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Technical Report

PowerLine Telecommunications (PLT);
MIMO PLT;
Part 1: Universal Coupler,
Operating Instructions - Description

Reference

RTR/PLT-00034

Keywords

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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Powerline Telecommunications (PLT).

The present document is part 1 of a multi-part deliverable covering the MIMO PLT as identified below:

Part 1: "Universal Coupler, Operating Instructions - Description";

Part 2: "Measurement Methods and Statistical Results of MIMO PLT EMI";

Part 3: "Measurement Methods and Statistical Results of MIMO PLT channels".

Introduction

In order to study and compare MIMO (Multiple Input Multiple Output) characteristics of the LVDN network in different countries the STF 410 (Special Task Force) was set up. The present document is one of three TRs which present the result of the work of STF 410. The work items in ETSI TC PLT dealing with the results of STF 410 are the present document, TR 101 562-2 [i.6] and TR 101 562-3 [i.7].

The present document specified the measurement tools, set-up and procedure to record parameters like MIMO channel transfer functions, impedances and noise. Statistical evaluations of the recoded data is given in clause 8.

A second document produced by STF 410 deals with the EMI of MIMO PLC. The third document presents the schematics and properties of the MIMO PLC couplers used for feeding and receiving signals into the mains grid. These couplers are used for the channel as well the EMI measurements.

1 Scope

The present document covers MIMO PLT channel transfer measurements and statistical analysis taking into account such matters as earthing variation, country variation, operator differences, phasing and distribution topologies, domestic, industrial and housing types along with local network loading. The present document is a description of the MIMO PLT couplers used for feeding and receiving signals to and from the mains grid.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] Terms of Reference for Specialist Task Force STF 410 (TC PLT) on "Measurements to Verify Feasibility of MIMO PLT", Version: 1.1, 6 May 2010.

[i.2] Sartenaer, T. & Delogne, P., "Powerline Cables Modelling for Broadband Communications", ISPLC 2001, pp. 331-337.

[i.3] R. Hashmat (1), P. Pagani (1), T. Chonavel (2), (1: Orange Labs, France), (2: Telecom Bretagne, France), "MIMO Capacity of Inhome PLC Links up to 100 MHz", Workshop on PLC 2009 - Udine - Italy.

[i.4] A. Schwager, "Powerline Communications: Significant Technologies to become Ready for Integration" Doctoral Thesis at University of Duisburg-Essen, May 2010.

[i.5] ETSI TR 102 175 (V1.1.1): "PowerLine Telecommunications (PLT); Channel characterization and measurement methods".

[i.6] ETSI TR 101 562-2: "PowerLine Telecommunications (PLT); MIMO PLT; Part 2: Measurement Methods and Statistical Results of MIMO PLT EMI".

[i.7] ETSI TR 101 562-3: "Powerline Telecommunications (PLT); MIMO PLT; Part 3: Measurement Methods and Statistical Results of MIMO PLT channels".

3 Symbols and abbreviations

3.1 Symbols

For the purposes of the present document, the following symbols apply:

dB	decibel (logarithmic unit)
dBm	$10 * \log_{10}$ (P / 1 mW)
Hz	Hertz
L	Inductance
m	meter
MHz	Mega Hz
nF	nanoFarads
nH	nanoHenry
Ω	Ohm
Z	Impedance

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AC	Alternating Current
BNC	Bayonet Nut Connector
C	"Center point" of the coupler
CM	Common Mode
DM	Differential Mode
E	protective Earth
EP	connection E to P
LVDN	Low Voltage Distribution Network
MIMO	Multiple Input Multiple Output
N	Neutral
NE	connection N to E
P	Phase
PE	Protective Earth
PLC	PowerLine Communication
PLT	PowerLine Telecommunications
PN	connection P to N
RCD	Residual Current Devices
Rx	Receive
S	Switch
SISO	Single Input Single Output
STF	Special Task Force
sym	symmetrical
t	Turns
TR	Technical Report
TTL	Tranverse Transfer Loss
Tx	Transmit

4 Major Project Phases

Table 1

No.	Period	Topic	Event
01	Sept. 2010	Project organization Definition of targets, what and how to measure	STF 410 preparatory meeting Stuttgart, Germany
02	Oct to Nov 2010	Specification of the measurements	
03	Dec. 2010 to Feb. 2011	Implementation of the STF 410 MIMO PLT couplers	
04	March 2011	Setup of measurement equipment at the site of each expert	
05	April to May 2011	Conducting field measurements in various European countries	
06	June to July 2011	Statistical evaluation of the data and drafting of the TRs	

5 Motivation

PLT systems available today use only one transmission path between two outlets. It is the differential mode channel between the phase (or live) and neutral contact of the mains. Such systems are called SISO (Single Input Single Output) modems. MIMO PLT systems do not use only one transmission path. The utilization of the third wire, the PE (Protective Earth) wire allows several combinations to feed and receive signals into and from the LVDN. The Terms of Reference of STF 410 [i.1] and various research publications [i.2], [i.3], [i.4] or [i.5] motivate MIMO PLT. They describe up to 8 transmission paths might be used simultaneously by MIMO PLT.

Channel measurements as described in these publications are verified by STF 410. In many countries of the world new electricity installations use 3 wires for connecting a single plug. Part 3 of this TR 6 provides information about the presence of the PE wire.

All flats protected with RCD (Residual Current Devices) are equipped with a separate protective earth wire installed. For example, the protective earth is mandatory for all new installations in Germany since the early 1970's. MIMO PLT modems also utilize the protective earth. This enables them to feed differentially between phase to neutral (P-N), phase to protective earth (P-PE) and neutral to protective earth (N-PE). The protective earth is grounded inside (e.g. at the foundations) or outside (at the transformer station) the building. The grounding has to provide low impedance for the 50 Hz AC power. However, high frequency signal measurements show the PE wire to be a rather excellent communication path which by no means represents a ground. This is due to the inductivity of the grounding wires.

If the differentially fed signals are converted to common mode, they propagate over the network, as well. For each pair of outlets, the DM and the TTL (Transverse Transfer Loss) [i.5] attenuation are measured and statistical comparisons are provided.

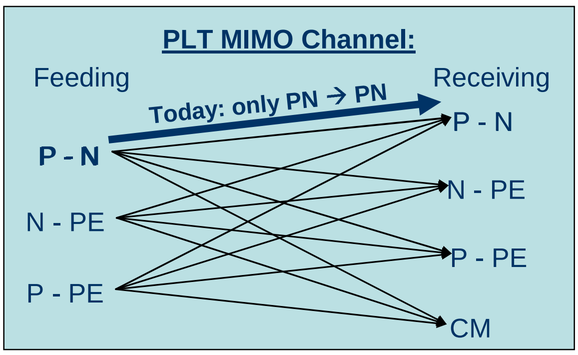


Figure 1: MIMO PLT channel matrix

Figure 1 presents the individual physical paths in a MIMO PLC channel. The DM path P-N at transmitter to P-N at receiver is the traditional channel between two SISO modems. All other paths contribute to multiple input and multiple output.

6 MIMO PLT Universal Coupler

Figure 2: Photograph of coupler from top

Figure 3: Photograph of coupler, case opened

7 Safety note

- STF 410 MIMO coupler are designed and built with great care.
- STF 410 couplers have to be used exclusively for tests carried out by instructed personnel.
- It is recognized that the connection of the Protective Earth of the STF 410 MIMO couplers does not comply with safety standards for commercial products.
- For best protection of the connected instruments, it is recommended:
  - to first switch off all interfaces;
  - then to connect the instruments;
  - then to connect the coupler to the mains; and
  - then switch on whatever is required for the operation (see clause 9).

