ETSI TR 101 562 V1.1.1 (2011-05)

Technical Report

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

Reference
DTR/PLT-00033

Keywords
coupling, MIMO, powerline

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Contents

Intellectual Property Rights

IPRs essential or potentially essential to the present document may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (http://webapp.etsi.org/IPR/home.asp).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Foreword

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

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 present document describes the universal couplers used for feeding and receiving MIMO PLT signals. The other TRs created by STF410 utilize the couplers described here.

1 Scope

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

[i.2] 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.3] A. Schwager: "Powerline Communications: Significant Technologies to become Ready for Integration" Doctoral Thesis at University of Duisburg-Essen, May 2010.

3 Symbols and abbreviations

3.1 Symbols

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

dB	decibel (logarithmic unit)
dBm	$10 * \log_{10} (P / 1 \text{ mW})$
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:

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
PLT	PowerLine Telecommunications
PN	connection P to N
Rx	Receive
S	Switch
SISO	Single Input Single Output
STF	Special Task Force
sym	symmetrical
t	Turns
T	Transformer
TR	Technical Report
Tx	Transmit

4 Major Project Phases

Table 1

No.	Period	Topic	Event
01	Jan. 2010	1st version of the present document for STF 410 internal use	14 identical couplers are manufactured and shipped to the STF experts.
02	Feb 2010 and later	Verification of couplers	Couplers are used by STF410 expert in field measurements in private homes.

5 Motivation

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

Further descriptions of:

- motivation for MIMO PLT;
- installation types and the existence of the PE wire in private homes;
- measurement setup description to record throughput communication parameters and their result;

can be found in the further documents published by STF410.

6 MIMO PLT Universal Coupler

Figure 1: Photograph of coupler from top

Figure 2: 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).

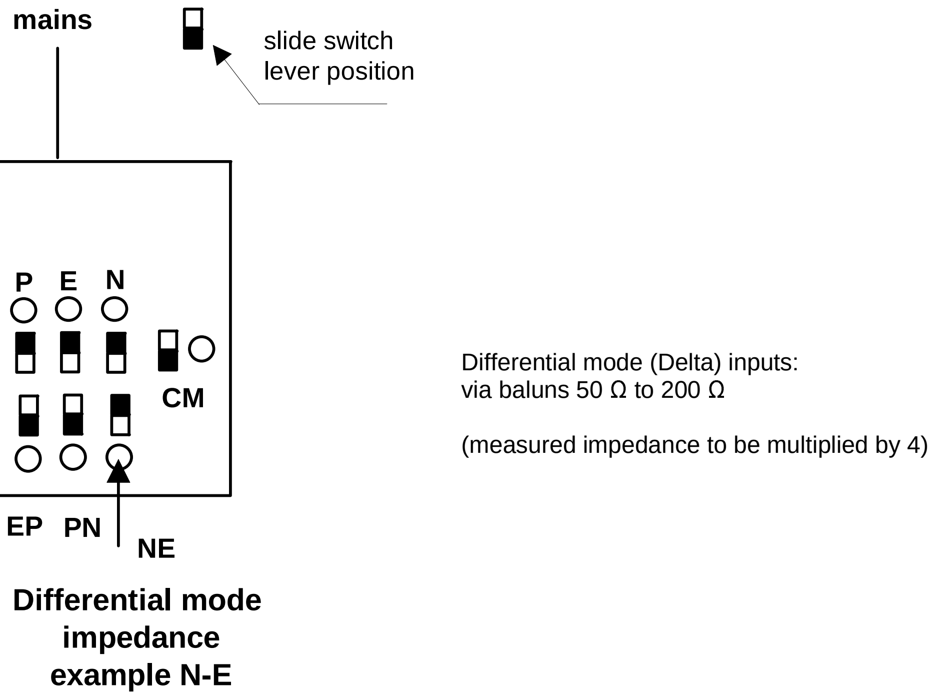


Figure 3: Coupler in impedance measurement mode

Common mode (CM) inputs:

- via balun 50 Ω to 200 Ω.

Star inputs (P, N, E):

- direct 50 Ω in each leg.

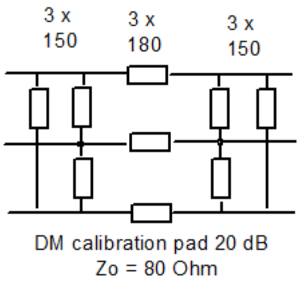
Characteristic impedance of mains cable, third conductor open circuited:

- 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.



