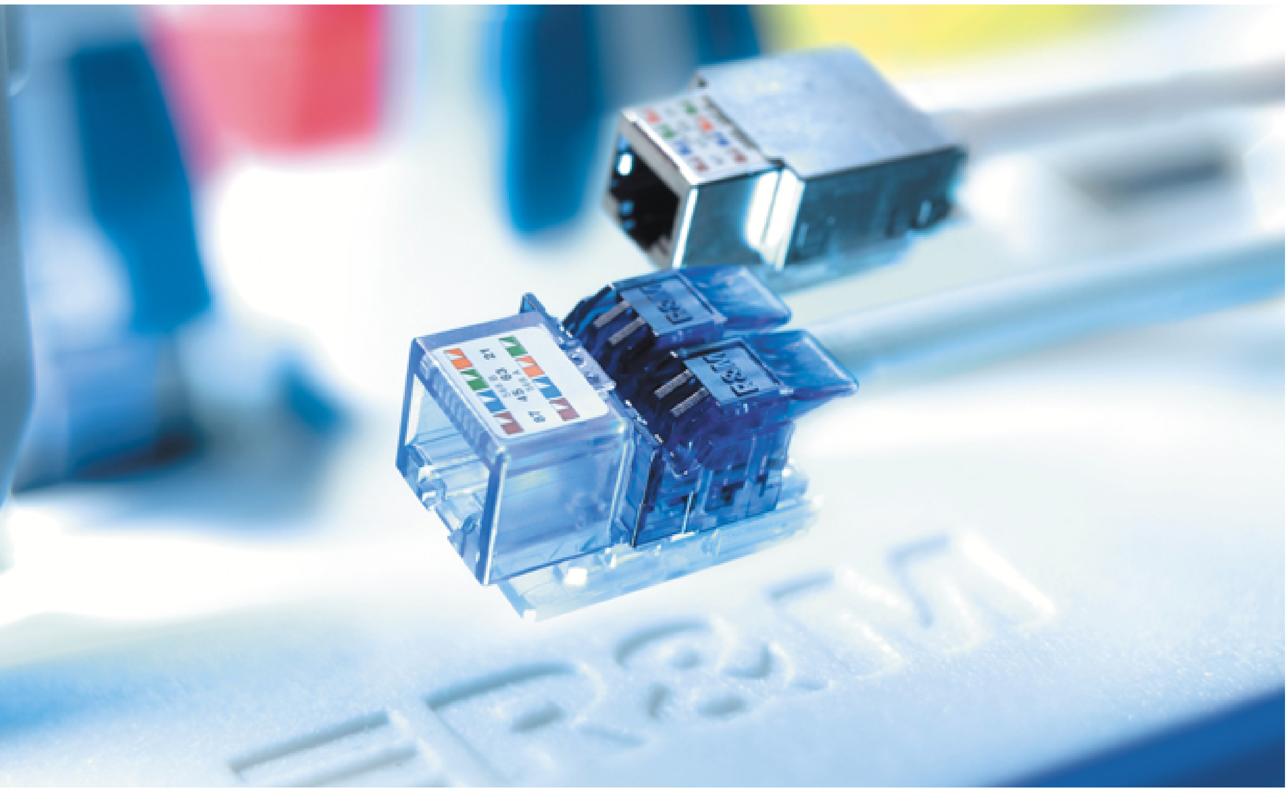
White Paper



WARP – the UTP Technology for 10GBASE-T

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1. Introduction

Application:	Enterprise Cabling
Technology:	Unshielded Twisted Pair, Wave Reduction Patterns (WARP), 10GBASE-T
Format:	White Paper
Subjects:	10 Gigabit Ethernet, protection against AFEXT and ANEXT, capacitive and inductive coupling, EMC, unshielded cabling, UTP, WARP technology, STAR Real10
Objective:	Introduction to WARP technology
Target group:	Planners, installers, end users, decision makers selecting future cabling
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Published:	January 2006

WARP is *the* UTP technology for 10GBASE-T. Because it is a new technology, it raises the following questions: Why do shielded cabling and WARP technology provide the best protection against alien crosstalk? Why does a WARP cable not have to be grounded? Can WARP also protect against common mode disturbance?

This white paper communicates to the technically interested reader how the new WARP technology works. It was developed by R&M in collaboration with a renowned cable manufacturer and was introduced to the market in 2005 as part of the cabling solution for 10 Gigabit Ethernet.

2. Overview

WARP stands for WAve Reduction Patterns. WARP cables and modules are protected from alien crosstalk with metal foil segments and metal plates, which do not have to be grounded. With WARP, R&M is bringing its know-how as a leading supplier of shielded solutions to the unshielded world.

In the following pages it is shown that

- alien crosstalk, the worst enemy of 10 Gigabit Ethernet transmission via UTP, is caused by inductive and capacitive coupling
- conventional UTP systems do not provide protection against this type of disturbance
- WARP protects against both causes of alien crosstalk
- WARP does not provide any additional protection against common mode interference.

3. Electromagnetic fields and EMC: Terms

Electromagnetic compatibility (EMC) is the capability of a system or a component to work satisfactorily in electromagnetic field environments without itself causing undue electromagnetic disturbances.

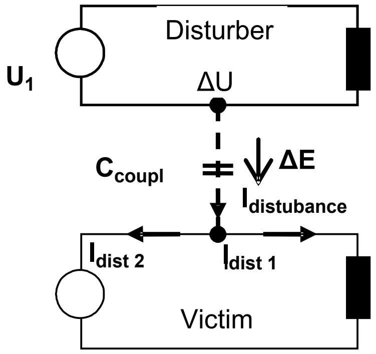
The term coupling is important for this discussion. It describes the interrelation between circuits where energy is transferred from one circuit to the other:

- Galvanic coupling (common conductive path)
- Capacitive coupling (electrical field coupling)
- Inductive coupling (magnetic field coupling)
- Radiation coupling (electromagnetic waves in space)

Below, the behavior of capacitive and inductive coupling is explained.

