# COUPLING UNIT FOR PLC SYSTEMS
# OVER HIGH-VOLTAGE LINES

## DESCRIPTION OF UAM-4

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# 1 INTRODUCTION

## 1.1 GENERAL

The coupling units allow, in conjunction with coupling capacitors, the transmission of carrier frequency signals over high-voltage power lines and, at the same time, offer an efficient protection against the effects of the power frequency voltage and transient overvoltages for personnel and equipment.

The UAM-4 unit is used for coupling Power-Line Carrier (PLC) equipment to a single phase of high-voltage power lines, carrying out the following:

- Tuning of coupling capacitor to minimize the coupling impedance, in such a way as to enhance the signal transmission at carrier frequencies.
- Impedance matching between power line and communication equipment, allowing matching at very low line impedance as in the case of the underground cables.
- Draining to earth of power frequency current, limitation of voltage surges coming from the power line and earthing of the coupling device for protection purposes.

There are two versions of the UAM-4. In the UAM-4 version, the protection elements are to be found on the outside of the cabinet. The UAM-4/D version also has a solid-state surge arrester.

The UAM-4 units can be used for phase-to-earth, phase-to-phase or three-phase couplings indistinctly. One UAM-4 unit is used for phase-to-earth coupling. Two UAM-4 units are required for phase-to-phase coupling, the two units being connected through a differential transformer acting as a hybrid circuit. If it is not necessary to guarantee the transmission when there is a fault in a phase, the connection can be made in parallel by means of a coaxial cable. However, the parallel connection may not be suitable for very low line impedance, such as in the case of the underground cables, where it could be necessary to use a differential transformer.

Three UAM-4 units and two hybrid circuits are needed for three-phase coupling.

## 1.2 CONSTITUTION

The UAM-4 coupling unit consists of three basic blocks which contain protection, tuning and impedance matching elements. Figure 1 shows the circuit diagram of the UAM-4.

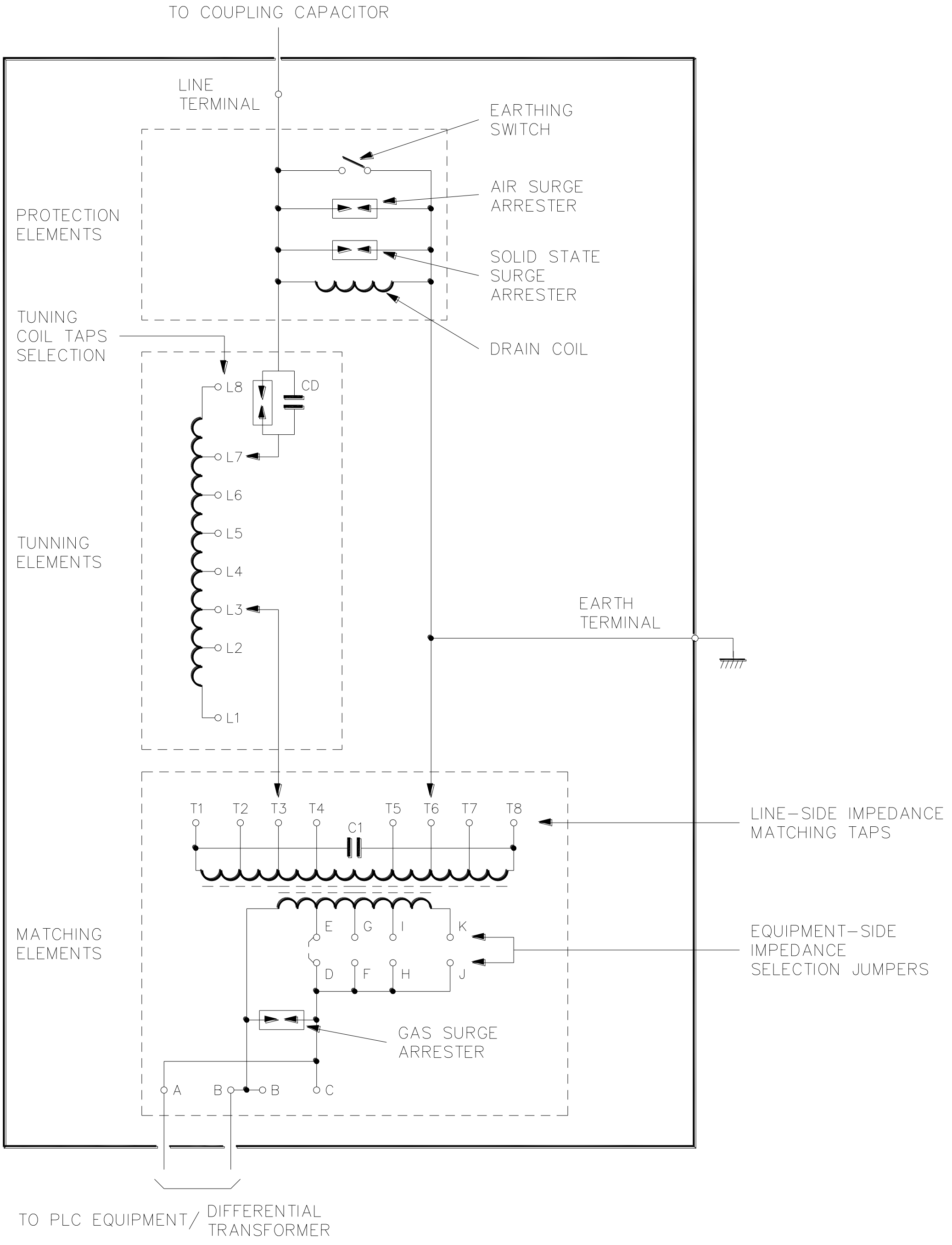



Figure 1 UAM-4 coupling unit circuit diagram

### 1.2.1 Protection elements

Line side, this block is made up of the drain coil, the earthing switch, the air surge arrester and the solid-state surge arrester. The latter, however, is not included in the UAM-4 version.

Equipment side, it comprises a gas surge arrester connected between the isolating transformer equipment-side terminals. The purpose of this surge arrester being to protect the PLC equipment.

The drain coil has an air core to minimize intermodulation, and is wound on a multisection coil former to reduce the distributed capacitance. In the UAM-4 and UAM-4/D versions it also carries out the function of connecting the unit to the coupling capacitor. The coil is moulded in an epoxide resin block, which also holds the earthing switch in the UAM-4 and UAM-4/D versions.

### 1.2.2 Tuning elements

Tuning elements of the UAM-4 coupling units consist of two resonant circuits forming a band-pass filter. The first circuit is made up of the leakage inductance of the matching transformer and a capacitor connected between the transformer line-side winding terminals. The second resonant circuit comprises the coupling capacitor and the tuning inductance (variable in steps).

According to IEC 481 Recommendations, the bandwidth is defined as the pass band within which composite loss is lower than 2 dB and return loss is greater or equal to 12 dB. The latter condition is more stringent as composite loss in points with return loss of 12 dB is normally lower than 1 dB. Bandwidth increases with frequency, capacitance value and line impedance. The tuning coil is provided with 8 taps to tune the coupling capacitor at different frequencies.

### 1.2.3 Matching unit

It consists of the isolating transformer, which matches the primary impedance of the phase-to-earth coupling, line side, to the secondary one, equipment side. Primary winding is referred to earth whereas the secondary one is balanced.

Line impedance matching is carried out by means of the primary-winding taps, which allow one of the 17 line impedance nominal values available to be selected, whilst one of the four secondary-winding jumpers is used for equipment impedance matching.

## 1.3 UAM-4 VERSIONS

According to the arrangement of the protection elements, the coupling units are presented in the two following versions:

UAM-4 It consists of an aluminium cabinet for outdoor mounting with only one compartment. The drain coil is mounted on the outside, together with the earthing switch.

UAM-4/D It is exactly the same as the UAM-4 but also has a solid-state surge arrester (see Figure 2).

## 1.4 HYBRID CIRCUITS

The connection of the UAM-4 units used in a phase-to-phase or three-phase coupling is carried out, respectively, by means of one or two differential transformers acting as a hybrid circuit. The use of the said circuits allows links to be designed that are fault tolerant, which means that if one or more phases fail only a moderate additional attenuation is introduced in the link.

The hybrid circuit is made up of a differential transformer, with a 1:√2 turn ratio between primary and secondary windings, and a resistor, the value of which is half that of the nominal impedance of the equipment, connected between the centre tap of the secondary-winding and the point where the shield of the coaxial cables is connected. This resistor only dissipates power if one of the phases used fails.

