Potential of Electronically Controlled Brake Systems

ABSTRACT

Air braking systems for commercial vehicles are undergoing a continuous development and improvement. New technologies like disc brakes and electronic brake control will increasingly be introduced in the next years. Compared to current state-of-the-art brake systems incl. ABS and ASR the EBS systems offer the potential to reduce stopping distances, to improve the brake force distribution and braking stability as well as the brake compatibility of vehicle combinations. Reduced stress for the driver and comprehensive monitoring of the brake system are further safety enhancements. As pure electrical brake control could still find some acceptance and compatibility problem, there will be partial or mixed EBS concepts initially. These will still have pneumatic control of some functions and/or pneumatic backup for the electronic functions. EBS is currently in the final stage of development with field validation in a considerable number of vehicles.

INTRODUCTION

A major share of the overall transport business is performed on roads by commercial vehicles. There are continuously increasing demands, due to higher traffic density, competition, increase of payload, environmental demands and driver workload. All this is taken into account in the continuous development of heavy goods vehicles to ensure their safety, economy and acceptancy. Also the braking systems of these vehicles are constantly undergoing a continued improvement. Milestones of that were for example, the introduction of dual circuit brake systems with two lines for trailer control or the development and introduction of antilock braking systems for HGVs [1, 2].

Both developments, driven by WABCO and Mercedes-Benz, found their first application in Germany and from there a rapid propagation in Europe, supported by the corresponding amendments in the legislation. An adoption of the concepts and a trend for harmonisation of regulations in important overseas markets is also evident. Meanwhile there is going to be a further technology step with HGV brake systems in the second half of this decade. This will bring an increased emergency and endurance brake performance, improved brake force proportioning and drive stability, less stress for the driver and thus higher passive safety as well as improved profitability of the vehicle. This will be achieved by increased brake torque and better control of engine brakes and driveline retarders, increasing fitment of air-operated disc brakes, installation of higher braking forces and electronic control of the total brake system, on which is the emphasis of this paper.

LAYOUT OF A "CONVENTIONAL" AIR BRAKE SYSTEM WITH ABS/ASR

The state-of-the-art dual circuit air brake system (Fig. 1) is characterised by:

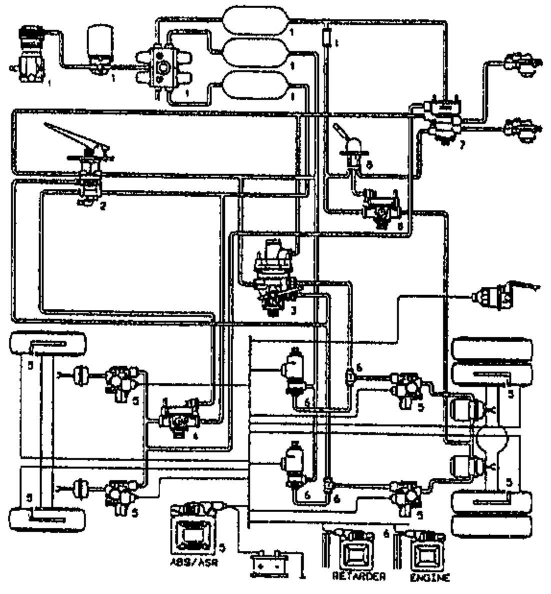
- A group of devices for generating, processing, storing and securing the control and actuating medium which is compressed air. These devices are still under continued development e.g. for functional integration and improvement or cost reduction, but are in the first step not affected by the introduction of an electronic brake control.

- A mechanical-pneumatic transmission in which the valves vent the brake chambers directly or - to improve the timing - indirectly via relay valves. In many cases pressure proportioning valves are added to adjust the brake pressure according to the axle load or to reduce lining wear. Such valves exist in a great number of variants and characteristics to achieve an acceptable system layout for every vehicle manufacturer, vehicle type and operating condition. This requires an excessive range of parts.

- The antilock braking system with its wheel speed sensors, solenoid valves, electronic control unit and wiring is superposed onto the service brake system. The ABS is in many cases extended by drive slip control (ASR) which is not a direct braking function, but actively actuates the brakes to control drive slip and ensure vehicle stability and traction. There are also interfaces of the ABS/ASR control unit to engine control systems and driveline retarders to reduce unnecessary high drive torque and prevent critical wheel slip caused by auxiliary brakes [3].