3.1. Capacitive Coupling

In a capacitor displacement of electrical charges occurs in the direction of the electrical field E if the applied voltage changes. The result is that an electrical current flows. The capacity is the ratio factor between charge displacement and voltage change. The capacitive coupling is described by the coupling capacity between the two circuits.



Based on Maxwell's first equation

$$I_{disturbance} = d\Psi_e/dt = C_{coupl} * (dU_1/dt) \text{ or}$$

$$I_{disturbance} = C_{coupl} * (\Delta U_1/\Delta t)$$

E	electrical field strength
Ψ_e (Psi)	electrical flow
C_{coupl}	coupling capacity

Figure 1: Capacitive Coupling

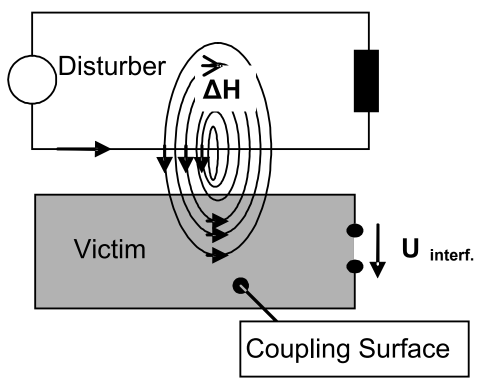
- The coupled current can be described by a current source I_{dist}.

The disturbing current I_{dist} is divided into I_{dist1} and I_{dist2} depending on the line impedance. If the line for the disturbing current I_{dist1}, for example, shows an infinitely large resistance, no current will flow in this direction. The entire disturbing current I_{dist} will flow off as I_{dist2}.

A changing voltage induces a disturbance current. Constant voltage does not produce disturbance currents. External electrical fields behave like current sources.

3.2. Inductive Coupling

Every electrical current is surrounded by a magnetic field. An electrical current in a conductor therefore develops a magnetic field around the circuit. A coupling of two circuits takes place via shared magnetic fields. That is, a part of the magnetic flow produced by one electrical circuit loop also penetrates the loop of another circuit.



Based on Maxwell's second equation

$$U_{disturbance} = d\Phi/dt = -L_{21} * (dI_1/dt) \text{ or}$$

$$U_{disturbance} = -L_{21} * (\Delta I_1/\Delta t)$$

H	magnetic field strength
Φ (Phi)	magnetic flow
L_{21}	differential/coupling inductivity

Figure 2: Inductive Coupling

- The induced voltage can be described by a voltage source U_{dist}

A changing magnetic field induces a disturbing voltage. Constant current and thus a constant magnetic field do not produce any interference voltage. External magnetic fields behave like voltage sources.

4. Balanced Transmission via Twisted Cables

In generic cabling systems for data transmission over copper twisted pairs, the conductors are designed to be balanced. Coupling on a twisted pair can take place in two ways:

- In differential mode, that is between the conductors of a pair,
- In common mode, that is between both conductors of a pair and ground.

The twisting of the pairs in the cable protects against differential disturbance voltage and the balanced transmission makes the cable less sensitive to common mode disturbing currents. This is described in greater detail below.

4.1. Twisted Cables and their Effects

Three effects are significant for disturbances on twisted pair cabling:

- capacitive coupling
- inductive differential coupling
- inductive common mode coupling

Capacitive coupling: The electrical coupling between each conductor of a pair and the outside disturber produce a disturbance, which flows off as current through the twisted pairs. The disturbance currents on the two conductors are of the same size. Twisting the pairs does not completely eliminate capacitive coupled disturbance, which transform into common mode currents. If the line is operated asymmetrically, some disturbance remains. The line must be operated symmetrically for these disturbances to be eliminated – see chapter 4.2.

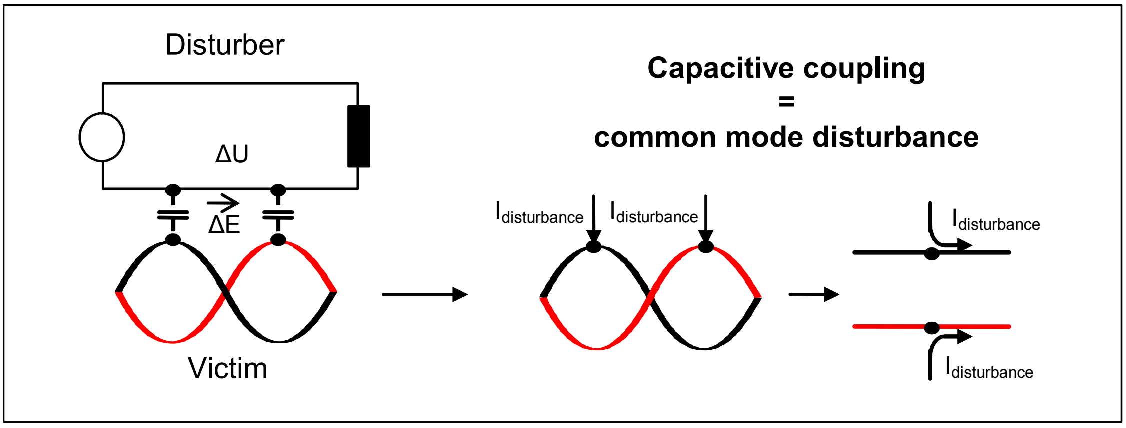


Figure 3: Capacitive coupling with twisted cables

Inductive differential coupling: Thanks to the twisting, the magnetic coupling is more or less reduced depending on the number of twists per meter. The voltage sources from two adjacent loops counteract each other. In theory, the disturbances by the magnetic field are eliminated, on the condition that the twisting of the cable is symmetric. In the practice this can only be implemented to a certain degree.

