Shielded or Unshielded Twisted-Pair for High Speed Data Transmission ?

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Abstract: Balanced transmission is the standard method for data transmission via twisted pair. A separate shield for the balanced twisted pair is used to improve the immunity or emission behavior of the transmission line. The different performance of shielded or unshielded twisted pair is investigated by numerical calculation with CONCEPT, a program based on the method of moments. In addition a two-dimensional model with length independent partial capacitances was used. The effect of a shield is discussed with respect to transmission characteristics and EMI-behavior. The additional shield has a less significant influence to data transmission aspects than attenuation and reflection. The model of partial capacitances shows that the shielded twisted pair provides a better symmetry of signal transmission and improves the suppression of crosstalk.

INTRODUCTION

In recent years the bit rate via twisted pair cables has been increased. At first the transmission lines were covered with one shield to avoid unwanted emission and to improve the immunity. In a second step each twisted pair was covered with a separate shield. It was reported that shielding would improve the transmission characteristics and thereby the possible distance for transmitting.

In the first step the effect of this individual shield around the twisted pair on data transmission is discussed. In a second step the improvement of EMC behavior will be investigated. Special emphasis will be laid on real world cable installations.

DATA TRANSMISSION / SIGNAL INTEGRITY

Attenuation and reflection on transmission lines are the determing factors limiting the transmission distance. Both, attenuation and reflection, are affected by shielding.

Attenuation:

To show the effect of an additional shield on the signal attenuation the poynting vector is considered, because the signal energy is guided by the field.

The poynting vector is given by:

$$\vec{S} = \vec{E} \times \vec{H} \qquad (1)$$

To examine the influence of an additional shield, a model of a twisted pair has been calculated numerically using CONCEPT.

The model consists of a balanced feeded and balanced terminated twisted pair. The diameter of a single wire is 0.25 mm. Both wires are situated in a distance of 1.5 mm to each other. The shield has a diameter of 3 mm. Next the concentration of the transmitted power is investigated in the area adjacent to the twisted pair.

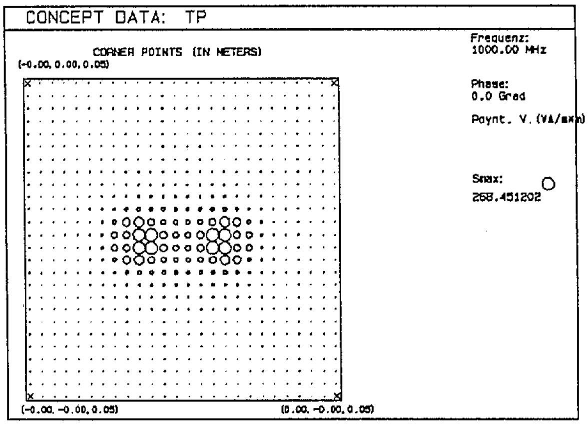


Figure 1. Twisted Pair

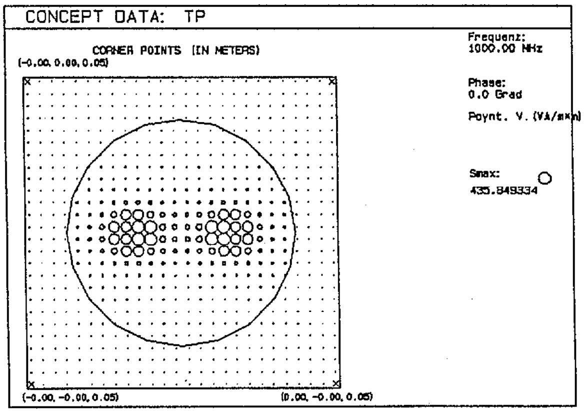


Figure 2. Shielded Twisted Pair

Comparing figure 1 and 2 the field pattern are quite similar to each other, but the maximum power density amounts to 268 VA/m² without a shield and to 436 VA/m² with a shield. Thus the power density is more concentrated in the insulating material (figure 3).

