EBS
Electronically controlled Brake system in the city bus CITARO / CITO

System and functional description

1. Edition

WABCO

Vehicle Control Systems
An American Standard Company

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Introduction

The demands made on braking systems are increasing steadily. Therefore, the development and introduction of an electronic braking system (EBS) is a logical step.

EBS increases traffic safety through reduced stopping distance and improved brake stability. The full diagnosis and surveillance functions as well as the display of brake lining wear offer an effective fleet logistics.

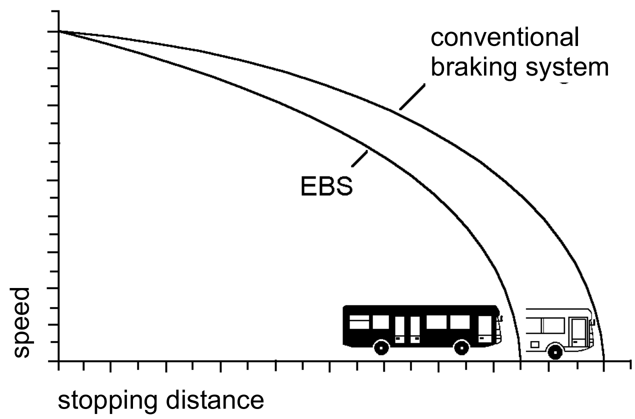
Advantages of EBS

EBS reduces service costs considerably.

- The electronic braking system has a lot of functions. The aim is to maximise braking safety at reduced costs, for instance by optimising wheel brake lining wear.

- Setting pressure, according to wear criteria, to the front and rear axle results in uniform lining wear. Overall wear is minimised by making the load on all wheel brakes uniform. Moreover, servicing and lining replacement are done at the same time. This reduces down-time costs.

- Depending on the vehicle utilisation profile and other factors, this also means considerable savings for the vehicle user. In terms of wheel brake service costs alone, a firsthand owner will save more money with an electronically braked bus than with a vehicle with a conventional braking system.

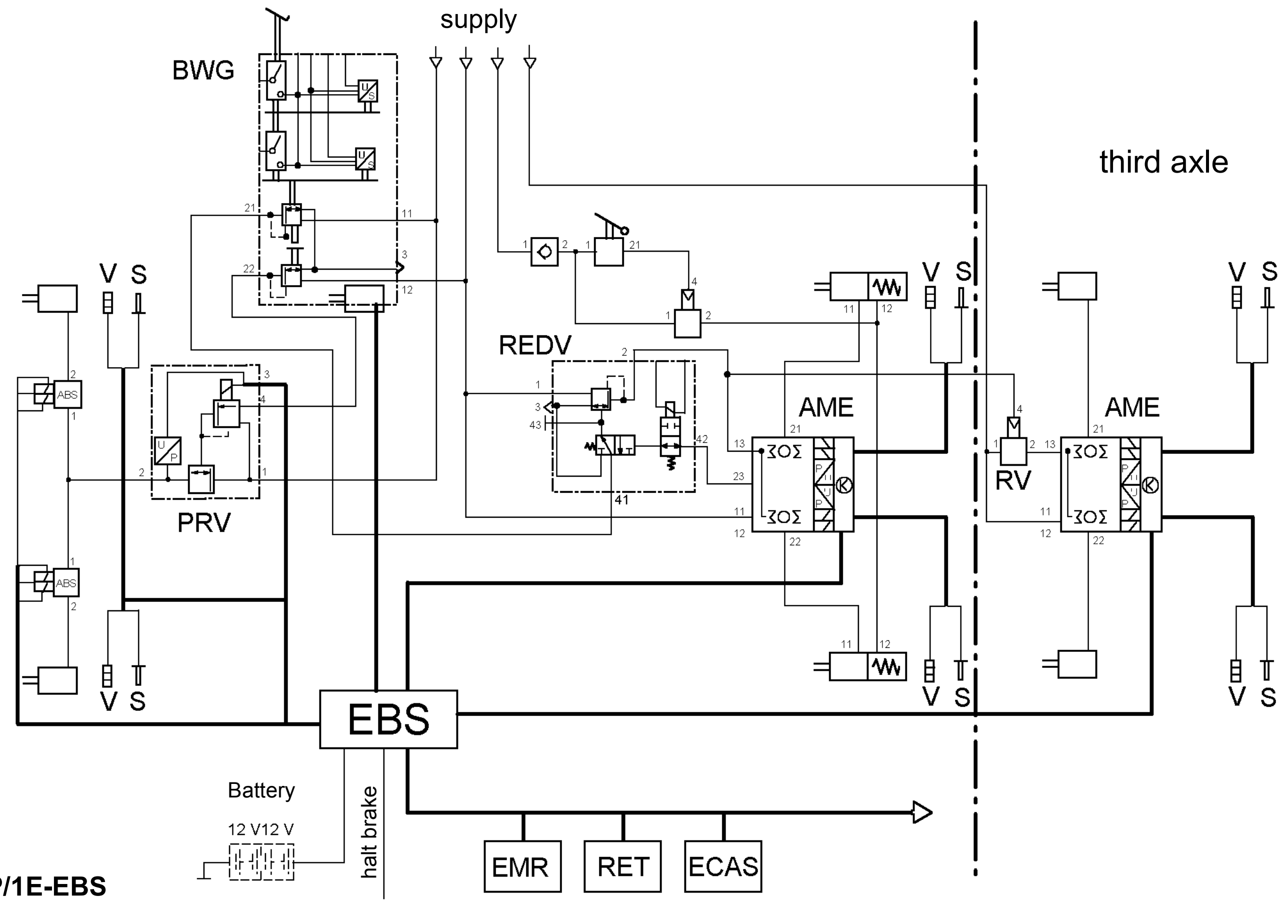


WABCO EBS construction kit

The design and structure of WABCO EBS allow high flexibility for vehicle manufacturers during system construction. In terms of range

- subsystem or full system
- addition and cut-off redundancy
- electrical interfaces

the most complex demands can, therefore, be met. To meet the main needs of the vehicle owner, WABCO recommends an EBS with an individual pressure control unit on the front and rear axle, and which provides for pneumatic redundancies in all brake circuits.