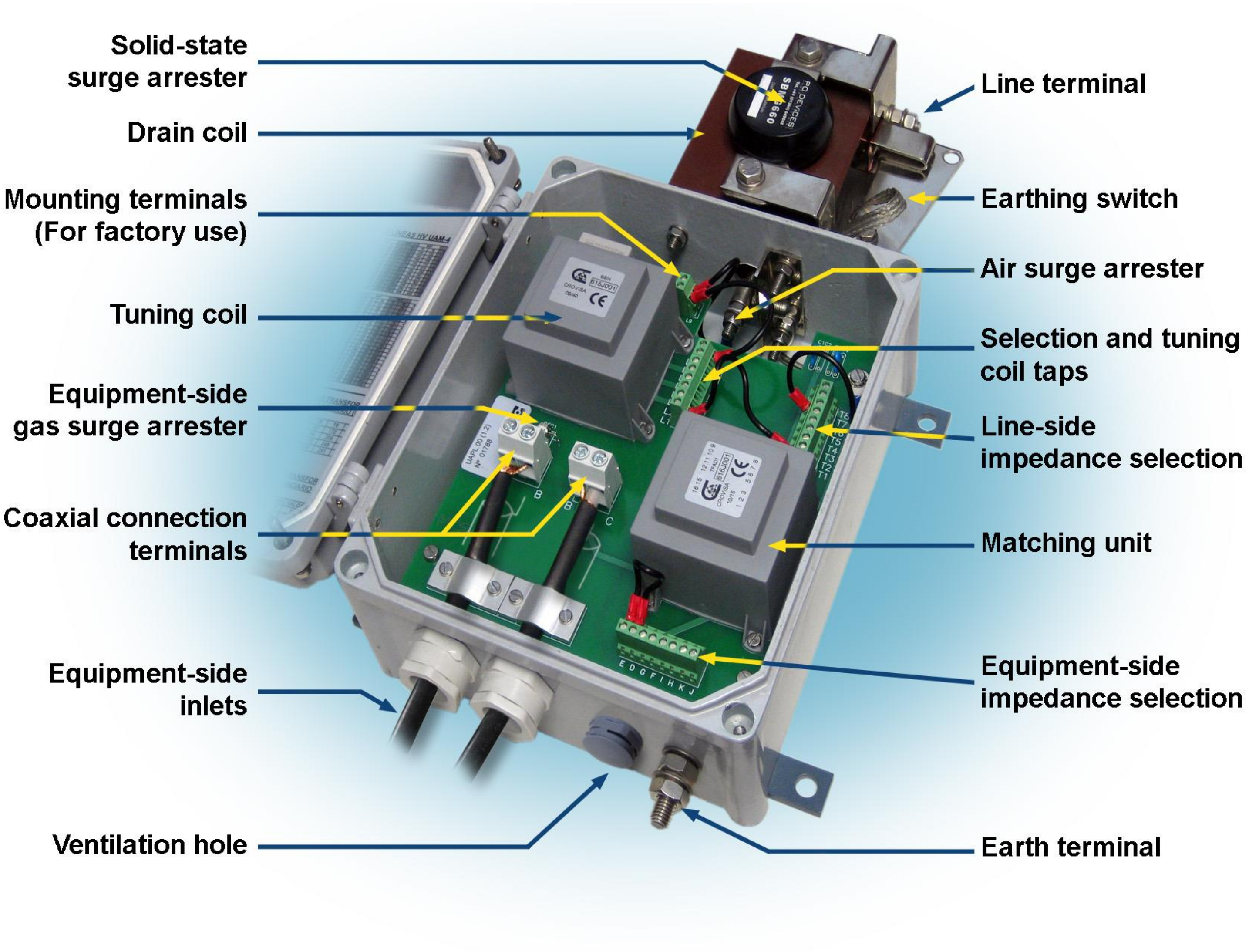



Figure 2 UAM-4/D coupling unit

## 1.5 TECHNICAL CHARACTERISTICS

### 1.5.1 Electrical characteristics

| | |
|---|---|
| Frequency range | 40 ÷ 500 kHz |
| Coupling capacitor | 2 to 10 nF |
| Nominal peak-envelope power (PEP) | 400 W for two tones |
| Nominal impedance | |
| Equipment side | 75, 125, 150 and 250 Ω, selected by jumpers. Others on request. |
| Line side | 25 to 750 Ω, selected by tap connection |
| Distortion and intermodulation | 80 dB below the level corresponding to the nominal PEP (IEC 481, cls. 9.6) |
| Bandwidth (corresponding to return loss >12 dB and composite loss <2 dB) | See figures of section 4.2.1, *Tuning* |
| Power frequency insulation | >5 $kV_{rms}$ (IEC 481, cls. 8.1) |
| Impulse voltage insulation | >2 $kV_{rms}$ (IEC 481, cls. 8.2) |
| Insulation between the UAM-4 connection terminals and chassis | >1.5 $kV_{rms}$/50 Hz |

### 1.5.2 Protection elements

Air surge arrester

| | |
|---|---|
| Nominal sparkover voltage | 1 $kV_{rms}$ |
| Impulse discharge current | >5 kA (8/20 µs) |

Solid-state surge arrester
(not included in UAM-4 version)

| | |
|---|---|
| Model | SBMG660 |
| Nominal voltage | 660 $V_{rms}$ |
| Impulse discharge current | 5 kA (8/20 µs) |

Equipment-side gas surge arrester

| | |
|---|---|
| Model | CG2-350L |
| Nominal voltage | 350 $V_{rms}$ |
| Impulse discharge current | 20 kA (8/20 µs) |

Drain coil

| | |
|---|---|
| Impedance | |
| from 40 kHz to 65 kHz | ≥5 kΩ |
| from 65 kHz to 500 kHz | ≥8 kΩ |
| Nominal inductance | 26 mH |
| Nominal resistance | 7 Ω |
| Maximum impedance at power frequency | 13 Ω |
| Current carrying capacity at power frequency | 1 $A_{rms}$ permanently.<br>50 $A_{rms}$ for 0.2 s |

Earthing switch

| | |
|---|---|
| Permanent current capacity | 150 $A_{rms}$ |

### 1.5.3 Mechanical characteristics

| | |
|---|---|
| Fixing | By four Ø 8.5 mm holes |
| Connection to line (coupling capacitor) | By means of M8 rod |
| PLC equipment side connection | By means of cable glands type PG-21, suitable for cables of between 9 and 18 mm diameter |
| Connection to earth | By means of M10 rod |
| Selection terminals | Internal. Suitable for conductors of 0.3 to 1 mm$^2$ |
| Equipment-side connection terminals | Internal. Suitable for flexible conductors of 0.5 to 10 mm$^2$ and rigid conductors of 0.5 to 16 mm$^2$ |
| Ventilation | By means of a hole with TVMP01UH type device |
| IP protection level | According to IP54 UNE 20.324-93 |
| Operating temperature range | From –25 °C to +60 °C |
| Type of finish | Outdoor polyester powder paint, metallic grey (BJC Ref. B-8515) |
| Dimensions | |
| UAM-4 and UAM-4/D | Height: 264 mm; Width: 214 mm; Depth: 132 mm |
| Weight | |
| UAM-4/D | 6.5 kg |

# 2 LINE COUPLING

The main types of line couplings used nowadays are phase-to-earth, phase-to-phase and three-phase coupling. This section gives a brief description of each one.

Phase-to-earth coupling requires less equipment, so it is widely used for short-lines and links which do not require high reliability under line fault. In this type of coupling, the PLC equipment is connected between a phase-conductor and earth, thus requiring a single coupling capacitor, one line trap, and one coupling unit at each end of the link. Although coupling is only carried out in one phase, the other conductors are also involved in the transmission, so that attenuation due to high loss of earth is partly bypassed. Nevertheless, this coupling offers the worst attenuation figures, and is the least reliable in case of line fault.

Phase-to-phase coupling is based on distributing the transmitted power equally between the two phase conductors used. This transmission mode reduces the attenuation at PLC frequency. The drawback is that at least twice as much equipment is required as for phase-to-earth coupling.

Link reliability against line faults can be increased by insulating the signals injected in the phase conductors, by means of a differential transformer acting as a hybrid circuit (see Figure 3). This is the operating principle of the phase-to-phase coupling with connection through a differential transformer. When there is a fault in one of the phase conductors used, the other conductor works as a phase-to-earth coupling, with an additional attenuation of 6 dB.

If this reliability is not required, the connection between the two coupling units can be carried out with a cable, so called a phase-to-phase coupling with parallel connection. However, for very low line impedance, such as in the case of the underground cables, the parallel connection may not be suitable, where a differential transformer may be needed.

Three-phase coupling consists of injecting the carrier signal power into the three power line conductors, half into the centre conductor and half equally shared between the outer conductors (see Figure 4).

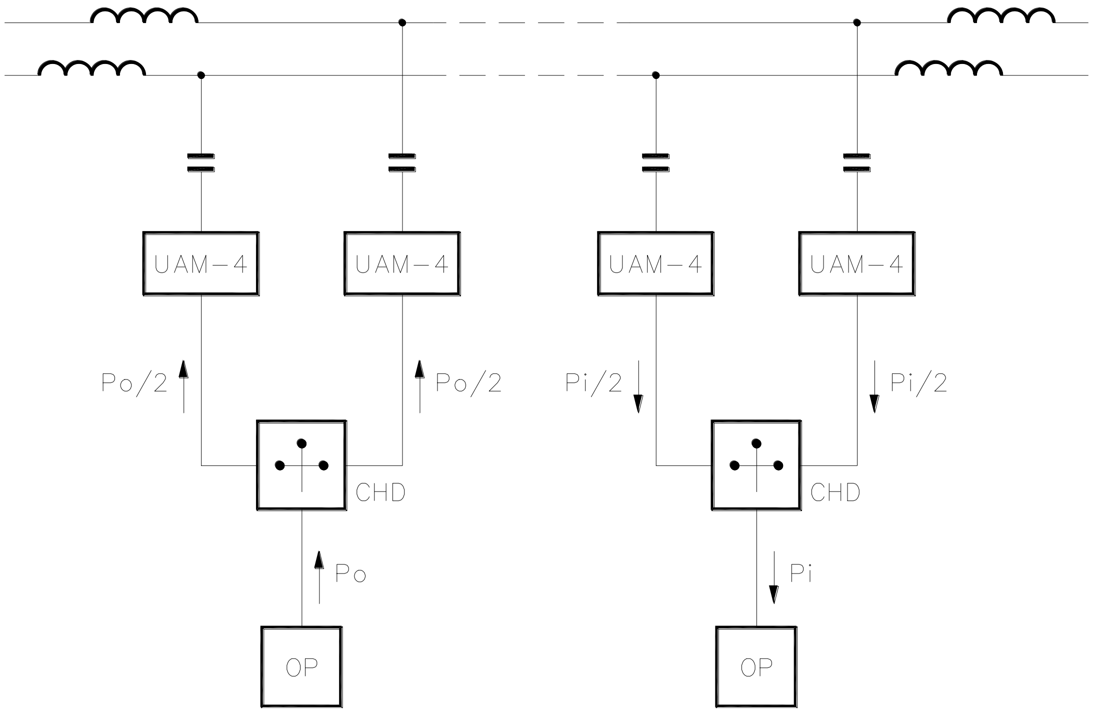



Figure 3 Phase-to-phase coupling with connection through differential transformer

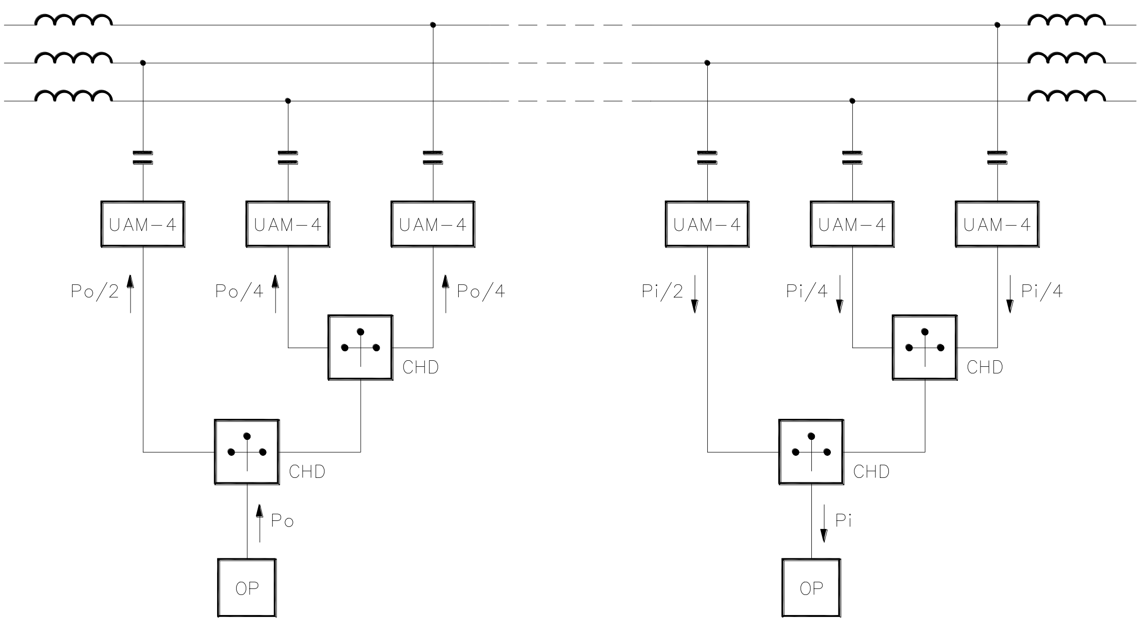



Figure 4 Three-phase coupling

The advantage of this type of coupling is that it has the lowest attenuation and allows communication to be maintained should there be a failure in one or two line phases. Supplementary attenuation in such conditions depends on the phase or phases involved and is slightly different according to whether open circuit or short circuit, or a combination of both, is involved. A failure in the centre phase or in both outer phases results in approximately a 6 dB supplementary attenuation, that of an outer phase in a 2.5 dB attenuation and that affecting the centre and one outer phase in a 12 dB loss.

# 3 SAFETY RECOMMENDATIONS ⚠

## 3.1 RECOMMENDATIONS BEFORE CARRYING OUT THE INSTALLATION

!