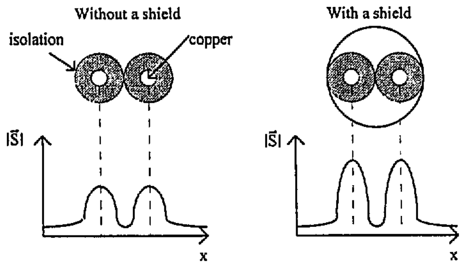


Figure 3. Power density

Normally the insulating material has a slightly higher conductivity and permittivity than air. This results in a higher electromagnetic field attenuation. So we can state that the resulting attenuation in the shielded case is higher than the resulting attenuation in the unshielded case.

Because a transmission cable mostly has one overall shield for all twisted pairs this effect can be neglected.

Reflections:

In transmission line theory the characteristic impedance Γ is defined by the effective resistance per unit length R', the shunt conductance per unit length G', the inductance per unit length L' and the capacitance per unit length C'

$$\Gamma = \sqrt{\frac{R'+j\omega L'}{G'+j\omega C'}} \tag{2}$$

These 4 parameters can be calculated by geometrical dimensions and material constants. Especially C' and L' depend on the mutual distance of the single lines, the distance to the shield and its wire and isolation diameter.

In real-world twisted pair lines run over edges and corners. This way the local position of a line may vary. Thus L' and C' change, too. Because the shield has only a very small effect to the magnetic field the inductance per unit L' will not differ very much with or without the individual shield.

This is different for the electric field component. In the following the influence of an additional shield on the capacitance per unit length C' is considered. For the calculation of C' a two-dimensional model with length independent capacitances is given. The capacitance C between electrode 1 an 2 is calculated with partial capacitances.
The capacitance C_E can be assumed to be infinite. This means the shield is connected to ground, e.g. the overall shield over four twisted pairs. Under this assumption for C_E the partial capacitances do not change their value. With an equivalent circuit for the partial capacitances the calculation of C becomes obvious.

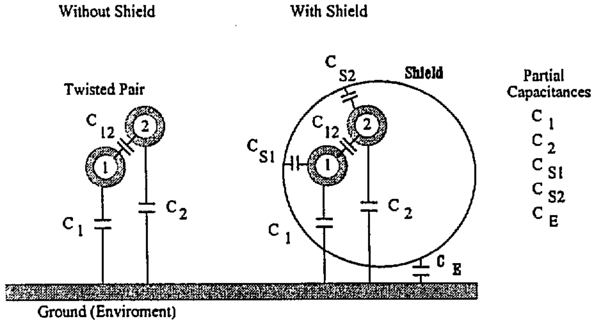


Figure 4. Partial Capacitances

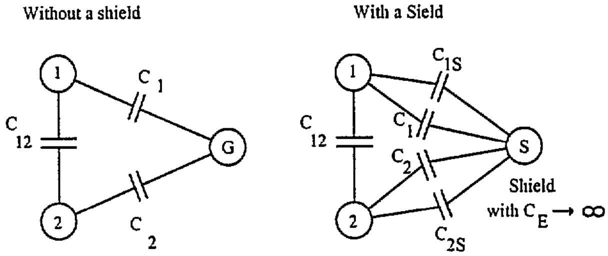


Figure 5. Equivalent Circuit with Partial Capacitances

The total capacitance C is given by:

Without a Shield With a Shield

$$C = C_{12} + \frac{C_1 \cdot C_2}{C_1 + C_2} \qquad C = C_{12} + \frac{(C_{S1} + C_1)\cdot(C_{S2} + C_2)}{C_{S1} + C_1 + C_{S2} + C_2} \tag{3}$$

Due to a local kink a difference $\Delta C = C_1 - C_2$ is assumed. The capacitances between the shield and the line C_{S1} and C_{S2} are always larger than the partial or parasitic capacitances to ground C_1 or C_2. This is always correct for a twisted pair line surrounded by a shield. C_{S1} and C_{S2} remain constant, because the lines do not change their position relative to the shield. The dependence of the total capacitance C by a difference in C_1 and C_2, can be neglected with the additional shield.