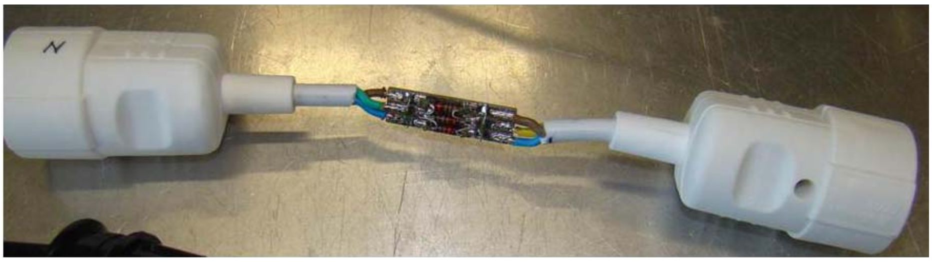


Figure 4: Test pad: Schematic and photo

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)

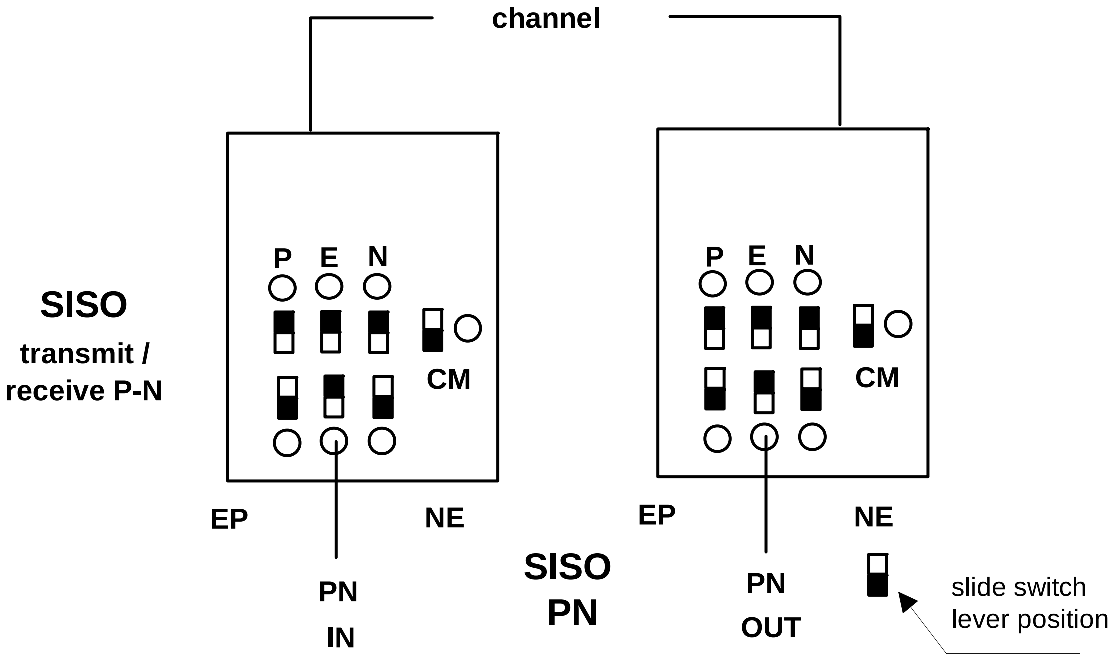


Figure 5: Coupler in SISO attenuation measurement mode

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

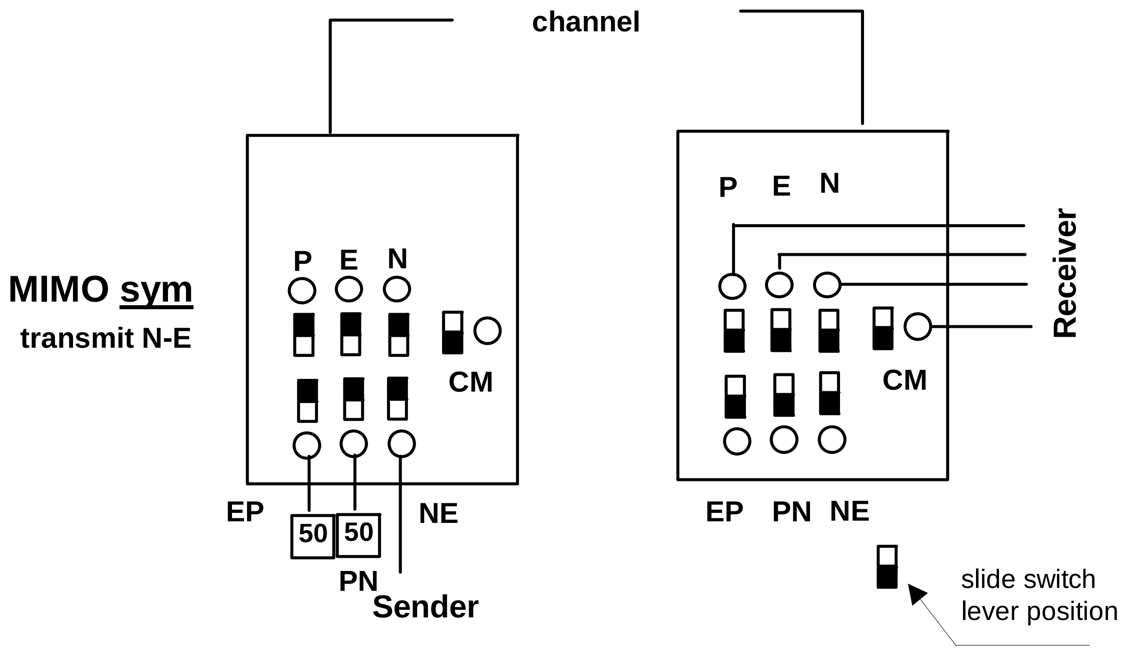


Figure 6: Coupler in MIMO symmetric transmit and MIMO receive (star plus CM) mode

