General Description

Digital communication in modern automation environments often requires robust data transmission over long distances, sometimes exceeding 1000 meters. These lines are not easy to drive due to the high capacitive load and the high attenuation of the signal in the cable. A high AC signal level and a high common mode rejection are required to withstand negative effects of harsh and noisy environments.

This application note shows how to design a high speed, high reliability balanced line driver with epc700 and epc701 devices for long distance communication and a data transmission rate up to 250kBaud using the example of a RS-485 transmission line.

Another important feature of this data transmission channel is the robustness against overloads and short-circuits. The epc700 and epc701 devices have an over-current detection with self-healing output mode which protects the driver output stages in case of failure such as short circuits.

Features

- High speed, high reliability twisted pair line driver for long distance applications: cable length max. 1'500m @ 250kBaud.
- High common mode suppression: > ±6.0V.
- Push-pull H-bridge line driver with epc700 & epc701.
- Over-current detection with status indication.
- Self-healing output mode

Applications

- Transmitter for differential serial bus in long distance application
  - RS-232, RS-422, RS-485,
  - USB, CAN-bus, Bitbus,
  - Fieldbus, Profibus, Interbus, Modbus, AS-interface
- Differential line driver for digital data and communication lines in a harsh environment with the need of high signal level and a high common mode rejection due to the environmental noise.

1. Block diagram

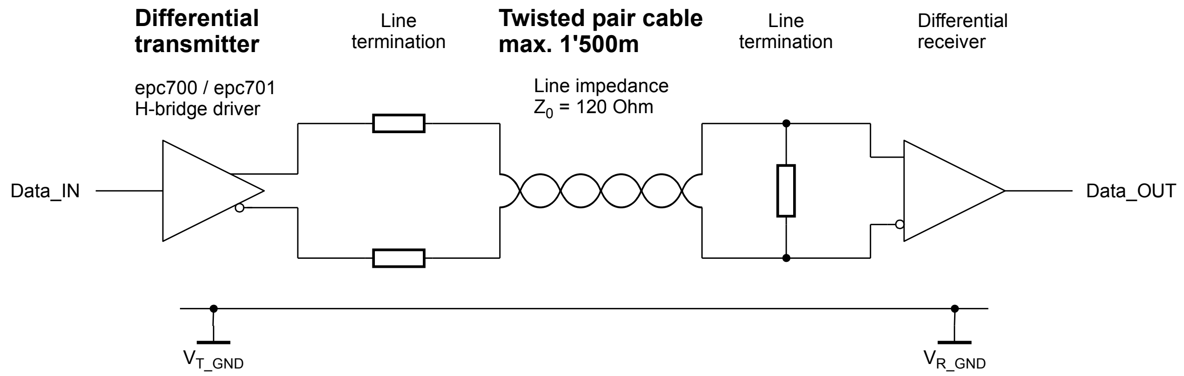

Figure 1: Block diagram

The block diagram Figure 1 shows the main elements of a differential data transmission (e.g. according the RS-485 standard).
A line driver converts the single-ended digital input signal to a differential output signal. The series line termination is needed to match the cable impedance with the output impedance of the driver minimizing signal reflections on the line. For long distance application a twisted-pair cable with an outer shield is suggested. The line impedance is 120Ohm. At the cable end, in parallel to the receiver input, is again a line termination to match the receiver's input impedance with the cable impedance. The receiver converts the differential signal back to a common single-ended by using a hysteresis of ±200 mV independent of the input common mode level.

Feature	General purpose line driver	epc700/epc701 line driver
Transmission standards e.g. RS-232, RS-422, RS-485, ...	fixed to standard	adaptable to standard
Mode of operation	half duplex	half duplex
Network topology	multipoint	point to point
max. distance	1'200m (standard dependent)	1'500m
max. data rate	250kbps @ 230m 90kbps @ 1'000m	250kbps @ 1'500m
max. output voltage	typ. ±5.0V	±24.0V
max. output current	> 50mA for multipoint devices	50mA
Load / termination	resistive	resistive or inductive (e.g. transformer)
Galvanic isolated operation	special devices necessary	possible

Table 1: Compare of general purpose line drive versus epc700/epc701 line driver

This benefits the differential data transmission to be nearly independent of the ground connection between driver and receiver. An other advantage is the load current to respectively from the load flows over the two differential lines only. In ideal case there is no voltage drop along the ground connection. This allows to have galvanic coupled transmission lines over long distances.