1. The installation of the coupling units in a High-Voltage substation is generically subject to the fulfilment of all the safety measures and prevention of risks established for this type of work by the electricity company that will use these devices and to the Safety standards. Therefore, only qualified personnel appointed by the electricity company that owns the installation should carry out the installation and handling of the coupling units.

2. The coupling unit must be placed near the coupling capacitor, avoiding a long cable between both devices. This place must also be easily accessible to the maintenance personnel.
   - **a.** The connection cable between the coupling unit and the PLC equipment must be suitable for the characteristic impedance of the last one and according to the adjustments of the coupling unit. These cables are usually of coaxial type, 75 or 50 Ω of characteristic impedance and suitable protection for the path they follow (in most cases underground cables).
   - **b.** For phase-to-phase coupling with the use of hybrid circuit it is recommended that the coaxial connection cable between both phase-to-earth units and the hybrid circuit are of the same length and the characteristic impedance is suitable for their equipment side impedance.

3. If the installation is carried out in a power line WITHOUT VOLTAGE, the general recommendations for any electrical device located in substations must be followed as well as those of each company.

4. If the power line is WITH VOLTAGE the following must be taken into account:
   - **a.** Earthing of the coupling capacitor.
   - **b.** Installation of the coupling unit (including the connection to the coupling capacitor **and the connection to earth**) following the recommendations indicated in point 3.
   - **c.** Make sure that the earthing switch of the coupling unit is closed.
   - **d.** Release the connection carried out in point 4a.

5. For normal coupling unit operation, the earthing switch must remain open.

## 3.2 RECOMMENDATIONS FOR MAINTENANCE

To carry out any adjustment or test on the coupling unit, the following must be taken into account:

!

1. Make sure that the coupling unit **is grounded** by means of its earth terminal (M10 rod).

2. Close the earthing switch incorporated in the coupling unit. The coupling units MUST NOT be handled WITH VOLTAGE without taking this precaution.

3. Adjustment of the equipment. An abacus, located inside the cover of the coupling unit, shows the connections to be carried out in typical operation conditions. Assuming the line impedance is of 300 Ω, and knowing the impedance of the equipment, the jumpers and settings are carried out based on the value of the abacus nearest that of the coupling capacitor.

4. Once the necessary adjustments have been carried out, the earthing switch must be opened to make the measurements or tests.
   Appendix A explains the composite and return loss measurement methods.

   In the case of return loss, a value greater than 12 dB is enough, although it is possible to obtain a higher value, especially in the centre of the band. As the values, of the coupling capacitor and the characteristic impedance of the line are never exact, the definitive value is obtained by trial and error.

5 When necessary to carry out a new adjustment, see point 2.

# 4 INSTALLATION AND COMMISSIONING

## 4.1 INSTALLATION

The coupling units are usually mounted on the structure that holds the coupling capacitor. The dimensions of the cabinets, as well as the position of the fixing holes, are shown in the drawings at the end of this description.

Each unit has two inlets for the coaxial cables coming from the PLC equipment or the hybrid circuit.

The coaxial cable shield should only be earthed at one end of the cable, usually equipment-side, in order to avoid the current flow caused by voltage differences between different points of the earth mesh.

There are four terminals in each unit for the connection of the coaxial cable coming from the PLC equipment or the hybrid circuit with the secondary winding of the isolating transformer. The A and C terminals are connected internally to simplify the parallel connection of two units, used in some phase-to-phase couplings. The middle terminals, B, are also connected internally and are usually used for connection to the coaxial shield.

The coupling capacitor and coupling unit are connected by means of a copper bar. If the coupling capacitor is not equipped with an earthing switch it is advisable to install one in an easily visible place, for personnel protection during installation operations. The earthing switch housed in the coupling unit should only be used during the adjustment or test of the unit.

It is also advisable to connect the coupling capacitor to the external earthing switch and then to the coupling unit instead of making separate connections between capacitor and the other two elements.

The installation procedure for each type of coupling is described in the following section.

### 4.1.1 Phase-to-earth coupling

In the phase-to-earth coupling, the central conductor of the coaxial cable is connected to terminal A or C, the shield being connected to terminal B.

Equipment-side nominal impedance is selected by carrying out one of the four jumpers shown in Figure 5.


| | |
|---|---|
| Position D-E: | for an impedance of 75 Ω. |
| Position F-G: | for an impedance of 125 Ω. |
| Position H-I: | for an impedance of 150 Ω. |
| Position J-K: | for an impedance of 250 Ω. |

Figure 5 Equipment-side nominal impedance selection jumpers

However, in order to obtain line-side impedance values different from the nominal values, impedances with a value different from that of the jumper can be connected equipment-side. Table 1 shows the different input combinations and the associated line-side impedance values, the nominal values being in bold.

| EQUIPMENT-SIDE IMPEDANCES | | | LINE-SIDE IMPEDANCES (Ω) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | T1-T3 | T1-T4 | T5-T6 | T5-T4 | T5-T3 | T5-T2 | T5-T1 | T6-T4 | T6-T3 | T6-T2 | T6-T1 | T7-T4 | T7-T3 | T7-T2 | T7-T1 | T8-T4 | T8-T3 | T8-T2 | T8-T1 |
| EQUIPMENT-SIDE IMPEDANCES | 75 Ω | D-E | | 16 | **28** | **62** | **84** | **110** | **139** | **172** | **208** | **248** | **291** | **337** | **387** | **441** | **498** | **558** | **622** | **689** | **759** |
| | | F-G | | <10 | 16 | 36 | 50 | 65 | 82 | 101 | 123 | 146 | 171 | 199 | 228 | 260 | 293 | 329 | 366 | 406 | 447 |
| | | H-I | | <10 | 13 | 31 | 42 | 54 | 69 | 85 | 103 | 122 | 143 | 166 | 191 | 217 | 245 | 275 | 306 | 340 | 374 |
| | | J-K | | | <10 | 18 | 25 | 32 | 41 | 50 | 61 | 73 | 85 | 99 | 113 | 129 | 146 | 163 | 182 | 202 | 222 |
| | 125 Ω | F-G | <10 | 15 | **27** | **61** | **83** | **108** | **137** | **169** | **204** | **243** | **286** | **331** | **380** | **433** | **488** | **548** | **610** | **676** | **745** |
| | | H-I | <10 | 13 | 23 | 51 | 69 | 90 | 115 | 141 | 171 | 204 | 239 | 277 | 318 | 362 | 409 | 458 | 511 | 566 | 624 |
| | | J-K | | <10 | 13 | 30 | 41 | 54 | 68 | 84 | 102 | 121 | 142 | 165 | 189 | 215 | 243 | 272 | 303 | 336 | 370 |
| | 150 Ω | H-I | <10 | 15 | **27** | **61** | **83** | **109** | **138** | **170** | **205** | **244** | **287** | **333** | **382** | **435** | **491** | **550** | **613** | **679** | **749** |
| | | J-K | | <10 | 16 | 36 | 49 | 64 | 82 | 101 | 122 | 145 | 170 | 198 | 227 | 258 | 291 | 326 | 364 | 403 | 444 |
| | 250 Ω | J-K | <10 | 15 | **27** | **60** | **82** | **107** | **136** | **168** | **203** | **242** | **284** | **329** | **378** | **430** | **485** | **544** | **606** | **672** | **741** |

Table 1 Line-side impedance corresponding to equipment-side impedance the same as the jumper carried out or different

### 4.1.2 Phase-to-phase coupling

For phase-to-phase coupling two UAM-4 units are needed at each end of the line. They can be connected to the PLC equipment by means of a differential transformer in order to establish a phase-to-earth coupling, in case of open circuit or short circuit of one of the phases used, or in parallel, by means of a coaxial cable, if it is not important to guarantee the transmission when there is a fault and, in the case of underground cables, as long as the line impedance allows it.

#### Connection through differential transformer

La **¡Error! No se encuentra el origen de la referencia.** shows the configuration of a phase-to-phase coupling using a differential transformer.

In order to adjust the input impedance of the coupling units to the nominal impedance of the differential transformer it is necessary to carry out D-E jumper in each UAM-4 (see Figure 5).

The coaxial cables used to connect the differential transformer to the coupling units should be the same length. The shields of these cables can be earthed with the help of jumper C-D of the hybrid circuit. In the same way, the shield of the coaxial cable coming from the PLC equipment, normally connected to earth, equipment side, can be earthed, coupling device side, by means of jumper A-B if desired.

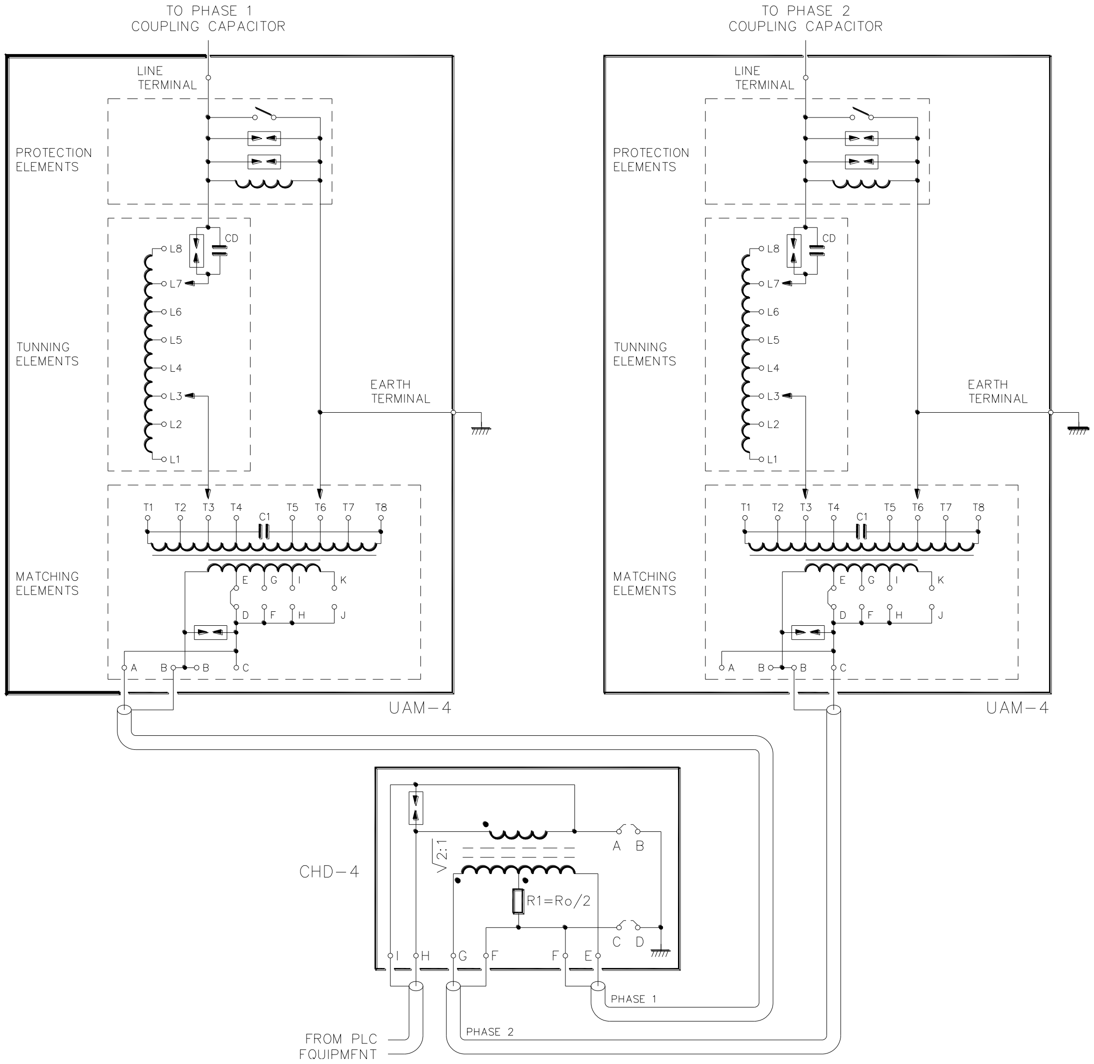



Figure 6 Phase-to-phase coupling

**Parallel connection**

The connection in parallel of the coupling units is carried out by means of the connections indicated in la Figure 7. The coaxial cable proceeding from the PLC equipment is connected to terminals A and B of one unit whilst the interconnecting cable goes from terminals B and C of the same unit to the A and B terminals of the other.