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

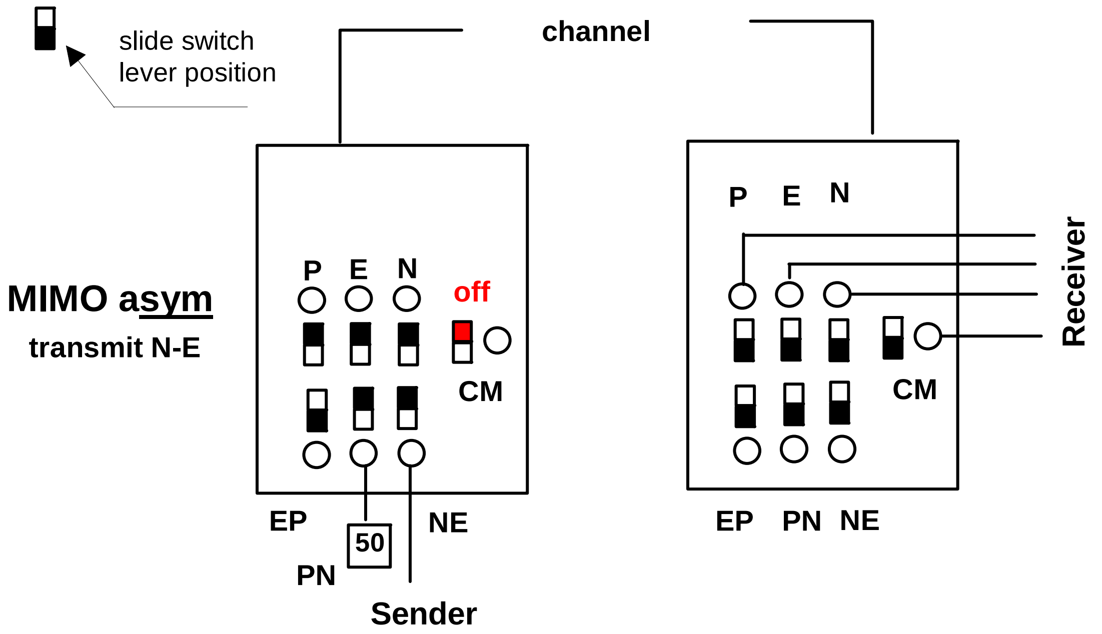


Figure 7: Coupler in MIMO asymmetric transmit and MIMO receive (star plus CM) mode

10.4 SISO common mode transmit and SISO common mode receive

(Not a proposal for practical deployment.)

