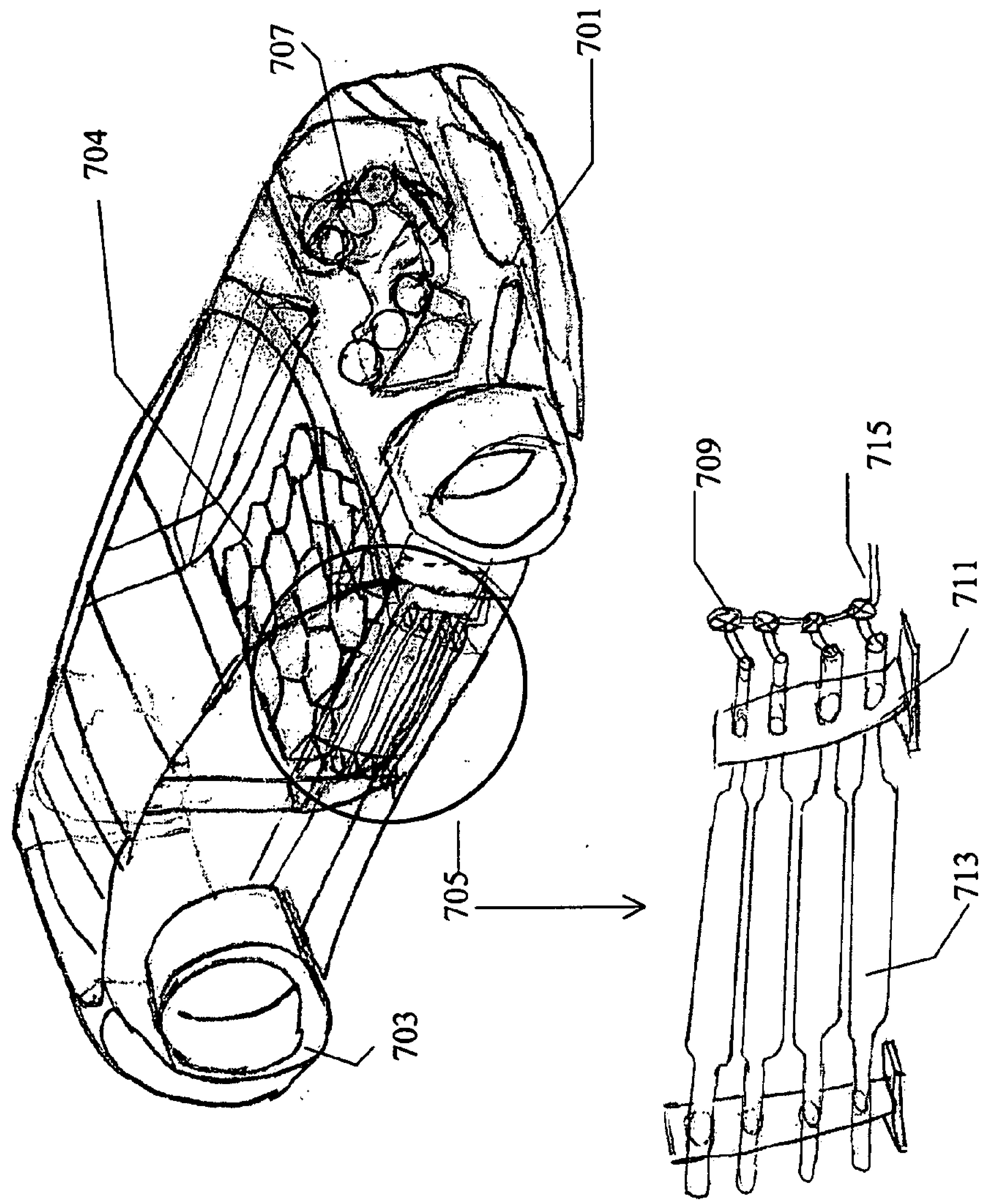


FIG. 7