- Components installed in the towing vehicle to supply a trailer brake system with compressed air and brake control signals. An ABS which may be installed in the trailer, is connected via an electrical connector for power supply and warning signal transmission [4]. The trailer control valve (in the tractor) and the trailer emergency valve (in the trailer) are again available in various characteristics and with adjustment means in order to achieve reasonable braking compatibility of the combination.

- Additional elements of the park brake system.



1 air supply
2 foot brake valve
3 load sensing relay valve
4 relay valve
5 ABS
6 ASR
7 trailer control
8 park brake

Figure 1: Air brake system with ABS/ASR

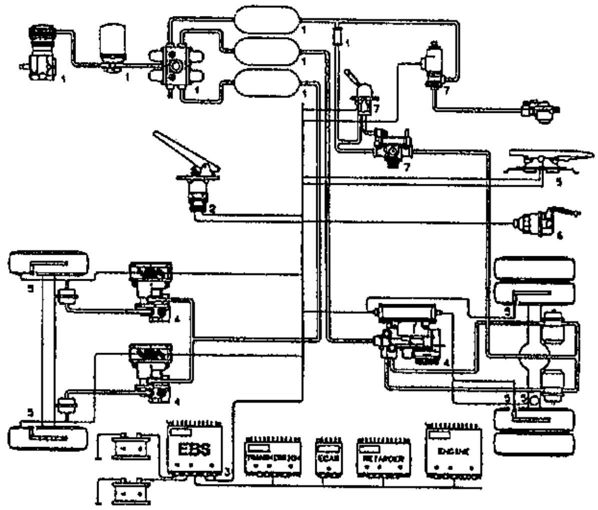
Such systems are applied widely and well-proven which particularly applies to the electronic ABS which thereby has demonstrated reliable operation and easy service in the field [5]. However there is potential for further improvement:

- The number of devices, connections, pipes etc. is large resulting in complication in vehicle production and service, implying also a corresponding probability of faults.
- There is a large number of valve variants and characteristics required for a reasonable brake system layout. However and in spite of in-service adjustments the optimum performance is rarely found.
- Consequently customers complain about excessive brake wear or "lazy" brakes on some axles of their combination, which results in extended service cost or also affects the emergency stopping capabilities.
- The stability of vehicle combinations under braking can be impaired by inappropriate brake force distribution or different brake response behaviour. As with the aforementioned wear problem, this applies particularly to changing combinations and may be of even more significance with the introduction of disc brakes on trucks.
- The effective, wear-reducing and safe usage of auxiliary brakes is largely depending on the skill of the driver.
- The monitoring of the brake system is limited to visual checks by the driver, regular inspections and the self-diagnosis of the ABS.

LAYOUT OF ELECTRONICALLY CONTROLLED BRAKING SYSTEMS

Electronically controlled braking systems - EBS for short - were under development from the beginning of the 1980s in different concepts. Fig. 2 shows one possible future possibility which is characterised by:

- Principally the same air supply as today.
- A strict dual circuit electrical system architecture incl. energy storage and electrical circuit protection.
- A dual circuit brake signal transmitter, operated by the pedal to transmit the driver demand for deceleration.
- A dual circuit electronic control unit, which serves as the central brake manager evaluating the driver demand as well as various other sensor signals (e.g. load, actual deceleration) and calculating request signals which are transmitted to all actuators for tractor brakes, trailer brakes and auxiliary brakes.



1 air brake supply
2 brake signal transmitter
3 central controller
4 pressure modulator
5 sensors
6 trailer control
7 park brake

Figure 2: Purely electronically controlled brake system

- Smart pressure modulators which are located close to the brake chamber and supplied directly with reservoir pressure. These modulators (Fig. 3) are an integration of pneumatic valve, solenoid, pressure sensor and electronic controller for closed loop control of the output pressure. The decentral electronic unit also reads local sensor signals like wheelspeed, axle load and lining wear. The data are used for local control functions (e.g. ABS, ASR) and/or are transmitted to the central controller for logical evaluation with corresponding signals.
- The sensors mentioned previously to measure driver input, brake pressure, wheelspeed, axle load

but also force sensors built into the coupling to measure the coupling forces between tractor and trailer.