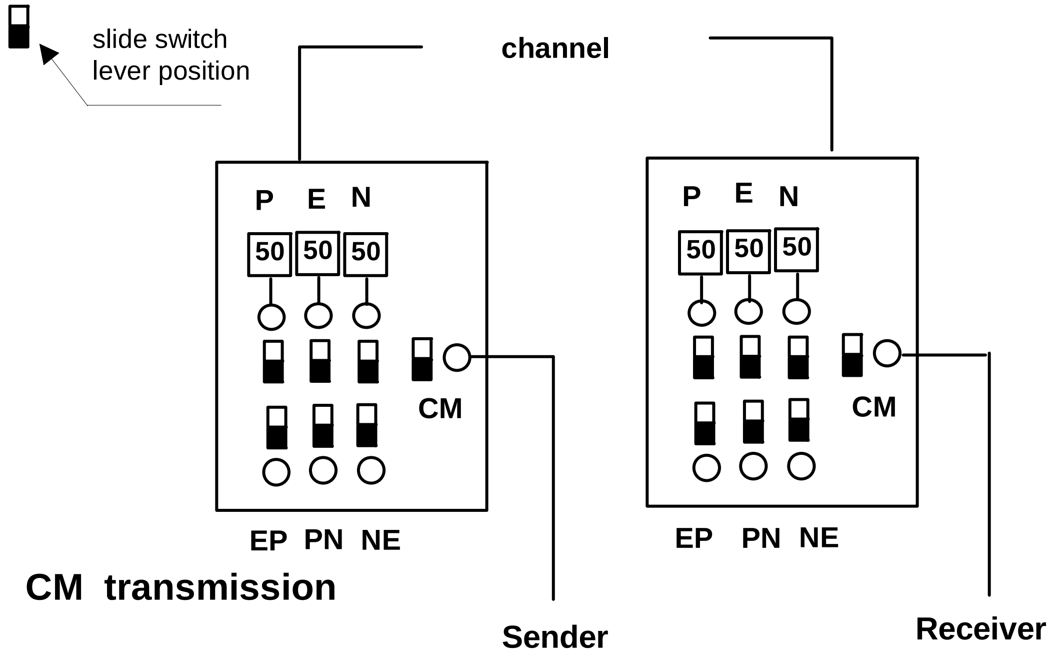


Figure 8: Coupler in SISO common mode transmit and receive mode

10.5 Alternative MIMO mode using dual wire feed

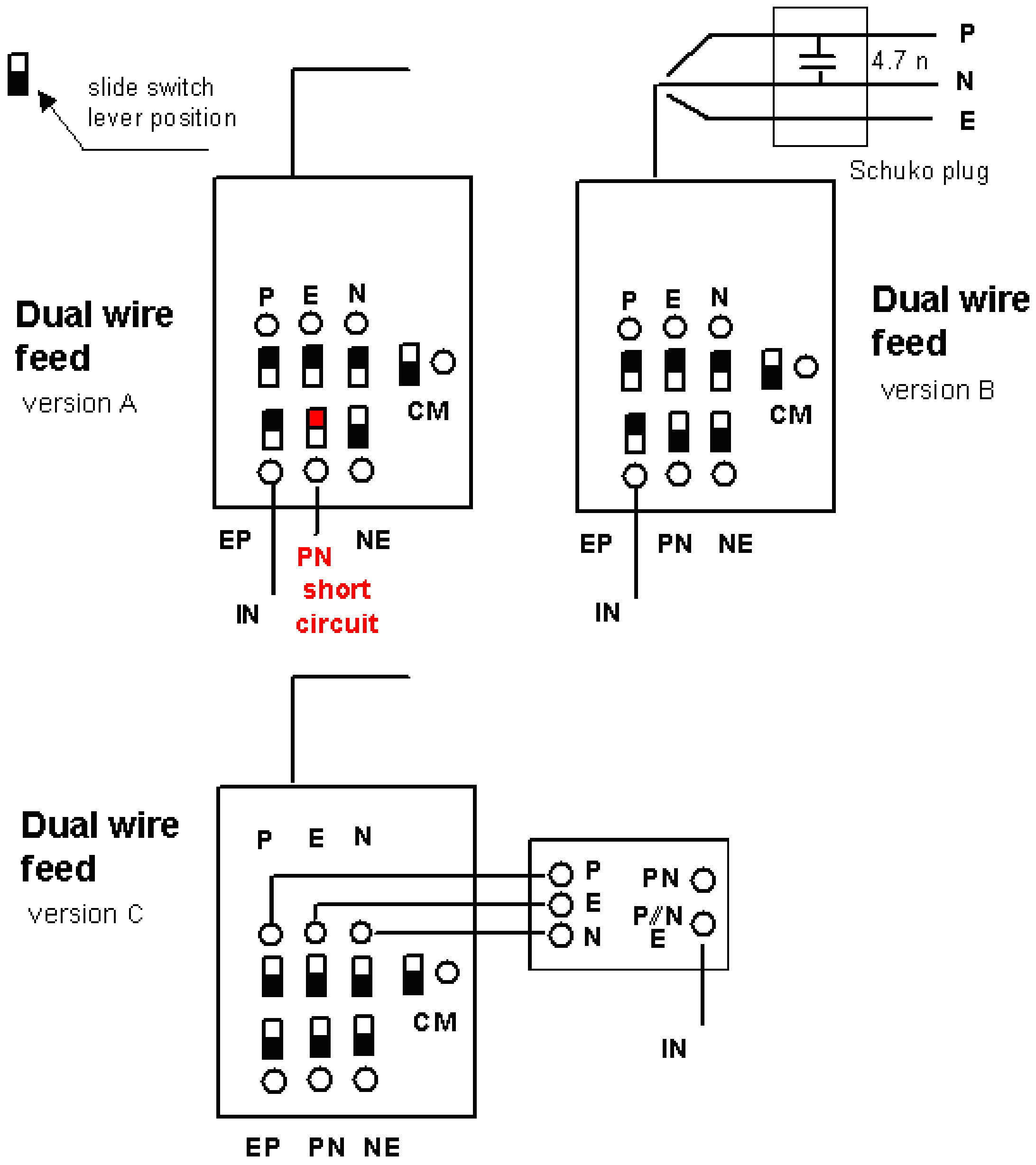


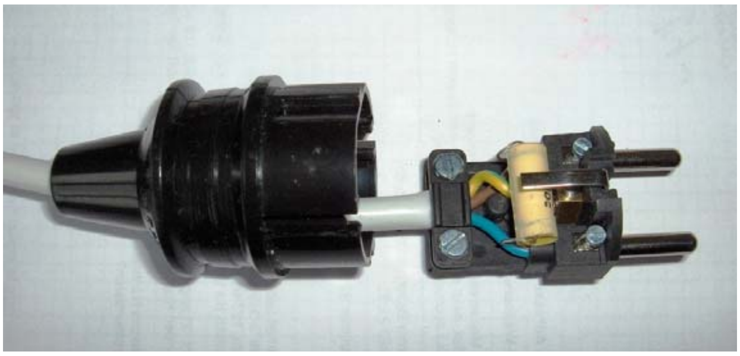
Figure 9: Coupler in dual wire feed mode

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 10: 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.

