Revisiting the Anti-Lock Braking System

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Abstract

Intense press of the brake pedal by the driver can lock the vehicle's wheels. Locked wheels can enlarge the braking distance, decrease the steering competence and wear off the tires. Anti-lock Braking System (ABS) aims at eliminating these problems. In this paper a subtle technique for implementing an Anti-lock Braking System is proposed.

Keywords: *ABS, locked wheels, steering.*

1. Introduction

Vehicles' braking systems produce friction of the brake pads against surfaces attached to the wheel with the aim of slowing the vehicle's speed by converting the kinetic energy of the vehicle to heat [1]. However, intense braking at high speed on slippery roads or even semi-slippery roads because of ice, oil or other reasons can be very dangerous [2].

With the move to autonomous vehicles underway, many functions of vehicles turn into automatic. One of them is the Anti-Lock Braking System that automatically reduces braking force in a case of locked wheels.

A vehicle without an Anti-Lock Braking System (ABS) [3] attempts to brake on slippery roads can completely stop its wheels. Such wheels are called locked wheels [4]. A locked wheel skids on the roads instead of going circularly can harm and even eliminate several critical functions of the vehicle:

- Loss of steering ability [5]: Steering is performed by combination of two elements - the steering wheel angle and the rolling tires. If the front wheels are locked, the steering ability of the vehicle will be lost. The driver will be able to turn the wheel effortlessly and the tires will indeed turn to the decided direction; however, the vehicle will not turn to the desired direction, but rather will keep moving forward.
- Lengthening the stopping distance [6]: The angle of the wheels may possibly place the side of the tire against the road. The side of the tire has a lower traction than the center of the tire, so as a result the stopping distance will be lengthened.
- Increased wear [7]: When a tire skids on a road, the friction between the tire and the road will slow down the vehicle instead of slowing down the vehicle by the usual way i.e. a friction with the braking pads. Additionally, this friction between the tire and the road will significantly wear off the tire

[8,9,10]. Such a vehicle with worn out tires will also have a longer stopping distance, because the friction will generate a molten rubber in the tire which has an inferior traction.

Anti-Lock Braking System (ABS) prevents slippage and facilitates control of steering by continuously sampling the speed of the wheels and comparing them to the speed of the vehicles. If an abnormality slowdown of a wheel that is not in accordance with the vehicle speed is detected, temporary brake pauses will be taken so as to resume the desired speed.

The method that shortens the braking distance to the minimum possible is the one in which the maximum traction is used to create a braking power. This point of the brakes is on the verge of locked wheels and it is called "threshold braking" [11] i.e. on the verge of locking.

Most modern ABS devices operate efficiently and accurately detect the threshold braking. The main advantage of ABS is on smooth roads like wet roads where the system is able to significantly and considerably shorten the stopping distance. In addition, ABS keeps the vehicle in control of the driver who will be able to maneuver in order to avoid obstacles, if the stopping distance is insufficient to stop the vehicle before it hits the obstacles. There are also security implementations for such technologies.

2. The Embedded Computing Component of Anti-Lock Braking System

The key challenge of anti-lock braking systems is how to detect the situation of an abnormality slowdown of a wheel that is not with accordance of the vehicle speed. Some mechanical devices and also some electronic devices have been suggested during the years [12]. We suggest to extract from conventional computer blueprints some known components and to build from these components a control unit that will be able to detect the situation of an abnormality slowdown of a wheel that is not with accordance of the vehicle speed.

An ABS is depicted in Figure 1. The ABS includes four wheel speed sensors which work as follows: A cogwheel is attached to each wheel. Each tooth of the cogwheel is magnetized. The sensors have a galvanometer which produces values according to the closeness of the teeth. When there is a tooth nearby the galvanometer, the galvanometer will generate a higher voltage, whereas when the teeth are not nearby the galvanometer, almost no voltage will be generated [13]. The output of the galvanometer is depicted in Figure 2.

The frequency of the changes in the output is depending on the rotation speed of the wheels.