The goal of this application note is showing possibilities to overcome limitations of the standard purpose line drivers as listed in Table 1.

Typical values for such components are:

Specification of the receiver (e.g. RS-485)

Data transmission input:	differential
Minimum input sensitivity:	± 200 mV
Maximum input common mode voltage:	-7V to +12V (≙ +5V signal level and ±7V common mode voltage)
Minimum input resistance:	12 kOhm
Maximum data rate:	12 Mbps

Specification of the cable e.g. Belden 9841 (e.g. for RS-485)

Conductor:	twisted pair with outer shield
Nominal impedance:	120 Ohm
Nominal DC resistance:	78.7 Ohm/km
Nominal attenuation:	-19.7 dB/km @ 1MHz

Specification epc700 & epc701

epc700:	Low-side power switch
epc701:	High-side power switch
Maximum supply voltage:	30V
Maximum current drive capability:	50mA
Typical on-resistance OUT to VDD or GND:	11Ohm
Minimum input voltage for logical HIGH:	2.0V
Maximum input voltage for logical LOW:	0.8V
Maximum response time (on/off):	1.2µs

2. High speed, high reliability twisted pair line driver with unipolar supply

Figure 3 shows the schematic of a high speed, high reliability twisted pair line driver with unipolar supply e.g. for RS-485 application. A H-bridge drives the line with differential signals. The DATA_IN signal from the communication line needs to be converted for this purpose in adequate two-phase signals according Figure 5 to control the DATA_IN1 and DATA_IN2 inputs.

The H-bridge of the driver is built by one epc700 and one epc701 on each side: IC1 - IC4. The epc700 is the low-side switch, whereas the epc701 is the high-side switch. The resistors R1- R4 at the outputs are the series line termination resistors. They build in combination with the r_{DS_ON} impedance of IC1 – IC4 of around 11Ohm the line termination of 2x 60Ohm to match the 120Ohm line impedance. The terminated outputs of IC1 & IC2 as well IC3 & IC4 are connected as push-pull drivers for the H-bridge. They drive the differential line signals on the twisted-pair cable. At the end of the cable R7 is the line termination matching the cable impedance to the receiver input. IC5 is the differential line receiver to convert the signal back to single-ended. The signal flow of the differential output signals in the DATA_IN1 HIGH-state is marked in Figure 2 in red. The current produces a positive voltage signal at R7 for the input (red arrow). In the DATA_IN2 HIGH-state IC3 & IC2 drive the line. This leads to an opposite current flow in the termination R7 and to a negative input signal (red dashed arrow).