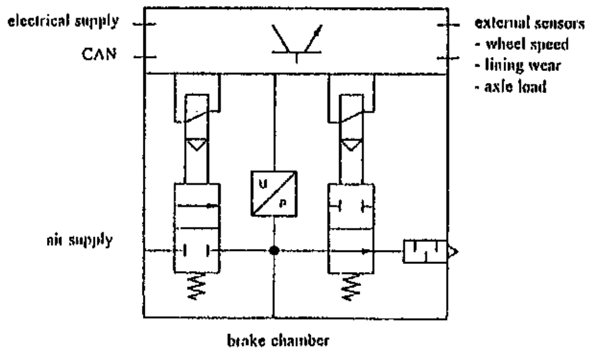


Figure 3: EBS pressure modulator

- An electrical connector incorporating an electronic tractor/trailer-interface to transmit control and status signals between the brake controllers of towing unit and trailer.

- An air supply line to the trailer which can be exhausted by solenoid valve actuation.

Before such consequent brake-by-wire systems are mature and accepted in the market, there is still some work to be done. In Europe there is an expert group (with participation of all major vehicle and brake system manufacturers) working on the necessary amendments to the EC braking regulation to accommodate this new technology [6], the modified regulation is expected to become effective in 1996/97. Also the compatibility with current systems which will be in the field still for many years, has to be considered.

Therefore there will on the way to full brake-bywire be various partial or mixed EBS concepts which are characterised by:

- single circuit electronic control,

- one or two pneumatically controlled brake circuits operating as today or as an underlying backup,

- and the capability of controlling conventional, current trailers.

An example of such a partial EBS is shown in figure 4. It consists of

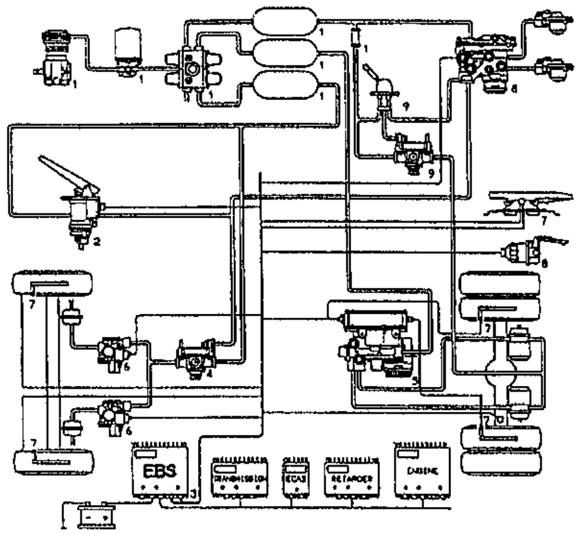
- conventional pneumatic brake control for the front axle with a relay valve for quick response and ABS modulator valves for ABS control according to the MIR-logic,

- at the rear axle where integration of devices and decentral data processing is most advantageous, a dual channel smart pressure modulator, called an axle modulator,

- a brake signal transmitter for generating the control signals for front axle, rear axle and trailer both in electronic and pneumatic form,

- an electro pneumatic trailer control valve which provides better trailer brake response and the possibility to increase or reduce the trailer control pressure in relation to the pilot signal.

The characteristic EBS components of this partial system are obviously very similar to those of the full EBS in figure 2. These and similar systems can be configured from the same "kit" of components.



1 air supply
2 brake signal transmitter
3 load sensing relay valve
4 relay valve
5 pressure modulator
6 ABS modulator
7 sensors
8 trailer control
9 park brake

Figure 4: EBS, partial system

ELECTRONIC SYSTEM CONCEPT

The main advantages of electronic brake control are achieved by having electronics instead of air to perform the functions below:

- Signal transmission and valve actuation are performed much quicker.

- Permanent monitoring permits self diagnosis and active safety.

- Increased functionality because of more sensors combined with component standardisation by achieving control characteristics by software rather than hardware.

Electronic systems in vehicles have reached a high reliability, safety and acceptability and are meanwhile integral parts in control of drive train, chassis and safety systems (e.g. ABS, airbag).

There have in the past been some shortcomings in the installation of wiring harnesses and connectors, but meanwhile reliable and cost-efficient solutions are available. The design of an EBS has taken especially these experiences into account. A simple replacement of pneumatic tubes by electrical wires would - in conjunction with additional sensors and solenoids soon have led to as many as 70 to 90 connector pins at the central ECU, causing complication and unacceptable wiring cost.

The multiplexing of signals from/to several devices on a data bus is now a proven technology. The CAN protocol has been developed especially for automotive applications and is in production [7] in some vehicles.