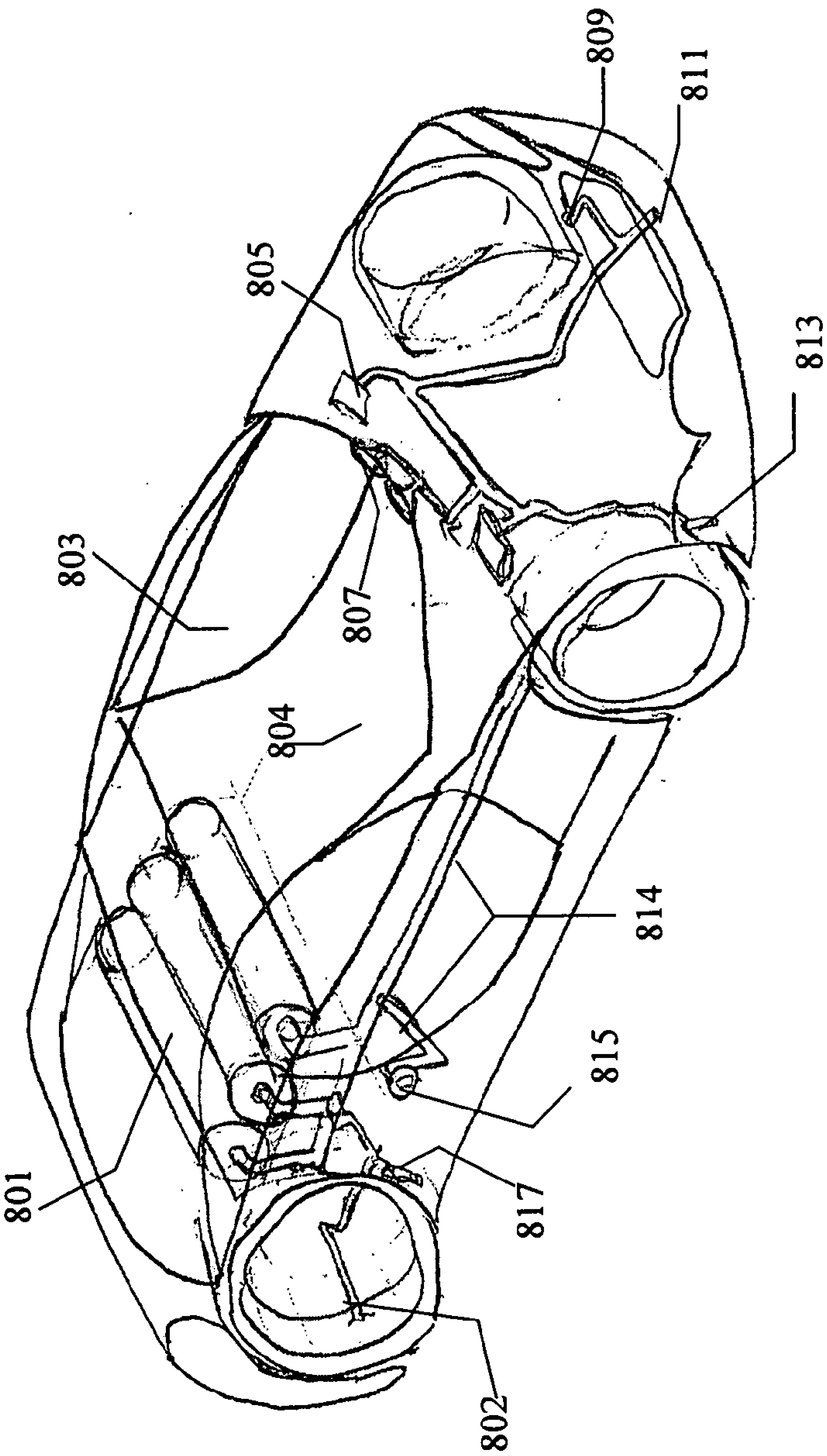
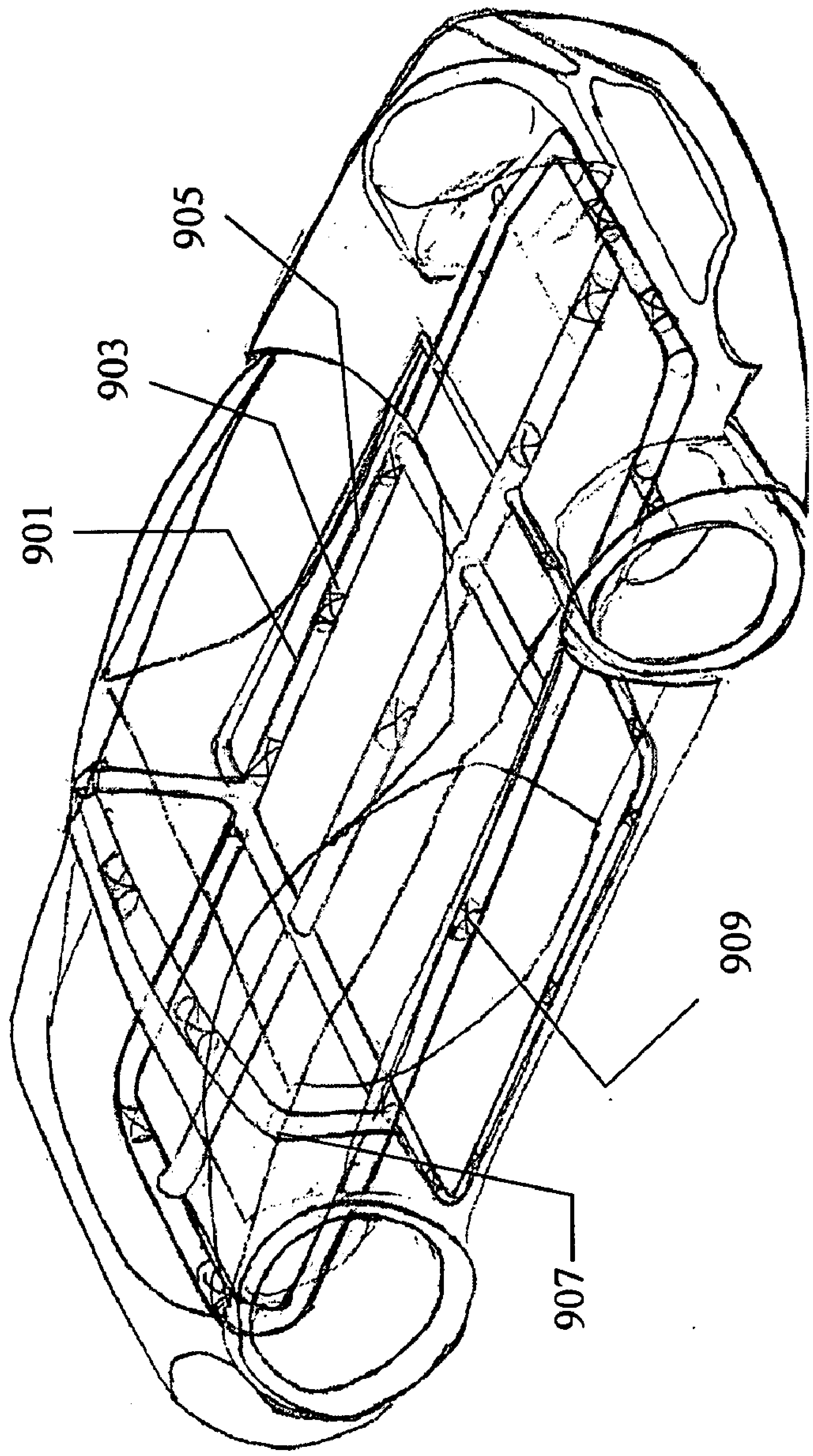