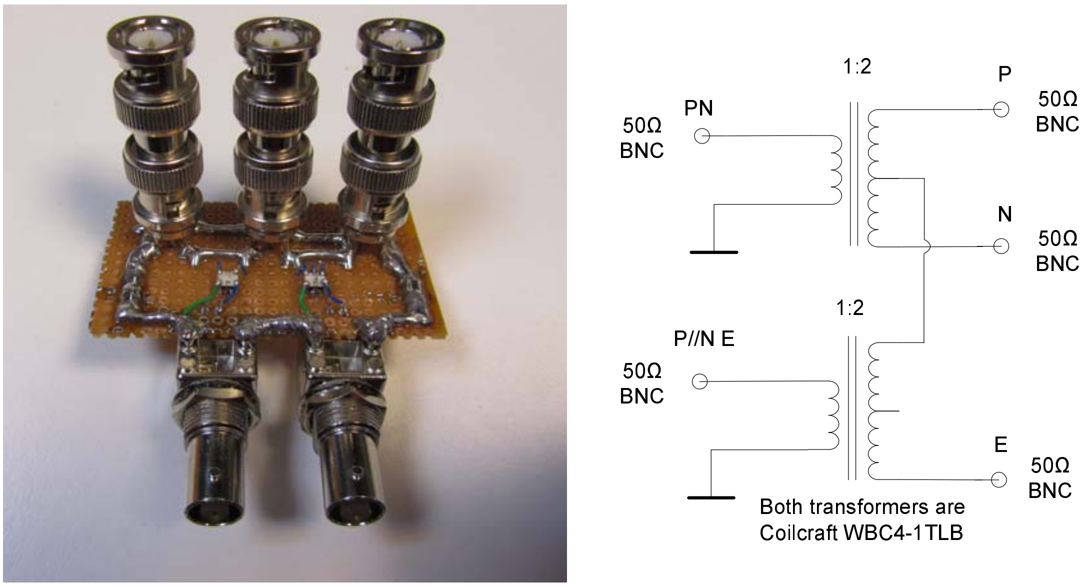


Figure 11: Coupler extension in dual wire feed version C mode

11 Circuit diagram

The center point C in the schematic diagram in figure 11 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.

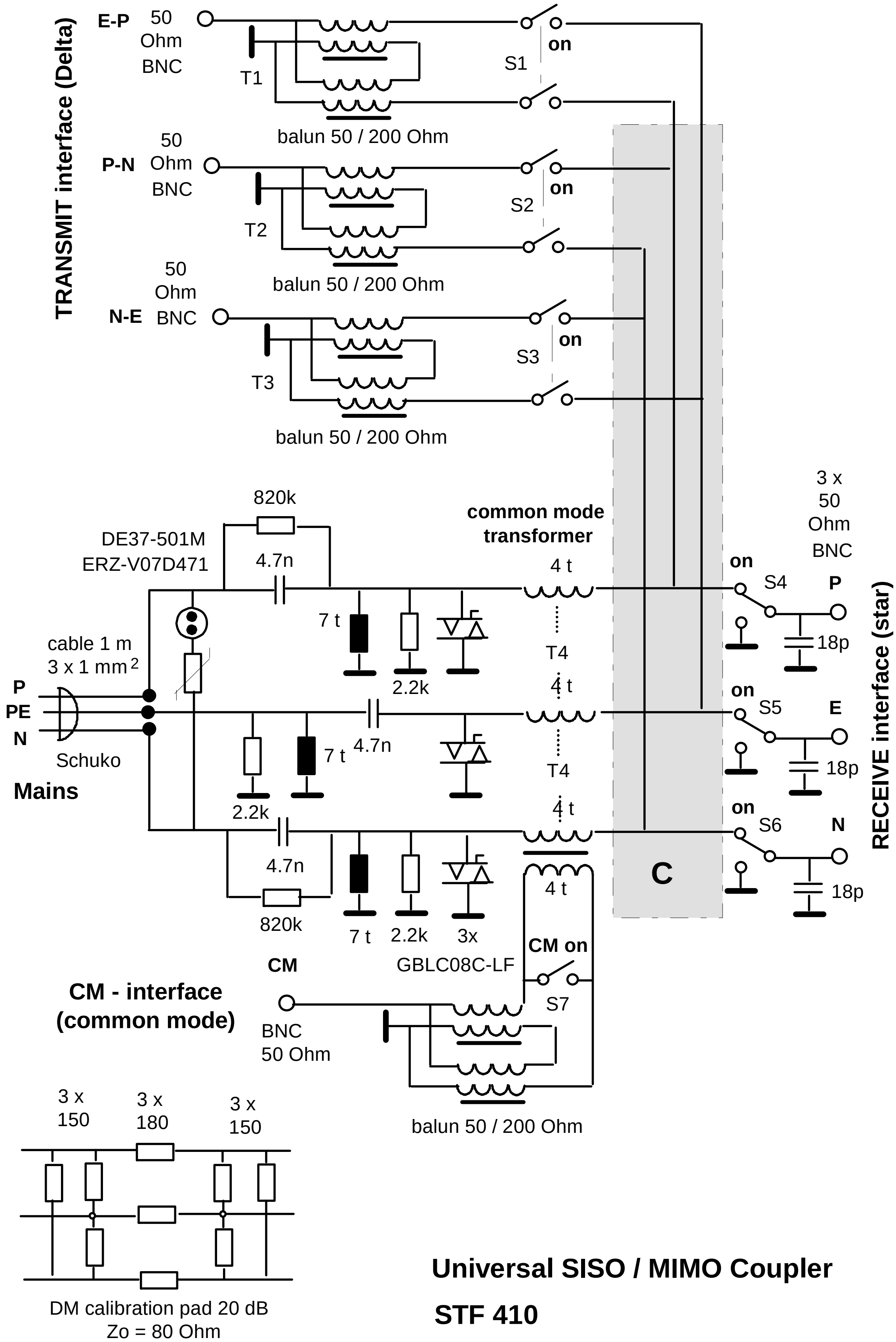
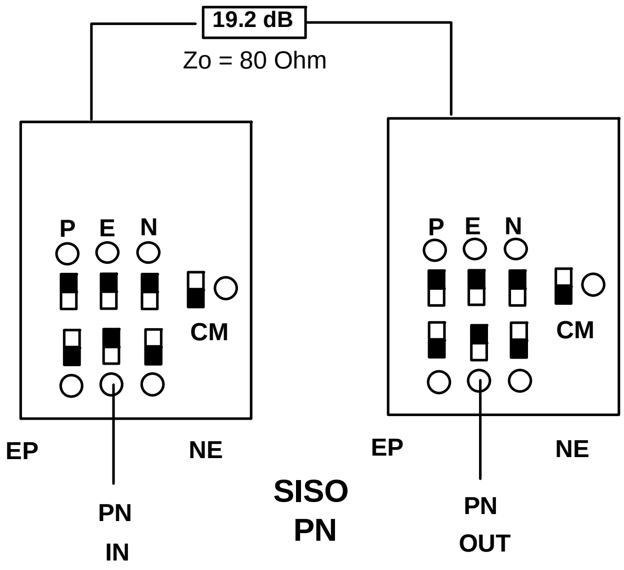