Using these possibilities the layout of the EBS was designed, characterised by "decentral" intelligence (Fig. 5):

- A central electronic module performs all general functions like "brake management", diagnosis, control of power supply etc.
- Single components located close to each other are packaged into integrated devices with their own control unit.
- These smart devices are interlinked by a system data bus (CAN).
- Extensive monitoring means provide permanent system self-check and preventive diagnosis information.
- Another bidirectional data interface according to ISO 11992 [8] serves as an electronic brake control line for signalling the electronically controlled trailer brake systems.
- On a third CAN interface the EBS can communicate with other electronic systems on the vehicle data bus (e.g. engine control for ASR). This concept is in line with a new generation of automotive control systems basing on the experience with today's systems and applying new mature technology.

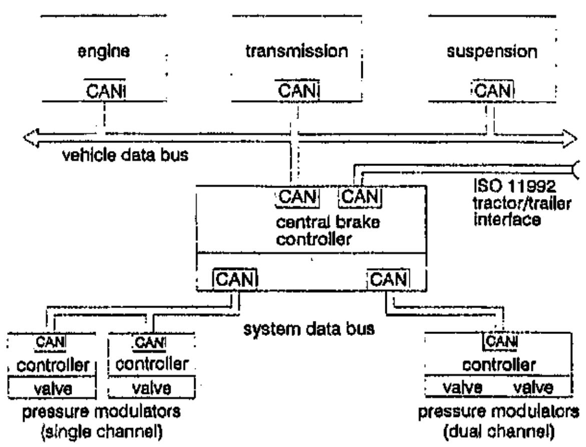


Figure 5: EBS network structure

Major advantages are:

- Fewer electrical connections enable the use of high quality connectors at reasonable cost.
- With less and shorter electrical connecting lines the electro-magnetic interference possibility is greatly reduced (in addition to an EM-compatible layout of hard- and software).
- Data bus systems with proven and high reliability of transmission provide multiplexing of signals.
- All adjustment and tuning takes place within the smart devices; there is no more costly adjustment after completion of the vehicle.
- The end of line test as well as the field diagnosis can be done quicker, easier and more reliably using the built-in sensors and intelligence. The initial installation itself is easier as the number of devices and connections is reduced.
- With the multitude of information, also from the vehicle data bus, there is also the possibility to check the plausibility of system reactions.

It is clear that with this increase in integration and functionality there is a much higher complexity leading to concerns about reliability and availability of such systems. An all-embracing design approach takes this into account:

- During the development of EBS, state-of-the-art methods for Failure Mode and Effect Analysis as well as risk analysis were applied.
- Complex functions, distributed in more than one device require methodical software engineering, applying structured programming. Static and functional tests are performed in the laboratory, with "hardware in the loop" simulators and in test vehicles.
- An extensive fault detection and reaction concept involves a selective disabling of partial functions if a fault is detected. The selection is based on criteria of stability and requirements on the driver. This means an improved failure performance compared to current systems.

As mentioned before there will be a transition period in which there will be pneumatic and electronic control functions, e.g. to ensure compatibility with current trailers. Such a system shall be considered with regard to its trailer brake control:

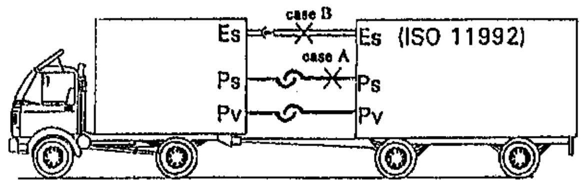


Figure 6: Vehicle combination with electronic and pneumatic trailer control

Fig. 6 shows a vehicle combination with one pneumatic and one electric trailer control line. Motor vehicles with such equipment can also be used to tow conventional trailers with pneumatic brake control. A fault (e.g. leakage) in the pneumatic brake line (case A) of a trailer with pneumatic brake control leads to these reactions:

- full braking of the trailer by exhausting of the supply line when the brakes are next applied by the driver,
- no advance fault detection or warning.

A fault in the dual wire data transmission (short circuit or interruption, case B) however leads to:

- continued full availability of the brakes in case of one single failure (one wire broken, shorted to plus, grounded or even short between the two signal lines),
- detailed diagnosis and information for the driver,
- in case of interruption of both signal wires reaction as for case A, but with immediate information for the driver, before the brakes are applied.

The main advantage being the higher system availability and the advanced warning to the driver.