2P/1E-EBS

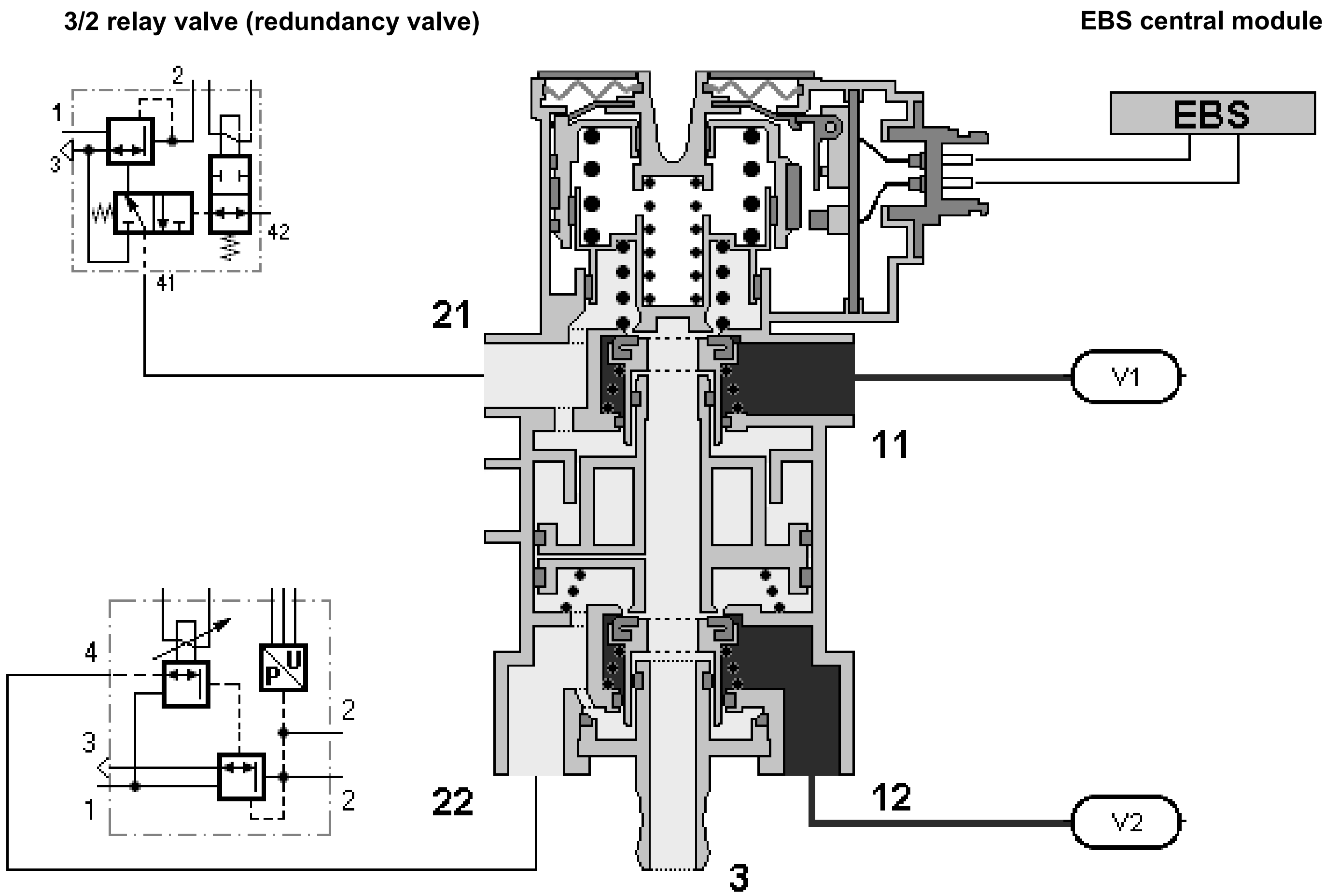
AME = Axle modulator
BWG = Brake signal transmitter
ECAS = Electronically Air Suspension System
EMR = Electronically engine control
PRV = Proportional relay valve
REDV = 3/2 relay valve (redundancy valve)
RET = Retarder
RV = Relay valve
S = Speed sensor
V = Wear indicator

The EBS described here consists of a dual-circuit, purely pneumatic unit and a superimposed single-circuit, electro-pneumatic unit. This configuration is described as 2P/1E system.
The single-circuit, electro-pneumatic unit comprises a central electronic control device (central module), the axle modulator with integrated electronic unit for the rear axle, and, if necessary, the axle modulator for the third axle, a brake signal transmitter with two integrated desired value sensors and brake switches, as well as a proportional relay valve and two ABS valves for the front axle.
In terms of structure, the dual-circuit pneumatic unit basically corresponds to that of a conventional braking system. This unit serves as redundancy and only becomes active in case of electro-pneumatic circuit failure.