Figure 12: Coupler schematic

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

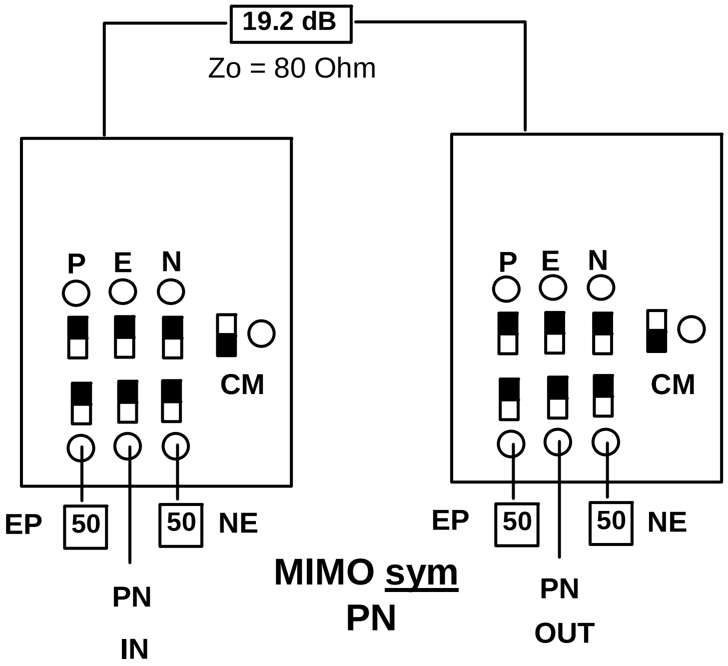
100 MHz < 2,4 dB

Figure 13: 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 14: 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