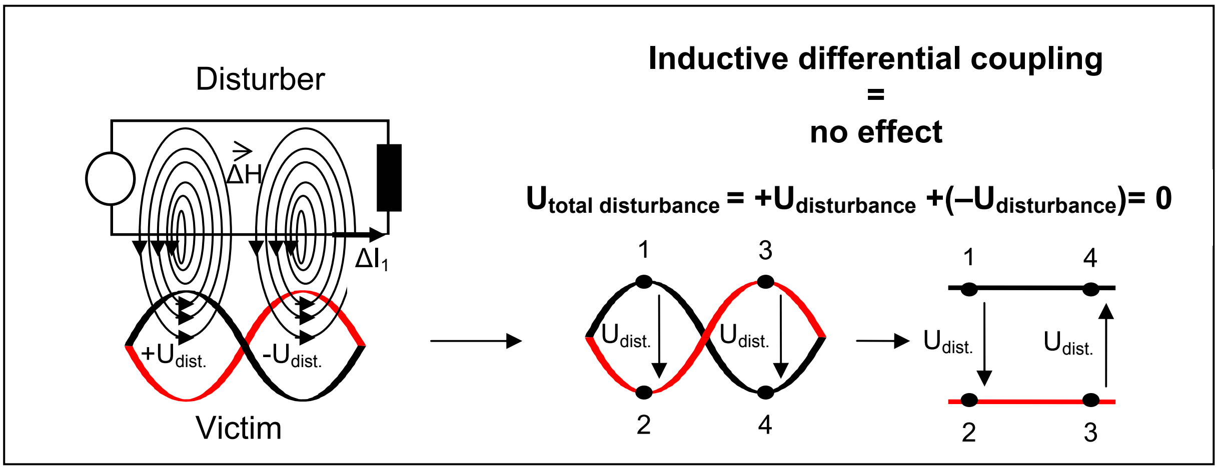


Figure 4: Inductive differential coupling with a twisted cable

Inductive common mode coupling: A disturbance voltage is induced between the cable and ground. Through the common mode termination of the active equipment this causes a disturbing current, which flows at equal level and in the same direction through both wires of a pair. If the cable is operated symmetrically the effect of the disturbance currents are eliminated – see chapter 4.2.

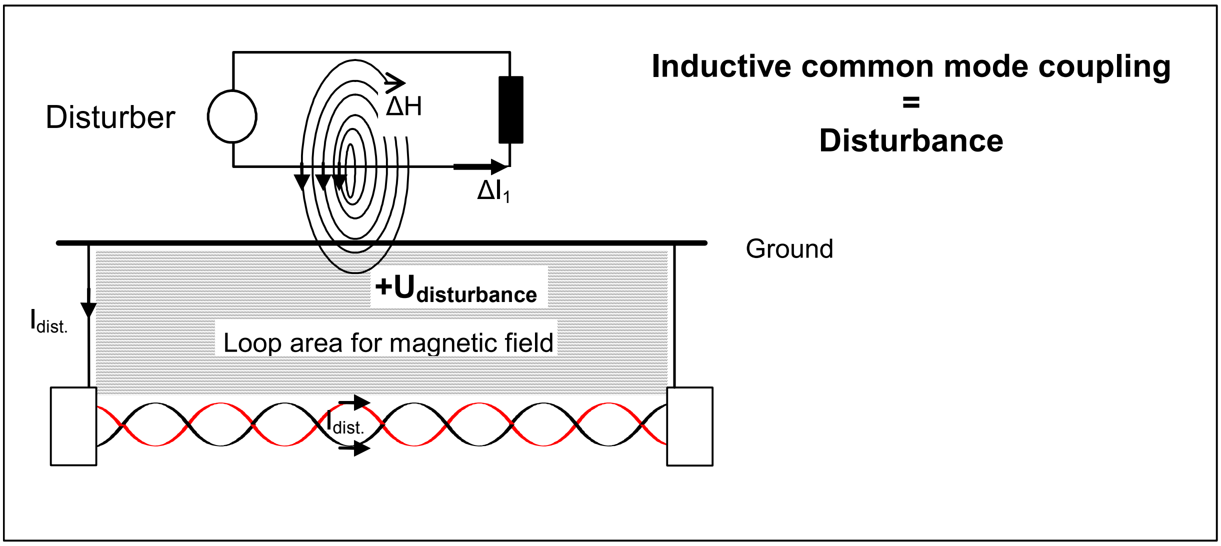


Figure 5: Inductive common mode coupling with twisted cable

But cabling standards only define a cable balance (Transverse Conversion Loss, TCL) of 20 dB at 100 MHz. Up to one tenth of the common mode disturbance is converted in this way into differential disturbance and vice versa. This limit is the same for all cabling categories.

4.2. Balanced Transmission and its Effects

In balanced transmission, the conductors of each pair have an opposite potential, +U and –U, in relation to the ground. Figure 6 shows the principle of a balanced transmission with baluns (symmetric transformers). In the case of the disturbing common mode currents, the disturbance voltages that develop in both balun windings on the cable side are in theory cancelled out because they are of opposite polarity. The two balun windings must be identical for that. In practice this can only be achieved imperfectly. In the best-case scenario, due to remaining asymmetry, common mode rejection ratios of approximately 1 to 1,000 can be obtained, which corresponds to 60 dB common mode rejection ratio.