Brake signal transmitter 480 001/ 002 ... 0

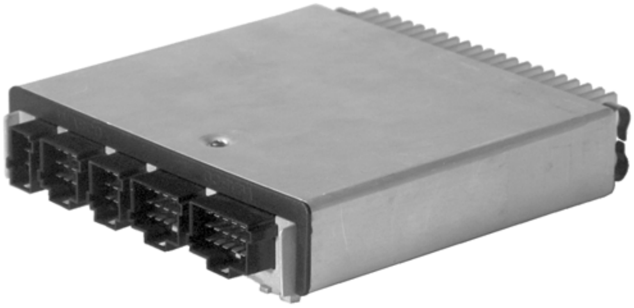
The brake signal transmitter is used to produce electrical and pneumatic signals, and to increase and decrease the air pressure of the electronically controlled braking system. The device has a dual-circuit pneumatic and a dual-circuit electrical structure. Actuation start is recorded electronically by a double switch. The operating tappet's route is controlled and transmitted as pulse-width modulated electrical signal. Further pneumatic redundancy pressure is delivered in circuits 1 and 2. The pressure in the second circuit is retained slightly in the process. In case of (electrical or pneumatic) failure of a circuit, the other circuits remain functional.
Depending on bus type, the brake signal transmitter is actuated via a running plate (480 002 ... 0, e.g. CITO) or via a hanging pedal and tappet (480 001 ...0 in the CITARO).

How it works:

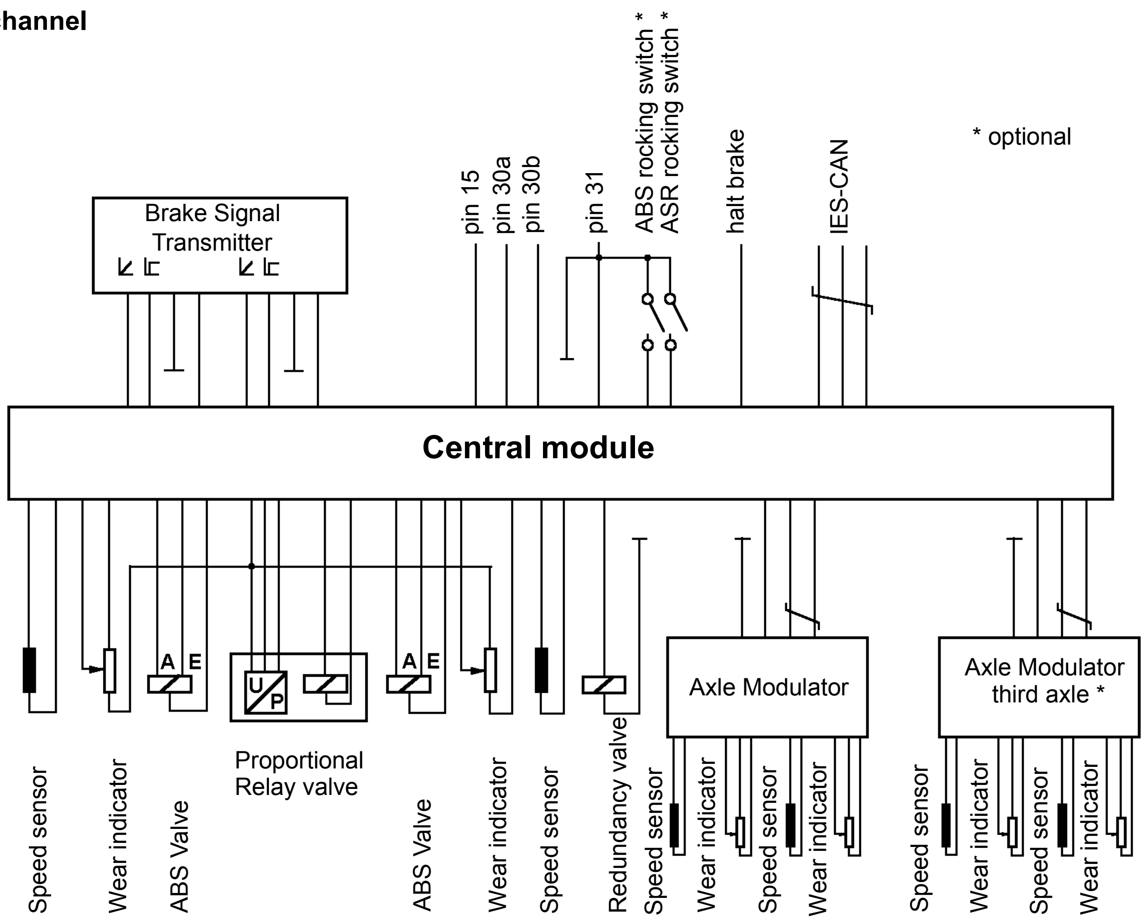


EBS central module 446 130 ... 0

The central module is used to control and monitor the electronically controlled braking system. It determines the vehicle's nominal delay from the signals received by the brake signal transmitter. The nominal delay and the wheel velocity measured by the speed sensors are input signal for the electro-pneumatic control unit, which uses it to calculate nominal pressure values for the front axle and rear axle. The front axle's nominal pressure value is then compared with the measured actual value, and any existing deviations corrected with the help of the proportional relay valve. Moreover, the wheel velocity is evaluated so that in case of locking, an ABS control can be carried out by modulating the braking pressure in the brake cylinders. The central module exchanges EBS system bus related data with the axle modulators. The central module communicates with other systems (engine control unit, retarder, etc.) via a vehicle data bus.