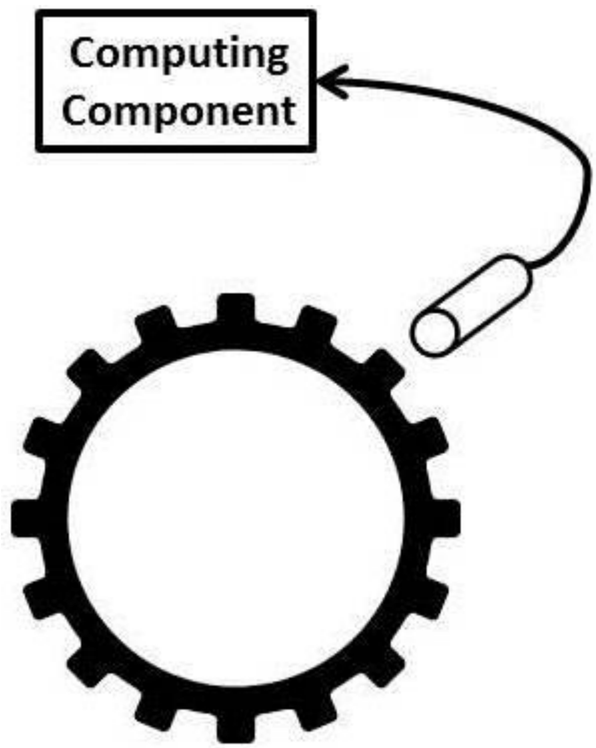

Figure 1. ABS using a galvanometer and a cogwheel

An ABS system has also four hydraulic valves within the brake hydraulics and an embedded computing component [14]. The embedded computing component repetitively observes the rotational speed of all the vehicle wheels and compares it to the vehicle speed. If the embedded computing component detects a wheel rotating much slower than the vehicle speed, it will put into action the valves so as to reduce hydraulic pressure to the brake of this wheel, with the intention of reducing the braking force on this wheel, so that the locked wheel will be released.

Contrariwise, if the embedded computing component detects a wheel turning much faster than the vehicle speed, it will augment the brake hydraulic pressure to this wheel with the aim of slowing down the wheel.

This comparison is repetitively performed in a rate of some hundredths of a second. As a result, it will be unfeasible to lock wheels of cars equipped with ABS even in the course of excessive braking.

On the other hand, the embedded computing component should be not so conscious of every difference in the wheel rotational speed. If a vehicle turns right, the wheels in the right side of the vehicle will turn slower than the wheels in the left side of the vehicle. Similarly, if a vehicle turns left, the wheels in the left side of the vehicle will turn slower than the wheels in the right side of the vehicle. The embedded computing component should not change the brake hydraulic pressure to any wheel because of these differences [15].

3. Implementation

The challenge of the embedded computing component of an anti-lock braking system is how to detect a difference in the rotational speed of the wheels and the vehicle speed that reflects a locked wheel and does not reflect just a variance resulting from a turn to right or left.

For putting our ABS into practice, we have used Hyundai I30 CW 2017 for our implementation. The tires of this vehicle are P195/65R15 which means the sidewall height is 195*0.65mm i.e. 12.675cm. The 15 in the end of the code means diameter in inches of the wheel that this tire is designed to fit i.e. 38.1cm. So the entire diameter of the tire plus the wheel is:

Diameter=12.675*2+38.1=63.45cm

Accordingly, the perimeter is 1.99334 meters. If this vehicle travels at a speed of 72 KM/H (45 MPH) i.e. 20 meters per seconds, it means that it will wholly rotate the tire 10 times each second.

We have used a cogwheel of 16 teeth for both the vehicle and the wheels. We have used a sampling rate of 8 teeth of the vehicle cogwheel. In a speed of 72 KM/H (45 MPH) it will be a sample rate of 20 times per seconds, whereas in a speed of 144 KM/H (90 MPH), it will be a sample rate of 40 times per seconds.