8 Objectives of the MIMO PLT (STF 410) design

General requirements:

- Safety for field use by instructed personnel (but no formal safety test).
- Safety for connected test equipment (50 Hz level, surge protection).
- Well defined electrical characteristics to get reproducible measurement results (namely well defined impedance matching conditions for sender and receiver).

Following objectives were defined by STF 410:

- The frequency range should be extended to 100 MHz.
- The coupler(s) should allow the measurement of:
  - Transfer function.
  - Noise level.
  - Symmetrical input impedances.
  - k-factor (i.e. strength of the radiated field at a distance of 10 m with an available source power of 0 dBm).
- If possible one single type coupler for all functions.

9 Technical Data of Couplers

9.1 Impedance conditions

Impedance conditions are defined to the center point C (see schematic diagram clause 10).

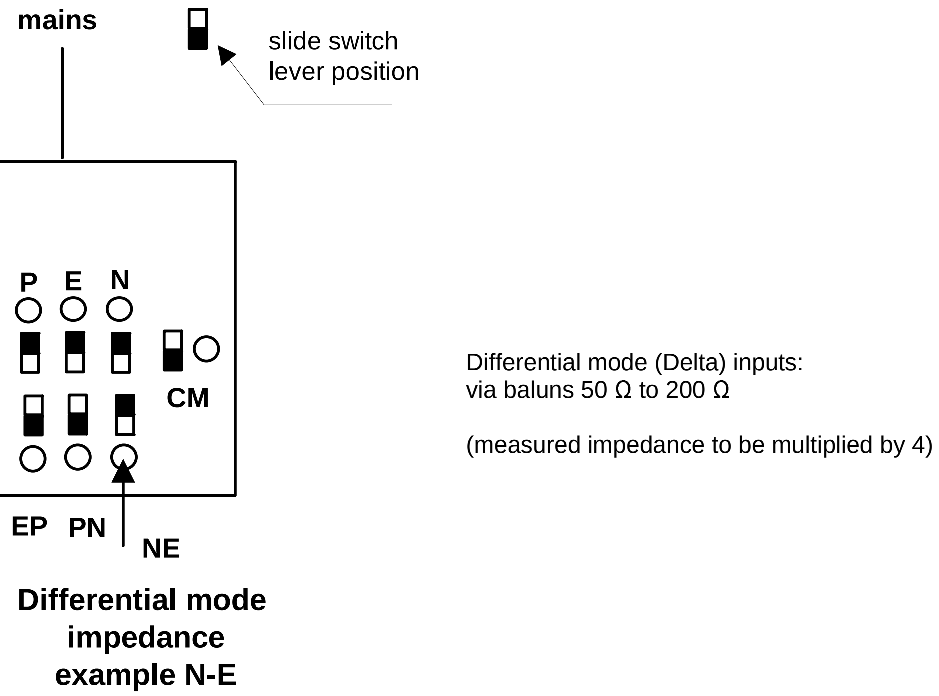


Figure 4: Coupler in impedance measurement mode

Common mode (CM) inputs:

- via balun 50 Ω to 200 Ω.

Star inputs (P, N, E):

- direct 50 Ω in each leg.

Characteristic impedance of mains cable, third conductor open circuited:

- approximately 80 Ω.

Characteristic impedance of common mode transformer windings:

- third conductor open circuited:
  - approximately 80 Ω.

Test pad: A test or calibration pad was realized to verify impedances of the probes.

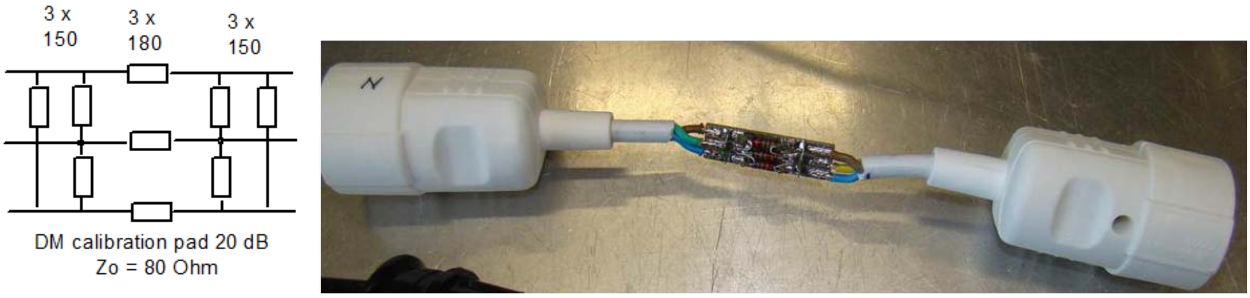


Figure 5: Test pad: Schematic and photo

Characteristic impedance of test pad, (without cables and Schuko connectors):

- third connection open circuited:
  - 80 Ω.

9.2 Insertion Loss

See measurement results in clause 11.

10 Operation

The following figures show the connections to MIMO sender and receiver and the position of the slide switches for the different operation modes.