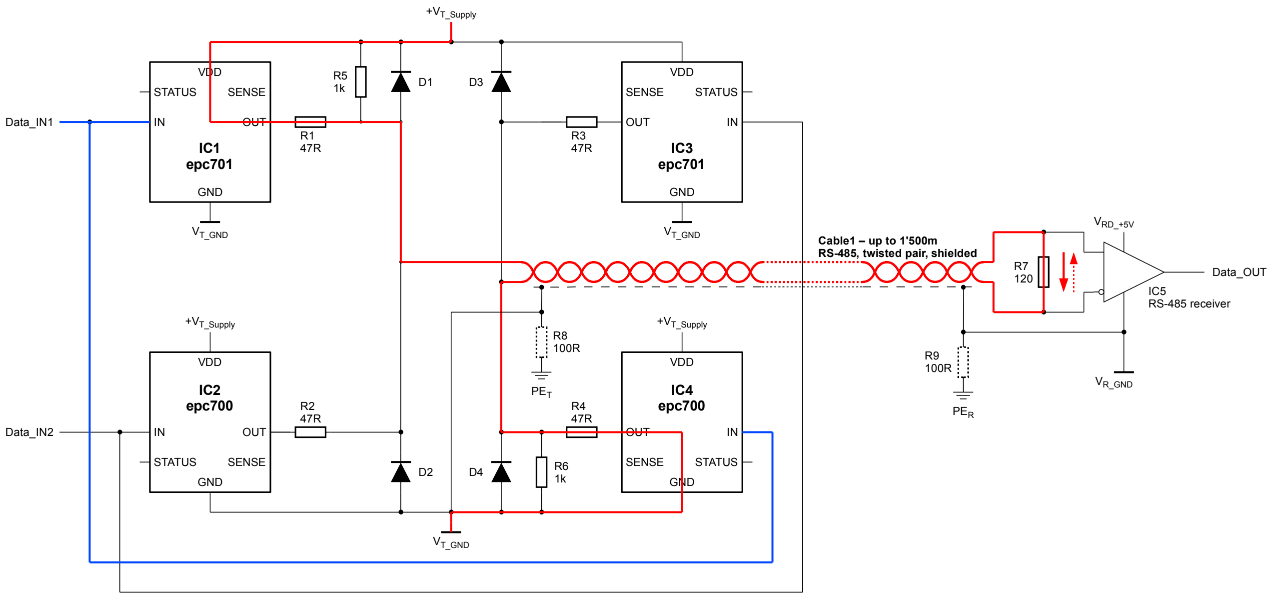

Figure 2: Signal flow
blue: control signal, DATA_IN1=HIGH;
red: corresponding active driving path, H-bridge1: ON

