

COUPLING UNIT FOR PLC SYSTEMS OVER HIGH-VOLTAGE LINES



DESCRIPTION OF UAM-4

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ZIV Antonio Machado,78-80 08840 Viladecans, Barcelona-Spain

Tel.: +34 933 490 700 Fax: +34 933 492 258 Mail to: ziv@zivautomation.com

www.zivautomation.com

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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.







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 $1:\sqrt{2}$ 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.







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 3.3.1, <i>Tuning</i>
Power frequency insulation	>5 kVrms (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
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 Vrms
	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	1 A _{rms} permanently.
	power frequency	50 Arms for 0.2 s
	Earthing switch	
	Permanent current capacity	150 Arms
1.5.2	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).

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 INSTALLATION AND COMMISSIONING

INSTALLATION AND MAINTENANCE 3.1 SAFETY RECOMMENDATIONS

3.1.1 Recommendations before carrying out the installation

- The installation of the coupling units in a High-Voltage substation is 1. 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.
 - If the installation is carried out in a power line WITHOUT VOLTAGE, the 3. 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.

3.1.2 Recommendations for maintenance

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

- Close the earthing switch incorporated in the coupling unit. The coupling units MUST NOT be handled WITH VOLTAGE without taking this precaution.
 - 2. 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 300Ω , 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.
 - **3.** 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.

4. When necessary to carry out a new adjustment, see point 1.





3.2 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.

3.2.1 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.





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.

3.2.2 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 Figure 6 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.



				LINE-SIDE IMPEDANCES (Ω)																	
			T1-T3	T1-T4	T5-T6	T5-T4	T5-T3	T5-T2	T5-T1	T6-T4	Т6-Т3	T6-T2	T6-T1	T7-T4	T7-T3	T7-T2	T7-T1	T8-T4	т8-тз	T8-T2	T8-T1
		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
	75 Ω	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
EQUIPMENT-SIDE	125 Ω	F-G	<10	15	27	61	83	108	137	169	204	243	286	331	380	433	488	548	610	676	745
IMPEDANCES		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
	H-I	H-I	<10	15	27	61	83	109	138	170	205	244	287	333	382	435	491	550	613	679	749
	150 Ω	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





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.







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.

3.2.3 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 viceversa.

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





3.3 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.

3.3.1 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 $\pm 10\%$.

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								



FT (KF12)	F2 (kHz)	B (kHz)
84	99	15
91	110	19
95	117	22
103	128	25
105	131	26
118	152	34
126	165	39
140	189	49
146	201	55
168	241	73
174	254	80
197	301	104
230	364	134
239	381	142
250	404	154
255	411	156
262	428	166
300	478	178
326	510	184
341	530	189
386	553	167
	84 91 95 103 105 118 126 140 146 168 174 197 230 239 250 255 262 300 326 341 386	84 99 91 110 95 117 103 128 105 131 118 152 126 165 140 189 146 201 168 241 174 254 197 301 230 364 239 381 255 411 262 428 300 478 326 510 386 553



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



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 300Ω)



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 300Ω)



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 300Ω)



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







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







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







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 according

19 Selection of tuning coil taps for a coupling capacitor of 8000 pF

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







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3.3.2 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.



(1) Pre-set for phase-to-earth impedance equal to Z1





b) Phase-to-phase coupling



Composite loss is given by the expression:

 $A_{c} = 20 \log(V_{0}/2V) + 10 \log(Z_{1}/Z_{2})$ (dB)

where V_0 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

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_0 constant.

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