The slip ratio of moving vehicle (i.e. when the vehicle speed is not zero) is defined as:

Slip ratio = (vehicle speed – wheel speed)/vehicle speed

If the slip ratio is 1 i.e. vehicle speed and the wheel speed are equal, it will mean that no lock occurs. Contrariwise, a slip ratio of 0 i.e. wheel speed is 0, will mean an absolutely locked wheel.

It depends on road surface and tire condition, but from a slip ratio of approximately 25%-30%, the slippage can set off the bad influence of poor stirring, longer stopping distance and increased wear.

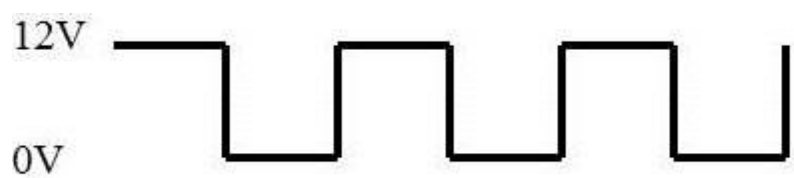

Figure 2. Output of the ABS galvanometer

Accordingly, the ABS checks for every shifting of 8 teeth in the vehicle cogwheel, whether the cogwheel of the tire shifts at least 6 teeth. If a cogwheel of one tire shifts 5 teeth or less, it will indicate that a lock takes place; therefore the braking force of this tire will be decreased.

Contrariwise, if the cogwheel of one tire shifts 8 teeth for 8 teeth of the cogwheel of the vehicle, i.e. the slip ratio is 1, the braking force can be increased, because it indicates that at this time no slippage takes place.

Figure 3 depicts the circuit for detecting these cases of decreasing the braking force and increasing the braking force. The circuit has 2 input lines and 2 output lines. The input lines are the outputs of the galvanometers reading the cogwheels of the vehicle and the outputs of the galvanometers reading the cogwheels of the wheels. The forms of the input lines are depicted in Figure 2.

These input lines go to asynchronous counters that count the pulses of the galvanometers produced.

The output lines make the decisions when to decrease or increase the barking force. They are calculated only when the counter of the vehicle gets to 7 i.e. 111 in binary. If a cogwheel of one tire shifts 5 teeth or less, the decrease barking force output line of this tire will be 1 which indicates a decrease of the braking force because of a locked wheel. If a cogwheel of one tire shifts 8 teeth, the increase barking force output line of this tire will be 1 which indicates an increase of the braking force, because the wheel is completely unlocked.

If a cogwheel of one tire shifts 6 or 7 teeth, none of the output lines of this tire will be 1, because the lock is not acute and the stirring will not be poor, but on the other hand an increase in the braking force can harm the stirring capability, so the braking force remains unchanged.

The implementation of the upper line in Figure 3 which indicates a decrease of the braking force has been designed based on the Karnaugh map [16] in Figure 4 that gives the expression:

Decrease force = $\overline{Q_2} + \overline{Q_1} \cdot \overline{Q_0} = \overline{Q_2} + \overline{Q_1 + Q_0}$

The implementation of the lower line in Figure 3 which indicates an increase of the braking force is quite trivial. It will give 1 just when all the lines of the wheel velocity counter are 1 like the lines of the vehicle velocity counter, so that gives the straightforward expression:

Increase force = $Q_2 + Q_1 + Q_0$

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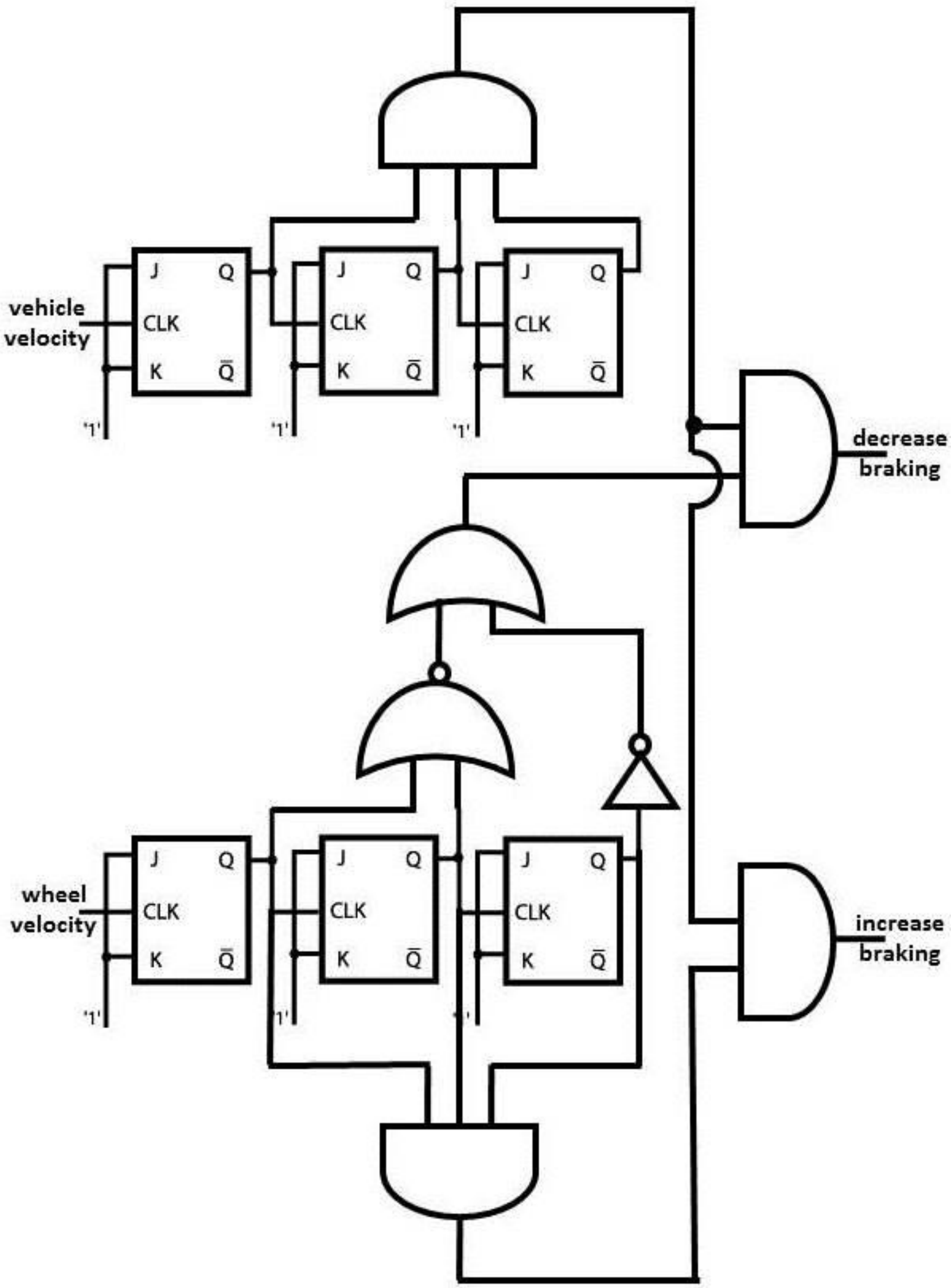

Figure 3. computing component for detecting the "locking" level.