10.1 SISO transmit and SISO receive (example P-N to P-N)

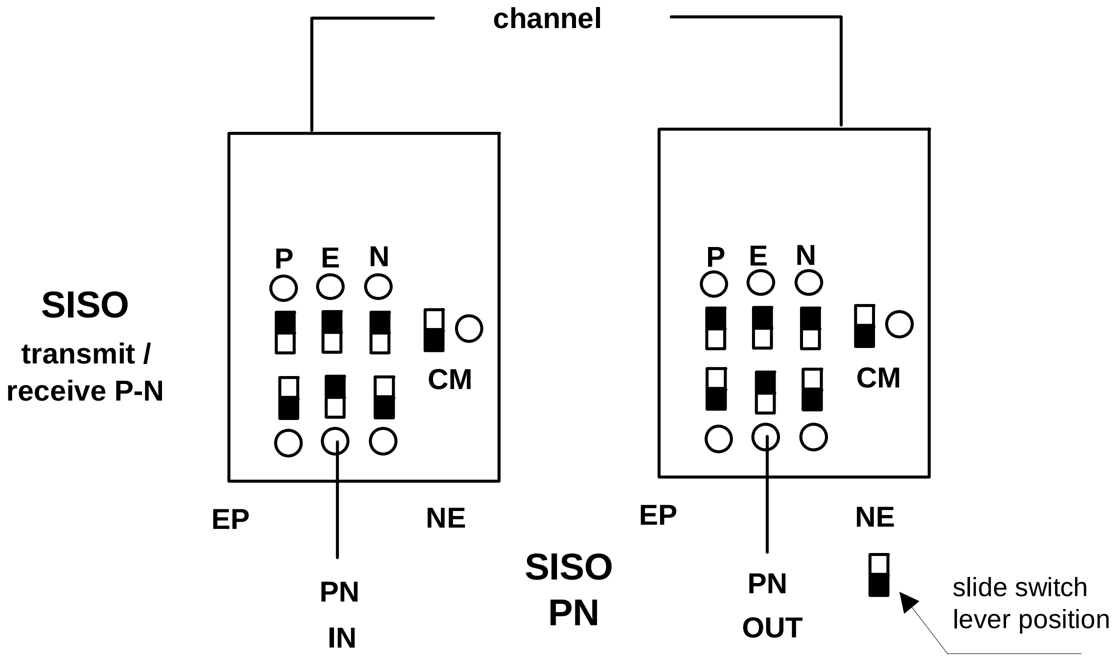


Figure 6: Coupler in SISO attenuation measurement mode

10.2 MIMO symmetric transmit (example N-E), MIMO receive star plus CM

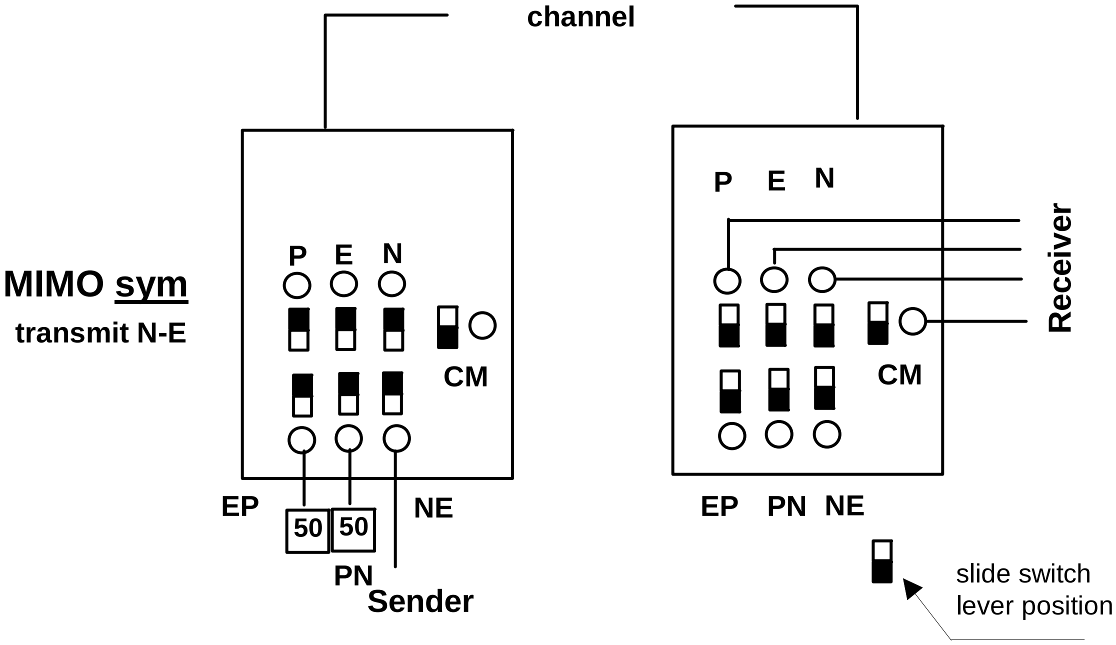


Figure 7: Coupler in MIMO symmetric transmit and MIMO receive (star plus CM) mode

10.3 MIMO asymmetric transmit (example N-E), MIMO receive star plus CM

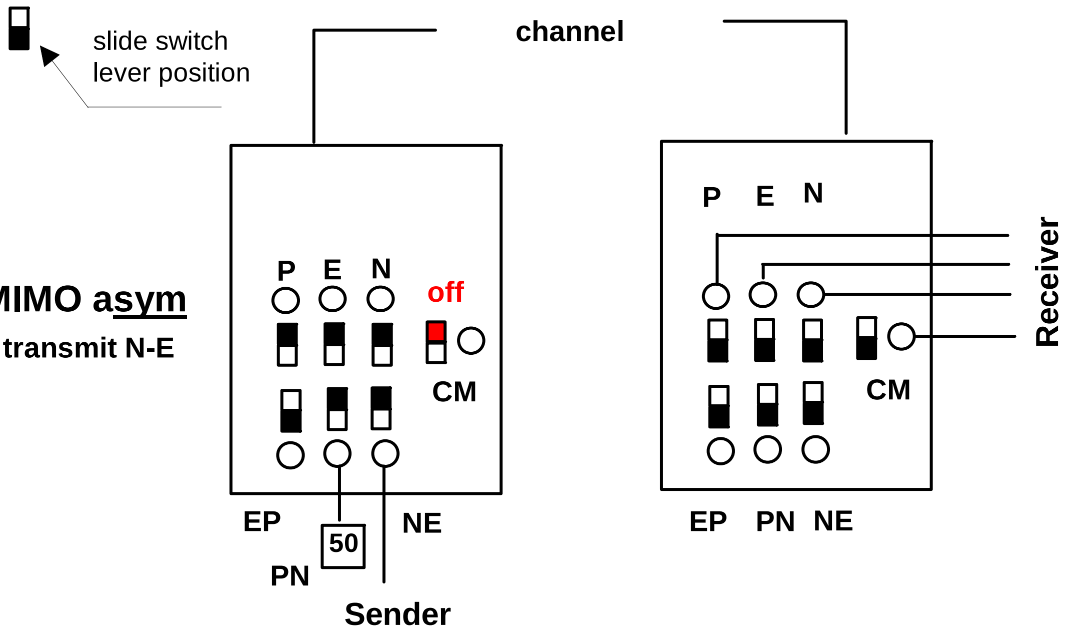


Figure 8: Coupler in MIMO asymmetric transmit and MIMO receive (star plus CM) mode

10.4 SISO common mode transmit and SISO common mode receive

(Not a proposal for practical deployment.)