FIG. 8



Compressed Gas Distributed Storage in Tubular Frame

FIG. 9

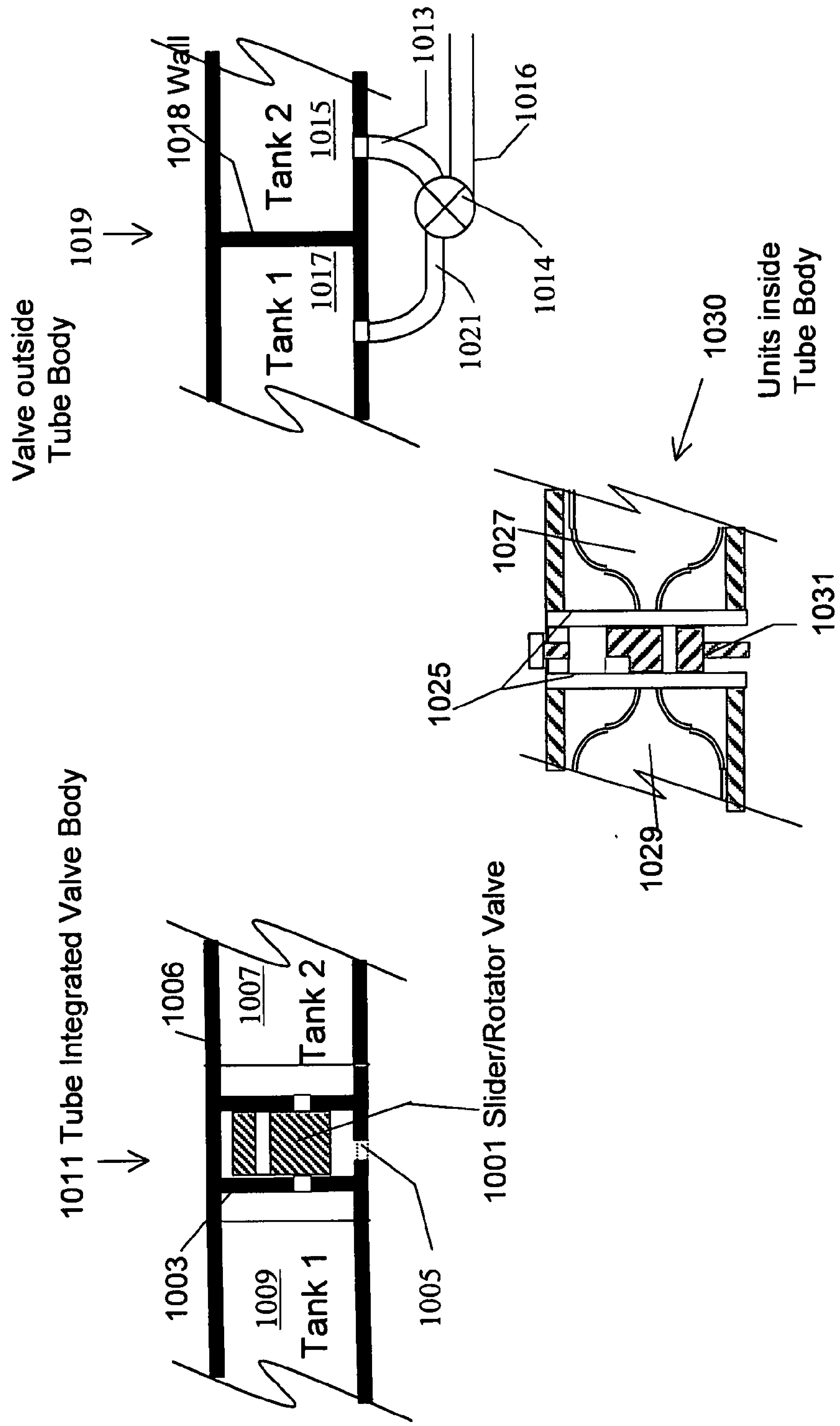

Valve outside
Tube Body
1019
1018 Wall
Tank 2
1015
Tank 1
1017
1013
1016
1014
1021
1030
Units inside
Tube Body
1027
1025
1031
1029
1011 Tube Integrated Valve Body
1006
1007
Tank 2
1001 Slider/Rotator Valve
1003
1009
Tank 1
1005

FIG. 10

COMPRESSED GAS MANAGEMENT SYSTEM

BACKGROUND

Field of the Invention

[0001] This invention generally relates to compressed gas storage systems for vehicles, and more particularly, to intelligent management of compressed gas as stored mechanical and fuel energy for multiple alternate uses and benefits.

[0002] With the advent of very fast digital valves, compressed gas can be applied in a continuous or analog sense as it is in current applications, or as impulse, or digital sense. Digital pneumatics is not currently used in applications, but can take better advantage of fluidic power efficiencies and resonance character of devices. Mostly fluidic transients are unwanted forces which must be designed around. However, fluidic transients in the form of timed pulses can be a powerful and very efficient method of energy delivery which is not currently exploited.

[0003] Compressed air has many pneumatic uses both onboard and off board vehicles. As the Air Hybrid engine develops, so does the availability of mobile compressed air sources. Most current Air Hybrid or Air Power Assist vehicle designs have an air storage tank to facilitate the generation of compressed air from braking and slowing the vehicle momentum, to transferring the energy normally thrown away to a later re-acceleration. The current single storage tank is inadequate, unreliable, payload space consuming and unable to supply all the uses and storage mechanisms possible for its intelligent exploitation and accommodation to vehicle constraints.

[0004] The present systems have one or two large compressed air tanks. These require time to charge, during which the efficiency of the air hybrid is not realized. The shear size and placement of the tank consumes strategic vehicle volume or cargo space, displacing normally used and valuable vehicle payload. Moreover, a tank leak disables the entire air-hybrid system, rendering the engine ineffective until the leak is found and repaired. Thus the one large tank air-hybrid is unreliable and vehicle space wasteful. What are needed are smaller, less cargo consuming space and reliable compressed air storage. Moreover, the current large high pressure tanks add concentrations of added weight becoming a liability against vehicle fuel performance and maneuverability performance. What are needed are schemes for lighter tanks with adequate pressure outputs to hand disparate requirements on short notice. The tank storage capacity also limits the vehicle range in efficient use. But large size tanks prevents a more strategic placement onboard the vehicle. Currently vehicles have many "hollow" spaces which can otherwise hold air, if only it could accommodate the large cylinder tanks. What are needed are tanks which conform to available unused space in current vehicle bodies yet provide adequate compressed gas storage capacities.

[0005] Pressurized gases on board vehicles can serve many uses, and not only in engine fuel regeneration or in performance enhancement through oxygen enrichment. Gas fuels such as propane, compressed natural gas, butane and hydrogen are good candidates for alternate fuel sources. There are alternate utility uses for compressed air while the vehicle is mobile or stationary. What is needed are compressed air management systems which monitor and control the charging and discharging of compressed air to can provide alternate and reliable compressed air sources.

[0006] Turning to mobile compressed air uses, air shocks are devices which use compressed air to stiffen or dampen a vehicle suspension system. Adjusting air pressure can alter the stiffness of not only shocks, but many designed structures including vehicle body, bumpers, chassis and suspension. A source of available and variable compressed air can accommodate many such uses, uses that cannot be exploited with the one-tank designs of current air-hybrids because of limiting pressure, volume, capacity or combinations of those. Mobile uses of compressed air include but are not limited to vehicle structure and body stiffness manipulation from compressed air pressure, tire inflation, light weight pneumatic motors for vehicle components, seat comfort, bumper stiffness, air bags, shock assemblies, windshield wipers and washer, tire road air brushes, air foil and stabilizer enhancements, electronic controlled thrust vectoring, etc

[0007] Current electric hybrid vehicle employ large heavy and expensive battery banks to store the energy recaptured for regeneration and use in engine or onboard components. What is needed is a comparable compressed air energy storage system for air-hybrid vehicles, to intelligently store and manage the compressed energy.

SUMMARY

[0008] The present invention discloses a system for storing and managing compressed gas in a vehicle having an engine with dynamically selectable cylinder compressed gas, at least one compressed gas storage unit, at least one pressure sensor for determining storage gas unit pressure, compressed gas storage units coupled to engine cylinder for channeling bi-directional gas flow, programmed logic for controlling bi-directional gas flow channeling gas flow from programmably selectable cylinder to programmably selected storage unit and from storage unit to cylinder, whereby compressed gas from programmably selected individual cylinders can flow to disparate alternate on or off vehicle uses or redirected back to a selected engine cylinder for further compression or use. The compressed gas storage units are coupled to a network of channels wherein electronic controlled valves using programmed logic maintain pressure ranges in selected gas storage units, cascading compressed gas flow to storage units in parallel or serial based on preset pressures, storage capacities and unit pressure. The compressed gas may be air or a fuel gas such as hydrogen or natural gas. Some embodiments include air as the compressed gas, and components as digital valves, wireless sensors and composite conformable gas tanks partitioned into cells and electronically managed.