To examine this effect the attenuation of a Screened/Unshielded and a Screened/Shielded twisted-pair cable with and without kinks is measured. The cable length is 80 m and the number of kinks 129. Each curve (figure 6 and 7) is the difference between the attenuation without and with the kinks. For each kink the cable is bend with an angle near by 180 degrees.

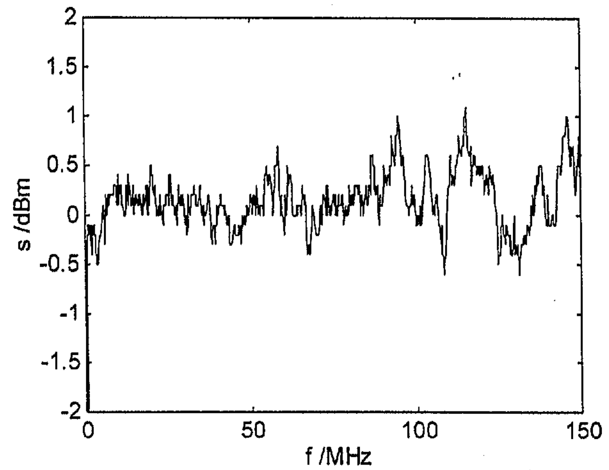


Figure 6. Attenuation without an additional shield

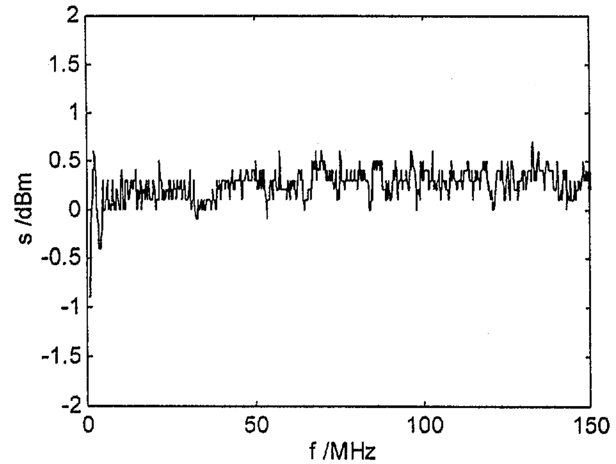


Figure 7. Attenuation with an additional shield

The results confirm the calculation up to 150 MHz, but the influence of the shield is to small to be significant. If we note that e.g. VDSL (Very High Bit Rate Digital Subscriber Line) uses only a frequency range up to 14 MHz with a bit rate of 50 Mbit/s [2], the shown effect will be less important. The situation will change if the used frequency range will extremly increases.

EMC-ASPECTS

This part deals with EMC aspects like crosstalk, emission and immunity noise. Therefore the coupling from external field to signal mode can be divided in two steps. Here we only consider the immunity situation. For emission the reciprocity theorem is valid.

In the first step an electromagnetic field generates a common mode current or voltage on both twisted-pair lines (figure 8).

The shielded twisted pair line acts as a coaxial cable with a single inner conductor. A measure for this coupling is the screening attenuation a_S like the transfer impedance is a measure for the shielding attenuation of coaxial cables.

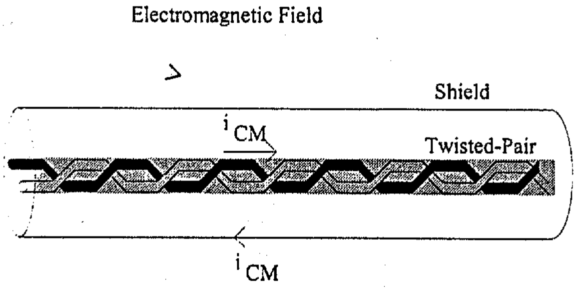


Figure 8. Coupling on the Twisted-Pair

$$a_S = 10 \cdot \log\left(\frac{P_1}{P_2}\right) dB. \tag{4}$$

The screening attenuation a_S is the logarithmic ratio of the emitted power P_2 to the feeded power P_1 and describes the quality of the screen.