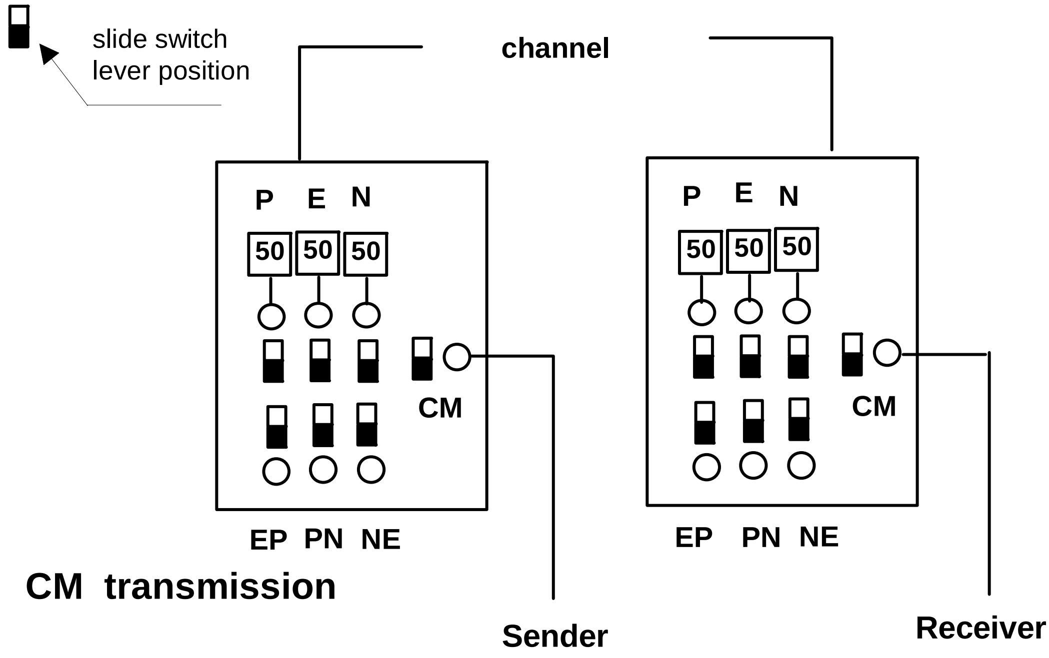


Figure 9: Coupler in SISO common mode transmit and receive mode

10.5 Alternative MIMO mode using dual wire feed

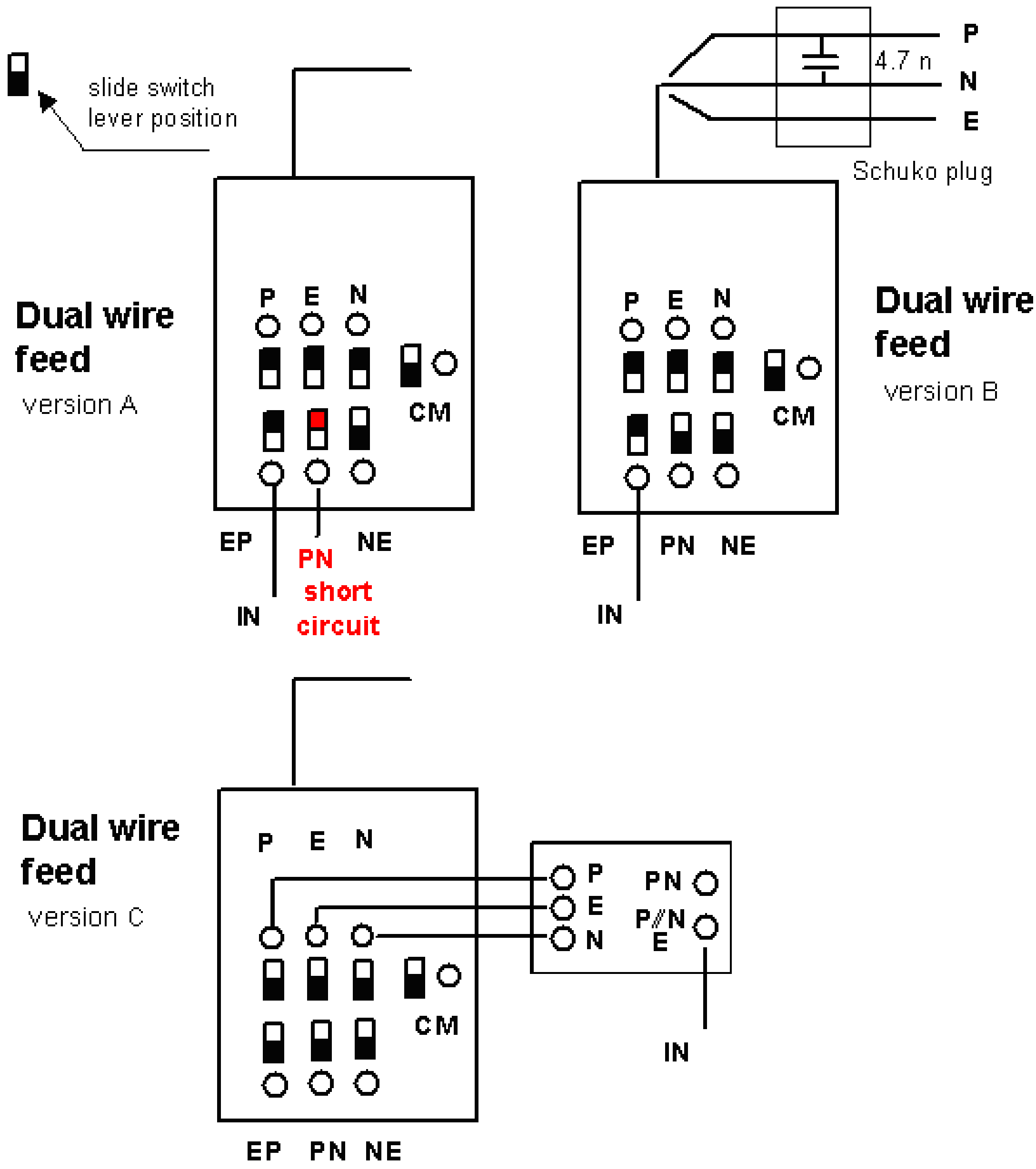


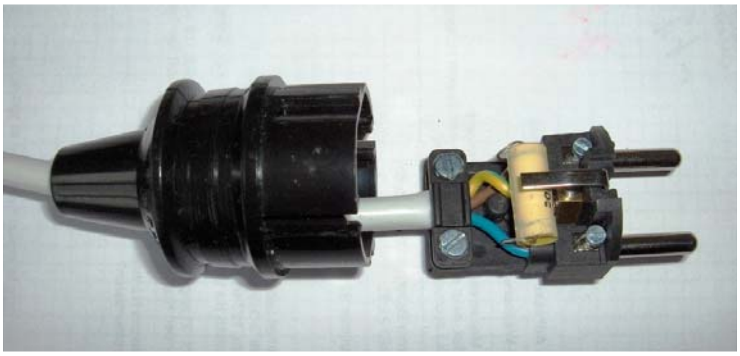
Figure 10: Coupler in dual wire feed mode

Version A:

- The short circuit between P and N is not perfect, because the balun represent a transmission line of about 34 cm of electrical length and Zo = 200 Ω at the secondary. At 30 MHz P and N are "shorted" with about j 43 Ω, at 80 MHz with j 115 Ω.

Version B:

- There is enough space inside the Schuko plug of the coupler, to mount a 4,7 nF capacitor inside. For frequencies above 5 MHz this type of short circuit is more effective. The internal coupling to the open third wire is small due to the symmetric construction of the coupler. It should be negligible.



Dual wire feed version B

4,7 nF 1 000 V polypropylene capacitor mounted into the Schuko plug

Figure 11: Coupler in dual wire feed version B mode

Version C:

- Using a differential choke to feed commonly P and N wires ensures a very symmetric dual feed injection for all the frequency range of interest. This is implemented in an additional extension box to avoid the need of modifying the original couplers. This box contains not only this choke, but both 50 Ω to 200 Ω baluns for the dual-wire (P//N E) and the classical differential (PN) injection modes. In this way, both modes (and additionally the CM) can be used at the same time to create an alternative set of MIMO modes. Such feeding or receiving are called the "T-style" mode.