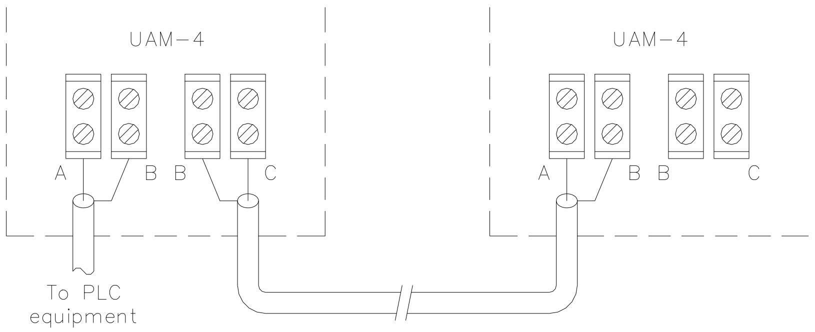



Figure 7 Parallel connection of two UAM-4 units

As the transformers are in parallel, the impedance value they present to the PLC equipment must be double the nominal value of the equipment, that is to say, of 150 Ω for a nominal impedance of the equipment of 75 Ω, which means that jumper H-I (see Figure 5) must be carried in both units, and of 250 Ω for a nominal impedance of the equipment of 125 Ω, which means that jumper J-K must be carried out in both units.

It must be taken into account that in the phase-to-phase coupling with parallel connection, the signal from the PLC equipment must be applied to each line conductor of opposite phase, therefore the primary winding (line side) of the isolating transformer must be connected in the opposite way from the other as indicated in Figure 8.

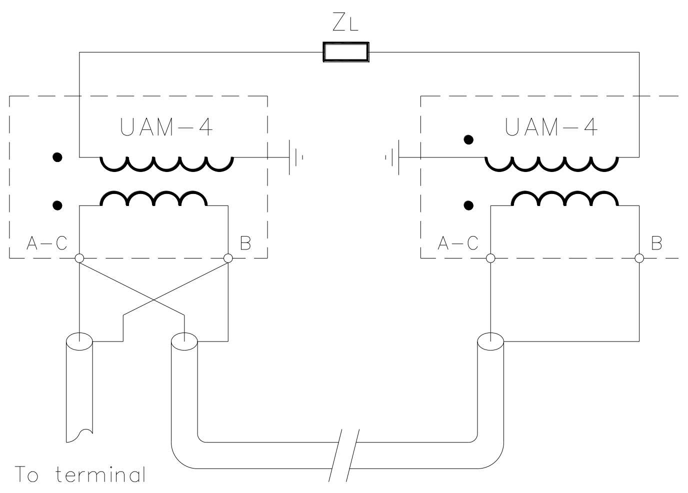



Figure 8 Primary winding connections in the phase-to-phase coupling with parallel connection

The transformer tap connected to the tuning coil in one unit must be earthed in the other and vice versa. The phase of either transformer winding is unimportant provided it is the opposite in the paralleled units.

### 4.1.3 Three-phase coupling

Figure 9 shows the test arrangement of the three-phase coupling, the power distribution between the phases being indicated.

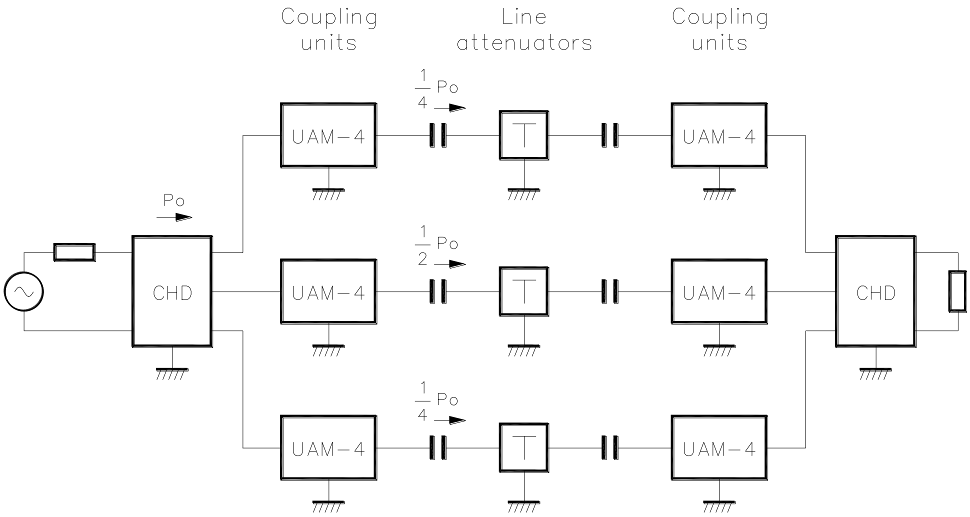



Figure 9 Test arrangement of the three-phase coupling

The composite-loss measurements must be carried out over the whole link, as shown in the test arrangement in Figure 9, and not on the devices at one end of the line, due to the fact that as the transmission is over three conductors, there cannot be bipolar elements line side.

The three-phase coupling configuration is shown in Figure 10. The three coupling units are identical but the transformer polarity of the unit connected to the OUTER PHASE 2 must be inverted so that the phase of the signals applied to the outer conductors is the opposite of that of the central conductor. In order to do this, the line-side taps of the transformer of the outer phase 2 unit must be connected the other way round. The tap connected to the tuning coil in the outer phase 1 unit must be earthed in the outer phase 2 unit and vice versa.

The shields of the coaxial cables connecting the coupling units to the differential transformer can be earthed by means of jumper C-D of the hybrid circuits. Likewise, if the shield of the coaxial cable proceeding from the PLC equipment is not earthed equipment side, can be earthed at the other side by means of jumper A-B of the hybrid circuit.

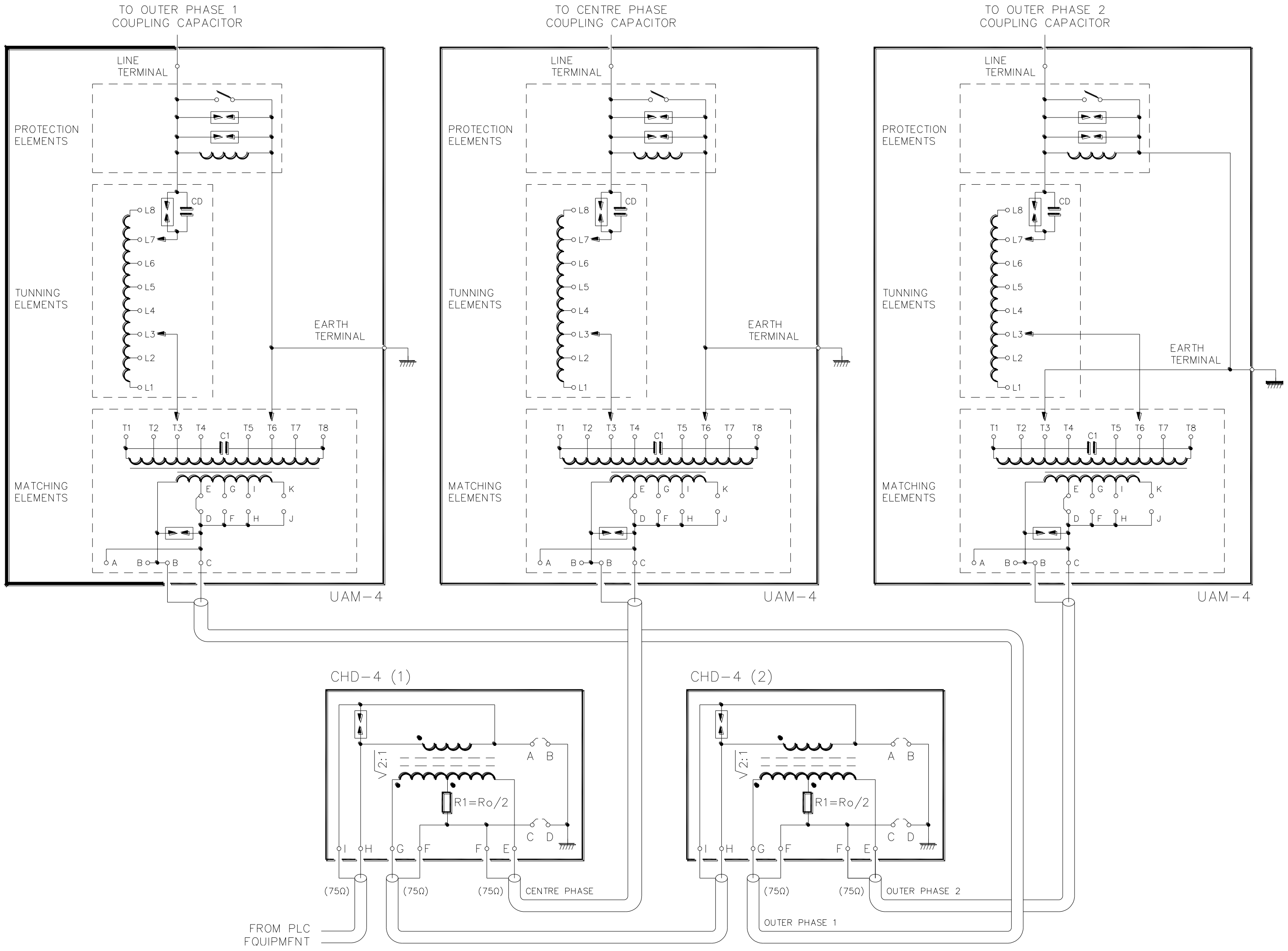



Figure 10 Three-phase coupling

## 4.2 COMMISSIONING

Before carrying out any tuning or impedance matching operations, the earthing switch of the UAM-4 unit must be in the closed position in order to drain any dangerous voltage. Once the adjustments have been made, the earthing switch must be in the open position.

### 4.2.1 Tuning

The adjustment is carried out by means of the tuning coil taps, and with the help of the following figures, F1 and F2 frequency values having a tolerance of ±10%.

The figures refer to a 300 Ω and 30 Ω nominal line impedance in a phase-to-earth coupling. It is advisable to check whether the adjustment carried out is optimum after impedance matching.

As far as two and three-phase coupling is concerned, the first stage consists of tuning each unit as for phase-to-earth coupling. After that, the set should be tuned to achieve the best return loss response possible over the whole bandwidth. A method for measuring such a response is given in section 2 of Appendix A.

When the value of the central frequency, Fo, and that of the coupling capacity, Ca, is known, the necessary inductance value can be found by means of the following formulae:

$$L = \frac{1}{4 * \pi^2 * Fo^2 * Ca}$$

Once the inductance value is found, the most suitable taps can be selected (see Table 2).