It is known from coaxial cables that the coupling dur to the electric field plays a minor role. So we can expect for shielded twisted pair cables a significant decreasing of the crosstalk.

The second step presumes a balanced transmission. This includes a differential mode signal on the line. Under ideal conditions common mode and differential mode signals are independent. But real cables are not perfectly balanced and a little part of each signal couples into the other. This is described by the common mode rejection a_u.

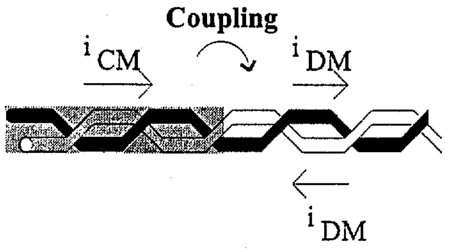


Figure 9. CM to DM coupling

The formula is given by

$$a_u = 20 \cdot \log\left(\frac{i_{CM}}{i_{DM}}\right) dB. \tag{5}$$

Values for a_S and a_u are given in [1] (Table 1).

Table 1: Screening attenuation a_s and common mode rejection a_u for different transmission cables [1]

with f = frequency

a_s = normalized screening attenuation

a_u = common mode rejection

Shield	f [MHz]	a_s [dB]	a_u [dB]	$a_s + a_u$ [dB]
without	1	-	40	40
	10	-	30	30
	30	-	25	25
	100	-	20	20
	300	-	20	20
foil or braiding	1	21	40	61
	10	35	30	65
	30	35	25	60
	100	35	20	55
	300	35	20	55
foil and/or braiding	1	35	40	75
	10	55	30	85
	30	55	25	80
	100	55	20	75
	300	55	20	75

For a pair covered with metal foil the normalized screening attenuation a_s is 21 dB and the common mode rejection a_u amounts 40 dB giving a total attenuation of 61 dB. Without the metal foil the common mode rejection factor has to be 61 dB. This is unrealistic for real cables. Looking at higher frequencies the advantage of shielded twisted pairs becomes obvious. The common mode rejection factor decreases to 20 dB. The attenuation factor for the shield stays constant giving a reasonable total attenuation of 55 dB.

One can state that a screened twisted pair cable is absolutely necessary for high speed data communication.

Now, another approach to calculate the main copling is shown. The coupling from a single line into the twisted pair is considered.

How can the signal or differential voltage on a twisted-pair be disturbed? Looking at the coupling path, the magnetic field interference is canceled by twisting the lines. Additional impedance coupling is not possible because different transmission lines do not have a common conductor. Crosstalk is possible via the coupling capacitance C. Figure 10 shows an ideal balanced transmission line, that is interfered by a single line.

Under ideal assumptions the spatial distances between the single interfering line, the transmission line and ground are considerable large in comparison to the dimensions of the twisted pair. As a result the capacitance C_{11} is equal to C_{12} and C_{1G} is equal to C_{2G}. With these conditions the bridge circuit consisting of C_{11}, C_{12}, C_{1G} and C_{2G} is balanced and the common mode voltage U_{CM} does not affect the differential voltage U_{DM}.