4- and 6-channel

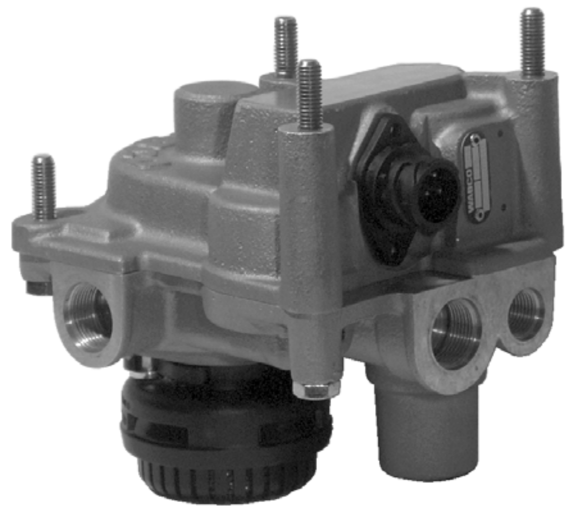


Proportional relay valve 480 202 ... 0

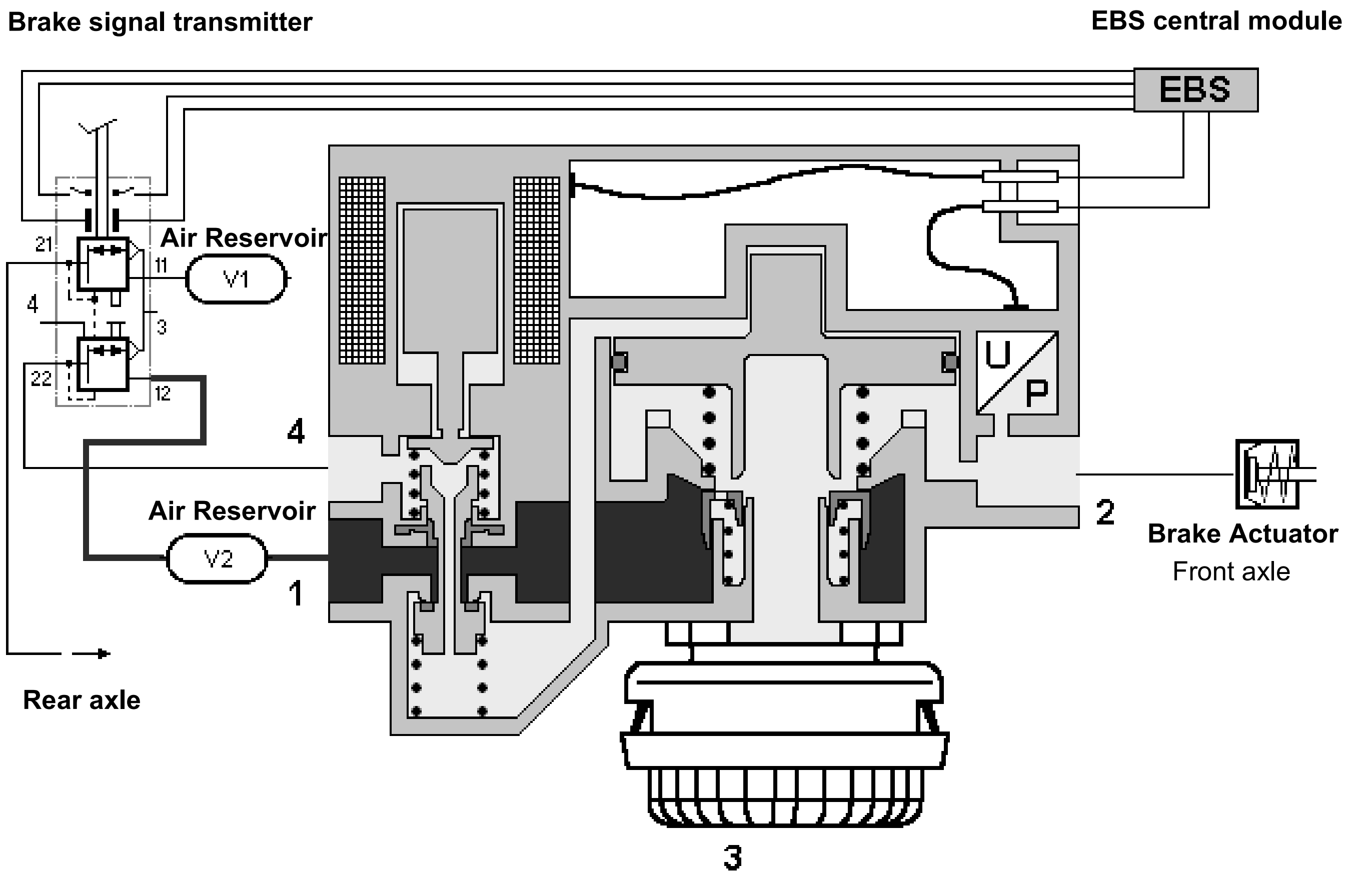
The proportional relay valve is used in the electronically controlled braking system to modulate the braking pressure on the front axle.

It comprises the proportional solenoid valve, relay valve and pressure sensor. Electrical drive and monitoring takes place via the central module of the hybrid system (electro-pneumatically / pneumatically).

The control current impressed by the electronic unit is transformed via the proportional solenoid valve into a control pressure for the relay valve. The proportional relay valve's output pressure is proportional to this pressure. The pneumatic drive on the relay valve takes place via the brake signal transmitter's redundant (back-up) pressure.



How it works:



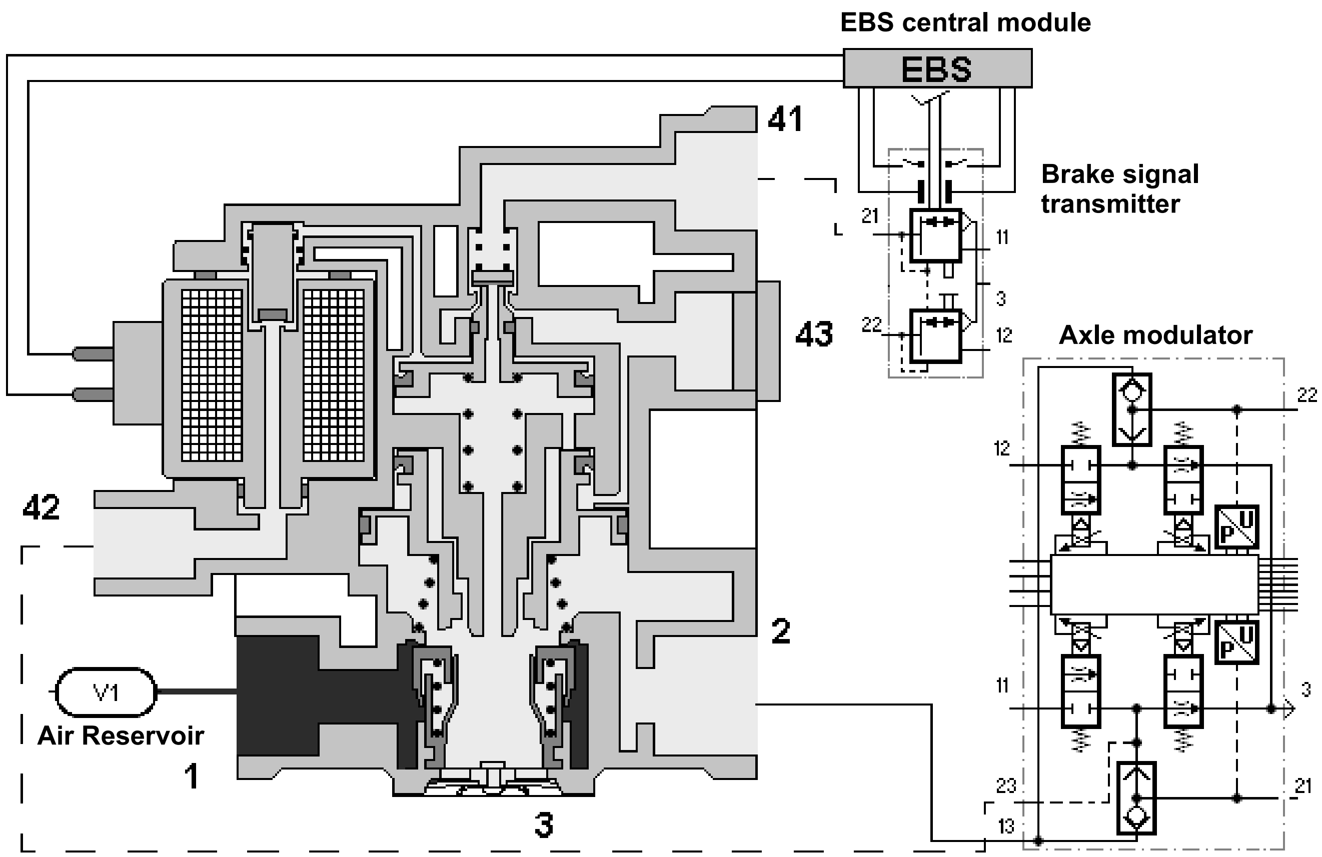
3/2 relay valve 480 205 ... 0

The 3/2 relay valve is used to supply air to and remove air quickly from the brake cylinder on the rear axle in case of redundancy, and comprises several valve units which must fulfil the following functions, among others:

- 3/2 solenoid valve function for restraining redundancy in intact electro-pneumatic braking circuit
- Relay valve function, to improve the time behaviour of redundancy,
- Pressure retention, to synchronise the beginning of pressure level control on the front and rear axle, in case of redundancy
- In case of redundancy, rear axle is controlled. 1:1

The 2/2 relay valve also has a 3/2 directional control valve to which current is supplied in case of ABS and is thus meant to prevent an involuntary drive through of the rear axle redundancy pressure during ABS control.
Port 43 must be plugged.

How it works:



Axle modulator 480 103 ... 0

The axle modulator controls the brake cylinder pressure on the two sides of a single or dual axle.

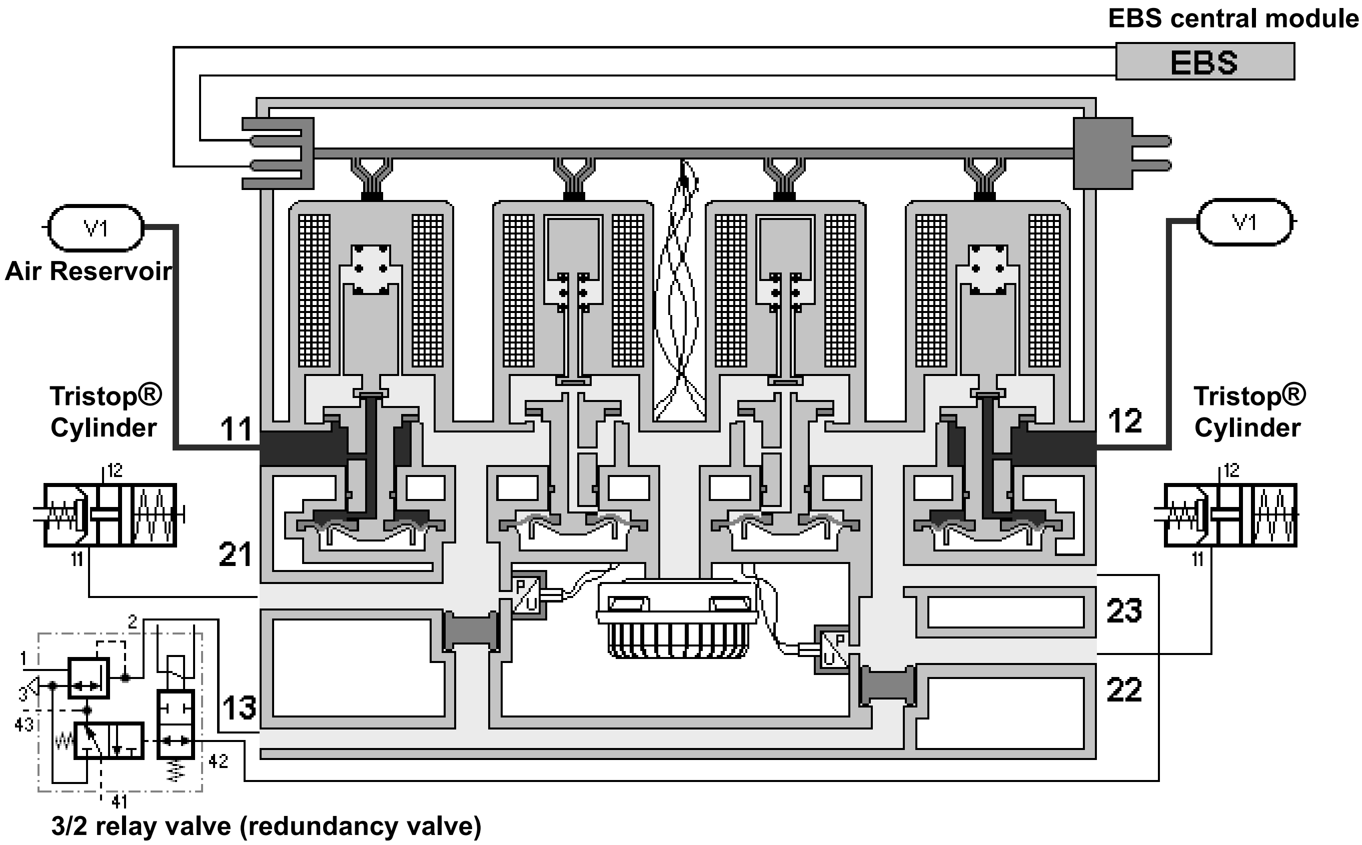
It has two pneumatically independent pressure control channels with an air admission and bleeder valve each, individual pressure sensors and a joint electronic control unit. Desired pressure definition and external surveillance take place via the central module.