BRIEF DESCRIPTION OF DRAWINGS

[0009] FIG. **1** is a schematic drawing illustrating the compressed gas energy storage and management system in accordance with an embodiment of the invention.

[0010] FIG. **2** is a schematic illustrating the compressed gas energy storage and management system switching and control components in accordance with an embodiment of the invention.

[0011] FIG. **3** is an exemplar conforming geometry compressed air storage array cell configuration in accordance with an embodiment of the invention.

[0012] FIG. **4** is a high level flow chart of compressed air storage array charge control in accordance with an embodiment of the invention.

[0013] FIG. **5** is a high level flow chart of compressed air storage array discharge control in accordance with an embodiment of the invention.

[0014] FIG. **6** is a graphical illustration of phased array pressure pulsing in accordance with an embodiment of the invention

[0015] FIG. **7** illustrates a distributed compressed air storage system within a vehicle in accordance with an embodiment of the invention

[0016] FIG. **8** illustrates a distributed compressed air storage system of uses and pneumatic applications on a vehicle in accordance with an embodiment of the invention.

[0017] FIG. **9** illustrates a distributed compressed gas storage bank in a vehicle tubular frame structure in accordance with an embodiment of the invention.

[0018] FIG. **10** illustrates tubular integrated compressed gas storage tank details in a tubular frame structure in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

[0019] Specific embodiments of the invention will now be described in detail with reference to the accompanying figures.

[0020] In the following detailed description of the invention embodiments, numerous specific details are set forth in order to provide a more thorough understanding of the invention. However, it will be apparent to one of ordinary skill in the art that the invention may be practiced without these specific details. In other instances, well-known features have not been described in detail to avoid unnecessarily complicating the description, in adhering to a fundamental mode and cycle of operation examples.

[0021] The presently disclosed system and method can be implemented using hardware, software or a combination of hardware and software. The disclosed system and method is comprised of hardware and electronic control components, which can be implemented using many different hardware configurations for applications as well as programmable control of features.

[0022] In general, embodiments of the invention provide a method and apparatus to allow a compressed air storage to be distributed and managed in a vehicle for multiple applications. The distributed and intelligent management of such a system overcomes many energy and utility challenges, providing many uses and benefits such as quick charge availability, compressed air storage versatility and reliability, reduced cost due, increased utility for disparate uses on-board and off-board the vehicle, stiffness variability for safety, ride comfort and other uses.

[0023] FIG. **1** is a schematic drawing illustrating a compressed gas storage and management system in accordance with an embodiment of the invention. Three schematic storage banks **141 116 131** are shown but more or fewer stages can be implemented as well. A cylinder-piston unit **101** in a compression or regeneration mode, will compress the cylinder gas, and will compel the compressed gas through a check valve **107** to a header or manifold **141** whereby it can be distributed to one or more high pressure gas storage **111** units. The storage bank most immediate to the cylinder will most likely be the highest pressure stage. During a pressurization, on regeneration or compression mode cylinder **101** intake stroke, a pressure control valve **105** actuated from an electronic control switch **109** controlled through control line **145** can receive the signal to open and admit compressed gas from a high pressure storage unit **111** through the valve port **103** and to the cylinder **101** for a re-compression to a higher pressure during a compression stroke. In some embodiments, the cylinder **101** exhaust valve can stay open on compressions stroke, allowing the pressurization to be continuously flow to the storage unit **111** through check valve **107**. This process is substantially adiabatic of compressed air storage units **111** have thermal insulation. This process is then repeated for pumping up and increasing pressure in storage **111** to a preset pressure level while the cylinder is in re-generation or compression modes. The switch **109** can be actuated as part of the air-hybrid engine mode change from power mode to regeneration mode and to continue under local control, with this individual cylinder only, a continued regeneration mode until another signal changes that the cylinder to another mode of operation. Furthermore, a regeneration mode can cycle until the storage pressure in the high pressure **111** stage reaches a preset level, at which time it is charged at full capacity. This unit **111** can be then partially discharged to other parallel units in the bank **111** or to serially connected lower pressure **117** stage units. Unit pressures are monitored and pressure energy is transferred to storage units below their capacity and until they reach capacity. Since storage units can also be discharging while serving some function or use, this process is dynamic, variably changing unit pressures through charging and discharging. Thus multiple parallel tanks **111** can be used to provide additional energy storage capacity, redundancy and reliability, with each tank cycling up in parallel sequentially to store or supply energy on demand. Upon reaching a pre-set pressure, a switch **112** to open a valve **113** will throttle **115** the pressure down to a preset intermediate pressure at a header **116** which can pressurize another stage bank **117** of units in parallel to a preset intermediate pressure. In an embodiment of the invention, this stage is directly connected to a common header **135** or manifold and in addition to storing compressed gas at an intermediate pressure, can provide compressed air to devices and application requiring an intermediate gas pressure. The electronic control switches **112 118** to turn valves **113 119** respectively are signaled by control lines **139** and **133** respectively.

[0024] Since valves and stitches are electronically controlled, preset levels are adjustable, requiring basic programming logic monitoring pressures and opening/closing switches and valves. Upon filling a unit to capacity or a preset level, individual unit tank combined pressures can be used to pressurize a third stage bank **131** through another valve **119** and throttle orifice **121** or to provide an intermediate pressure compressed gas at header **135** for any number of alternate uses at lower or alternate use pressures. Another storage stage of lower presser storage **123** is received through the admitting valve **119** throttled **121** to the preset lower pressure in storage **123** bank stage **131**. As with the other stages, the storage units can be in parallel, to increase reliability, safety, redundancy, and other advantages. A safety relief valve **127**, is provided to vent **125** to atmosphere should the need arise to protect the equipment.

[0025] Schematic key symbols **150** represent the compressed Air Storage Tank (CAST) units, valves, an electronically controllable pressure regulator valve—one where response time is essential as several modes of operation may require engine piston following time responses with knowledge of pressures upstream and downstream of the valve, throttling orifice, pressure relief valve, check valves and electronic controlled switches. One skilled in the art will be capable of substituting for many of these components as they there are many ways of controlling gas flow and electronic controlled piping and gas storage are well known to those skilled in the art The schematic legend **150** will apply to FIG. **2** as well.

[0026] FIG. **2** is a schematic illustrating the compressed gas energy storage and management system switching and control components in accordance with an embodiment of the invention. Pressure, temperature, other sensors and computer control components enable the distributed compressed gas to be used for many applications and in many ways, charging available storage capacity and discharging to demands via valved tubes, ducts and channels. Some one cycle of operation controls are illustrated elsewhere and mentioned here to point out the controls in the architecture require pressure and temperature sensor not shown on FIG. **2** schematic, but their states are known and used in the manipulation of flow control as specified.