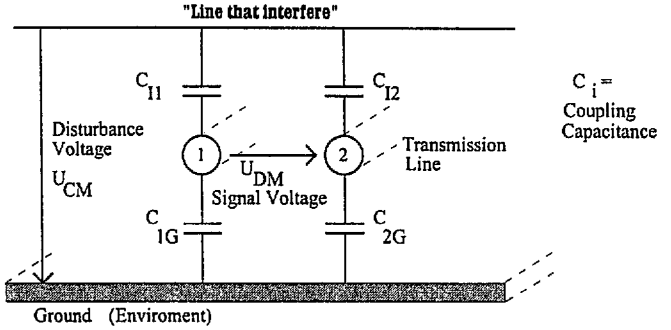


Figure 10. Coupling in an ideal balanced transmission line

In real-world this symmetry can be disturbed. To show the influence of the shield the capacitance of one electrode is calculated with and without this shield. To keep the consideration simple the bridge in figure 10 is unbalanced by C_{1G} and C_{2G} and not by C_{11} and C_{12}. In practice each capacitance could be different from on another, but the effect of shielding the electric field component will be the same in both cases.

Similar to the considerations in section "Data Transmission" one calculates the capacitance of one electrode to ground.

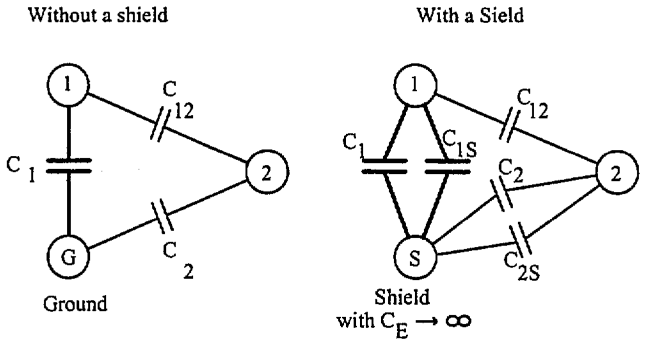


Figure 11. Equivalent Circuit with Partial Capacitances

With the equivalent circuit in figure 11 the capacitance C_{1G} of one electrode to ground amounts

Without Shield With shield

$$C_{1G} = C_1 + \frac{C_{12} \cdot C_2}{C_{12} + C_2} \qquad C_{1G} = C_1 + C_{S1} + \frac{C_{12} \cdot (C_{S2} + C_2)}{C_{12} + (C_{S2} + C_2)} \quad (6)$$

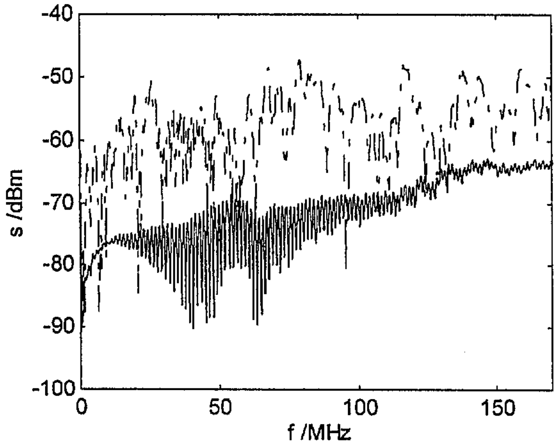
If one line of the twisted pair is nearer to ground or to the interfering line the partial capacitance C_1 will differ about ΔC from C_2. The other partial capacitances stay constant. With an additional shield three circuit branches instead of two lead from electrode 1 to electrode G or S. Each circuit path, instead of the path with C_1, has considerable capacitances compared to the unshielded situation.

As a result ΔC will change C_{1G} much less and the difference becomes less significant for the unbalance of the bridge circuit. The shield has a balancing effect.

Using partial capacitances the main coupling mechanism via the electric field component is described. In comparison to this the screening attenuation a_s and the common mode rejection a_u include the entire electromagnetic coupling.

Crosstalk

Many transmission cables consist of 4 twisted-pair lines. For crosstalk the interfering line is one of these twisted-pairs. Considering the entire shield as ground an individual shield will have exactly the described balancing effect for each transmission line. The influence of the additional shield can be seen in the near end crosstalk (NEXT). One twisted pair lines is feeded over a balun with an output signal of a tracking generator. On an other twisted pair the differential voltage between the lines is measured. The next figure shows how the NEXT is affected by an individual shield.



upper curve: Screened/Unshielded TP-Cable
lower curve: Screened/Shielded TP-Cable

Figure 12. NEXT with and without an additional shield

To interpretate figure 12 correctly one has to consider that the cable is connected via a plug and a jack. Thus the attenuation includes the crosstalk of this connections, too. The shield additionally decreases the crosstalk about 10 to 20 dB up to 170 MHz.