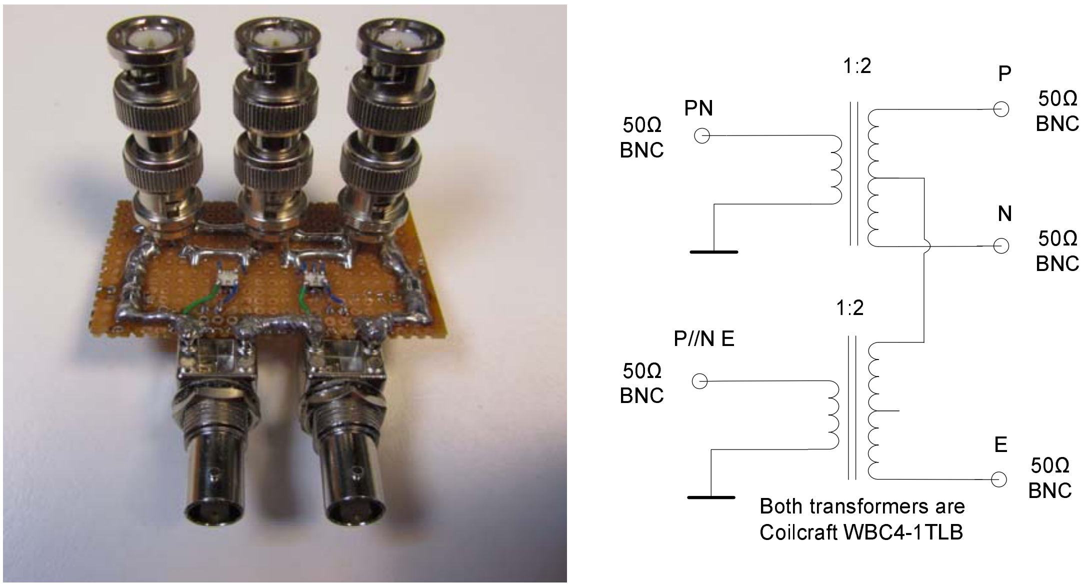


Figure 12: Coupler extension in T-style (dual wire feed version C) mode

11 Circuit diagram

The center point C in the schematic diagram in Figure 12 is the heart of the coupler. It is built in a very compact form in order to reduce spurious inductances and capacitances for proper operation up to more than 100 MHz.

All baluns are of the same type (Guanella transformers 1:4). They are of very low loss.

The common mode transformer is magnetically coupled (Faraday type). Its loss is not negligible.

If the CM switch is on and the CM interface is open then the CM transformer acts as an effective CM choke.

If the CM switch is off then the impedance of the common mode transformer gets low.

The instruments connected to the coupler are protected in several ways:

- gas discharge and varistor between P and N;
- surge protection diodes on P, N and PE;
- switches S1 to S7 that allow to disconnect the instruments.

The receiver interface using the ports P,E and N is called 'Star-syle' because the termination of the lines might be drafted in a way to present a star (Y).

The transmit interface using the ports E-P, P-N and N-E is called 'Delta-style' because the 3 lines are terminated using T1, T2 and T3 which might be presented to show a delta (Δ).

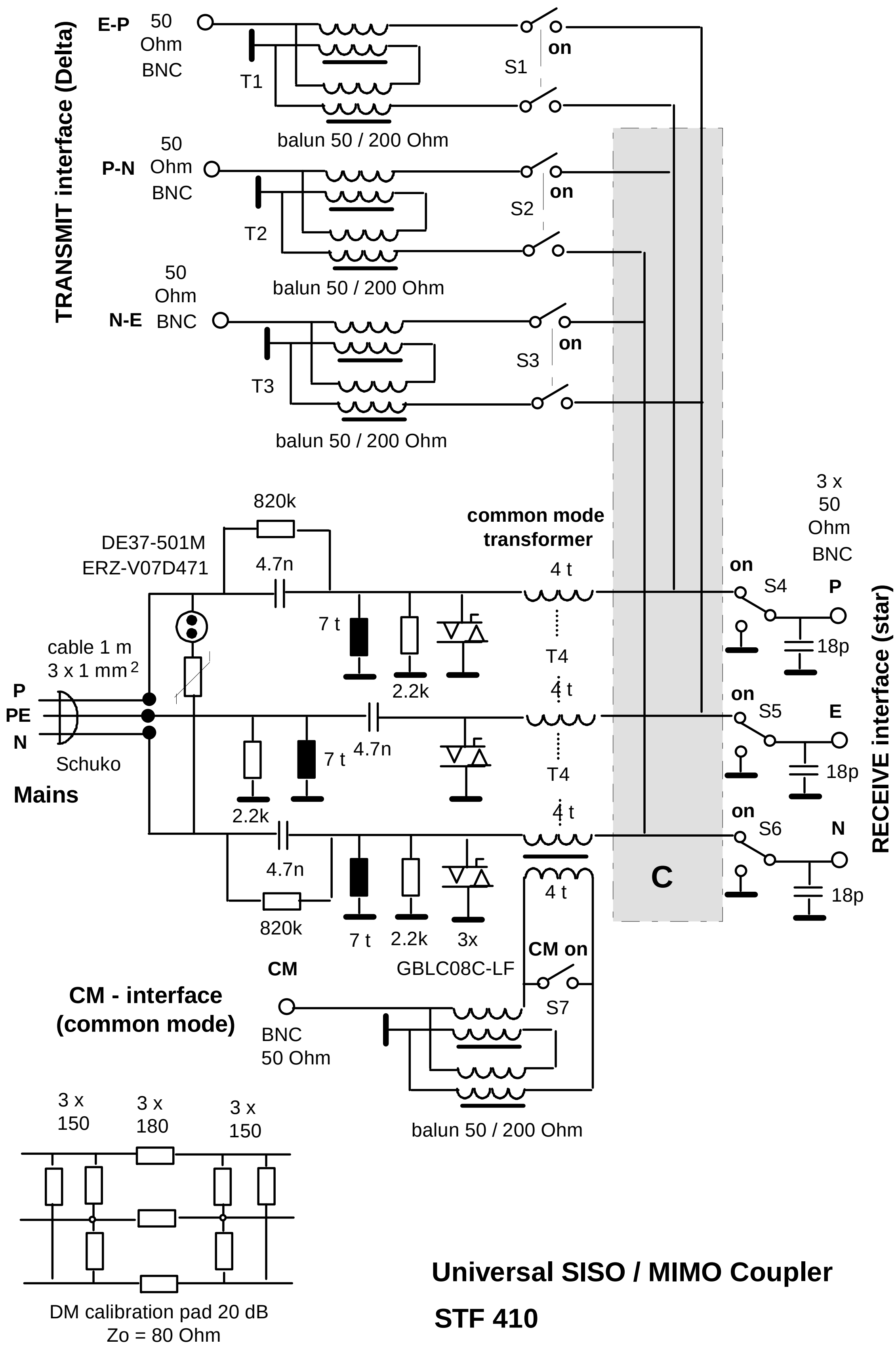
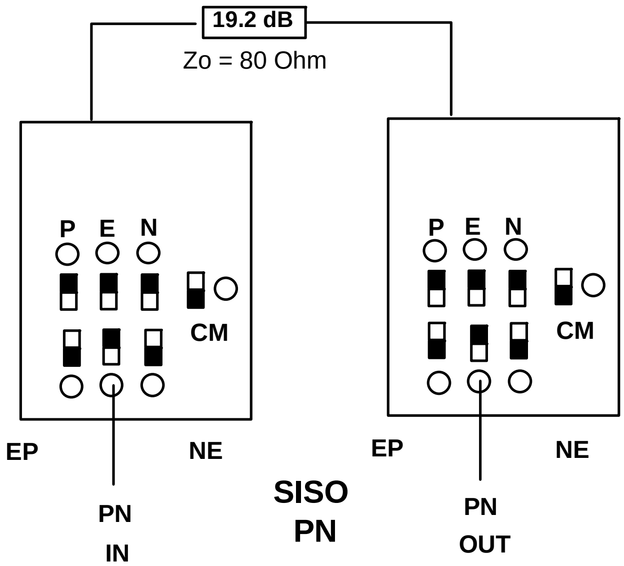


Figure 13: Coupler schematic

12 Measurement Results

12.1 SISO



Insertion loss with ideal coupler:

total: a = 21,0 dB

Excess insertion loss per coupler:

3 MHz < 0,4 dB

30 MHz < 0,3 dB

60 MHz < 0,5 dB

80 MHz < 0,7 dB

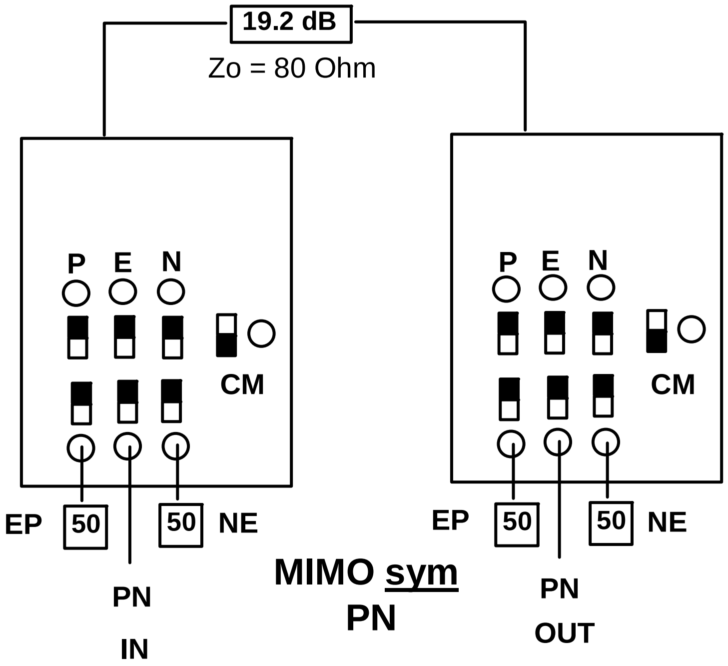
100 MHz < 2,4 dB

Figure 14: Coupler Settings: SISO

Table 2

Coupler Pad	MHz	3	10	30	60	80	100
01 to 02	-S21 PN-PN (dB)	21,7	21,7	21,4	21,8	23,5	25,2
A	-S21 NE-NE (dB)	21,7	21,8	21,5	21,7	22,6	24,1
	-S21 EP-EP (dB)	21,8	21,8	21,6	21,8	22,6	24,2
03 to 04	-S21 PN-PN (dB)	21,7	21,7	21,5	21,9	23,3	25,3
B	-S21 NE-NE (dB)	21,8	21,8	21,5	21,6	22,6	24,2
	-S21 EP-EP (dB)	21,8	21,8	21,6	21,7	22,4	24,1
05 to 06	-S21 PN-PN (dB)	21,8	21,8	21,5	21,9	23,6	25,7
C	-S21 NE-NE (dB)	21,8	21,8	21,6	21,8	22,8	24,4
	-S21 EP-EP (dB)	21,8	21,8	21,7	21,9	22,7	24,1
07 to 08	-S21 PN-PN (dB)	21,7	21,7	21,4	21,7	23,0	24,9
D	-S21 NE-NE (dB)	21,7	21,8	21,5	21,5	22,3	23,8
	-S21 EP-EP (dB)	21,8	21,8	21,7	21,8	22,3	23,6
09 to 10	-S21 PN-PN (dB)	21,7	21,7	21,4	21,9	23,3	24,3
E	-S21 NE-NE (dB)	21,8	21,7	21,5	21,4	22,1	23,5
	-S21 EP-EP (dB)	21,8	21,8	21,7	21,7	22,3	23,7
11 to 12	-S21 PN-PN (dB)	21,7	21,7	21,4	21,9	23,3	25,3
F	-S21 NE-NE (dB)	21,8	217	21,5	21,4	22,1	23,5
	-S21 EP-EP (dB)	21,8	21,8	21,7	21,8	22,3	23,7
13 to 14	-S21 PN-PN (dB)	21,8	21,8	21,5	21,9	23,3	25,2
G	-S21 NE-NE (dB)	21,8	218	21,6	21,6	22,2	23,6
	-S21 EP-EP (dB)	21,8	21,8	21,7	21,9	22,6	24,0

12.2 MIMO symmetric



Insertion loss with ideal coupler:

total: a = 23,3 dB

Excess insertion loss per coupler:

3 MHz < 0,9 dB

30 MHz < 0,6 dB

60 MHz < 0,8 dB

80 MHz < 1,2 dB

100 MHz < 2,1 dB

Figure 15: Coupler Settings: MIMO symmetric

Table 3

Coupler pad	MHz	3	10	30	60	80	100
01 to 02	-S21 PN-PN (dB)	24,8	24,7	24,5	24,8	25,4	26,5
A	-S21 NE-NE (dB)	24,8	24,7	24,5	24,6	24,7	25,3
	-S21 EP-EP (dB)	24,8	24,7	24,5	24,7	24,8	25,5
03 to 04	-S21 PN-PN (dB)	24,6	24,5	24,4	24,8	25,8	27,4
B	-S21 NE-NE (dB)	24,6	24,5	24,3	24,5	25,2	26,4
	-S21 EP-EP (dB)	24,6	24,5	24,3	24,4	25,1	26,4
05 to 06	-S21 PN-PN (dB)	24,6	24,6	24,3	24,8	25,7	27,1
C	-S21 NE-NE (dB)	24,6	24,5	24,3	24,6	25,2	26,6
	-S21 EP-EP (dB)	24,7	24,5	24,4	24,3	25,1	26,3
07 to 08	-S21 PN-PN (dB)	24,7	24,6	24,3	24,9	25,9	27,5
D	-S21 NE-NE (dB)	24,7	24,6	24,4	24,7	25,3	26,6
	-S21 EP-EP (dB)	24,7	24,6	24,4	24,7	25,2	26,3
09 to 10	-S21 PN-PN (dB)	24,6	24,5	24,3	24,7	25,4	26,8
E	-S21 NE-NE (dB)	24,7	24,5	24,3	24,5	25,0	26,4
	-S21 EP-EP (dB)	24,6	24,5	24,4	24,6	24,9	25,9
11 to 12	-S21 PN-PN (dB)	24,6	24,5	24,3	24,8	25,6	27,2
F	-S21 NE-NE (dB)	24,6	24,5	24,3	24,5	24,9	25,9
	-S21 EP-EP (dB)	24,6	24,5	24,3	24,6	25,0	26,1
13 to 14	-S21 PN-PN (dB)	24,7	24,6	24,4	24,8	25,7	27,1
G	-S21 NE-NE (dB)	24,7	24,6	24,4	24,6	24,9	26,0
	-S21 EP-EP (dB)	24,7	24,5	24,4	24,7	25,1	26,2