SYSTEM FUNCTIONS

With such electronically controlled braking systems a multitude of braking and secondary functions can be performed. The performance of the system is dependent on its specification (see also Fig. 7).

BRAKE FORCE DISTRIBUTION - By accurate determination of the axle load by sensors with minimum hysteresis and by feedback of the actual brake pressure a precise distribution of braking forces is possible to obtain optimum utilisation of adhesion at all axles. Thus a higher braking stability is achieved and the ABS control cuts in at all axles at the same braking rate. Instead of selecting or designing the components to generate a certain system, the characteristics can be parametrised into the controllers or even obtained by their adaptive control. This is a major advantage over the conventional brake system

system function / system layout	conventional air braking system incl. ABS/ASR	partial EBS • rear axle only	partial EBS • rear axle EBS • EBS trailer control	full EBS • front axle EBS • rear axle EBS • EBS trailer control
brake force distribution (adhesion / wear optimum)	0	+	+(+)	++
deceleration control	0	+	+	++
trailer compatibility control	0	0	++	++
integration of auxiliary brakes	-	+	+	++
ABS/ASR	0	+	+	++
automatic roll brake	-	+	+	++
system monitoring	-	+	+(+)	++

Figure 7: Comparison of EBS functions

which is tuned via design data like slack adjuster length, chamber size and valve characteristic. The requirement for equal lining wear on all brakes which is contradictory to optimum utilisation of adhesion - can be fulfilled by the adjustment of pressure distribution at lower braking rates. A closed loop lining wear control is also possible with wear sensors installed.

DECELERATION CONTROL - This function leads to an improved brake feeling and feedback with a brake characteristic which is not influenced by the load. There is always the same deceleration obtained at the same pedal position regardless of whether the vehicle is laden or unladen. Additional improvement of comfort and ergonomics is achieved by compensation of brake threshold ("crack") pressures and hysteresis and generally by the more responsive signal transmission. For safety reasons an increase of pedal force/keystroke is required in case of brake fade in order to give the usual feedback to the driver. Actuation of a warning light is also possible.

TRACTOR/TRAILER COMPATIBILITY With electro pneumatic trailer control valves or electronic data transmission to the trailer it is possible to considerably speed up the brake response of the trailer and to match the trailer brake performance to that of the tractor. Thus the overrun push is minimised, the braking stability of the combination is enhanced and the wear reduced. Especially with the use of force sensors for measuring the coupling forces an accurate coupling force control is possible which ensures that each axle of a combination brakes just its own axle load. This results in a coupling force near zero for drawbar combinations, and an appropriate rear axle brake force of the tractor for articulated combinations.

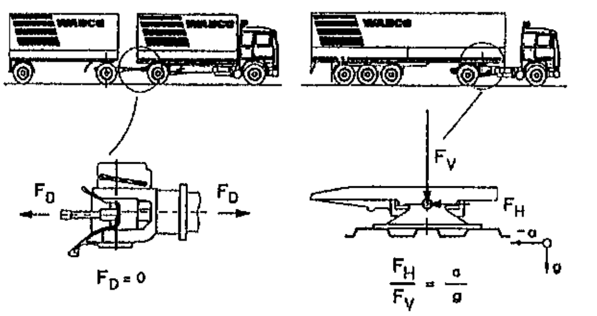


Figure 8: Coupling force control, basic principle

INTEGRATION OF AUXILIARY BRAKES - Zero wear brakes like driveline retarders or engine brakes which are currently undergoing a development for increased brake torque are operated by hand lever or pedal following various concepts. In all cases their effective usage is depending on driving style and skill of the driver. If they are controlled by the brake pedal the characteristics change e.g. with speed which leads to an irritating effect including longer initial stroke in low-speed manoeuvring. With EBS it is now possible to decelerate a vehicle according to the driver's demand generating as much torque as actually possible (depending on dynamics, load, temperature, wheelslip) by the auxiliary braking adding only the differential braking torque required from the service brake. This means that at any time the auxiliary brake is used to its maximum which leads to foundation brakes remaining cool for emergency stops. At the same time the overall wear is reduced.

IMPROVED ABS AND ASR - These functions are integrated into an EBS and can be developed towards even better control efficiency and comfort using the additional information like pedal status, demand signal, axle load and brake pressure. With the EBS modulators the pressure control is both very responsive and accurate. The ASR control can be further improved using the extended communication on the vehicle system data bus.