[0027] Three storage banks **210 207 215** are shown but more or less stages can be implemented. A cylinder-piston unit **201** acting in compression mode will compress the cylinder **201** gas, and will compel this compressed gas through a check valve **207** to a header or manifold **210** whereby it can be distributed to one or more storage first stage storage **235** units. This stage **210** storage bank most immediate to the cylinder **201** is in most embodiments likely be the highest pressure storage, and can be placed very near the engine, perhaps adjacent to the engine heads in insulated spherical-cylindrical compartments. During a pressurization or compression mode, a pressure control valve **205** actuating from an electronic control switch **211** controlled through control line **209** can receive the valve open or close signal and admit or receive gas flow through the check valve **207**, compressed gas from the high pressure storage **235** through the valve port **203** or back to the cylinder for a re-compression to a higher pressure respectively, and in thus fashion repeated for pumping up or increasing pressure to storage pressure header **210**. This cycle can continue until the storage pressure in the high pressure **235** stage reaches a preset level through the operation of the switch control lines **237** for high pressure storage valves **239**. Multiple parallel tank units **235** can be used to provide redundancy and reliability, and also higher cumulative pressures at the header **210** should the need arise. These are isolated from the header manifold **210** pressure in this embodiment. Upon reaching a pre-set pressure, a switch **211** to open a valve **213** which will throttle **215** the pressure to a preset intermediate pressure at a header **207** which will supply pressurize to another stage bank stage **227**. Switches **231** to valves **228** are electronically and individually controlled **229** to allow storage units **227** to receive or cease gas flow. Switch **209** is electronically controlled to flow gas via valve **211** to be throttled **213** to a lower pressure header or manifold **215** for storage **219** at lower pressures **215** or alternate uses from a lower pressure gas. These decisions are programmable using the switches **217** individually controlling **225** flow to gas storage units **219**. Storage units **219** can be duel ported with valves **221** for discharge or intake and discharge, to facilitate the alternate use scheme designed for a storage unit bank or stage of pressurization. Electronic control **223** of the valves **221**, as in the control **237 239** of other stage pressure units is by individual storage unit, to facilitate yet another aspect of the invention.

[0028] Upon filling all parallel storage units to capacity at a individual pre-set levels, lower pressure storage units can be fed overflow pressurized gas. Although parallel units appear symbolically identical, their strength, size and capacities may differ, even in a common bank. They also may spring leaks, which will require that they be isolated for non-use and flagged for repair. Alternatively, another aspect of the inventions provides for lower pressure tanks through transient pressure wave combinations. This is done through time pressure releases from known unit pressures and pressure wave travel time which upon convergence an a target location, pressure waves combine lower pressures to achieve a higher pressure for storage or use.

[0029] As with the all banks, the storage units can be in parallel, to increase reliability, safety, redundancy, and other advantages, but they can also be configured in serial for other benefits.

[0030] FIG. **3** is an exemplar conforming geometry compressed air storage array cell configuration in accordance with an embodiment of the invention. A hexagonal cell array is shown but other cell geometries can be used. The width, breath and depth dimensions of this flattened or slab shape gas tank can be conformal to many **3**-D surfaces as vehicle floor, side panel, door and ceiling body volumes. Thus storage array characteristics provide ways to house underutilized volumes, adding gas storage capacity with additional and additional safety features, without consuming valuable cargo space or adding appreciable weight.

[0031] FIG. **3** illustrates a top and front view of a compressed air storage array of hexagonal storage cells **317**, each cell **301** with independently operated electronic controlled valves **313 315**. Fast acting electronic valves **313 315** are known to those skilled in the art, and are the gateways to flows in **319** and out **307** of the cell array **317**. The cells **301** are shown to be hexagonal but can be of any geometrical construction, including an array of cylinders or long tubular tanks in parallel. Each storage cell **301** is connected via a network of channels **303 305** or conduits of material strength commensurate with the maximum pressures existing during operation of the storage array **317**.

[0032] The duct or channels connecting the cells can also vary depending cell design pressures and expected required output pressures and flows. For example, if the cell pressures are high and the required flow is high, critical or chocked flow conditions may arise. For this reason, a network of channels may be necessary to avoid the choke locations and conditions. The network **303 305** will allow the known cell location and distance to output required location to be calculated along different paths. The acoustic character of the gas wave and speed are known which then allow a straight forward calculation of the flow along different paths. More valves **313 315** may be implemented along the channel network **303 305** for flow control as well, steering the flow along optimal and selected conduit paths.

[0033] FIG. **4** is a high level flow chart of compressed air storage array charge control in accordance with an embodiment of the invention. The procedure begins **401** by selecting a Compressed Gas Storage (CGS) or Compressed Air Storage (CAS) bank X_n for charging and then setting the charge increment from the present known pressure **403** from P_a to P_{a+1}. Switches for valve actuators and valves are then opened in a programmed sequence **405** to receive gas from an external source to each of the cells of the bank X_{n+1} to P_{a+1} for all the bank cells **407**. At completion, another CAS bank X_{n+1} is selected **409** for charging to an incremental pressure P_{a+1}. Switches and valves are opened in the programmed sequential manner to sequentially fill the cells in the selected bank until all cell banks are pressurized **411** to the selected pressure P_{a+1}. If this pressure is below a preset pressure P_{max}, **415** then X_n is selected for another incremental charge **403** and the processes is repeated until all selected banks have been charged to the programmed pressure. When the preset maximum storage cell pressures are reached, charging is suspended **417** until a signal to recharge **401** is received.

[0034] FIG. **5** is a high level flow diagram of a compressed air storage array discharge procedure in accordance with an embodiment of the invention. A use application will signal a request for a pressure starting **501** the programmed logic for a requested application **503** pressure P_{sink}. CAS cell pressures will be sensed for status of individual cell pressures and the top X cells will be selected, whose pressures will sum to a margin over the requested P_{sink} **505**. Since each cell distance from the application use orifice is known, the pressure wave travel distance is known and with the channel temperature, the wave travel speed and time can be determined. Thus, the time of cell valve opening and open duration period can be set to provide the accumulated calculated pressure at the application point orifice **507**. As the cell pressures drop, other cells whose sum pressures are above the required minimum pressure P_{min} margin are brought on line to deliver the required flow at the required pressure. This process will repeat **509** until a signal to stop **511** is reached which will signal a switch close of participating cell outlet valves **513** and are program suspend **515**.

[0035] CAS banks and individual cells in banks are programmably controlled with pressure sensor data, each cell and channel scanned for pressure data at the appropriate time for a real time response. Thus, cells losing pressure due to leaks, can be shut down and flagged for maintenance, without bring the whole storage system to a common mode failure when compressed gas is requested. CAS insulation will preserve the compressed gas energy in the cell for timely use.

[0036] Many other CAS cell charging and discharging algorithms are possible and for many other objectives. A primary objective may to be to delivery pressure to sink point or use orifice. A secondary objective in the algorithm may be to discharge or charge the cells in a particular order. For example to reduce the required cell wall strength requirements, cells may be structured inside other cells and so forth, such that the step differential increase in cell pressure is all that produces wall stresses and the incremental step charging and discharging never exceeds a lower cell wall stress as cells are charged and discharged in accordance to a particular sequence.