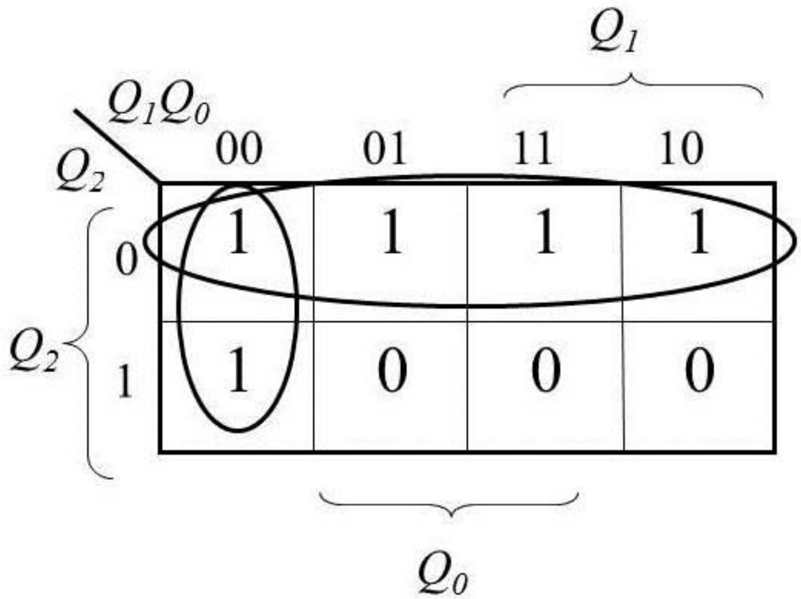

Figure 4. Karnaugh map for braking force decrease.

4. The ABS Counter

The two groups of 3 flip-flops in Figure 3 actually form two asynchronous counters. Asynchronous counters consist of JK flip-flops or T flip-flops whose inputs are connected to a voltage that represent the logical value of "1" [17]. When there is a change in the clock, the "1" input will set the current output of the flip-flops to be the inverse of its previous value. Each of the flip-flops stores one bit, so the entire counter can count from 0 to 2^n-1 where n is the number of the flip-flops in the counter. Then, the counter's value will return to 0 instead of 2^n. Actually an overflow occurs in the counter, but it is usually ignored.

The value stored in the left flip-flop will change in each clock cycle; therefore it will take two clock cycles until the left flip-flop returns to its original value. In each clock cycle, the left flip-flop's value will be changed from 0 to 1 or from 1 to 0, so as a result, the output of the left flip-flop generates another clock cycles whose frequency is a half of the original clock cycle frequency, that is, the duration of the second clock cycles is as twice as the duration of the original clock cycles. The double duration clock is connected as the clock cycles of the second flip-flop. The second flip-flop is like the first flip-flop, a one-bit counter, but its frequency is a half of the frequency of the first flip-flop. Similarly, the output of the second flip-flop is connected as the clock cycles of the third flip-flip that its frequency will be a half of the frequency of the second flip-flop.

Such a combination of several flip-flops together produces a several bit counter, as we used in our implementation in Figure 3. Particularly, each of the two counters in Figure 3 consists of three flip-flops where Bit 0 is the left flip-flop which toggles the fastest and Bit 2 is the third flip-flop which toggles the slowest. The range of the numbers in these flip-flops is 0-7.

The use of the flip-flops' outputs as a clock causes time discrepancies between the bits of the counter, because when a counter value is modified, initially the flip-flop that stores Bit 0 will be modified and it will take some more time until a possible modification is propagated to the rest of the flip-flops in the counter [18]; therefore, this counter is called asynchronous counter.

Because of this modification characteristic, an asynchronous counter is not suitable for use in conventional synchronous circles where all components are modified at the same time by a single clock signal; thus, a short modification time is imperative. A modification that propagates in linear time in the number of the flip-flops is likely to be too slow for several implementations; however, in the implementation of ABS, anyway the clock cycle frequency is slow enough, so such a longer modification time will not make a problem.

The most important usage of ABS is in fast moving. In slow movement like during a parking or a vehicle creeping forward in a traffic jam, the possibility of locked wheels is unlikely.

As was calculated above, if the vehicle travels at a speed of 72 KM/H (45 MPH) i.e. 20 meters per seconds, it means that it will wholly rotate the tire 10 times each second and at an enormous speed of 450 KM/H (281 MPH), it will wholly rotate the tire 62.5 times each second. Since the cogwheel has 16 teeth, even at an enormous speed of 450KM/H, it will have a clock rate of just 1KH. The delay time of common flip-flops is just a few nanoseconds [19], so accordingly there is no problem to use asynchronous counters in ABS.