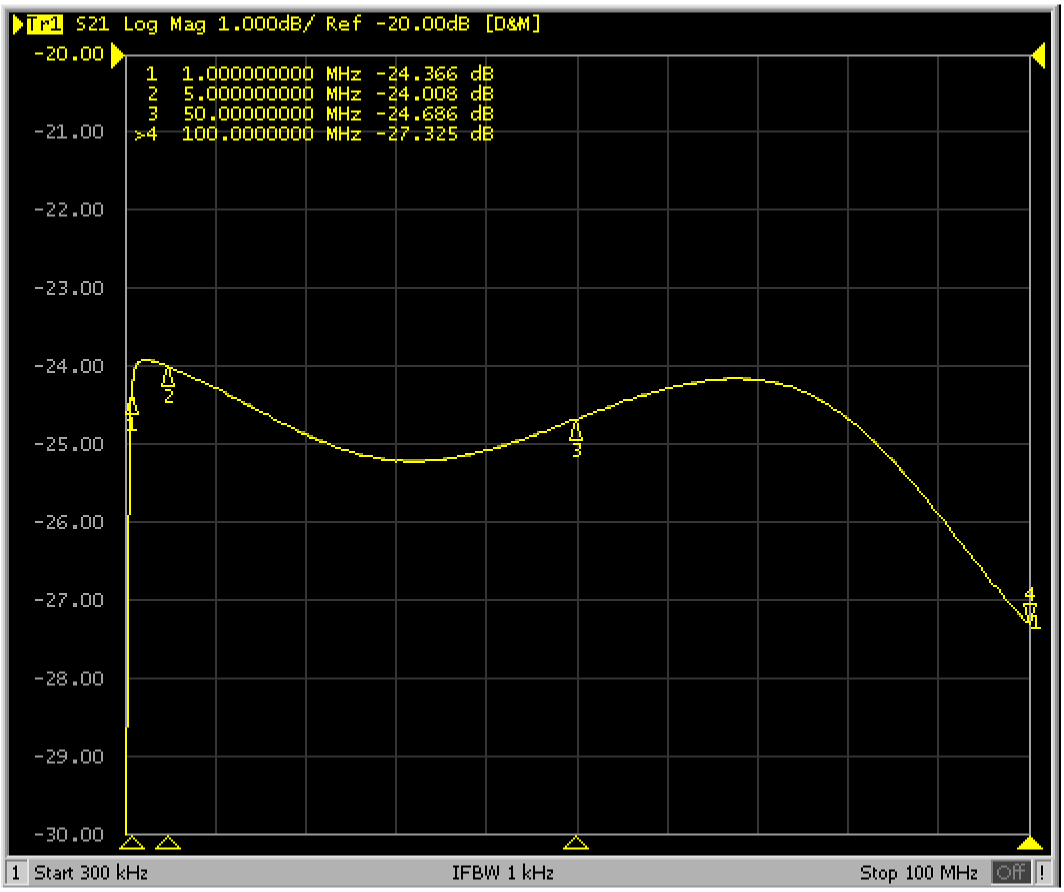
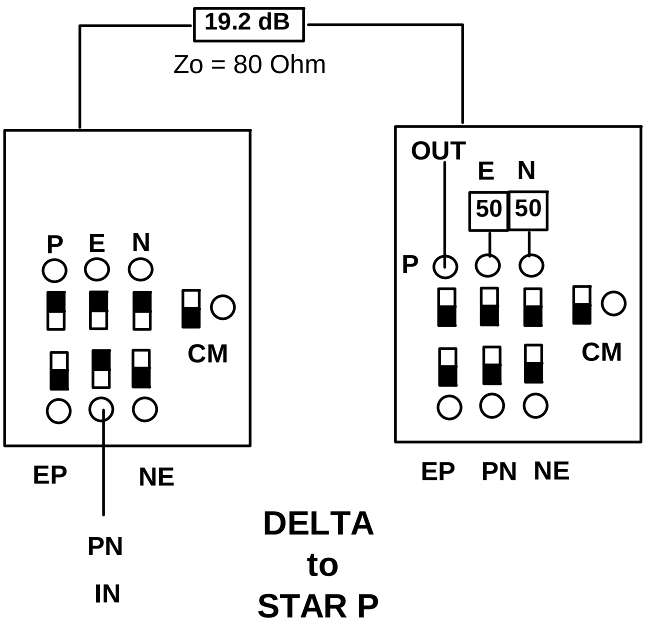


Figure 15: Frequency Sweep MIMO symmetric

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 16: 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