[0037] FIG. **6** is a graphical illustration of phased array pressure pulsing in accordance with an embodiment of the invention. Most pneumatics are analog in nature and steady state pressures are required and most cheaply attained without computer control ore fast actuating valves, switches and sensor components. However, where valves and actuators can act rapidly and under electronic or programmable control, digital pneumatics can be used to harness advantage of combining transient pressure releases in programmed phased pneumatic pulses with defined pulse amplitude, frequency, pulse width or intermittency. Thus digital pneumatic pressure control can be made to accommodate most any required pulse frequency and amplitude requirement.

[0038] In a slab storage embodiment CAS bank **609** of cells, the channel geometries, temperatures, and cell pressures are known. Hence pressures in cell P**1** **601** and cell P**2** **602** are to be used to obtain a required pressure P**3** for a pulse width W **637**. The total pressure wave travel length from P**2** **602** to a common point is L**2** **615**. The total travel distance from P**1** **601** to the common point is L**1** **617**, the sum of X **603**, Y **605** and Z **607**. The pressure wave travel time dT**1** **637** and dT**2** **636** from P**1** and P**2** to the intersection point **639** could be determined by L**1**/c and L**2**/c respectively, where c is the acoustic speed in the gas at the temperature in the channel. For the FIG. **6** geometry shown, it would take P**1** **601** pressure longer to reach the intersection point **639** than it would take a pressure transient from P**2** **602**, by a time difference of dT**1**−dT**2**. Thus to achieve the combined pressure of P**1** and P**2**, P**1** outlet valve **601** would be open dT**1**−dT**2** before P**2** outlet valve **602** for a duration W **637**, such that P**1** pressure traveling L**1** **617** would precisely meet pressure P**2** **629** released dT**1**−dT**2** time **621** after P**1** **629** and traveling L**2** **615** at an intersection point **639** to combine with transient P**1** pressure traveling L**1** **617** to a pressure P**3** **631** much like waves on a beach passing through each other and growing to their combined height at maximum height. Channel dimensions have much to do with the magnitude of the combination P**3** but assuming similar channel areas for P**1** and P**2**, the combined pressure P**3**. This is also dependent upon P**1** and P**2** not above critical pressures, or for orifice, channel dimensions and states parameters giving less than critical mass flow rates. To avoid reflection, channels can contain one way pressure valves at intersection points **639**, directing the full combined wave where needed.

[0039] In some embodiments individual storage units or cells each have pressure sensors indicating the cell or storage unit pressure. These may also have a switch and valve under processor control, such that logic can be applied in real-time to engage the valves to release or acquire compressed gas. Many valve and switch configuration may suffice and most recently digital valves have become available and offer many advantages. There as some digital valves and some used in the auto industry which are rated at 10,000 cycles/sec. Pressure pulses traveling at acoustic speeds of 1100 feet/sec can easily be pulsed in digital pulse trains also, tuning the pressure pulse for certain applications requiring a resonant or tuned pressure pulses. The algebra of pulse addition and subtraction then becomes an arithmetic exercise easily programmed in logic by those skilled in the art, where the state conditions, travel lengths and paths, channel dimensions and wall properties and such parameters are known. In some embodiments sensors and components can be electronic, wired or wireless controlled. The illustration shows that a gas pressure pulse can be released, and since the pulse travel time is known by its acoustic properties and the distance is known from source to sink, then the time of opening and duration for cells can be calculated and programmably implemented to produce a summed pressure at any intersection or application sink location. As mentioned above, the channels connecting the compressed air storage (CAS) cells and banks can be in a channel or conduit network with flow control valves to allow selected paths from cells to sink locations at real-time determined pressures and flows. Pressures can be analog pneumatics or digital pulses, depending on design and design requirements and applications. Pressure, pressure pulses and pressure pulse trains of various frequency, duration and amplitude can be pre-determined and obtained through valve actuation from an array of compressed air units coupled with a connecting network of communication tubes or conduit and electronic valve actuation under processor control. Air hammers and variable pressure pulse acceleration from impulse pressure are also possible applications.

[0040] The advantages of such systems are that 1) no individual CAS cells need have the required sink or application pressures or volumes as application pressures of many kind can be achieved algebraic combinations from individual cells, 2) reliability is increased because cells can be brought on or taken off line to deliver component pressures and flows, 3) the combined tank banks can be conformably manufactured for most curved shaped volumes, 4) the CAS bank arrays can be made lighter and cheaper for equivalent volumes by using inherently stronger but more efficient geometry such as the honeycomb structure, 5) higher sink pressures are attainable from lower CAS pressures, 6) quicker charge time because CAS cells can be charge ready will some are not, net the bank charge cell locations are know and can be called upon to deliver pressure, 7) the CAS bank pressures can be varied to provide a variable structural stiffness, yet another useful property offered for no extra cost.

[0041] Phased Array Pressure Pulse (PAPP)

[0042] Most current pneumatic systems use compressed air in an analog fashion, with continuous gas pressure dynamics. We introduce the capability to shape pressure pulses and to combine pressure pulses by timing for constructive or canceling pressures where required. An embodiment of the invention provides digital pulse or impulse pressure intelligently. PAPP can provide total pressures which are larger than individual storage unit pressures by timing the transients such that small pressure pulses together from selected storage cells can additively attain larger pressures at known target location to deliver a summation or pressure resultant pulse. Thus a digital form of pneumatic application is introduced. This is done knowing the distance that a pressure wave travels in a known medium, knowing the acoustic properties of the medium, selecting the tanks with known pressure and location and sequencing the valve openings to channel a pressure pulse to the target location, combining the transient pressure pulses where they are pre-determined to meet such that their transient pressure pulses are additively directed. Thus it can still be useful to have source pressures in any one tank unit which are low in pressure. Furthermore, bypassing locations which would otherwise serve as choke points can be accomplished by placing valve to open and close specific flow channel, using the combination peak pressure pulses only at location and times needed. Storage unit costs can thus be lower because thick walled CAS volumes may not be needed for some applications and embodiments, utility is higher because applications vary in pressure and flow requirements but can be managed smartly with programmable controls. For example, a PAPP application can enable an air cannon type application, where impulse pressures or pressure pulses can be delivered on demand in a particular acoustic pulse pattern, without expensive high pressure metal cylinder storage units acting in an analog or continuous pressures.

[0043] In another embodiment, a purely air impulse engine is envisioned. The PAPP can be programmed such that large pressure pulses are delivered to the appropriate cylinder intake ports for initiation of an intake or power stroke. Thus a two stroke impulse air engine can very efficiently make use of compressed air storage energy by not having a continuous bleeding of compressed air analog fashion, and the compounding energy contribution from additive pressure pulses in digital fashion in concert with the engine cylinder power strokes.