Especially for high bit rates the individual shield becomes additionally more important, because the crosstalk increases with increasing frequency. New digital services with data rates up to 50 MBit/s and more use a frequency interval that exceeds by far the range of 0.4 to 4 kHz of an analogue telephone. A table for the used frequency ranges of different services is given in [3].

Table 2. Used frequency range of analog/low speed digital services

With A = used amplitude
M = measurable spectrum
f_{20dB} = frequency after 20dB attenuation

service	A [V]	M [kHz]	f_{20dB} [kHz]
analog telephone	± 0,3	4	4
telex	± 0,15	4	4
data connection 4,8 kbit/s	± 0,4	100	19
data connection 19,4 kbit/s	± 0,4	120	38
ISDN U_{k0}-interface 160 kbit/s	2 ± 10%	350	105
data connection 2 Mbit/s	2,36 ± 10%	10000	1200
VDSL [2] 50 Mbit/s	-	30000	13000

Table 2 points out that the used frequency range for digital services increases with the bit rate. The measurement results (figure 12) show that NEXT for balanced signal transmission is at least 50 dB up to a frequency of 170 MHz. The useful frequency range is limited by the signal attenuation and the cable length. In [4] the upper frequency boundary for a transmission lines with a length of 300 m is given to 20 MHz. This frequency boundary decreases to 10 MHz for a cable length of 1000 m. All these values refer to an useful frequency range for transmission via VDSL with quadrature amplitude modulation.

This indicates that crosstalk will become less significant on transmission lines with balanced transmission, because the usable frequency range is primarily limited through the signal attenuation. To ensure standard limits for NEXT e.g. given with CAT VI there is no way to avoid a shield around the twisted pair cable.

Radiation and Immunity

Considering the mechanism of coupling via the electric field component in figure 10 the voltage U_{DM} will proportional increase with the disturbance voltage U_{CM}. This dependency becomes significant for a transmission line nearby a power line. Under this circumstances an additional shield for every transmission line will increase the screening attenuation a_s and the unbalance attenuation a_u. Future measurements have to show how much the individual shield will improve the shielding. With repect to the screening attenuation it is expected that the shielded screened twisted pair is similar to double shielded coaxial cable.

CONCLUSION

With a numerical calculation of a twisted pair model using CONCEPT it has been shown that the resulting attenuation in the shielded case is higher than the resulting attenuation in the unshielded case. In the unshielded case more signal power is transmitted via the area with the higher attenuation constant than through the air, which has nearly no attenuation. This effect is very small and could be neglected, because in most cases one total shield exists to avoid radiation or immunity.

A balancing effect of the additional shield with respect to the characteristic impedance Γ has been shown by using a two-dimensional model with length independent partial capacitances. The effect has been investigated by measuring the attenuation of a Screened/Unshielded and a Screened/Shielded twisted-pair cable with and without kinks. The results confirm the calculation up to 170 MHz, but the influence of the shield is to small to be significant.

In the second part of the paper the coupling mechanism in a balanced transmission was divided into two steps. For the first step an electromagnetic field generates a common mode current on both twisted-pair lines (screening attenuation a_S) and in a second step this signal couples into the differential mode signal (via common mode rejection a_u). Using partial capacitances the main coupling mechanism via the electrical field component was described.

By investigating the near end crosstalk of transmission lines with and without an individual shield an attenuation of at least 50 dB up to a frequency of 170 MHz was measured. To ensure standards limits for NEXT e. g. given with CAT VI there is no way to avoid a shield around the twisted pair cable.

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