Due to the tolerances of the devices involved in the coupling, it is possible that the selected taps do not coincide exactly with the calculated value. In this case, in order to centre the coupling band, the inductance must be increased or decreased taking into account that when it is increased the central frequency decreases.

| TAPS | L (µH) | TAPS | L (µH) | TAPS | L (µH) |
|---|---|---|---|---|---|
| L1:L8 | 1558 | L3:L8 | 427 | L4:L6 | 63 |
| L1:L7 | 1299 | L2:L4 | 313 | L3:L4 | 52 |
| L1:L6 | 1174 | L3:L7 | 282 | L6:L8 | 46 |
| L1:L5 | 1000 | L3:L6 | 218 | L5:L7 | 31 |
| L2:L8 | 919 | L4:L8 | 201 | L4:L5 | 23 |
| L1:L4 | 757 | L3:L5 | 139 | L7:L8 | 22 |
| L2:L7 | 712 | L2:L3 | 118 | L5:L6 | 11 |
| L2:L6 | 615 | L1:L2 | 114 | L6:L7 | 6 |
| L2:L5 | 484 | L4:L7 | 101 | | |
| L1:L3 | 441 | L5:L8 | 97 | | |

Table 2 Tuning-coil nominal inductances

| CONNECTION | F1 (kHz) | F2 (kHz) | B (kHz) |
|---|---|---|---|
| L1-L8 | 84 | 99 | 15 |
| L1-L7 | 91 | 110 | 19 |
| L1-L6 | 95 | 117 | 22 |
| L1-L5 | 103 | 128 | 25 |
| L2-L8 | 105 | 131 | 26 |
| L2-L7 | 118 | 152 | 34 |
| L2-L6 | 126 | 165 | 39 |
| L2-L5 | 140 | 189 | 49 |
| L3-L8 | 146 | 201 | 55 |
| L2-L4 | 168 | 241 | 73 |
| L3-L7 | 174 | 254 | 80 |
| L4-L8 | 197 | 301 | 104 |
| L3-L5 | 230 | 364 | 134 |
| L2-L3 | 239 | 381 | 142 |
| L1-L2 | 250 | 404 | 154 |
| L4-L7 | 255 | 411 | 156 |
| L5-L8 | 262 | 428 | 166 |
| L4-L6 | 300 | 478 | 178 |
| L3-L4 | 326 | 510 | 184 |
| L6-L8 | 341 | 530 | 189 |
| L5-L7 | 386 | 553 | 167 |

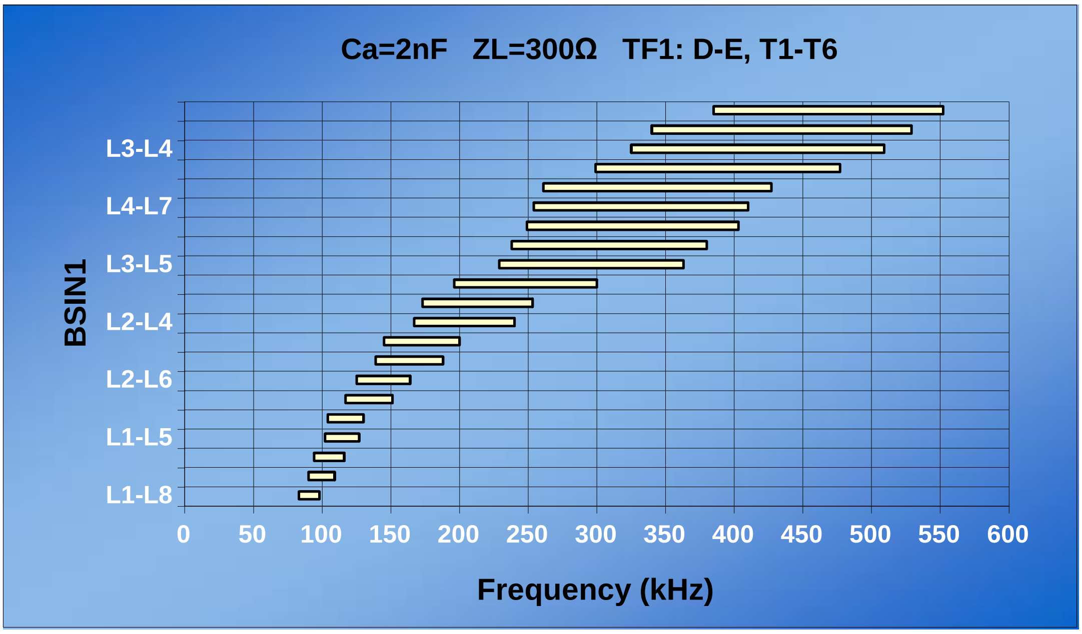



Figure 11 Selection of tuning coil taps for a coupling capacitor of 2000 pF according to the coupling band (line impedance of 300 Ω)

| CONNECTION | F1 (kHz) | F2 (kHz) | B (kHz) |
|---|---|---|---|
| L1-L8 | 57 | 73 | 16 |
| L1-L7 | 62 | 81 | 19 |
| L1-L6 | 65 | 86 | 21 |
| L1-L5 | 70 | 96 | 26 |
| L2-L8 | 72 | 98 | 26 |
| L2-L7 | 80 | 115 | 35 |
| L2-L6 | 85 | 126 | 41 |
| L2-L5 | 94 | 147 | 53 |
| L3-L8 | 97 | 157 | 60 |
| L2-L4 | 110 | 194 | 84 |
| L3-L7 | 114 | 205 | 91 |
| L4-L8 | 127 | 248 | 121 |
| L3-L5 | 147 | 316 | 169 |
| L2-L3 | 152 | 335 | 183 |
| L1-L2 | 158 | 361 | 203 |
| L4-L7 | 159 | 368 | 209 |
| L5-L8 | 162 | 384 | 222 |
| L4-L6 | 184 | 446 | 262 |
| L3-L4 | 195 | 481 | 286 |
| L6-L8 | 199 | 550 | 351 |
| L5-L7 | 222 | 536 | 314 |

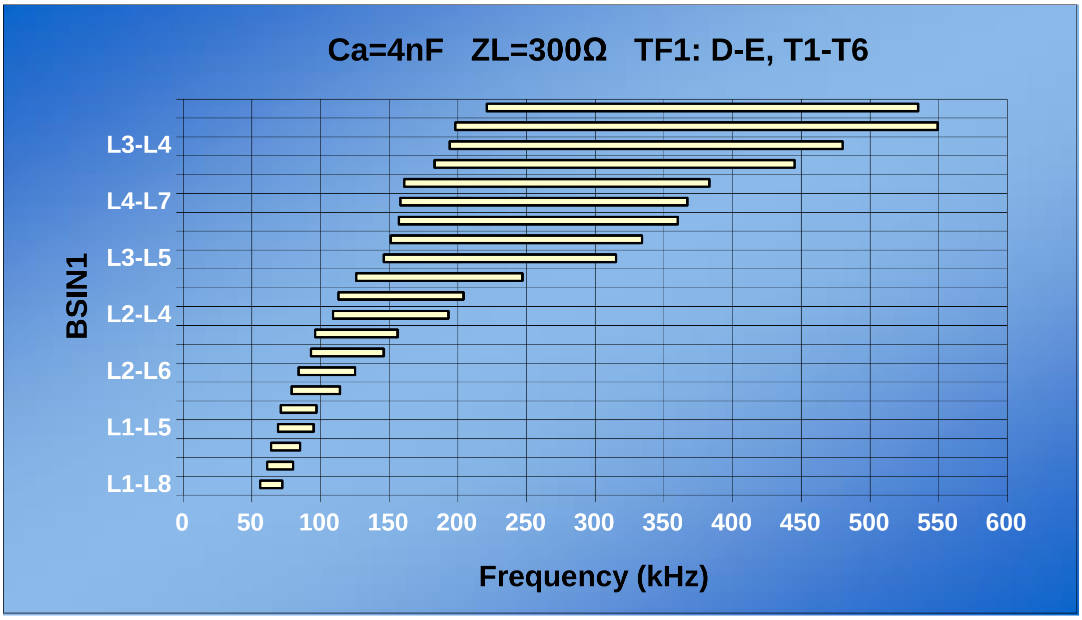



Figure 12 Selection of tuning coil taps for a coupling capacitor of 4000 pF according to the coupling band (line impedance of 300 Ω)

| CONNECTION | F1 (kHz) | F2 (kHz) | B (kHz) |
|---|---|---|---|
| L1-L8 | 46 | 61 | 15 |
| L1-L7 | 50 | 69 | 19 |
| L1-L6 | 52 | 73 | 21 |
| L1-L5 | 56 | 81 | 25 |
| L2-L8 | 56 | 83 | 27 |
| L2-L7 | 63 | 98 | 35 |
| L2-L6 | 66 | 107 | 41 |
| L2-L5 | 73 | 126 | 53 |
| L3-L8 | 76 | 135 | 59 |
| L2-L4 | 86 | 169 | 83 |
| L3-L7 | 88 | 179 | 91 |
| L4-L8 | 97 | 221 | 124 |
| L3-L5 | 110 | 289 | 179 |
| L2-L3 | 115 | 309 | 194 |
| L1-L2 | 118 | 338 | 220 |
| L4-L7 | 119 | 343 | 224 |
| L5-L8 | 120 | 361 | 241 |
| L4-L6 | 134 | 431 | 297 |
| L3-L4 | 142 | 469 | 327 |
| L6-L8 | 144 | 493 | 349 |
| L5-L7 | 156 | 535 | 379 |

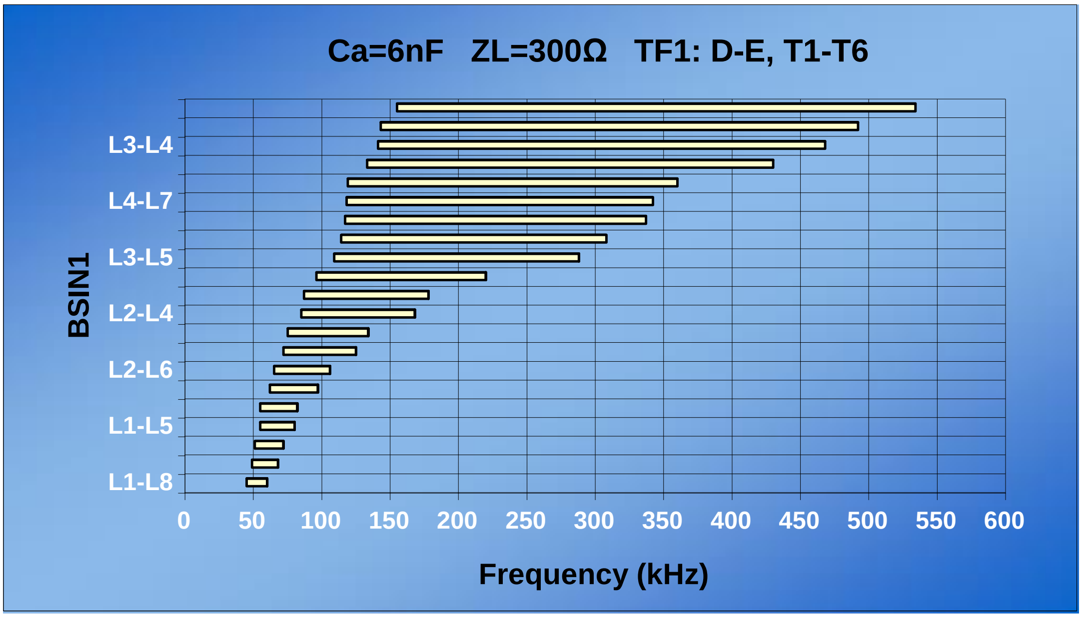



Figure 13 Selection of tuning coil taps for a coupling capacitor of 6000 pF according to the coupling band (line impedance of 300 Ω)

| CONNECTION | F1 (kHz) | F2 (kHz) | B (kHz) |
|---|---|---|---|
| L1-L8 | 39 | 54 | 15 |
| L1-L7 | 41 | 61 | 20 |
| L1-L6 | 43 | 65 | 22 |
| L1-L5 | 46 | 72 | 26 |
| L2-L8 | 47 | 74 | 27 |
| L2-L7 | 52 | 88 | 36 |
| L2-L6 | 55 | 97 | 42 |
| L2-L5 | 60 | 115 | 55 |
| L3-L8 | 62 | 123 | 61 |
| L2-L4 | 69 | 156 | 87 |
| L3-L7 | 71 | 166 | 95 |
| L4-L8 | 78 | 207 | 129 |
| L3-L5 | 88 | 277 | 189 |
| L2-L3 | 90 | 297 | 207 |
| L1-L2 | 93 | 326 | 233 |
| L4-L7 | 94 | 332 | 238 |
| L5-L8 | 94 | 349 | 255 |
| L4-L6 | 103 | 422 | 319 |
| L3-L4 | 108 | 462 | 354 |
| L6-L8 | 109 | 487 | 378 |
| L5-L7 | 115 | 532 | 417 |