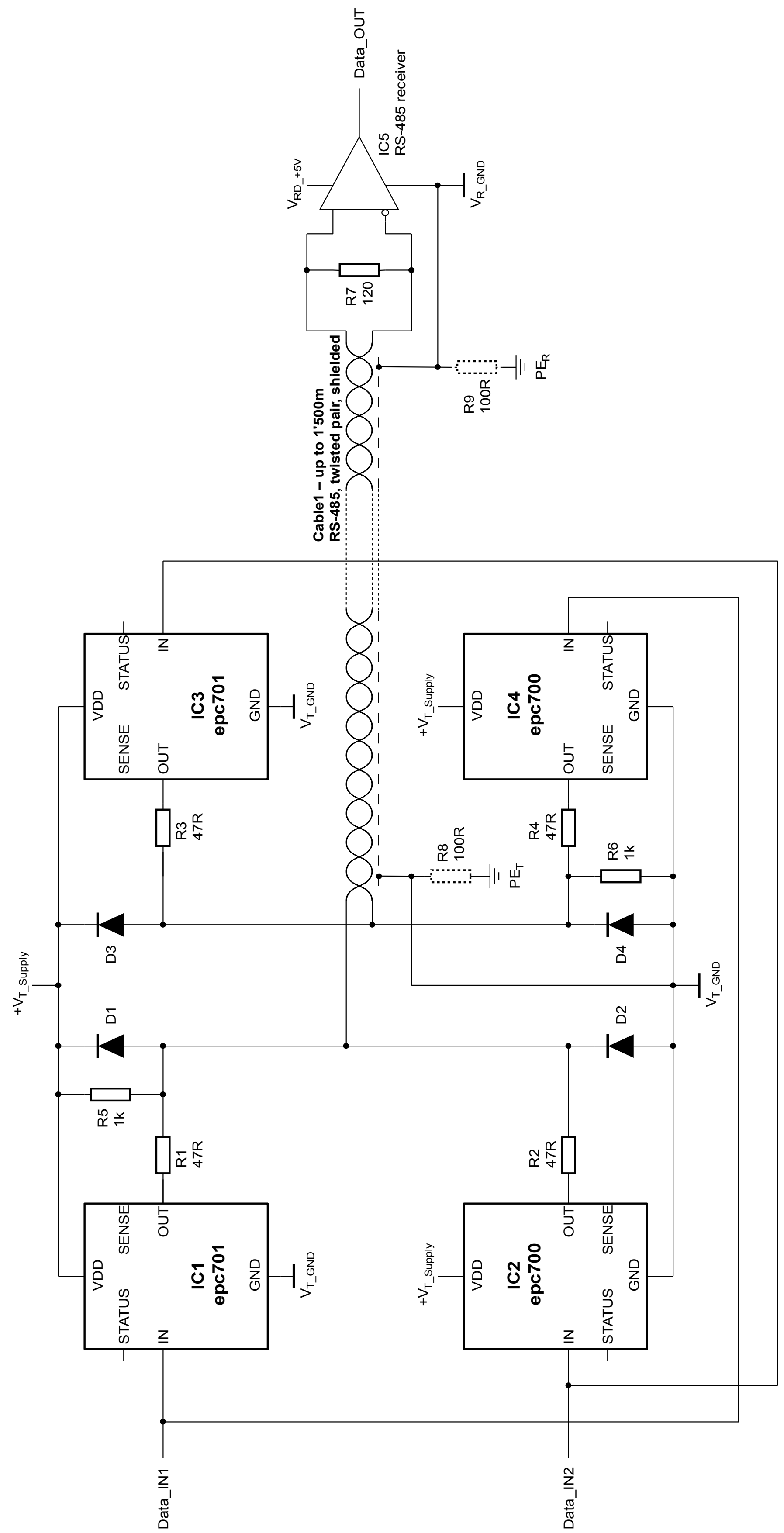

Figure 3: Schematic of the RS-485-driver with unipolar supply

The supply voltage $+V_{T\_Supply}$ defines the usable length of the cable. The limitations are given by the maximum supply voltage (24V typ.) and current drive capability (50mA typ.) of IC1 – IC4, the maximum input voltage levels allowed at the input pins of the differential receiver (+12V / -7V) and the minimum input signal level at IC5 (±200 mV). The schematic in Figure 4 illustrates the corresponding voltage levels in the circuit.

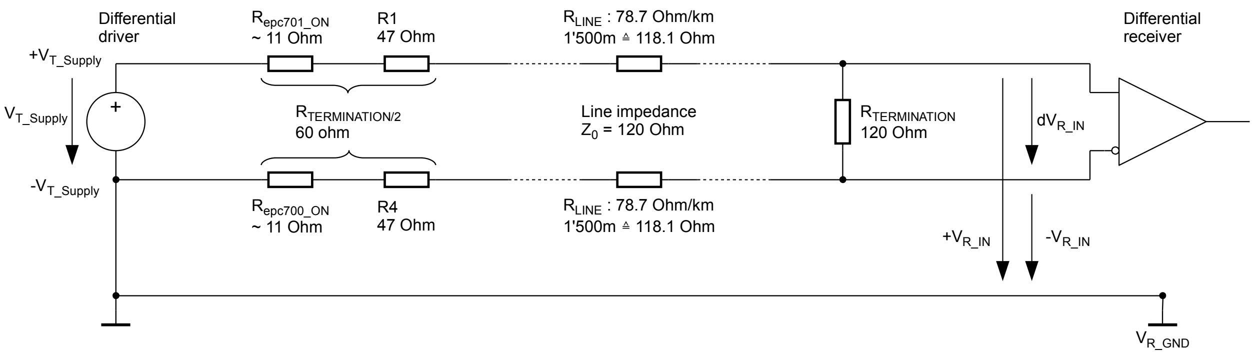

Figure 4: Voltage levels on differential transmission line

It is possible either to optimize the circuit for a maximum cable length variation (refer to Table 2, case 2), for a maximum output signal level (refer to Table 2, case 3) or for a maximum common mode rejection. Table 2, case 1 is a comparison listing the maximum transmission length for +5V supply of the H-bridge. It is around 1'000m.

	Cable	**Receiver input**				**Driver supply**				**Comment**
						H-Bridge			**Logic**	
	Length	**AC @1MHz**	**DC voltage**			**Voltage**		**Current**	**Voltage**	
	L_{Cable}	$dV_{R\_IN\_AC}$	$dV_{R\_IN\_DC}$	dV_{R_COM}	$+V_{R\_IN\_DC}$	$+V_{T\_Supply}$	$-V_{T\_GND}$	I_{T_Supply}	V_{TD_+5V}	
	[m]	[V]	[V]	[V]	[V]	[V]	[V]	[mA]	[V]	
1.	0 - 1'000	> ±0.26	> ±1.5	> ±8.2	< +3.8	**+5.0**	0.0	< 20.8	+5.0	+5V supply
2.	**0 - 1'500**	> ±0.20	> ±3.0	> ±3.0	< +9.0	+12.0	0.0	< 50.0	+5.0	Max. cable length variation
3.	1'500 only	**> ±0.27**	> ±4.0	> ±2.0	< +10.0	+16.0	0.0	33.6	+5.0	Optimal AC input signal