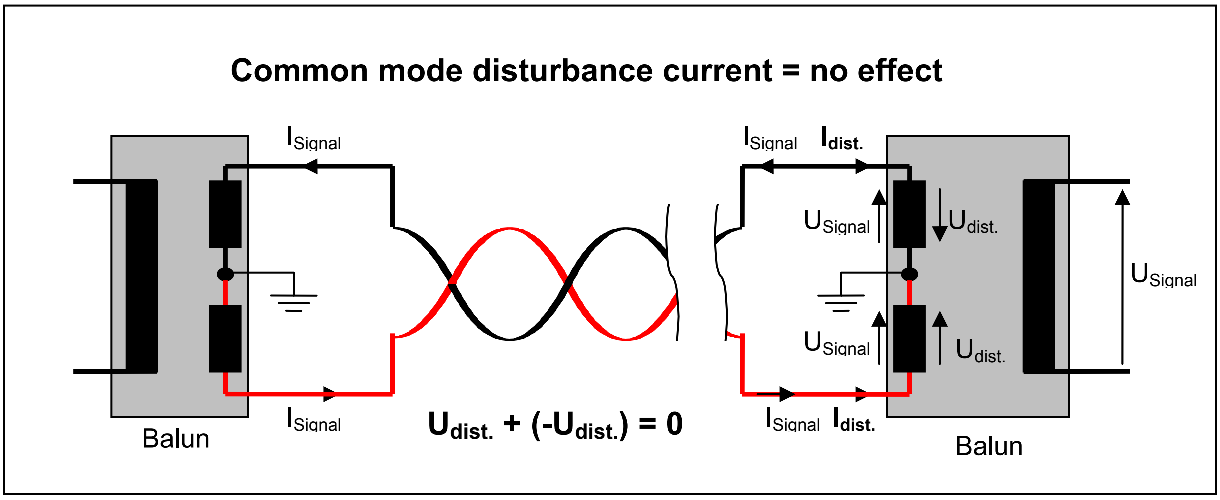


Figure 6: Balanced transmission with baluns

5. WARP Technology for 10GBASE-T

With WARP technology, R&M has developed an innovative solution for the transmission of 10GBASE-T via UTP cable. There is a good reason for this:

Current U/UTP systems provide no protection against alien crosstalk, the worst enemy of 10 Gigabit Ethernet transmission. The alien crosstalk is composed of inductive and capacitive disturbances originating primarily from pairs with the same lay length in adjacent cables. The only possibility to reduce alien crosstalk in conventional U-UTP cabling is to increase the distance between the components. However, the controlling of these distances is difficult.

WARP technology protects against both components of alien crosstalk, that is, inductive and capacitive. The WARP UTP cable has 30 dB better Alien NEXT values than a traditional Cat.6 U/UTP cable.
However, WARP, as any other UTP cabling, does not provide additional protection against common mode disturbances from other sources.

5.1. Background

10GBASE-T uses a sensitive coding method to transmit 10 Gigabit per second with a relatively low bandwidth: The number of voltage levels, which represent the digital information, is much higher compared to 1GBASE-T, and the voltage differences are correspondingly smaller. Consequently, a 10GBASE-T signal at the receiver is approximately 100 times more sensitive to disturbances than a 1GBASE-T signal.

The near-end crosstalk parameter (NEXT) is a measurement for the coupling between pairs within the same cable. Since the signals within a system are known, NEXT can be cancelled in the active component. Thus, the high requirements of 10GBASE-T in terms of NEXT can be achieved. The noise reduction provided by the active devices results in an improvement of approximately 40 dB.

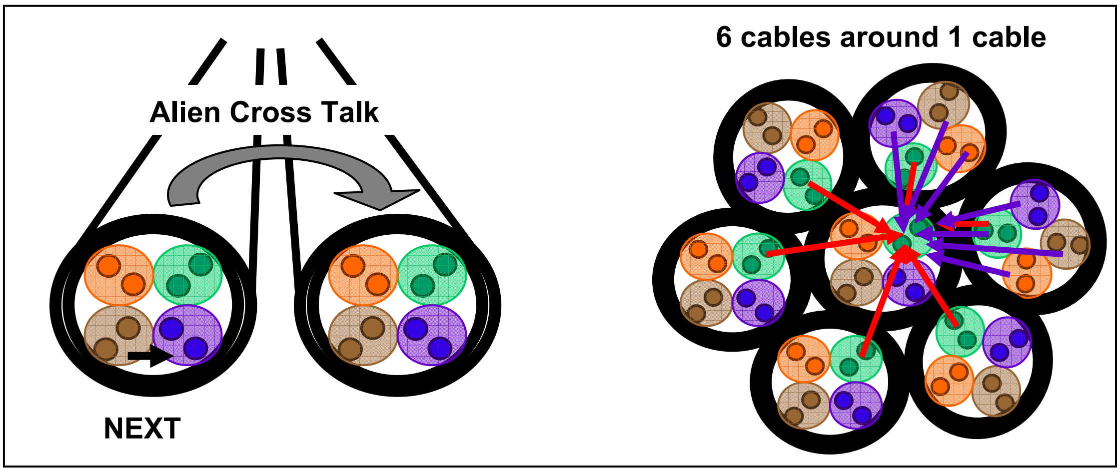


Figure 7: Alien Crosstalk

This can not work for crosstalk between adjacent cables and components, and this results in a serious new problem. A term has been created for this type of disturbance, alien crosstalk (ANEXT, AFEXT).

Adjacent cables have pairs with the same lay length. The disturbance source and the victim have pairs with the same twisting. The resulting disturbing current flows evenly on both wires of the pair, however, it flows in opposite directions. The effect of differential disturbance current is therefore not eliminated, even in balanced transmission.

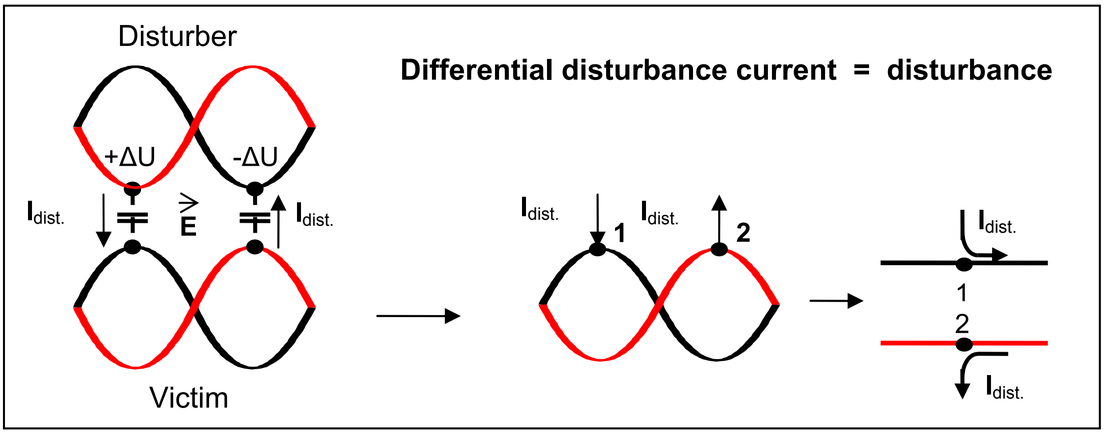


Figure 8: Capacitive Differential Coupling in twisted cables with the same lay length