4. The ABS State Machine

Like the implementation of many other Intelligent Transportation Systems, the Embedded Computing Component of the ABS includes a Moore state machine [20]. The state machine is depicted in Figure 5.

The input lines of the machine come from the circuit in Figure 3. The lines are increase braking and decrease braking and they are abbreviated as i.b. and d.b. in Figure 5.

As the state machine is a Moore machine, the output is set only according to the current state. The output goes to the hydraulic valve and sets the braking force. If the braking force is 100% and a decision about reducing braking force is taken, the reduction will be higher i.e. the new barking force will be 80%. However, if the braking force is 20% and a decision about reducing braking force is taken, the new breaking force will be only 10%. In general, the higher percent the current braking force is, the higher the reduction will be.

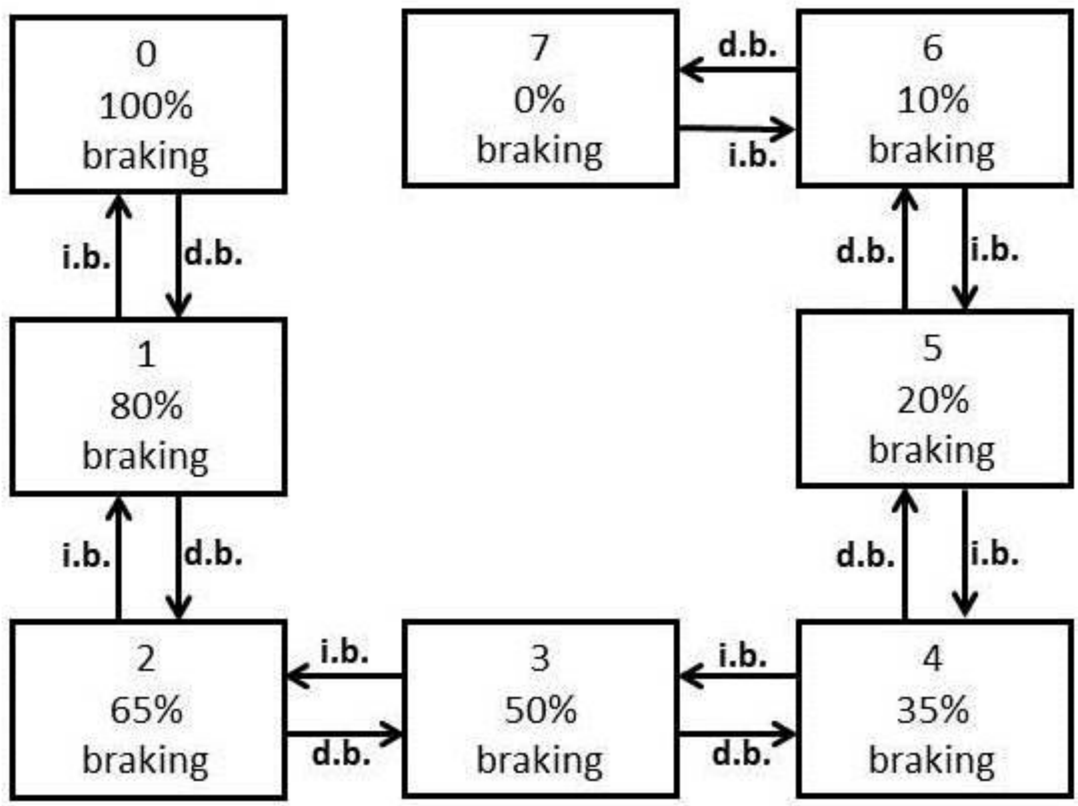

Figure 5. ABS state machine

6. Conclusions

The proposed ABS device can be implemented in both regular vehicles and autonomous vehicles, so as to fabricate a more efficient embedded computing component. This better efficiency is an important advantage in avoiding vehicle accidents, because locked wheels or even semi-locked wheel [21] may possibly lead to a poor steering capability causing a collision and as a result, a fatal accident might occur, so the ABS should be as accurate as possible so as to avoid accidents and save lives.

7. References

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