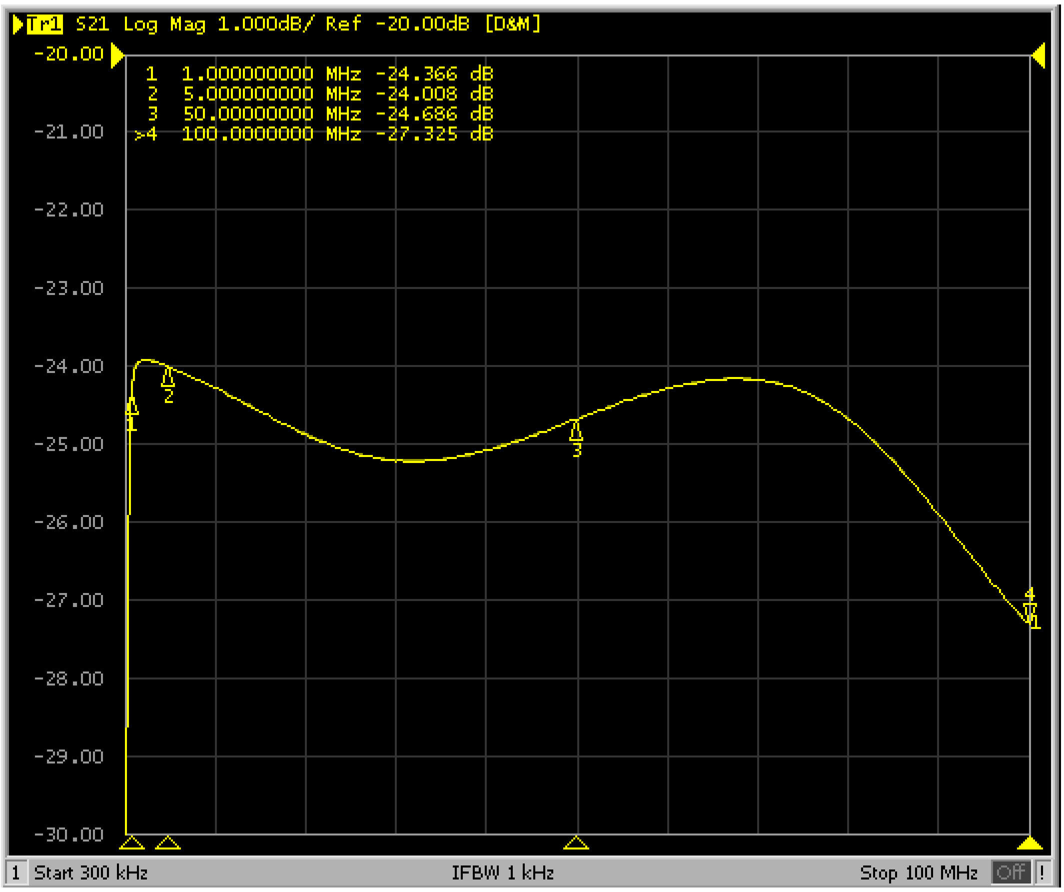
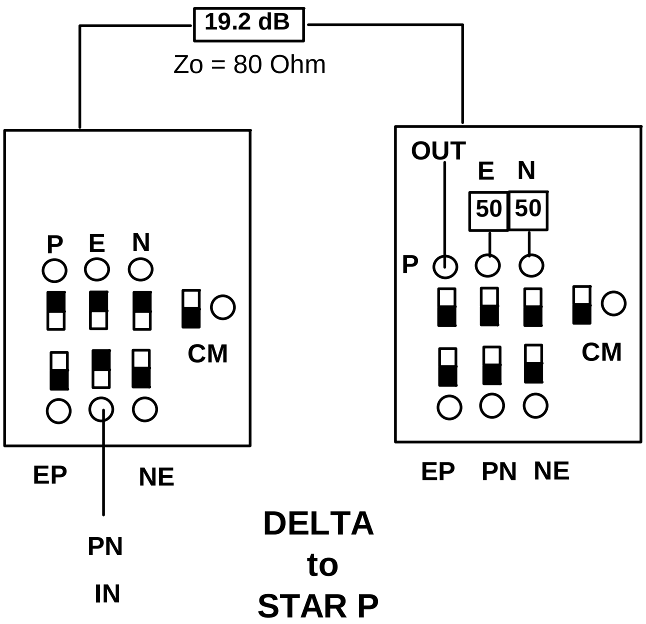


Figure 16: Frequency Sweep MIMO symmetric

12.3 MIMO Delta transmit to star receive



Insertion loss with ideal coupler:
total: a = 23,2 dB

Excess insertion loss per coupler:
(ex prototypes)
3 MHz < 0,4 dB
30 MHz < 0,3 dB
60 MHz < 0,5 dB
80 MHz < 0,7 dB
100 MHz < 2,1 dB

For **symmetric** MIMO feed the insertion loss increases by 1,5 dB
For **asymmetric** MIMO feed the insertion loss increases by 0,5 dB

Figure 17: Coupler Settings: MIMO delta Tx to star Rx

Table 4

Coupler pad	MHz	3	10	30	60	80	100
01 to 02	-S21 PN to P (dB)	25,4	25,2	25,3	25,5	26,7	27,3
A	-S21 PN to N (dB)	25,4	25,3	25,3	25,2	26,3	26,8
prototype	-S21 PN to E (dB)	69	67	63	59	58	56
03 to 04	-S21 PN to P (dB)	23,7	23,7	23,5	24,5	25,6	27,2
B	-S21 PN to N (dB)	23,9	23,9	23,5	24,3	25,6	27,3
	-S21 PN to E (dB)	58	57	51	44	43	42
05 to 06	-S21 PN to P (dB)	23,7	23,7	23,6	24,5	25,3	26,8
C	-S21 PN to N (dB)	23,9	23,9	23,6	24,3	25,4	26,9
	-S21 PN to E (dB)	58	59	54	44	43	44
07 to 08	-S21 PN to P (dB)	23,8	23,7	23,7	24,5	25,8	27,4
D	-S21 PN to N (dB)	24,0	23,9	23,6	24,4	25,4	27,0
	-S21 PN to E (dB)	59	63	67	53	52	50
09 to 10	-S21 PN to P (dB)	23,7	23,7	23,7	24,6	25,5	27,3
E	-S21 PN to N (dB)	23,9	23,9	23,6	23,9	24,2	25,4
	-S21 PN to E (dB)	58	61	57	49	45	42
11 to 12	-S21 PN to P (dB)	23,7	23,7	23,6	24,7	25,8	27,4
F	-S21 PN to N (dB)	24,0	23,9	23,6	24,3	24,3	26,9
	-S21 PN to E (dB)	62	61	59	65	55	51
13 to 14	-S21 PN to P (dB)	23,7	23,7	23,6	24,6	25,7	27,3
G	-S21 PN to N (dB)	24,0	24,0	23,7	24,2	25,0	26,4
	-S21 PN to E (dB)	61	74	64	59	67	60