A similar effect occurs with inductive differential coupling. Due to the same lay length of the disturber and the victim the magnetic fields are of opposite direction and the voltages that occur will now accumulate.

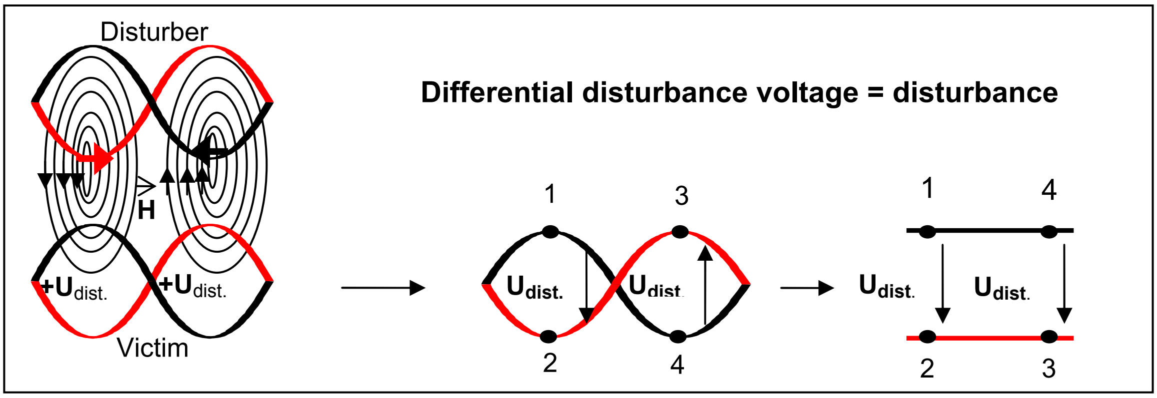


Figure 9: Inductive Differential Coupling in twisted cables with the same lay length

5.2. WARP – the Innovative Solution

WARP was developed by R&M in collaboration with a renowned cable manufacturer. R&M has incorporated this technology into its unshielded copper cabling solution to attain a guaranteed 10 Gigabit Ethernet performance.

WARP stands for WAve Reduction Patterns. It provides non-continuous shielding for unshielded cabling components with short conductive patterns which are isolated from each other.

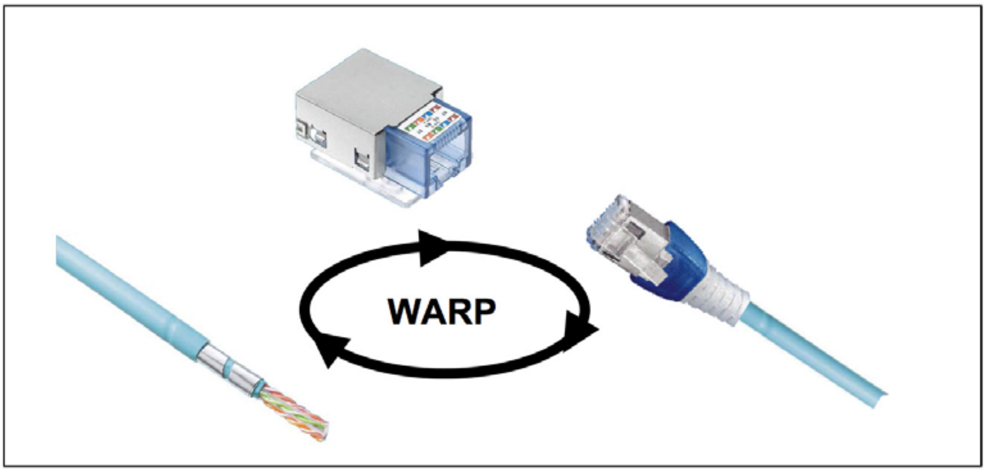


Figure 10: WARP Products

This technology enables alien crosstalk values for a UTP system, which until now have been considered unattainable. The WARP technology is based on shielding and therefore, provides an effective protection against alien interferences, without needing grounding.

5.2.1 Alien Crosstalk – the External Effect

Capacitive coupling: Since the WARP shield is not grounded, its potential is initially neutral. Thanks to balanced transmission, the conductors of each pair have an opposite potential, +U and –U. They are connected to each other via the coupling capacity. The shield adjusts to zero or ground potential.