[0044] FIG. **6** illustrates a distributed compressed air storage in a vehicle in accordance with an embodiment of the invention. Many locations are available in a typical vehicle, if the tank volume is in conformance with the available vehicle volume. Distributed CAS can vary in shape and size, to accommodate the available space and non-used space and add CAS energy capacity.

[0045] FIG. **7** illustrates a distributed compressed air storage system within a vehicle in accordance with an embodiment of the invention Although compressed gas is relatively light weight, the tank volumes can displace valuable cargo space. Therefore an aspect of the invention is to introduce non-cargo space distributed compressed gas storage unit locations and designs. Compressed gas can be stored in vehicle bumpers **701** which can add strength and stiffness to the bumper by pressurization. The tires **703** can be made to withstand a range of pressures which also house compressed air, receiving and withdrawing compressed air within a comfortable design window. Door panels **705** can house an array of cylinders **713** with pressure sensors held firmly in place by a brace **711**, array feeding a manifold **715** with electronically controlled valves for controlling inflow and outflow of gas as needed. Spherical high pressure compression units **707** are shown positioned proximate to the engine cylinders, which their controlling electronic valves not shown here, for electronic local and central control actuation in various modes to provide the air-hybrid function facilitation and also high pressure air storage. The small high pressure storage units also provide a much shortened charge time. Where a conventional storage tank would take much pumping to be of use, an embodiment of the invention illustrated here in the form of small high pressure storage units coupled to a network of channels, act to quickly charge so that energy can be used for vehicle propulsion almost immediately, or discharged to other units for storage and alternate uses. The smaller size also allows storage placement in volumes which are not conducive for competing payload space. Multiple high pressure smaller units can also be synergistically used where any one unit is insufficient to provide adequate pressure, in compressed air power mode. The vehicle sub floor can house a planar conformal compressed gas storage cell array **704** functioning as described in FIG. **3** and elsewhere. Vehicle rear sides, side panels, windows, roof and other non-cargo space areas are fair game for conformal or tank array banks as shown for the bumper **701**, floor **704** and door panel **705**. The distributed storage units will each have a dynamic pressurized gas and that equates to stored energy, which is monitored and controlled to serve a multitude of purposes much like electrical power in an electrical hybrid. Each unit will be charged, discharged and recharged as designed, to regenerate vehicle braking energy, but unlike the electrical energy, the storage units will contain gas not heavy liquids, chemical solids and metal electrodes or heavy housing. The gas storage units are furthermore mechanically charged much quicker than electrical charging can accomplish in electrical batteries because the stored energy remains mechanical, rather than undergoing a complete energy transformation of form.

[0046] FIG. **8** illustrates a vehicle distributed compressed air storage system of uses and applications in accordance with an embodiment of the invention. A compressed air storage bank **801** is shown situated in a rear vehicle location for illustration purposes. Tire **802** re-pressurization for storage can also be an application where tire depressurization from leakage, rupture or just maintenance occurs. An acceptable pressure maintenance time can quickly be calculated since pressure sensors monitor pressures dynamically and or makeup pressurized air can be produced by diverting the necessary engine cylinders to re-generation or compression mode. Only the one tire is shown with automatic tire re-pressurization but all four can be included. This feature can be very useful where service cannot be found or provided for any reason, such as an emergency. Rainy weather, wet or slick roads can be cleared or dried immediately forward of tires with air jets **817 813 809**. Sensors finding loose gravel or debris on road can signal clearing road air jets as well. Air source pressure can also be received from external sources **815** where compressed air can act as a storage energy media from external sources. Available electricity and on off peak hours can be exploited to provide a source of vehicle air charge, storing compressed air by trickle pumping up of the storage tanks for transportation energy or fuel as hydrogen gas. Thus electric cars are not the only applications for cheap off peak home electrical power, as gas storage unit vehicles can accept stored energy in the form of compressed gas or fuel gas.

[0047] A network of compressed gas conduits **814** have valves, switches and sensors to programmably maintain compressed air energy and distribute to the demanding application. The bumpers **811** or any vehicle collision surface can be strengthened or stiffened by use of pressurization. Mature applications such as air bags **805**, seat softness **804**, and air windshield wipers **807** are other practical uses for on board vehicle compressed air applications. Air motors, piston actuators and conventional mechanical pneumatic components can replace electric motors using weighty metal coils metal rotors, and many of the electric motors applications in vehicles, with the advantage of weight reduction using non-metallic materials. Moreover, most current vehicles carry many electric motors in implementing all manner of features which can be replaced by compressed air driven motors, pistons and other mechanical devices. Electrical mechanisms add significant weight to the vehicle, as well as cost of maintenance and replacement, extra fuel required to haul extra weight, etc. Thus sources of compressed air on board a vehicle with an programmable compressed gas management systems can provide an analogous solution to the electric hybrid not only from the propulsion efficiency through regeneration, but also from a gross vehicle weight reduction by eliminating heavy battery banks, metal wire, wire coils, cores and metal rotors, and without a reduction in applications, features and vehicle advantages. Many additional compressed air applications can be served with mobile compressed air supplies, as pneumatic tools and recreational equipment industry growth will attest.

[0048] FIG. **9** illustrates a distributed compressed gas storage bank in a vehicle tubular frame structure in accordance with an embodiment of the invention. In some embodiments, a tubular framed vehicles provide yet a high integrity and ultra safe CGS. In some embodiments of the invention, the chassis or uni-body construction is used for distributed CGS or flammable gas fuel. The safety is increased because the chassis, frame or structure are inherently stronger than any other part of the vehicle, because they are designed for higher stresses and structural requirements. These structures can be exploited for storing fuel such as hydrogen, propane, butane, compressed natural gas, etc, for fuel storage capable of withstanding more than minor vehicle collisions and remaining intact, above which even current liquid fuels pose a greater hazard. In some embodiments, electronic control systems are programmed to empty some tanks by virtue of their locations before other tanks, for example a collision in the front of a vehicle may signal gas compartments on the opposite side to vent if the gas can be dumped safely.

[0049] The frame chassis itself can become a part of the distributed CAS, with an additional benefit of a potentially adjustable stiffness and frame strength capacity to withstand higher vehicle forces and or damaging collision frequencies by tuning stiffness to an otherwise too stiff a frame. The control signal lines, not shown, and components are designed into the frame to provide ease of manufacturing as well as maintenance.

[0050] In an embodiment of the invention, a vehicle tubular frame **901** can act as a chassis but can also have a tubular roll bar **907** built in as well, providing more storage volume for compressed gas. In addition to providing a vehicle platform, the frame can house a compressed gas storage system. In an embodiment of the invention, cylinders **901 905** are separated by valves **903**. The valves and cylinders can be an integral part of the tubular frame or not. Since the cylinders can be pressurized, their stiffness can be variable, adding another function to a tubular frame, adjustable flexibility or stiffness. The cylinder compartments can be directly connected one to another serially, allowing an orderly discharge of pressure and re-charge serially, with check valves or electronic controlled valves. In the alternative, cylinder valves can be configured to output and input in parallel, by running conduits or channels outside of the frame to the input source or output manifold. Since the tubular frame would naturally lend itself to high pressures, the frame can serve as a high pressure gas storage system, it following that the source could be the engine cylinders for gas fuels or a sink for cylinder high pressure air. Because the valves are electronically controlled and monitored, as they are emptied of a fuel gas, they can also be used as storage for compressed air, regenerating energy from vehicle braking or down hill slowing. Not shown are insulation of the storage cylinder units, providing an adiabatic environment for the gas where necessary.