AUTOMATIC ROLL BRAKE - For short stops especially on gradients - it is advantageous to hold the vehicle stationary without the park brake just pushing a switch to maintain pressure in the brakes. When releasing the clutch (in gear) the brakes are released automatically to drive away easily. This function, principally possible also with ASR is enhanced in EBS by braking all wheels and matching the brake pressure to the gradient of the road.

COMPREHENSIVE MONITORING - The additional sensors and intelligence of the system allow for monitoring functions and plausibility checks far beyond today's ABS diagnostics. Thus a self-check of the more complex electromechanic devices is made possible. Furthermore the total brake system can be monitored either by direct measurement or indirectly for wear, leakage and brake performance. This will result in driver information either requiring immediate action in case of severe faults or providing a preventive maintenance advice in case of less significant problems.

ADDITIONAL FUNCTIONS - The functions above mainly lead to an extension or optimisation of the service brake functionality. Further applications can be realised only with EBS for the first time: a selective, active brake actuation on single wheels to optimise the drive stability [9] or an active deceleration, commanded via a system network independent of the driver. This is a pre-requisite for future collision avoidance or autonomous traffic guidance systems.

As can be seen from fig. 7 some of these functions require electronic brake control on all axles of the tractor and for the trailer. Consequently there is only a limited set of functions available with partial EBS. For full integration of the auxiliary brakes e.g. a reduction or hold back of the front axle service brake pressure is necessary. For wear control between the tractor axles it is advantageous to have them all EBS-controlled and improving the trailer response requires electro pneumatic or electronic trailer control.

SUMMARY

ADDITIONAL SAFETY - ECONOMIC BENEFITS It is obvious that the EBS functions described result in advantages for vehicle manufacturer, vehicle operator and the general traffic by higher safety and economy: Rapid transmission of control signals, improved brake force distribution, higher emergency braking performance but however optimum compatibility between tractor and trailer as well as an optimised ABS control provide a potential to reduce the stopping distances of heavy vehicles thereby reducing the difference in performance to cars.

Direct graduation and feedback, reduced hysteresis, constant ergonomics and stable trailers result in considerable stress-relief for the driver. In many EBS demonstrations the first observation is the "car-like" brake feeling of a 40-tons-combination.

The brakes of solo vehicles or combinations are used evenly and effectively and can be monitored for performance. The duty for the friction materials is reduced, their availability increased. Thermal fading is reduced or even avoided, glazed linings are prevented by appropriate actuation algorithms. Relinings are required less frequently and then for all brakes at the same time.

The compatibility control matches the brake performance of tractor and trailer which becomes especially relevant with the introduction of disc brakes for trucks/tractors leading to a mix of foundation brakes in the combination. Again the duty for all brakes is distributed more evenly leading to higher available reserves for emergencies.

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REFERENCES

[1]: Mischke, A.: Antiblockiersystem (ABS) für Nutzfahrzeuge. VDI-Bericht Nr. 418, 1981.

[2]: Reinecke, E.: Neues Anti-Blockier-System mit erveiterter Sicherheits- und Systemfunktion. VDI-Bericht Nr. 515, 1984.

[3]: Petersen, E.; Hesse, K.-H.; Kaess, H; Lindemann, K.: A New ABS with Integral Automatic Traction Control for Air-Braked Trucks and Buses. SAE paper 90 22 10.

[4]: Petersen, E.; Hesse, K.-H.; Kaess, H.: New modular anti-lock braking system (ABS) for trailers. Second international EAEC conference on new developments in powertrain and chassis engineering, Straβburg, June 1989.

[5]: Göhring, E.: Reliability of Daimler-Benz/ WABCO Anti-Lock-Systems - Five Years of Experience after Production Began. SAE paper 880986.

[6]: Straub, L.: Electronic control of braking systems Legislation (ECR R 13). I MECH E C 444/015/93, London, 1993.

[7]: Schruf, W.: Drei Mann an einem Bus. Auto Motor und Sport Nr. 19, 1991, S. 83 - 88.

[8]: Neuhaus, D.; Kalter, J.: Zuverlässige Datenkommunikation zwischen Motorwagen und Anhängefahrzeugen. VDI-Bericht Nr. 1009, 1992.

[9]: Müller, A.; Achenbach, W.; Schindler, E.; Wohland, T.; Mohn, F.-W.: Das neue Fahrsicherheitssystem Electronic Stability Program von Mercedes-Benz. Automobiltechnische Zeitschrift 96 (1994) 11, S. 656-670.