Table 2: Design parameters for the H-bridge design with unipolar supply

While the DC signal levels are given by the ohmic rules, the AC signal level is defined by the formula

$$20 * \log\left(\frac{dV_R}{V_{T\,Supply}}\right) = G_{Termination} + G_{Cable} * L_{Cable}$$

V_{T_Supply} is the supply voltage of the H-bridge. dV_R is the receiver input signal level. $G_{Termination}$ is the attenuation given by the line terminations = -6.0dB ≙ 0.5. The attenuation of the cable is given by the length L_{Cable} multiplied by the AC attenuation factor G_{Cable}. G_{Cable} depends on the frequency. e.g. -19.7dB/km @ 1MHz for the mentioned twisted pair cable type.

The diodes D1 - D4 clamp over-voltages and guarantee the current flow (free-run) caused by the inductive component of the circuit during the transition-state ON-OFF and OFF-ON. In transition-state all four drivers are switched off to avoid short-circuit situation.

To prevent an unexpected toggling of the output signal at the receiver side, R5 and R6 are balancing the bridge to half of the driver supply voltage during transition-state.

The H-bridge is controlled by the two-phase signals DATA_IN1 and DATA_IN2. They are generated fromthe DATA_IN signal of the communication line according Figure 5. DATA_IN1 corresponds to the DATA_IN with a switch-on delay t_{DELAY}. Whereas the DATA_IN2 is the inverted DATA_IN signal again with the switch-on delay t_{DELAY}. The switch-on delay time is in order not to have all drivers of the push-pull stage (IC1 & IC2 / IC3 & IC4) at the same time in the ON-state (Short-circuit). This guarantees a switch faster to OFF state than to ON state.

The timing condition is
OFF-time of the H-bridge $t_{H\text{-}OFF} > 0 \quad = \quad t_{DELAY} + t_{ON} > t_{OFF}$

$t_{H\text{-}OFF}$ is the time between the conductive phases of the outputs of H-bridge1 and H-bridge 2.

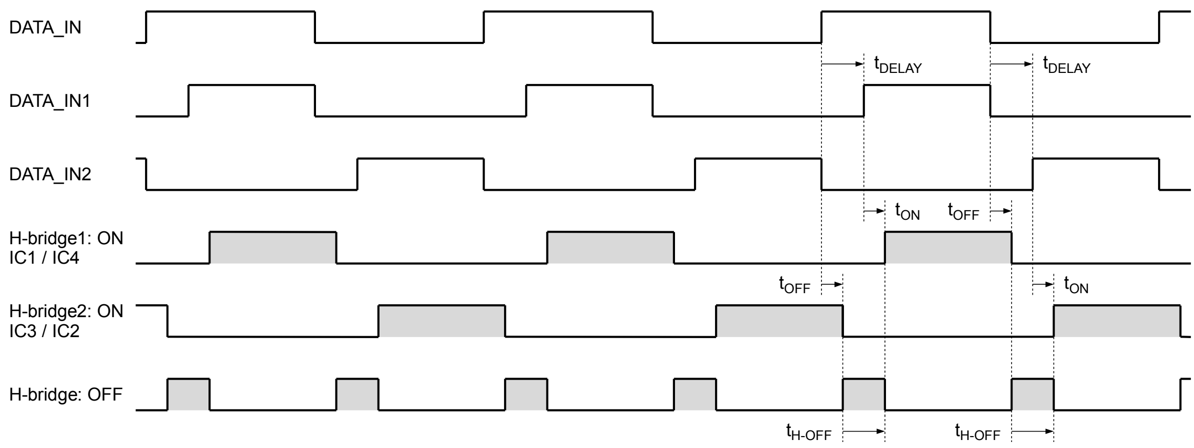

Figure 5: Timing diagram of the H-bridge

Under the assumptions of

the response times t_R of the epc700 & epc701 drivers are $t_R = t_{ON} = t_{OFF}$ and $0 < t_R < 1.2\mu s$

is the switch-on delay-time $t_{DELAY} > t_{OFF} - t_{ON} = 1.2\mu s - 0\mu s = 1.2\mu s$.

The cut-off data rate for the data transmission is $R_{Cut-off} < \frac{1}{2 * t_{DELAY}} = 416 kBit/s$

The outer shield of the twisted pair cable needs to be connected to the local ground at transmitter and receiver side.