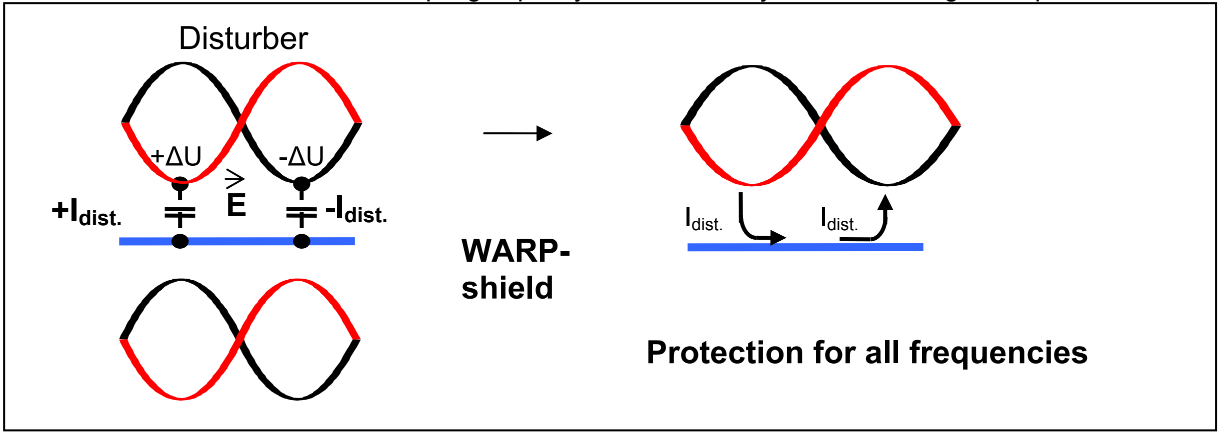


Figure 11: WARP shield against Alien Crosstalk from Capacitive Coupling

Thanks to balanced transmission, capacitive coupling to the outside is prevented by the WARP shielding of cable, jack and connector.

Inductive coupling: If a time-varying magnetic flow penetrates a conductor, it creates eddy fields within the conductive material, e.g. the WARP shield. These eddy currents themselves create a magnetic field, which opposes the original magnetic field. Therefore a displacement of the magnetic flow from the conductor occurs– the higher the frequency the more apparent the displacement (skin effect). Because the WARP shield forms a circumferential sheath around the pair, it prevents the magnetic fields from escaping or penetrating neighboring cables.

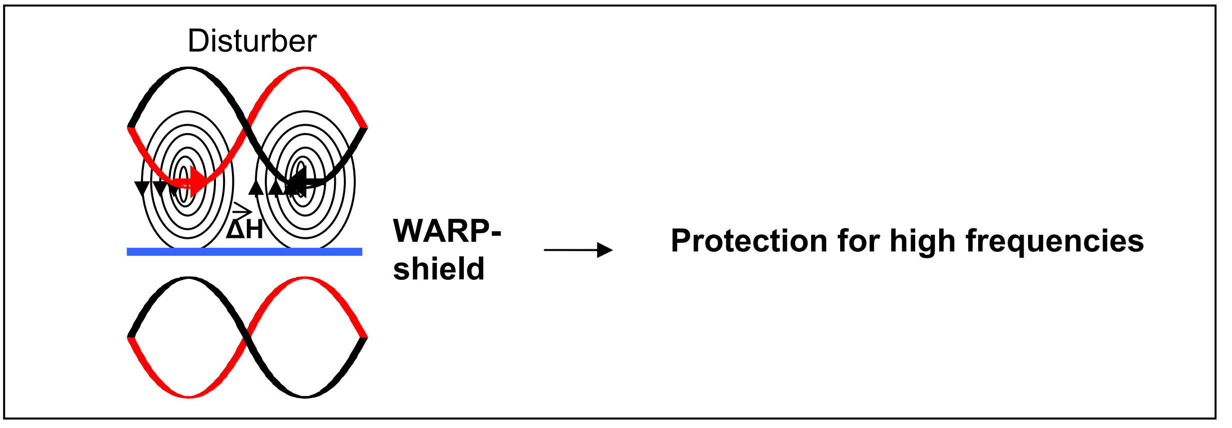


Figure 12: WARP Shield Against Alien Crosstalk from Inductive Coupling

The WARP shielding of cable, jack and connector
is effective on magnetic fields at high frequencies.
It is of no effect that the shielding is not grounded.

To demonstrate the capability of the WARP shield against alien NEXT, the PS ANEXT was measured on a cable, which was surrounded by six other cables – the worst possible configuration in practice. Figure 13 shows the results.

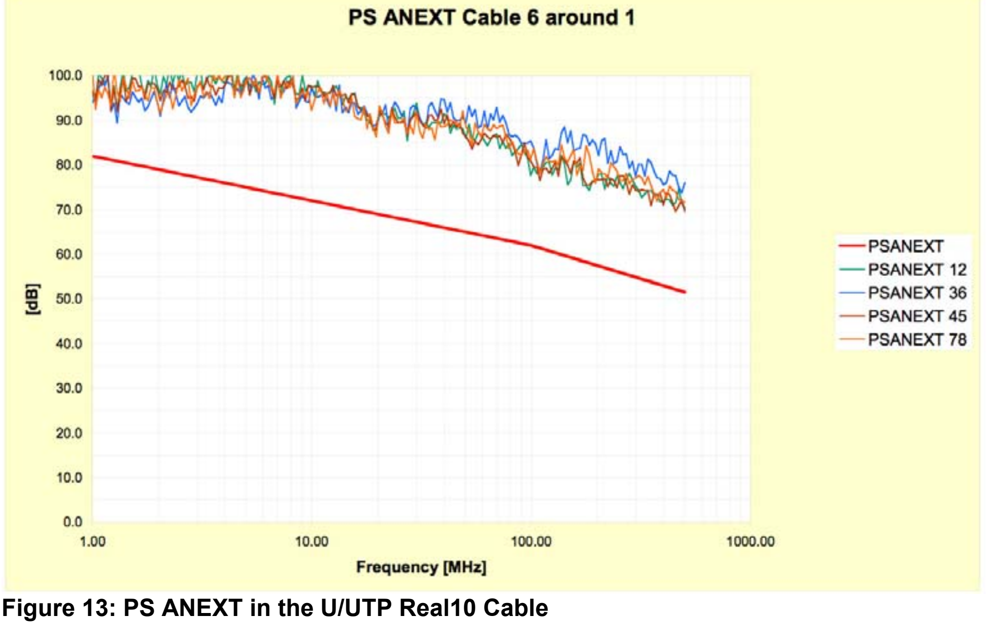


Figure 13: PS ANEXT in the U/UTP Real10 Cable

Compared to a normal Cat. 6 U/UTP cable, WARP improves the alien NEXT values by approximately 30 dB. Because the shield is not continuous, WARP behaves like a normal U/UTP system.