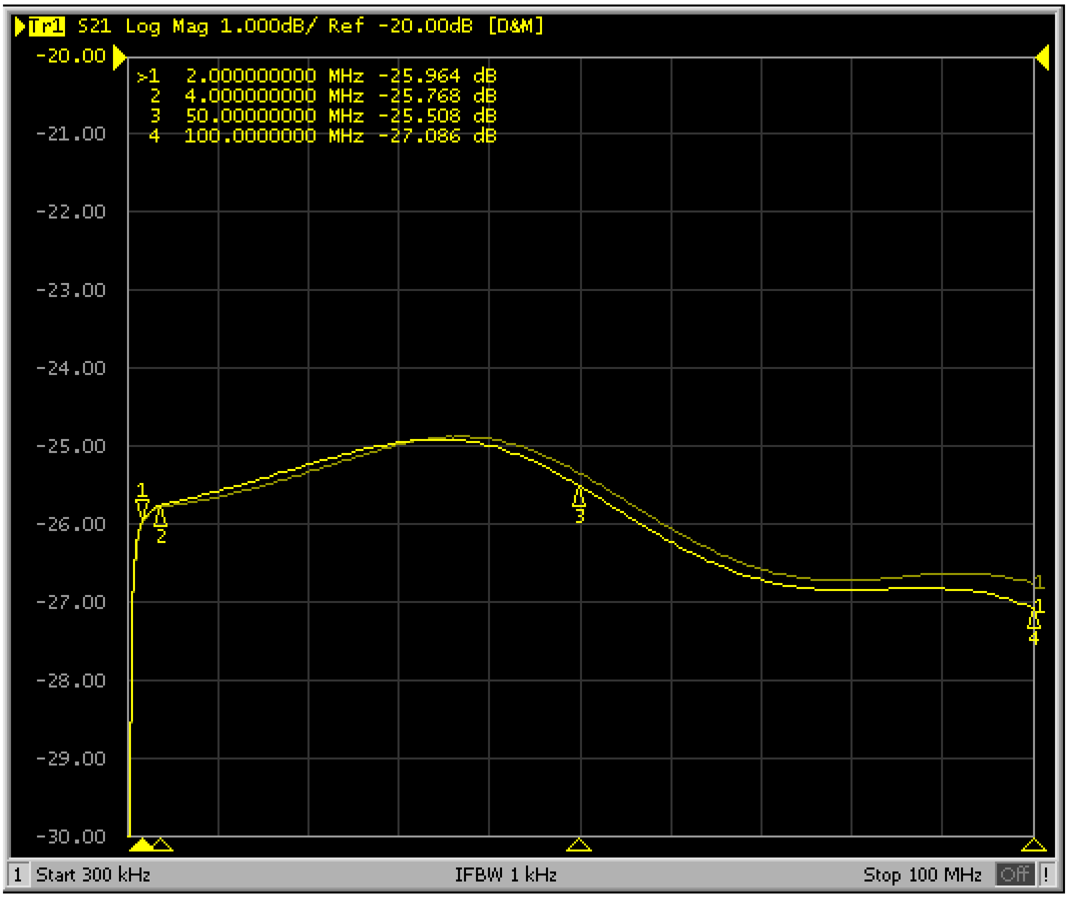
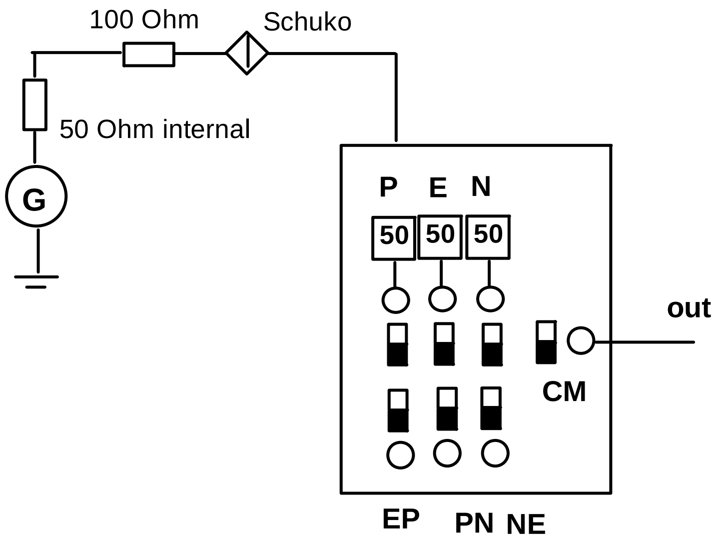


Figure 17: Frequency Sweep MIMO delta Tx to star Rx

12.4 Common mode Reception



Insertion loss with ideal coupler:
total: a = 5,3 dB

Absorption and mismatch
per coupler:
(ex prototypes)
3 MHz < 3,3 dB
30 MHz < 3,4 dB
60 MHz < 4,2 dB
80 MHz < 5,2 dB
100 MHz < 5,8 dB
this loss has no impact on the receive function!

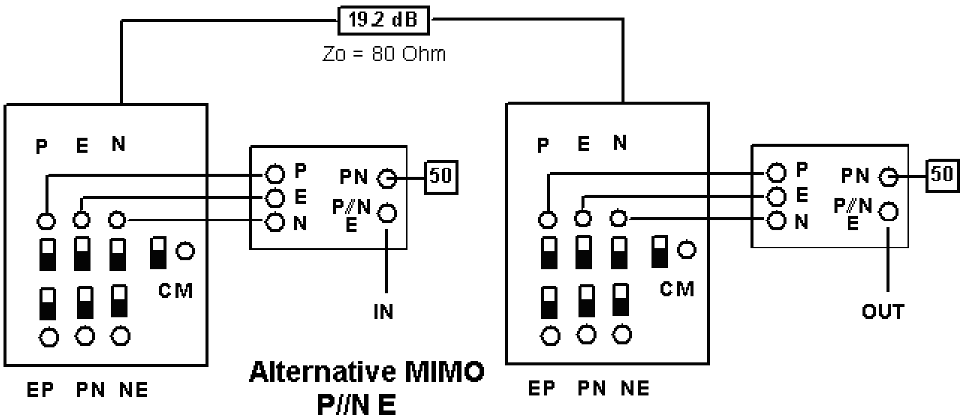
Figure 18: Coupler Settings: CM reception

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 19: Probe in CM reception mode

12.5 Alternative MIMO modes (dual wire feed)



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

3 MHz -1,6 dB
30 MHz -1,3 dB
60MHz -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 18pF capacitors at P, E, N ports of the coupler.

Figure 20: 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