In many cases local and chassis ground are connected. Than standards (e.g. RS-485) recommend adding some resistance R8 and R9 between local and chassis ground to avoid excess ground-loop currents. This approach reduces loop current, but the existence of a large ground loop keeps the data link sensitive to noise generated somewhere else along the loop.

3. High speed, high reliability twisted pair line driver with bipolar supply

In a harsh environment more enhanced specifications for cable length variation, input signal level or common mode rejection at receiver side can be achieved with a bipolar supply of the bridge to place the centre voltage of the bridge to +2.5V, as given by the RS-485 specification.

The schematic in Figure 6 shows the differences compared to the unipolar supply:

- V_{T_GND} is changed to a $-V_{T\_Supply}$.
- The common transmitter ground is new V_{D_GND} .
- The +5V supply V_{TD_+5V} of IC6 and IC 7 is not anymore referenced to V_{T_GND}. It is now based to $-V_{T\_Supply}$.
- The DATA_IN1 and DATA_IN2 signals are level-shifted by IC6 and IC 7 to have the correct control signal levels for the H-bridge.
- The supply voltage of the DAT_IN1 and DAT_IN2 signals and the divider R10 and R11 define the threshold level for the input signals.
- The outer shield of the cable is connected to the common ground V_{D_GND} .

In Table 3 design parameters are listed, either to optimize the circuit to a maximum cable length variation (refer to Table 3, case 1), to maximize the output signal level (refer to Table 2, case 2), or to maximize common mode rejection. A good choice is case 2, which combines a well balanced variation of the cable length with a good AC input signal level and common mode rejection.

	Cable	**Receiver input**				**Driver supply**					**Comment**
						H-Bridge				**Logic**	
	Length	**AC @1MHz**	**DC voltage**			**Voltage**			**Current**	**Voltage**	
	L_{Cable}	**$dV_{R\_IN\_AC}$**	**$dV_{R\_IN\_DC}$**	**dV_{R_COM}**	**$+V_{R\_IN\_DC}$**	**V_{T_Supply}**	**$+V_{T\_Supply}$**	**$-V_{T\_Supply}$**	**I_{T_Supply}**	**V_{TD_+5V}**	
	[m]	[V]	[V]	[V]	[V]	[V]	[V]	[V]	[mA]	[V]	
1.	**0 - 1'500**	> ±0.20	> ±3.0	> ±6.5	< +5.5	+12.0	+8.5	-3.5	< 50.0	+1.5	Max. cable length variation
2.	900 - 1'500	**> ±0.28**	> ±4.3	> ±6.8	< +5.2	+17.0	+11.0	-6.0	< 44.5	-1.0	Optimal AC input signal