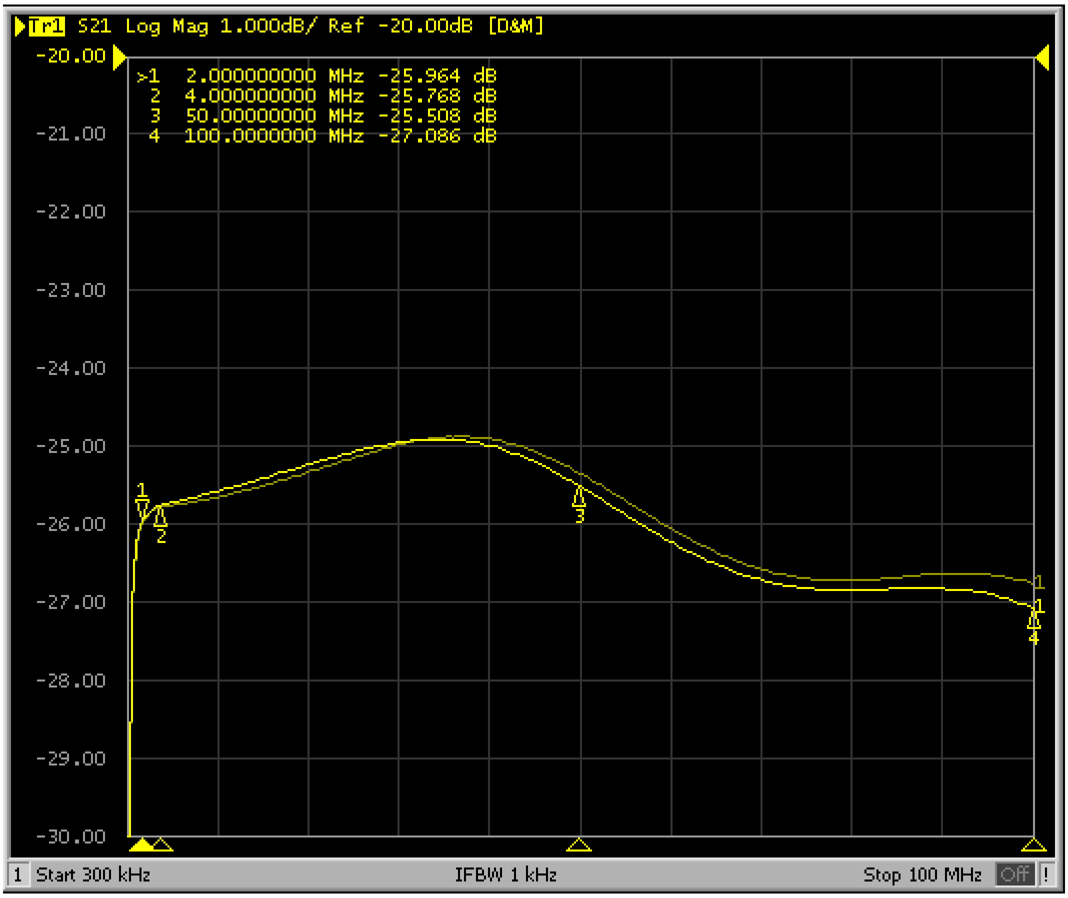
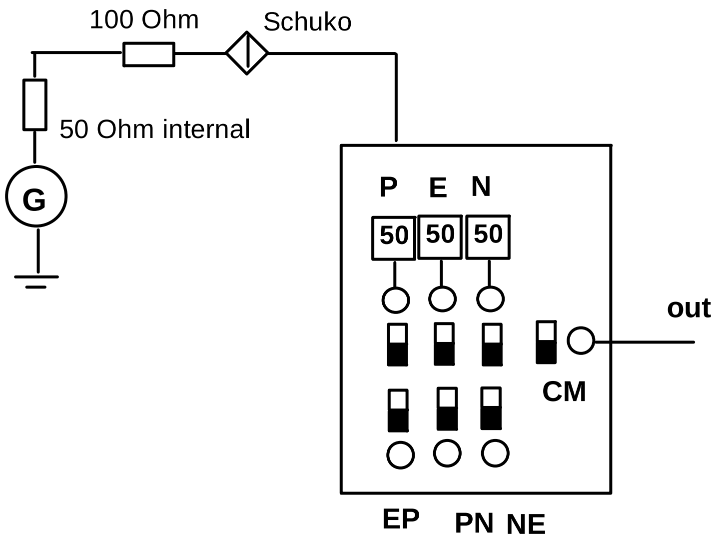


Figure 18: Frequency Sweep MIMO delta Tx to star Rx

12.4 Common mode Reception



Insertion loss of test setup with ideal coupler:
total: a = 4,9 dB

Absorption and mismatch of coupler:

3 MHz	3,7 dB
10 MHz	3,2 dB
30 MHz	< 3,8 dB
60 MHz	< 4,6 dB
80 MHz	< 5,6 dB
100 MHz	< 6,2 dB

Linear approximations:Correction for channel (- S_{21}) of "any DM" to CM transmission:
eff. **- S_{21}**) = measured - (2,8 - f (MHz)/ 30)

Correction for channel (- S_{21}) of CM to CM transmission:
eff. **- S_{21}**) = measured - (5,6 - f (MHz)/ 15)

Correction for k-factor (radiation)
eff. k-factor = measured + (2,8 + f (MHz)/ 30)

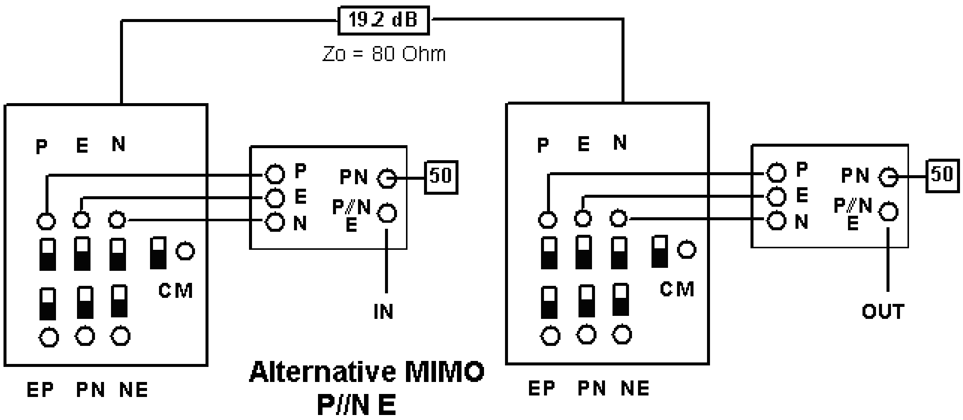
Figure 19: Coupler Settings: CM reception

Table 5

Coupler	MHz	3	10	30	60	80	100
01	-S21	9,2	8,7	9,2	9,7	10,5	11,0
02	-S21	9,2	8,7	9,2	9,9	10,8	11,4
03	-S21	8,6	8,1	8,7	9,4	10,4	11,0
04	-S21	8,6	8,1	8,6	9,4	10,4	10,9
05	-S21	8,6	8,1	8,6	9,4	10,2	10,8
06	-S21	8,6	8,1	8,6	9,4	10,4	11,0
07	-S21	8,6	8,1	8,6	9,3	10,1	10,7
08	-S21	8,6	8,1	8,6	9,4	10,2	10,9
09	-S21	8,6	8,1	8,6	9,2	10,1	10,6
10	-S21	8,6	8,1	8,6	9,5	10,5	11,1
11	-S21	8,6	8,1	8,6	9,4	10,2	10,8
12	-S21	8,6	8,1	8,7	9,3	10,2	10,8
13	-S21	8,6	8,1	8,6	9,5	10,5	11,1
14	-S21	8,6	8,1	8,6	9,4	10,3	10,9

Figure 20: Probe in CM reception mode

12.5 Alternative MIMO modes (dual wire feed)



Comparative losses respect to previous MIMO symmetric injection (clause 12.2) in PN-PN mode (coupler/pad - 11 to 12/F):

3 MHz -1,6 dB
30 MHz -1,3 dB
60 MHz -0,2 dB
80 MHz +1 dB (see note)
100 MHz +2,1 dB (see note)

NOTE: The attenuation increment at higher frequencies comes from the 18 pF capacitors at P, E, N ports of the coupler.

Figure 21: Coupler Settings: MIMO symmetric

Table 6

Coupler pad	MHz	3	10	30	60	80	100
11 to 12	-S21 PN-PN (dB)	23,0	22,8	23	24,6	26,6	29,3
F	-S21 P//N E-P//N E (dB)	23,9	23,8	24,0	24,9	26,6	29,6

Annex A: Bibliography

Terms of Reference for Specialist Task Force STF 410 (TC PLT) on "Measurements to Verify Feasibility of MIMO PLT". Version: 1.1, 6 May 2010.

History

Document history		
V1.1.1	May 2011	Publication as TR 101 562
V1.2.1	August 2011	Publication