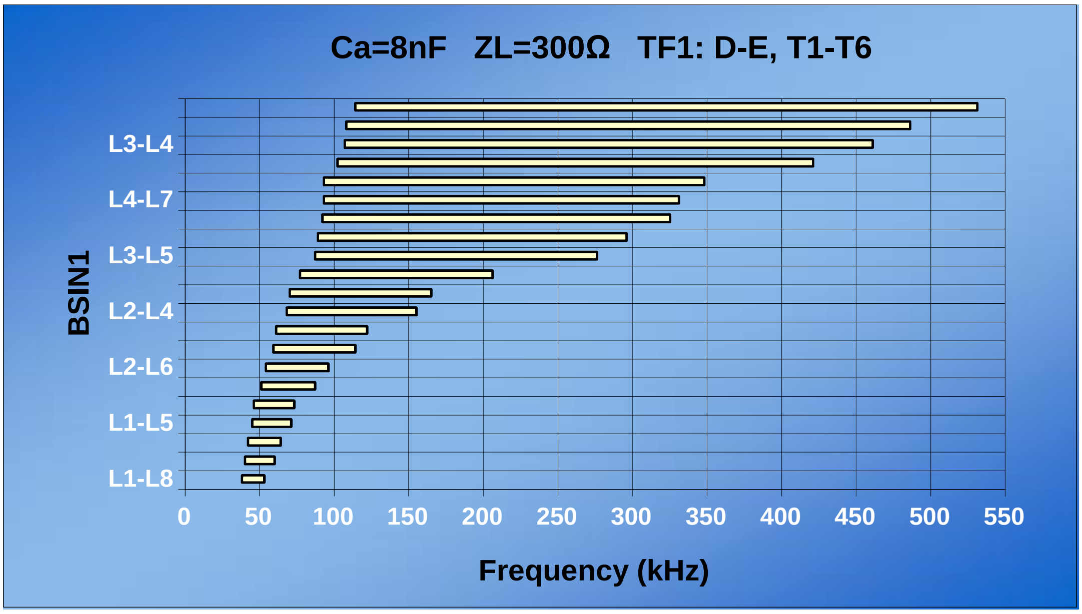



Figure 14 Selection of tuning coil taps for a coupling capacitor of 8000 pF according to the coupling band (line impedance of 300 Ω)

| CONNECTION | F1 (kHz) | F2 (kHz) | B (kHz) |
|---|---|---|---|
| L1-L8 | 34 | 49 | 15 |
| L1-L7 | 37 | 56 | 19 |
| L1-L6 | 38 | 59 | 21 |
| L1-L5 | 40 | 66 | 26 |
| L2-L8 | 41 | 68 | 27 |
| L2-L7 | 45 | 81 | 36 |
| L2-L6 | 47 | 89 | 42 |
| L2-L5 | 52 | 106 | 54 |
| L3-L8 | 54 | 114 | 60 |
| L2-L4 | 60 | 145 | 85 |
| L3-L7 | 61 | 155 | 94 |
| L4-L8 | 67 | 194 | 127 |
| L3-L5 | 74 | 264 | 190 |
| L2-L3 | 76 | 286 | 210 |
| L1-L2 | 79 | 315 | 236 |
| L4-L7 | 79 | 320 | 241 |
| L5-L8 | 80 | 337 | 257 |
| L4-L6 | 86 | 414 | 328 |
| L3-L4 | 89 | 458 | 369 |
| L6-L8 | 90 | 484 | 394 |
| L5-L7 | 95 | 529 | 434 |

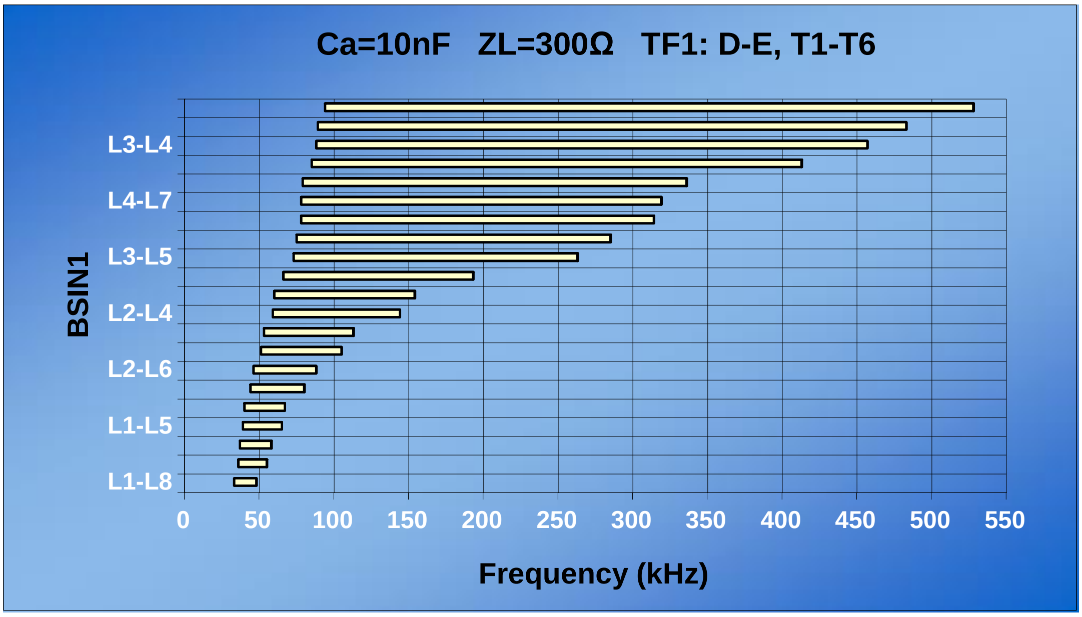



Figure 15 Selection of tuning coil taps for a coupling capacitor of 10000 pF according to the coupling band (line impedance of 300 Ω)

| CONNECTION | F1 (kHz) | F2 (kHz) | B (kHz) |
|---|---|---|---|
| L3-L5 | 190 | 207 | 17 |
| L2-L3 | 199 | 217 | 18 |
| L1-L2 | 209 | 229 | 20 |
| L4-L7 | 212 | 232 | 20 |
| L4-L6 | 250 | 280 | 30 |
| L3-L4 | 271 | 306 | 35 |
| L6-L8 | 280 | 319 | 39 |
| L5-L7 | 314 | 362 | 48 |
| L4-L5 | 334 | 387 | 53 |
| L7-L8 | 346 | 407 | 61 |
| L5-L6 | 389 | 463 | 74 |
| L6-L7 | 430 | 520 | 90 |

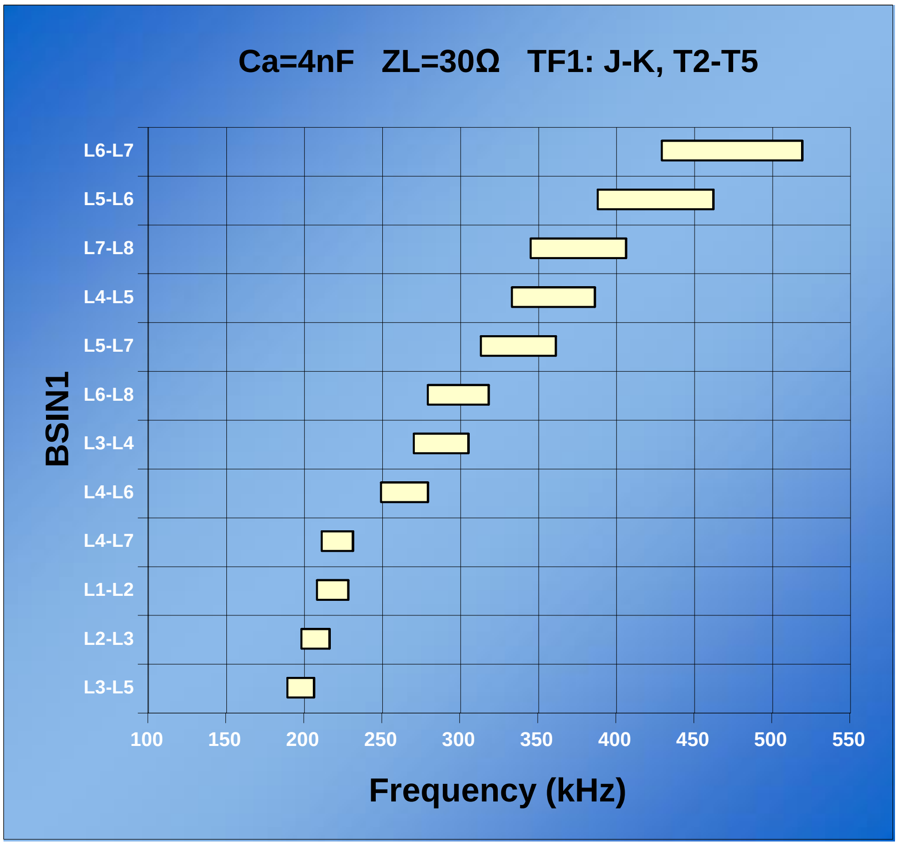



Figure 16 Selection of tuning coil taps for a coupling capacitor of 4000 pF according to the coupling band (line impedance of 30 Ω)

| CONNECTION | F1 (kHz) | F2 (kHz) | B (kHz) |
|---|---|---|---|
| L3-L5 | 171 | 188 | 17 |
| L2-L3 | 178 | 197 | 19 |
| L1-L2 | 187 | 208 | 21 |
| L4-L7 | 190 | 211 | 21 |
| L4-L6 | 225 | 255 | 30 |
| L3-L4 | 244 | 280 | 36 |
| L6-L8 | 252 | 292 | 40 |
| L5-L7 | 283 | 334 | 51 |
| L4-L5 | 302 | 359 | 57 |
| L7-L8 | 312 | 376 | 64 |
| L5-L6 | 352 | 434 | 82 |
| L6-L7 | 389 | 496 | 107 |