Moreover, wheel rotation speed is measured and evaluated via two speed sensors. In case of wheel-lock or wheel-spin, the set nominal value is modified.

Provision has been made for the connection of two sensors to detect brake lining wear.

The axle modulator has an additional connection for a redundant pneumatic braking circuit. A two-way check valve on each side drives the higher pressure (electro-pneumatic or redundant) through to the brake cylinder.

How it works:



Function of the electro-pneumatic unit

The electro-pneumatic unit of the bus and its signal path work via

- **Brake signal transmitter**
  two distance sensors determine the nominal value which is transmitted as pulse-width modulated signal; two integrated switches are used for nominal value confirmation, among others
- **Central module**
  for determining the desired pressure for each axle, and system control
- Proportional relay valve
  for pressure control on the front axle
- **ABS solenoid valves**
  for the quick ABS pressure control cycles on the left and right wheel brakes of the front axle
- **3/2 relay valve (redundancy valve)**
  for restraining the rear axle redundancy pressure
- **Axle modulators**
  with integrated control unit for regulating brake pressures on each side of the rear axle(s).

EBS can be activated electrically via the driving switch (pin 15) or by actuating the brake signal transmitter via the integrated brake switches.

The measured brake pedal distance is interpreted as the desired delay and converted by the central module into desired pressure standards for the rear and front axle, using various criteria.

The nominal value standard for the axle modulators is transmitted by the central module via a central module. The axle modulators regulate and record the braking pressures of the rear axles' left and right wheel brake. The braking pressure of the front axle is regulated by the central module via the proportional relay valve with integrated pressure sensor.

The wheel rotation speeds are recorded via the sensors known to the ABS system and serve, among others, as input quality for the pressure control algorithms, for the ABS function and for the ASR function.

Before carrying out a wear control operation, the brake lining wear sensors analyse the brake lining wear on each wheel brake. The sensor signals from the front axle are recorded by the central module whereas those from the rear axle are recorded by the axle modulators.

Signals are processed and errors monitored for the rear axles in the axle modulators, so that the sensor values can be subsequently transmitted to the central module via the data bus.

Function of pneumatic redundancy

Front and rear axle circuits work with different redundancy methods. The front axle circuit works according to the additional redundancy principle, the rear axle circuit is equipped with a redundancy unit which can be activated with a valve.

Additional redundancy on the front axle

The front axle circuit which functions pneumatically and serves as redundancy works via

- **Brake signal transmitter**
  with 2 pneumatic circuits (front and rear axle)
- **Proportional relay valve**
  relay valve with combined pre-control via pneumatic front axle circuit and the proportional solenoid valve

on the front axle brake cylinder.

Electro-pneumatic pressure is delivered via the proportional valve when the brake signal transmitter is activated. Depending on the control force, pressure is supplied to the proportional valve by the brake signal transmitter in a delayed, pneumatically redundant manner.

This is added to the pressure delivered already electro-pneumatically. The pressure delivered by the proportional valve is adjusted to the set desired pressure by varying the electro-pneumatic pressure.

In case of electro-pneumatic unit failure, the pneumatic pressure part alone affects the proportional valve which can be raised to p_{max} by actuating the brake pedal further.

Due to the need to restrain the front axle redundant brake pressure vis-à-vis the electro-pneumatic pressure output (for instance, measures to optimise wear, or integration of endurance brake), the ”electrical” nominal value predominates the pneumatic front axle pressure output on the brake signal transmitter (2nd pneumatic circuit of the brake signal transmitter).

Rear axle redundancy

The pneumatic redundancy of the rear axle works via

- **Brake signal transmitter**
  with 2 pneumatic circuits (front and rear axle)
- **3/2 relay valve (redundancy valve)**
  with a 2/2 solenoid valve, a 3/2 way valve and a relay valve
- **Relay valve**
  for the additional axle
- **Shuttle valves**
  integrated in the rear axle modulator

on the brake cylinder of the rear axles.

During hitch-free EBS operation, i.e. an electronic pressure control is possible on the rear axle, the 3/2 solenoid valve in the 3/2 relay valve is set to ”switch off redundancy”, due to the electronically controlled pressure at the left rear wheel.

The brake signal transmitter is separated electrically and has a dual circuit. The actuation process is recognised via two switches. The switches have the following functions:

- Sensing the beginning of the braking process
- activating the EBS (if the driving switch is in the ”off” position)
- the offset values of the nominal value sensors are calibrated and monitored without being activated

The inactivated distance sensors transmit the electrical brake nominal value as pulse-width modulated signals to the central module. Both signals of the redundant electrical transmitter are evaluated equally.