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5.2.2 EMC – the Effect from Outside

Capacitive coupling: Can the WARP shield protect against capacitive coupled disturbances? The short patterns isolated from each other have no defined potential based on the fact that they are not grounded. Therefore:

> **The WARP shield provides no additional protection against capacitive coupling.**

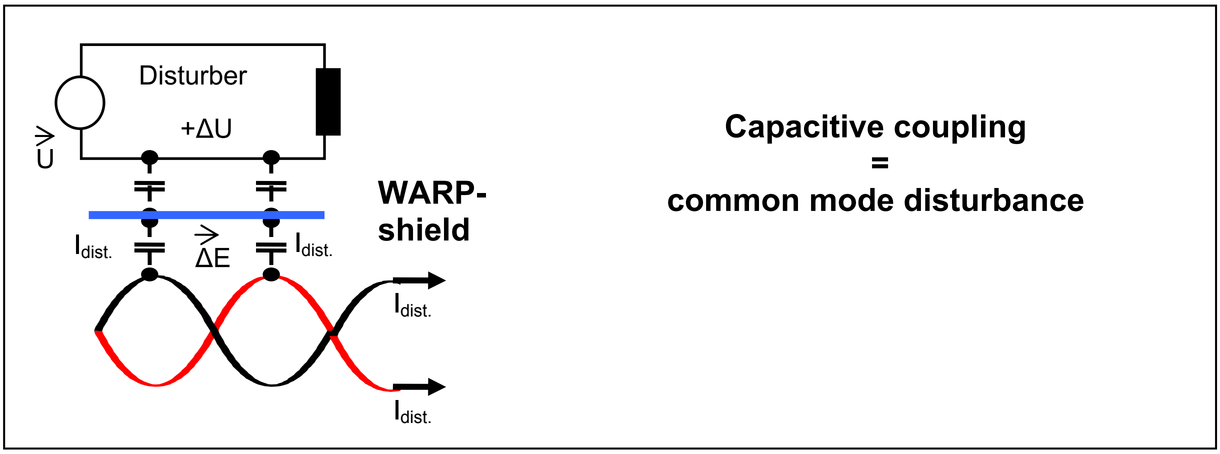

Figure 14: WARP and Capacitive Coupling

As demonstrated in Chapter 4, effects of common mode interference currents can be eliminated to the greatest extent with symmetric baluns.

Inductive differential coupling: The WARP shield functions the same way as with alien crosstalk. The eddy currents lead to a displacement of the magnetic flow in the conductor – the higher the frequency the more apparent the displacement. Therefore:

> **The WARP shield provides additional protection against inductive differential coupling.**

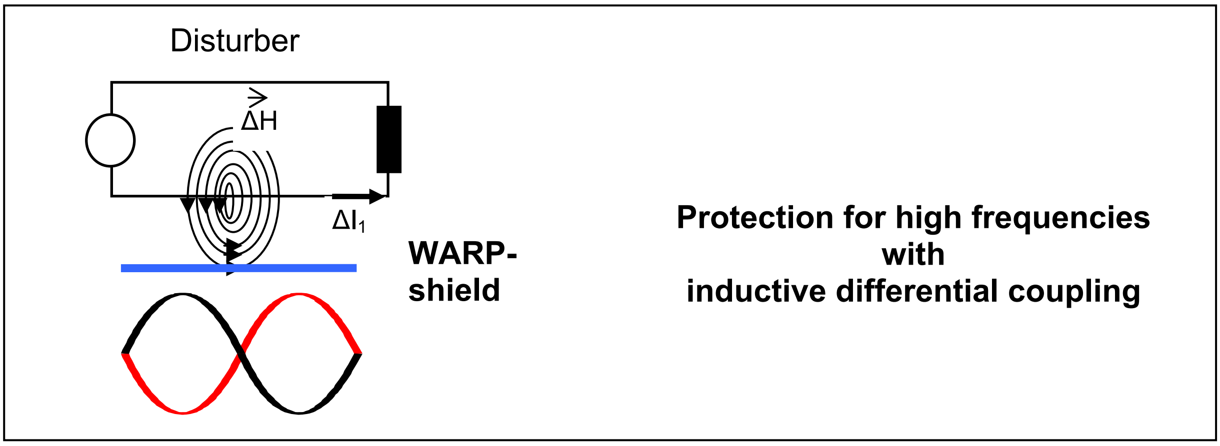

Figure 15: WARP and Inductive Differential Coupling

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Inductive common mode coupling: Inductive common mode coupling induces a disturbance voltage between the ground and the cable. It causes a disturbing current, which flows equally over the pair. Therefore:

> **The WARP shield provides no additional protection against inductive common mode coupling.**