Table 3: Design parameters for the H-bridge design with bipolar supply

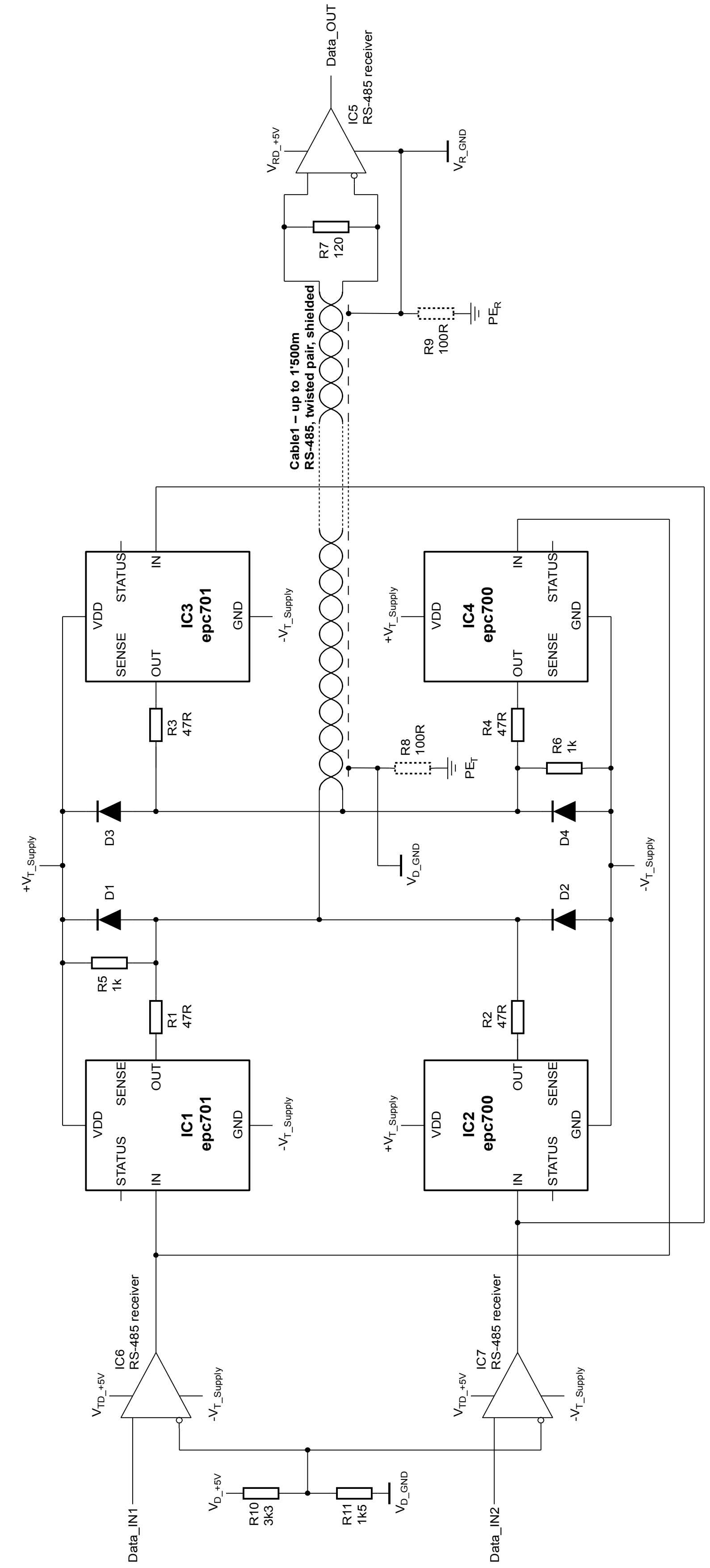

Figure 6: Schematic of the RS-485-driver with bipolar supply

4. High speed, high reliability twisted pair line driver with isolation

Galvanic isolation of the signal and supply lines of a bus transceiver from its local signal and supply sources allows to tolerate ground potential differences up to several kilovolts across a robust differential data transmission link and over long distance. In this case, signal isolators, such as transformers, prevent current flow between remote system grounds and avoid the creation of current loops. The non-isolated transceiver on the left provides the single-ground reference for the entire bus.

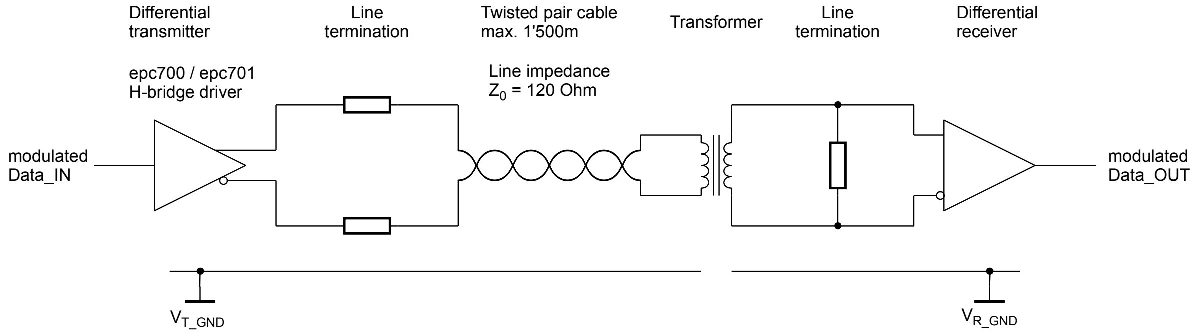

Figure 7: Block diagram with a transformer configuration

Due to the AC-coupling of the signal line steady-state DC levels cannot be transmitted. The data signal needs to be modulated either by a carrier or a coding modulation with AC characteristics like a Manchester protocol.