The braking pressure on the front axle is regulated with electrically controlled proportional valves. The actual-pressure sensors are integrated into the valve subassemblies. The actual values are transmitted as analogue signals.

Axle load sensing is not required. The braking pressure on each axle is determined by a special braking force distribution function. The valves are actuated by the central module.

The EBS system status, for instance available errors, is transmitted by the EBS to a display unit via the vehicle bus (data line).

Potentiometers must be provided (or possibly alternative limit switches for drum brakes) for sensing brake lining wear, and which are read in for the front axle by the central module. The activities of each rear axle wear sensor is recorded by the axle modulator; the results are transmitted via the system bus brake to the central module. The sensors are supplied individually and per axle with short circuit-proof 5V.

Control functions

Endurance brake integration

The braking system has an integrated brake management function which always regulates the endurance brake when the brake pedal is activated based on an optimum delay of the vehicle. Optimum service brake wear is attained through the distribution of endurance and service brake. This function is an important part of delay control. The integration of endurance brake can be deactivated via the switch.

Delay control

Delay control is used to adapt the braking pressure level to the driver’s desired braking rate (def. As z in %).

When the same amount of pressure is applied on the pedal, the vehicle is often braked in the same manner, irrespective of the amount of load it is carrying.

If the coefficient of friction on a wheel brake changes (for instance when the vehicle is moving downhill), the delay control unit ends every adaptation process when a predefined, fixed maximum is attained, to enable the driver to also to feel the deterioration.

Adapting to the braking system hysteresis is also part of delay control. Each time the brake is released, the releasing process is chosen in such a way that an immediate braking force modification is adjusted. This function results in quick release of the brakes, i.e. car feeling.

Braking force distribution

The distribution of braking forces on the front and rear axles depends, among others, on the comparison made in the program range ”Delay control” between the actual and nominal value of vehicle delay. The pressure on the front and rear axles is set in such a way that there is optimum braking pressure output on these axles.

Brake lining wear control

When the brake is applied partially, the braking pressure distribution is adjusted, notwithstanding the available wear signals, i.e. the detected wear difference. The pressure on the wheel brakes with more lining wear is reduced slightly, whereas the pressure on the wheel brakes with less lining wear is increased adequately, so that there is no change in the overall braking rate required by the driver.

The EBS contains the following renowned functions:

Anti-lock braking system (ABS)

The control logic determines from the wheel rotation speed whether one or more wheels can be blocked and decides whether to decrease, maintain, or increase the braking pressure on it. The rear axle wheels are controlled in their optimum area in a similar manner (individual control ⇨IR).

On roads with extremely different adhesion levels between the right and left sides, vehicles are uncontrollable or difficult to control using the different braking forces in ABS (yawning moment development).

As a result, the braking pressure on the front axle brakes is not adjusted independent of each other, so that the driver can have a steering reaction (modified individual control ⇨ MIR).

If the driving wheels are locked when the endurance brake is applied on low adhesion levels, possibly resulting in vehicle instability, the ABS endurance brake is deactivated via the vehicle's CAN bus to maintain vehicle stability.

Traction control system (TCS)

Just like in the ABS function, while the vehicle is in motion, the electronic control system determines whether the wheels are in the stable area of the μ slip curve.

In case of wheel-spin, the engine output and/or driving axle wheel braking is adjusted by the axle modulator via the CAN bus and engine control system. An activated traction control system is displayed on the functions display.

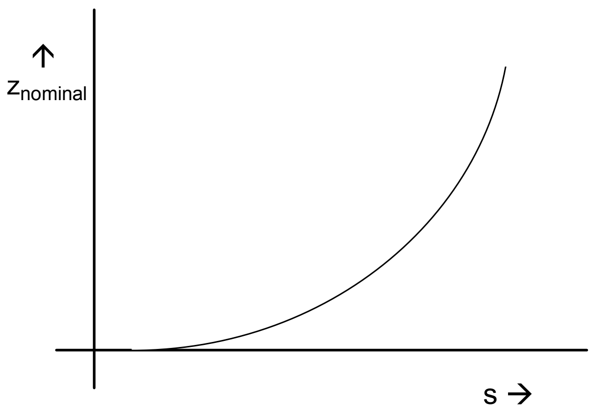
Drag torque control

Drag torque occurs in the drive line due to actuation or change of gas. The resultant braking torque can lead to driving wheel locking and thus to vehicle instability. Drag torque control prevents this situation. When a slip state is exceeded, the engine torque increases and the brake torque is reduced, irrespective of the driving wheel velocity. The function of the traction control system ends when the driving wheel values become stable again.

Backup functions

Generating brake nominal value

The brake pedal distance measured by the sensors in the brake signal transmitter is transmitted to the central module where it is "processed". The distance is converted into a nominal delay, based on the characteristic curve described in the chart.



Determining brake nominal value

Pressure control on the front and rear axles

The nominal pressure derived from the brake nominal value using the higher control algorithms is controlled in the front and rear axle's pressure control circuits. In order to improve the pressure control properties, the solenoid current in the solenoid valves are controlled.

Wheel speed sensing and wheel adjustment

Wheel speed sensing corresponds to the sensing function known to ABS. Automatic wheel adjustment makes up for the nominal wheel sizes and thus the rolling circumferences between the axles. If unacceptable wheel combinations are used, this is recognised as an error.

If the wheel sizes change, the system requires a change of parameters.

Halt brake

When the halt brake switch in the dashboard is activated, the command ”Activate halt brake” is transmitted to the central module via the FPS and the emergency switch ”release halt brake”. This latter sends the command to the proportional relay valve and axle modulator(s), so that 2 bar braking pressure is exerted on the brake cylinder of the front and rear axle.
Either the halt brake is released or actuation is given via door electronic unit and afterwards with the brake signal transmitter, the requirement ”halt brake” via FPS, emergency switch and central module is cancelled.