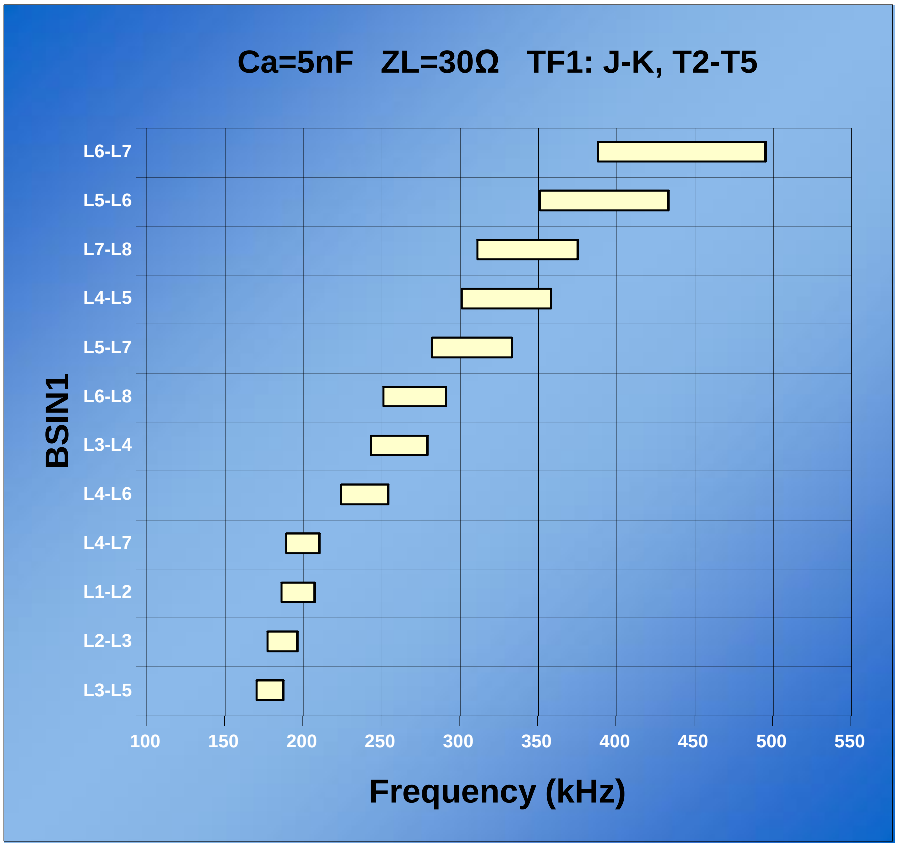



Figure 17 Selection of tuning coil taps for a coupling capacitor of 5000 pF according to the coupling band (line impedance of 30 Ω)

| CONNECTION | F1 (kHz) | F2 (kHz) | B (kHz) |
|---|---|---|---|
| L3-L5 | 156 | 173 | 17 |
| L2-L3 | 163 | 182 | 19 |
| L1-L2 | 171 | 192 | 21 |
| L4-L7 | 173 | 195 | 22 |
| L4-L6 | 205 | 237 | 32 |
| L3-L4 | 223 | 261 | 38 |
| L6-L8 | 230 | 271 | 41 |
| L5-L7 | 259 | 312 | 53 |
| L4-L5 | 277 | 337 | 60 |
| L7-L8 | 285 | 353 | 68 |
| L5-L6 | 323 | 411 | 88 |
| L6-L7 | 357 | 473 | 116 |

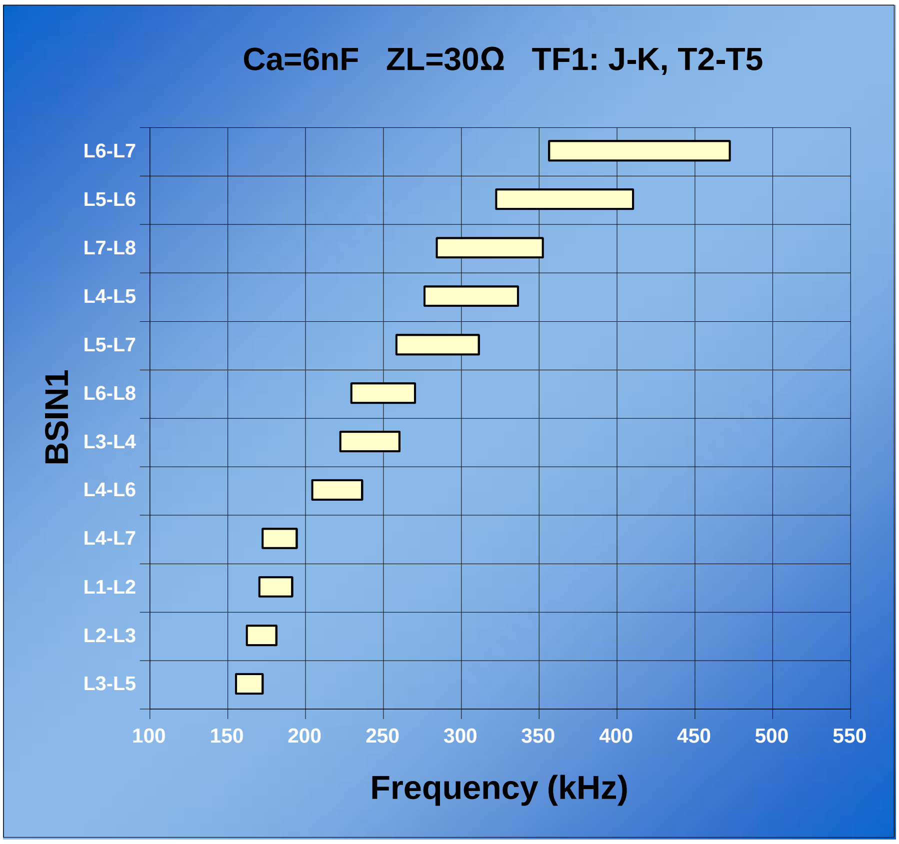



Figure 18 Selection of tuning coil taps for a coupling capacitor of 6000 pF according to the coupling band (line impedance of 30 Ω)

| CONNECTION | F1 (kHz) | F2 (kHz) | B (kHz) |
|---|---|---|---|
| L3-L5 | 134 | 152 | 18 |
| L2-L3 | 141 | 160 | 19 |
| L1-L2 | 148 | 169 | 21 |
| L4-L7 | 149 | 172 | 23 |
| L4-L6 | 178 | 210 | 32 |
| L3-L4 | 193 | 232 | 39 |
| L6-L8 | 198 | 241 | 43 |
| L5-L7 | 224 | 279 | 55 |
| L4-L5 | 240 | 303 | 63 |
| L7-L8 | 246 | 317 | 71 |
| L5-L6 | 280 | 374 | 94 |
| L6-L7 | 308 | 433 | 125 |

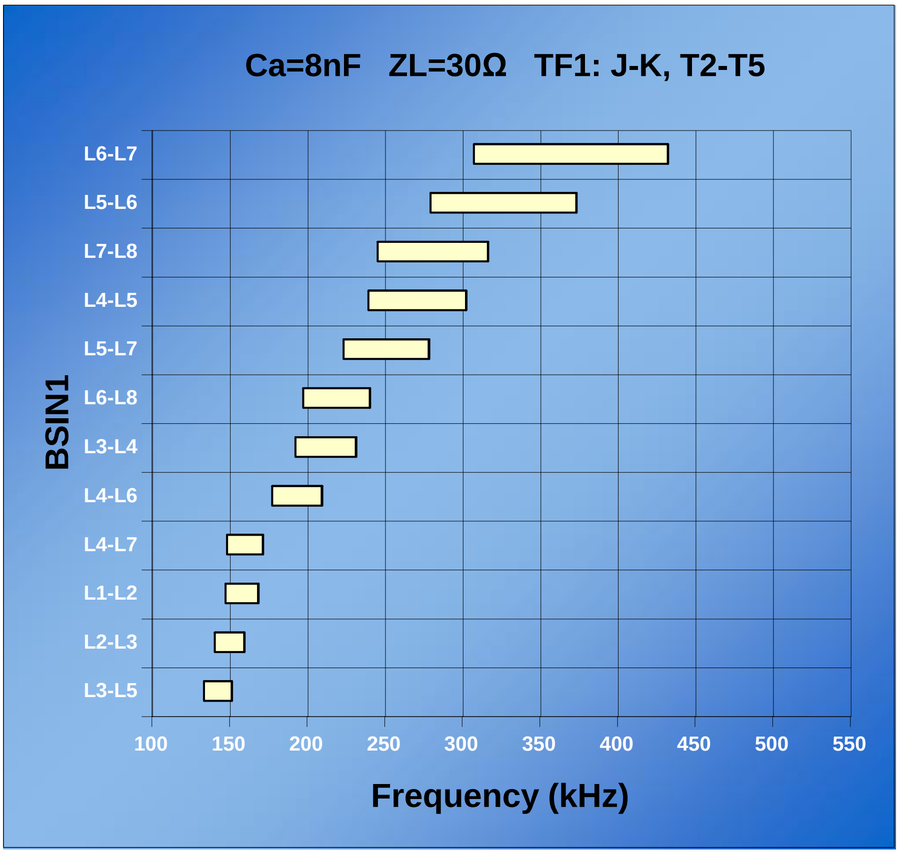



Figure 19 Selection of tuning coil taps for a coupling capacitor of 8000 pF according to the coupling band (line impedance of 30 Ω)

| CONNECTION | F1 (kHz) | F2 (kHz) | B (kHz) |
|---|---|---|---|
| L3-L5 | 119 | 137 | 18 |
| L2-L3 | 126 | 145 | 19 |
| L1-L2 | 132 | 153 | 21 |
| L4-L7 | 133 | 155 | 22 |
| L4-L6 | 158 | 191 | 33 |
| L3-L4 | 172 | 212 | 40 |
| L6-L8 | 176 | 219 | 43 |
| L5-L7 | 199 | 256 | 57 |
| L4-L5 | 213 | 281 | 68 |
| L7-L8 | 218 | 291 | 73 |
| L5-L6 | 248 | 345 | 97 |
| L6-L7 | 273 | 402 | 129 |

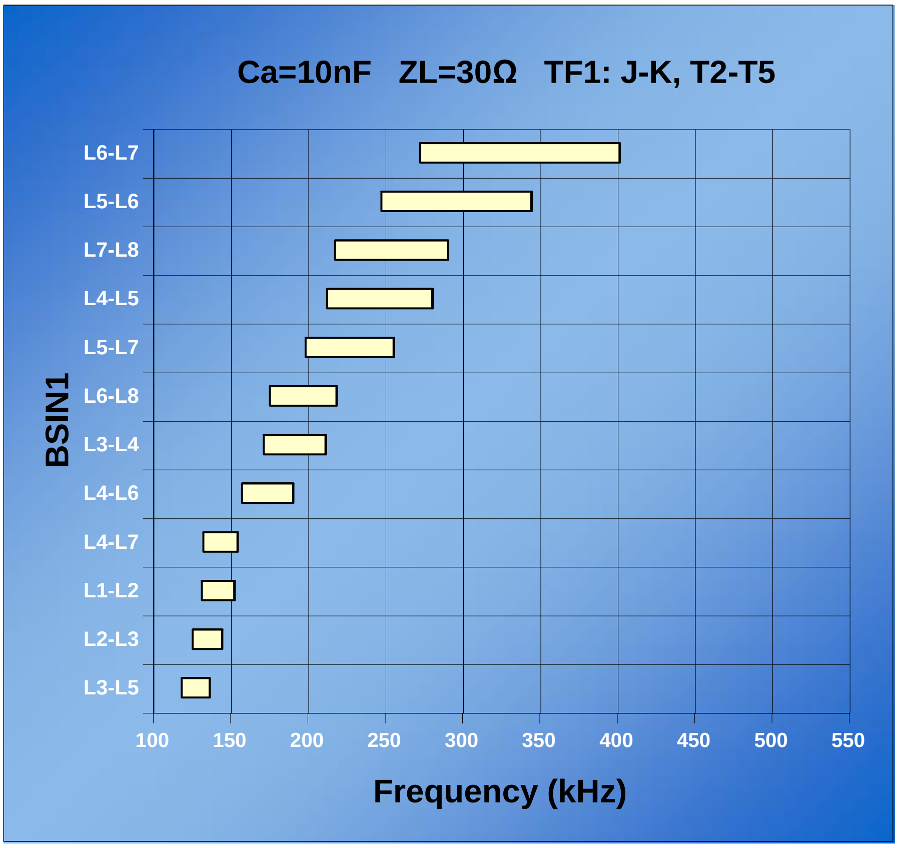



Figure 20 Selection of tuning coil taps for a coupling capacitor of 10000 pF according to the coupling band (line impedance of 30 Ω)

### 4.2.2 Impedance matching

Impedance matching is done by selecting the transformer combination taps which give the best composite-loss response. Section 1 of Appendix A gives a method for measuring the composite loss.