[0051] FIG. **10** illustrates tubular integrated compressed gas storage tank details in a tubular frame structure in accordance with an embodiment of the invention.

[0052] In one embodiment **1011** illustrates a tube frame integrated valve, where storage units Tank**1 1009** and unit Tank **2 1007** are separated by a slider or rotator valve **1001**.

The valve is integrated fully into the tubular frame **1006** wall, separated by a double in tube valve wall **1003**. An orifice **1005** provides an alternative flow path from Tank **1** or Tank **2** to outside the frame tube. The slider/rotator is electronically actuated for flowing gas between units or directing gas out through the port **1005**.

[0053] In another frame tube unit valve embodiment **1019** illustrates an valve outside tube frame construction, the units Tank **1 1017** and Tank **2 1015** are separated by a physical wall **1018**, and communicate flow through an out of frame tube valve **1014**, which can flow Tank**2** gas through Tank**2** spigot **1013** to manifold **1016** or alternatively to Tank **1 1017** via Tank **1** spigot **1021**. The valve **1014** is electronically controlled and pressure sensors giving gas pressures in separate units are used in logic to flow gas in the state and direction programmed.

[0054] Another tubular frame valve embodiment **1030** illustrates an a valve partially in the tubular frame body. Units **1029 1027** are separated by an integrated tube valve **1031** partially exposed outside of tube outside diameter. The valve separates the storage units **1029 1027** by a double wall **1025** and allows flow through directly across to adjacent unit or purge to outside of tube frame. As with the other units, the valves are electronically controlled, but with failsafe mechanisms.

[0055] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

[0056] Other aspects of the invention will be apparent from the following description and the appended claims.

What is claimed is:

1. A system for storing and managing compressed gas in a vehicle, comprising:
- an engine having selectable cylinder compressed gas,
- at least one compressed gas storage unit,
- at least one pressure sensor for determining gas storage unit pressure,
- compressed gas storage units coupled to engine cylinder for channeling bi-directional gas flow,
- programmed logic for bi-directional flow control channeling gas from a programmably selectable cylinder to programmably selected storage unit and from the storage unit to the cylinder,
- whereby compressed gas from dynamically selected individual cylinders can be flowed to disparate storage units for alternate on or off vehicle uses or redirected back to a selected engine cylinder for further compression or use.

2. The system of claim **1**, wherein the compressed gas storage units are coupled to a network of channels wherein electronic controlled valves using programmed logic actuates electronic controlled valves to maintain pressure ranges in selected gas storage units, cascading compressed gas to storage units in parallel or in series based on preset pressure limits, storage capacities and storage unit pressure.

3. The system of claim **1**, wherein the gas in the storage units is chosen from a group consisting of air, hydrogen, propane, methane, natural gas, nitrous oxide or combinations.

4. The system of claim **1**, wherein the storage unit comprises a plurality of gas storage units operatively connected in a gas flow channel network wherein actuation of valve opening and closing times are pre-determined based on gas travel time in mapped channels from source unit to channel target location, whereby transient pressures of compressed gases from more than one storage unit additively combine at a selected location, providing a cumulative higher pressure transient than the individual units could provide.

5. The system of claim **1**, further comprising logic for mapping available storage capacity to a required gas pressure and location wherein compressed gas storage units having electronically actuated valves isolating channel flow directing gas to mapped locations in without branching to other channels.

6. The system of claim **1**, further comprising small volume gas storage units operatively connected to a network channel for programmable controlling gas flow to reduce storage unit charge time in selected storage units.

7. The system of claim **1**, further comprising the compressed gas storage in a vehicle frame chassis.

8. The system of claim **7**, wherein separated vehicle chassis storage units are communicatively coupled in a network of channels connecting vehicle chassis storage units in series, parallel or combinations.

9. An energy storage and management system for compressed gas, comprising:
- computer readable memory and at least one processor;
- sensors measuring gas state at pre-determined gas locations;
- sensor data in communication with processor;
- compressed gas sources;
- a plurality of compressed gas storage units;
- a net work of channeling conduits, headers or plenums coupling the compressed gas storage units via electronic controlled valves;
- logic stored in memory for enabling a computer application, under the control of a processor, to perform:
  - receiving compressed gas data from sensors,
  - determining compressed gas target locations,
  - determining compressed gas state,
  - identifying valves isolating a channel from compressed gas unit to target location,
  - actuating the opening and closing of electronically controlled identified channel valves, and

executing the logic to manipulate valve components channeling gas flow from the plurality of gas storage sources to the target locations at the gas state required.

10. The system of claim **9**, wherein the compressed gas is chosen from a group consisting of air, hydrogen, propane, methane, natural gas, nitrous oxide or combinations.

11. The system of claim **9**, wherein the coupling network comprises wireless electronic components such as and including all types of valves, electronically controlled, varieties of pressure, temperature, flow sensors, and signal transmission.

12. The system of claim **9**, wherein the storage unit comprises a plurality of gas storage units operatively connected in a gas flow channel network wherein actuation of valve opening and closing times are pre-determined based on gas travel time in mapped channels from source unit to channel target location, whereby transient pressures of compressed gases from more than one storage unit additively combine at a selected location, providing a cumulative higher pressure transient than the individual units could provide.

13. The system of claim **9**, further comprising logic for mapping available storage capacity to a required gas pressure and location wherein compressed gas storage units having electronically actuated valves isolating channel flow directing gas to mapped locations in without branching to other channels.

14. The system of claim **9**, further comprising small volume gas storage units operatively connected to a network channel for programmable controlling gas flow to reduce storage unit charge time in selected storage units.

15. A method of storing and managing a compressed gas in a vehicle, comprising the steps of:

programmably identifying sources of individual cylinder compressed gas from an engine, identifying capacity available storage units,

selecting identified units based on a pre-determined pressure,

allocating a plurality of compressible gas storage units operatively connected with flow controlled through electronically controlled valves, for controlling gas flow from engine compressed air sources and to the allocated storage units,

accepting compressed gas from a identified compressed gas sources one or more pre-determined identified units,

accepting data from channel and storage gas pressure sensors,

storing the compressed gas in the allocated units, and

flowing gas from compressed gas source to storage unit or from storage unit to selected engine cylinder through a gas channel network programmably controlled by electronic controlled valves,

whereby compressed gas from engine generated sources can be directed to disparate alternate on or off vehicle uses or redirected back to the engine for further compression or use.

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