Failure diagnostics

Error recognition functions are used to avoid the effects of system failures and/or to inform the driver about functional problems. The error recognition principles correspond partly to those of a conventional ABS device (monitoring the ABS valves, the wheel speed sensors, the computer hardware).

On the other hand, a big part of the surveillance functions concerns EBS-specific functions (EBS-specific sensor analysis, EBS-specific solenoid control, braking pressure control, data transmission via CAN bus).

In addition to the wheel speed sensor signals, the EBS evaluates many other sensor signals and checks that these signals are error-free.

Nominal value sensing (sensors and switches)

The brake signal transmitter provides two sensor and two switch signals. The (pulse-width modulated) sensor signals are checked to see whether they conform with the authorised values, and for mutual deviations. The correctness of the (digital) switch signals are then tested.

Braking pressure sensing (on the front and rear axles)

The pressure sensor’s (analogue) signals in the pressure control circuits are checked to see whether they correspond to the authorised values.

Note: The cabling for the two rear axle sensors is not accessible from outside, since it is an internal axle modulator cabling.

Wear sensing (on the front and rear axles)

The (analogue) signals from the wear sensors are checked to see whether they correspond to the admissible values.

The EBS monitors EBS-specific solenoid valve control.

Front axle proportional relay valve
The frequent solenoid (pressure proportional to the solenoid current) of the front axle proportional relay valve is checked to see whether control is carried out correctly.

Rear axle redundancy valve
The rear axle redundancy valve’s solenoid switch is monitored to see that control takes place correctly.

Rear axle modulator’s inlet and discharge valve
The rear axle’s inlet and discharge valves are located inside the axle modulator. The solenoid cables are not accessible from outside.

The EBS monitors braking pressure control. The electrically controlled braking pressure and the pneumatically redundant pressure are also monitored.

Too low front axle braking pressure
The availability of minimum braking pressure (on the front axle at a certain solenoid current supply level) is checked.

Too high rear axle pressure deviation (from left to right)
In normal braking processes (neither ABS nor traction control system – TCS -controls) the measured braking pressure on the left and right sides of the rear axle must almost be equal. If the braking pressure deviation exceeds the admissible value, an error is reported.

Rear axle redundancy fails
In certain situations (vehicle stand still, parking brake in stop position), an electonically control of brake pressure on front- and rear brake is prevented. If the driver will now actuate the pedal, brakes on front- and rear brakes are controlled via pneumatical redundancy. If the front axle braking pressure exceeds a certain value, the rear axle must have a specified minimum pressure. A failure is recognized if this not applies.

Rear axle redundancy cannot be switched off
Normally, pneumatic redundancy pressure control in the rear axle is prevented by the redundancy valve. If an error makes this deactivation impossible, the rear axle braking pressure can no longer be reduced during ABS control, etc. (because there is inlet of non-ABS-compatible rear axle redundancy pressure into the rear axle brake cylinder). Error recognition takes place in this case.

EBS monitors data transmission

- between the EBS central module and the axle modulator (System bus)
- between the EBS and other system control devices (vehicle bus)

If communication is impossible or is suddenly cut, an error is reported.

EBS ”emergency modes”

As a rule, certain EBS functions are deactivated when an error is detected. Functions not impaired by the failure are maintained. For the EBS-drive with limited functions, the term ”emergency mode” is used.

The following functions can be deactivated if an error occurs:

Operation without ABS function
The ABS function can be deactivated on a wheel, an axle, or the entire vehicle. Possible causes: faulty speed sensor signal, ABS valve error, etc.)

Operation without ASR function
The traction control system can be switched off completely or partially. Complete deactivation means that both the braking system and the engine control unit are deactivated. Partial deactivation means that only the braking system is deactivated. Possible causes: (faulty speed sensor signal, etc.)

Pressure control / auxiliary pressure control
Normally, braking pressure control requires braking pressure sensor signals. When these signals are no longer available, electrical braking pressure can be produced. In this case, we talk in terms of pressure control operation or auxiliary pressure control. However, the accuracy of this pressure production is limited, compared to hitch-free pressure control. Possible causes: Pressure sensor signal failure, etc.)

Redundancy operation
If electrical pressure control becomes impossible, the corresponding axle is braked with the help of the pneumatic redundancy pressure. Possible causes: damaged solenoid, or faulty solenoid cabling, etc.)

EBS test types

The following peculiarities must be observed while testing the electronically controlled braking system:

- **Test of the 3/2 relay valve (redundancy valve)**
  A vehicle stand still, with parking brake in stop position and ignition on together with an actuation at the brake pedal will switch off the axle modulator. Now, the function of the redundancy valve can be tested with a pressure gauge, connected to the rear axle's brake cylinder. The failure of the electronical circuit is simulated. The measured pressure must correspond to the supply pressure.
- **Maximum pressure level control:** When the brake is applied > 80% of the pedal stroke and ignition is off, the full pressure must work on the front and rear axles.
- **Roller dynanometer test:**
  (Roller dynanometer function)
  A roller dynanometer function was integrated into the EBS electronic unit so that an electronically braked bus can be tested on a roller dynanometer. This function is used to test the braking pressure at full load (permitted total weight).
  The roller dynanometer function is activated if the EBS is not switched on via the ignition (pin 15) when the vehicle is braked again, but rather through activation of the brake signal transmitter via the integrated brake switches. The front axle and/or rear axle speed must be < 3 km/h.
  Special EBS controls such as endurance brake integration, delay control and brake lining wear control are not active when the roller dynanometer function is active. The maximum braking pressure can now be measured. The EBS is working correctly if the measured braking pressure corresponds to the basic loaded vehicle design.

For WABCO Diagnosis tools please refer to brochure 820 001 029 3