A first setting can be carried out by obtaining, at the input of the unit, equipment side, a voltage the same as the one measured in a dummy load of the same value as the nominal impedance.

For phase-to-phase and three-phase coupling, the line-side impedance initially selected in each unit is that corresponding to a phase-to-earth coupling, afterwards being necessary to adjust all the units.

It is advisable to repeat the tuning operation after impedance matching.

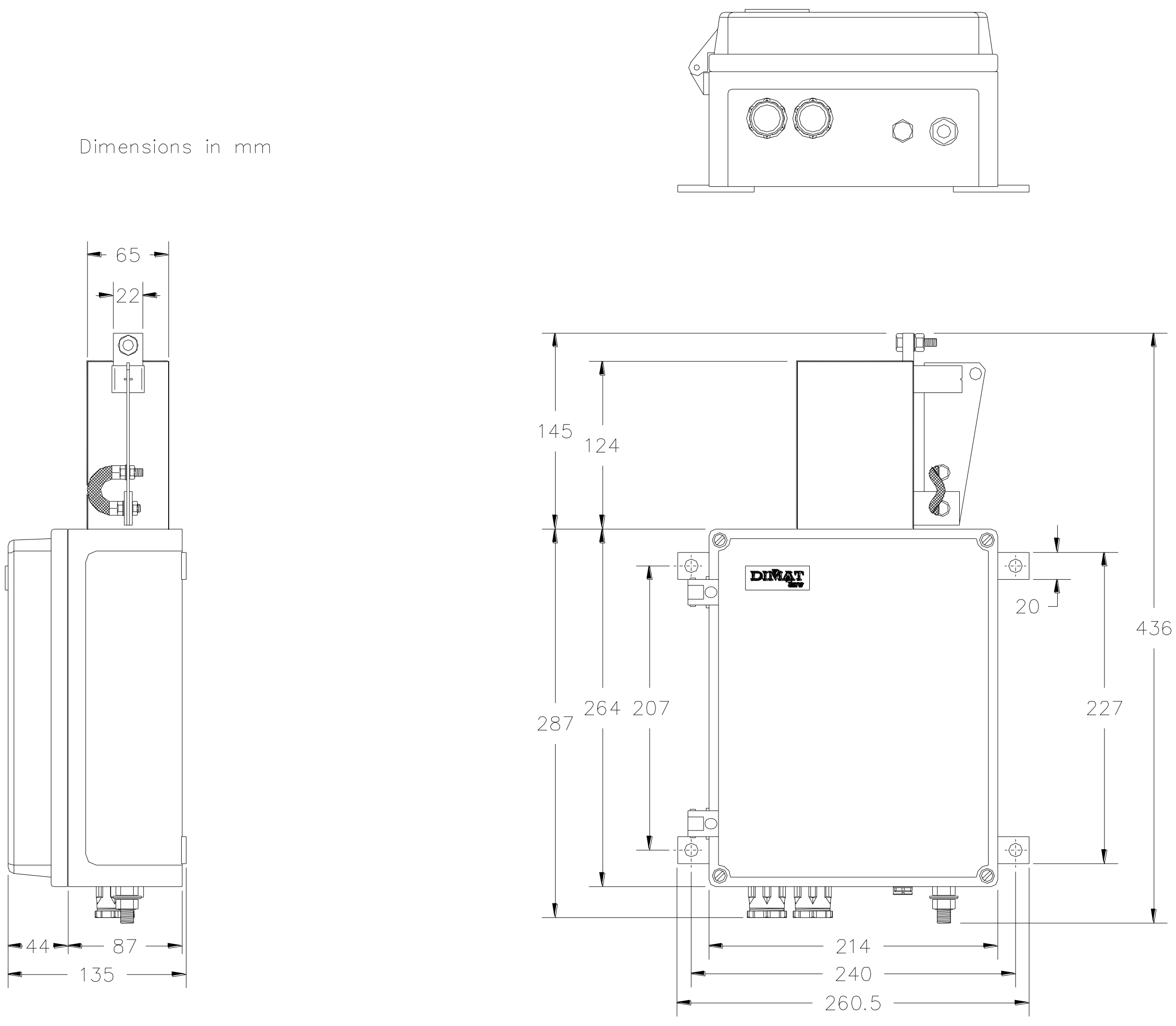



Figure 21 Overall dimensions of the UAM-4 and UAM-4/D units

# APPENDIX A

# METHOD FOR MEASURING COMPOSITE AND RETURN LOSS

# APPENDIX A

# METHOD FOR MEASURING COMPOSITE AND RETURN LOSS

## A.1 COMPOSITE LOSS

A method for measuring the composite loss is shown in the following figure.

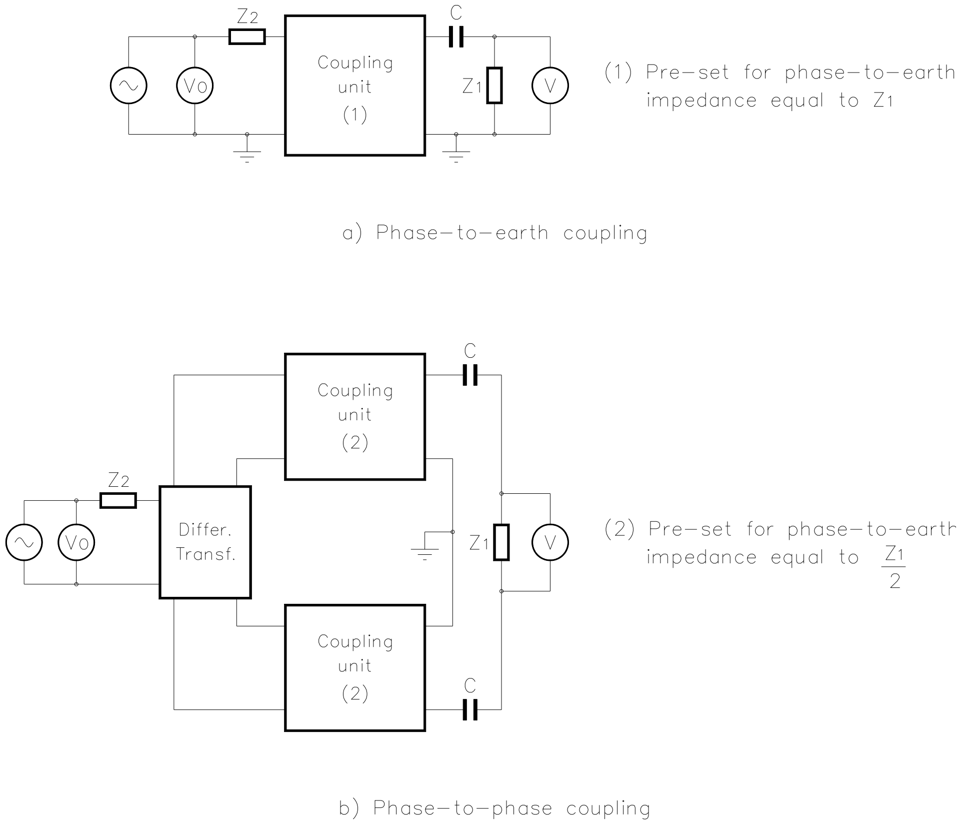



Figure A.1 Composite loss measurement

Composite loss is given by the expression:

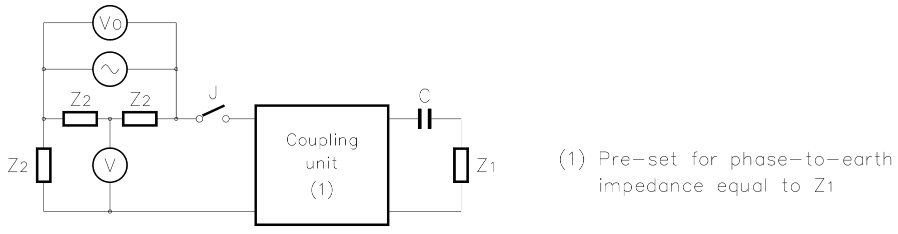
$$A_C = 20 \log(V_O/2V) + 10 \log(Z_1/Z_2) \qquad \text{(dB)}$$

where $V_O$ is the open circuit voltage of the generator with internal impedance $Z_2$ and V the output voltage across the nominal line impedance $Z_1$.

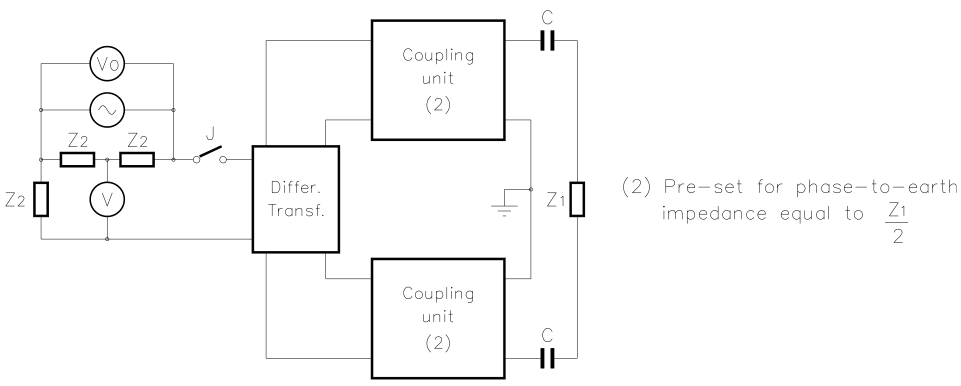
According to IEC 481 Publication, composite loss has to be lower than 2 dB within the coupling device band.

## A.2 RETURN LOSS

A method for measuring the return loss is shown in the following figure.




a) Phase-to-earth coupling




b) Phase-to-phase coupling

Figure A.2 Return loss measurement

Return loss is given by the expression:

$A_r = 20 \log(V_1/V_2)$ (dB)

where $V_1$ and $V_2$ are the voltmeter readings when switch J is open and closed respectively, keeping $V_O$ constant.

According to IEC 481 Publication, return loss has to be higher than 12 dB within the coupling device band.