Figure 8 and Figure 9 are scope screenshots demonstrating the superb performance of such a transmission line with Manchester protocol.

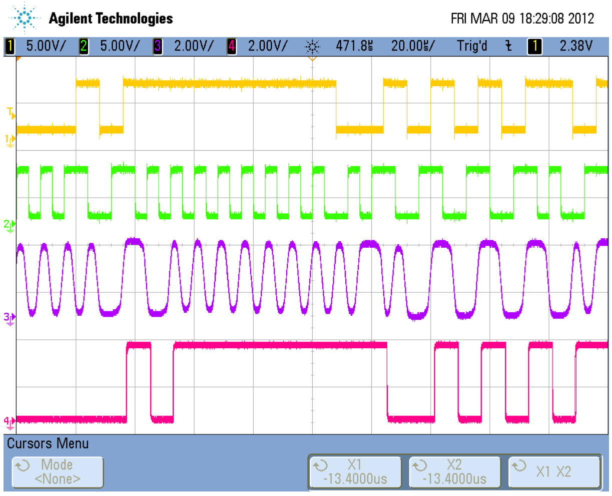

Figure 8: Signal transmission over 1'000m @ 128kbps:
1: Data signal input
2. Manchester-coded input signal to the driver
3. Line signal at receiver side
4. Receiver output signal

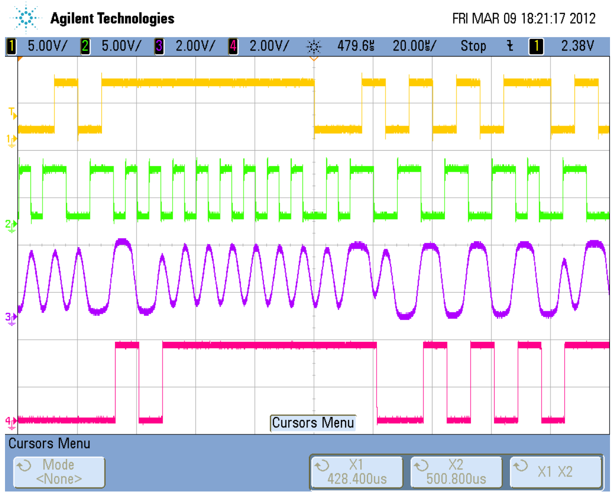

Figure 9: Signal transmission over 1'500m @ 128kbps:
1: Data signal input
2. Manchester-coded input signal to the driver
3. Line signal at receiver side
4. Receiver output signal

5. Over-current detection with self-healing output mode

An advantage of the epc700 and epc701 devices is the over-current detection with the self-healing output mode. It helps to protect the data transmission channel against overloads and makes it more robust. The following features are implemented in the epc70x drivers:

- Programmable short-circuit detection delay-time and recovery time.
- Static (epc700/epc701) or flashing (epc702/epc703) indication of the over-current status.
- Self-healing output mode.

If the current through the external load exceeds the specified threshold during a predefined time period, the output is turned off to protect the output switch. The switch is turned on again after a predefined off-time thus enabling the load again in a self-healing mechanism. The over-current information is indicated on the STATUS pin. For more information refer to the corresponding datasheet.

6. The push-pull driver with epc700 and epc701 in safety applications

If the differential signal transmission is used in a safety application, epc700 and 701 allow to read back the information, if the line is faulty. The output STATUS will indicate, if the device is detecting an overload on the individual drivers. For more details refer to the corresponding datasheet.

In combination with reading back the cable input signal by an additional differential receiver on the transmitter side locally, a full control over the condition of the line is given.

7. Conclusion

With the epc700 and epc701 devices ESPROS Photonics offers low- and high-side power switches ideally suited to build robust push-pull transmitters for high data rate >250kBit and long differential communication lines up to 1'500m. The need of only a few additional components and the small size of the devices allow to realize cost competitive solutions for harsh industrial environments.

If you need more information, please got to www.espros.ch or contact us at info@espros.ch.

8. References

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2. DATASHEET epc700/702, ESPROS Photonics corp., 2011
3. APPLICATION GUIDELINES FOR TIA/EIA-485-A, Telecommunications Industry Association (TIA), 2006
4. RS-422 and RS-485 Standards Overview and System Configurations, Texas Instruments, 2010