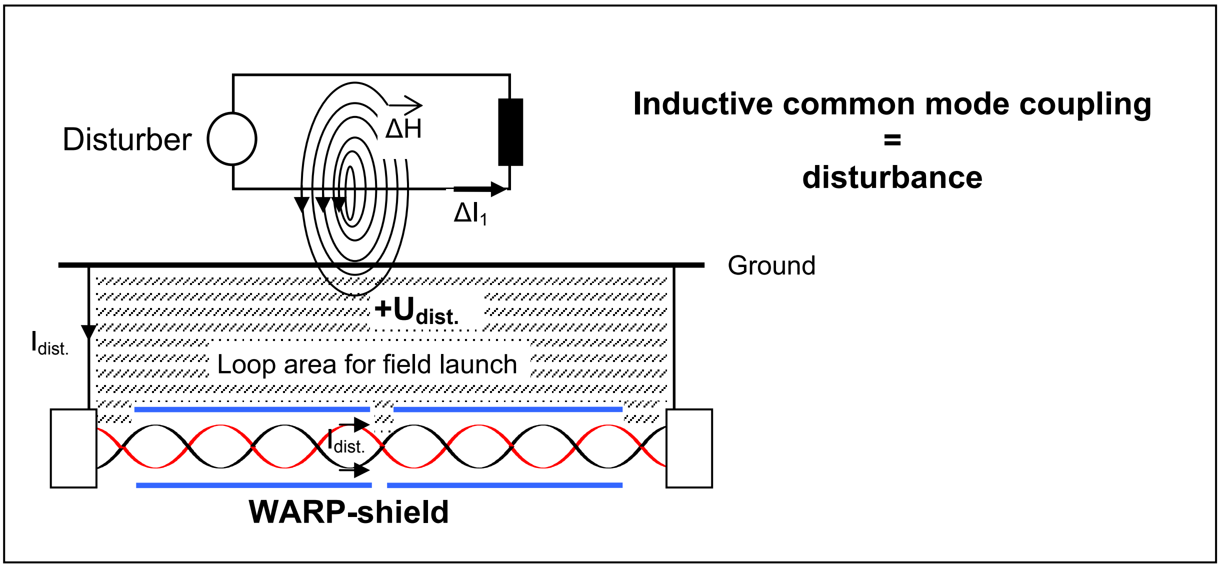

Figure 16: WARP and Inductive Common Mode Coupling

However, as demonstrated in the chapter “Balanced Transmission“, effects of common mode interference currents can be eliminated to the greatest extent with symmetric baluns.

6. Conclusions

R&M, as a leading supplier of shielded solutions, has brought their shielded know-how to the unshielded world.
The advantages of WARP technology are obvious compared to a UTP Cat. 6/Class E transmission system:

- Protection against alien NEXT (capacitive and inductive disturbances)
- Protection against inductive differential coupling

However, there is no additional protection against

- inductive common mode coupling,
- capacitive coupling.

The three innovative Real10 UTP components with WARP technology– installation cable, connector and patch cable – form, in combination with the existing R&M distribution panels and outlets, a channel with optimal performance for 10 Gigabit Ethernet via unshielded cabling links over a distance of up to 100 meters. System measurements show that this solution guarantees a sufficient reserve to ANEXT or AFEXT values and limits according to the standards draft.

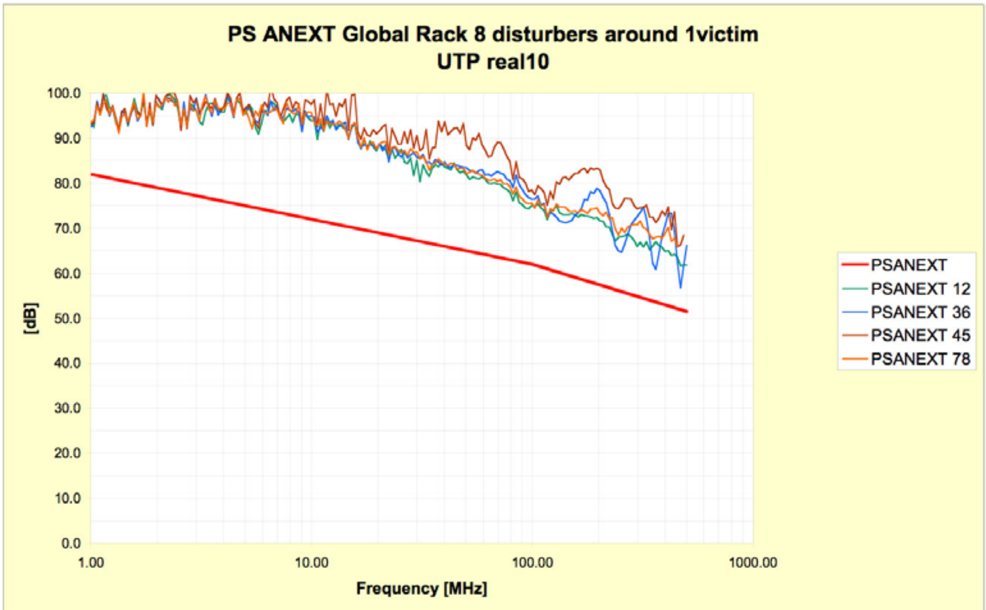

Figure 17: PS ANEXT in the Channel

As always, special importance should be given to the concept of a clean building grounding, since UTP installations are significantly more susceptible to noise and interferences in 10 Gigabit Ethernet operations. These risks must not be ignored.

With WARP, R&M continues its tradition and commitment to the highest quality, groundbreaking product development and easy installation. The new R&Mfreenet system family with the modularly designed STAR Real10 – whether shielded or unshielded – offers customers a real 10 Gigabit solution, which lives up to its promises.

7. Terms

AFEXT	Alien Far-End Crosstalk, crosstalk between adjacent cables at the far end of the link
ANEXT	Alien Near-End Crosstalk, crosstalk between adjacent cables at the near end of the link
EMV EMC	Elektromagnetische Verträglichkeit [electromagnetic compatibility] Electromagnetic Compatibility
NEXT	Near-End Crosstalk, crosstalk within the same cable at the near end of the link
PS ANEXT	Power-Sum ANEXT, the power sum of crosstalk between adjacent cables at the near end of the link
STAR Real10	R&M product group which guarantees 10 Gigabit performance. WARP UTP cables and modules are components of the product group
TCL	Transverse Conversion Loss. A measurement (in dB) for the conversion of common mode voltage into differential voltage on one end of the pair
UTP	Unshielded Twisted Pair, unshielded twisted copper conductors
U/UTP	Precise designation for UTP: The twisted pairs are neither individually nor jointly shielded as a cable
WARP	WAve Reduction Patterns. WARP cables and modules are shielded with metal foil segments and metal plates to which no contact has to be established.

8. Additional Information

R&M White Paper

- Effect of 10GBASE-T on Cabling, September 2005
- Positioning Paper "10 Gigabit Ethernet", August 2004
- Alien Crosstalk, November 2003
- 10 Gigabit Ethernet over Copper, July 2003

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