MAN#: LT-TI-HIGH
TUNING INSTRUCTIONS
HIGH-PASS LINE TUNER
Rev. 0

1.0 GENERAL DESCRIPTION

This document describes the tuning procedure of a high-pass line tuner. Tuning means setting the components to certain values in order to fulfill customer requirements. The customer requirements are defined in the order acknowledgment or the factory work order (FWO). The settings will be verified by routine testing in the factory and test reports are provided with every unit.

2.0 DESCRIPTION OF THE LINE TUNER AND PRINCIPLE OF OPERATION

The line tuner is a device inserted between the power line carrier equipment (PLC equipment) and the coupling capacitor. It has three main functions:

- Protect the PLC equipment from voltage and current surges arriving from the power line
- Provide optimum path for the carrier signal from and to the PLC equipment
- Provide optimum impedance matching between the power line and the PLC equipment

The tuner consists of the following parts (reference schematic diagram provided with the unit):

- Protective unit
- Inductor unit (L unit)
- Capacitor unit (C unit)
- Impedance matching transformer (IMT)

The high-pass line tuner provides a low impedance path for the carrier signal above a certain frequency, called cut-off frequency ($f_{cut-off}$). The values of the components are set to provide a high return loss and a low insertion loss above the cut-off frequency. This is accomplished by means of a high-pass L-C filter formed by the coupling capacitor, the blocking capacitor, the inductor of the L unit and the capacitor of the C unit.

For in-factory tuning please reference the FWO for the specification of the line tuner. For customer tuning please reference the drawings provided with the unit.

3.0 INSTRUMENTATION RECOMMENDED FOR TUNING

The following instruments, devices are needed for performing the tuning:

- Impedance analyzer (HP4192A LF impedance analyzer or similar)
- Capacitor with low dissipation factor for substituting the coupling capacitor

- Low capacitance, low-inductance resistors to simulate the line and the coaxial side impedances

4.0. CALCULATING THE VALUES OF THE COMPONENTS (SKIP THIS SECTION FOR IN-FACTORY TUNING)

In order to calculate the values of the line tuner components, the following parameters are needed:

- Line side impedance (R_L)
- Coaxial side impedance (R_C)
- Coupling capacitor (C_C)
- Blocking capacitor (C_B)
- Resonant frequency (f_1)

The following designations are used in the rest of the document:

- L_1: inductance of the L unit
- C_1: capacitance of the C unit

Table 1 shows the minimum cut-off frequency achievable for certain coupling capacitor values:

Coupling capacitor [nF]	Minimum achievable cut-off frequency [kHz]
1	320
2	170
3	115
4	85
5	70
6	60
7	50
8	45
9	40
10	35
11	33
12 up to 20	30*

Table 1. Minimum cut-off frequencies

Note. These values were calculated assuming 10dB return loss at the cut-off frequency, 300 Ohms line side impedance and 100nF blocking capacitor. * However lower cut-off frequencies could be achievable for 13…20nF coupling capacitors, the lower limit of the communication band for PLC equipment is 30kHz

The values of C_1 and L_1 are determined and set by Ritz to provide 10dB return loss at and above the specified cut-off frequency (must be greater or equal to the minimum frequency shown in the table above). If the cut-off frequency, the line side impedance or the value of the coupling capacitor is to be changed, C_1 and L_1 need to be recalculated.

For the sake of simplicity, choose C_1 to be equal to the coupling capacitor:

$$C_1 = C_C \tag{1}$$

Note, that this is not a design requirement, but simplifies the tuning if only the cut-off frequency changed because C_1 can remain unchanged.

In order to calculate L_1 the following equation needs to be solved for L_1:

$$\left| \frac{Z_{CC1} + \dfrac{Z_1 \cdot Z_L}{Z_1 + Z_L} + R_L}{Z_{CC1} + \dfrac{Z_1 \cdot Z_L}{Z_1 + Z_L} - R_L} \right| = 10^{\frac{R_{LOSS}}{20}} \tag{2}$$

where

$$Z_{cc1} = \frac{1}{j \cdot 2 \cdot \pi \cdot f_{cut-off} \cdot C_{C1}} \tag{3}$$

$$C_{C1} = \frac{C_C \cdot C_B}{C_C + C_B} \tag{4}$$

$$Z_1 = R_L + \frac{1}{j \cdot 2 \cdot \pi \cdot f_{cut-off} \cdot C_C} \tag{5}$$

$$Z_L = j \cdot 2 \cdot \pi \cdot f_{cut-off} \cdot L_1 \tag{6}$$

Note that $j = \sqrt{-1}$ and R_{LOSS} is the return loss that the line tuner shall provide at the cut-off frequency.

Table 2 contains the value of L_1 for certain coupling capacitors and the minimum cut-off frequency achievable for that specific coupling capacitor (see Table 1 for these frequencies):

Coupling capacitor [nF]	Inductance L_1 [µH]	Coupling capacitor [nF]	Inductance L_1 [µH]
1	145	11	1350
2	260	12	1500
3	390	13	1420
4	520	14	1380
5	650	15	1340
6	760	16	1310
7	900	17	1290
8	1000	18	1270
9	1100	19	1255
10	1280	20	1240

Table 2. Inductance L_1

Note. These values were calculated assuming 10dB return loss at the minimum cut-off frequency as given in Table 1, 300 Ohms line side impedance and 100nF blocking capacitor.

5.0 PREPARATIONS BEFORE TUNING

The IMT must be set to the closest line side and coaxial side impedances available. See drawing R4.301240 for details on the IMT. The nominal line side impedances can be increased by 10% by reconnecting the "IMP CORR" link.

The following nominal line side impedances are available (without correction, I.e. "IMP CORR" link is connected to the stud labeled 0%):

- 175 Ohms
- 210 Ohms
- 265 Ohms
- 320 Ohms
- 380 Ohms
- 450 Ohms

The following nominal line side impedances are available with the 10% correction (I.e. "IMP CORR" link is connected to the stud labeled 10%):

- 192 Ohms
- 231 Ohms
- 291 Ohms
- 352 Ohms
- 418 Ohms
- 495 Ohms

The following coaxial side impedances are available:

- 50 Ohms
- 75 Ohms
- 100 Ohms
- 125 Ohms
- 150 Ohms

For in-factory tuning reference FWO (simplified schematic) for the line and coaxial side impedances. Connect links "LINE IMP", "IMP CORR" and "COAX IMP" accordingly.

For customer tuning select the closest line and coaxial side impedances to the desired values and connect links "LINE IMP", "IMP CORR" and "COAX IMP" accordingly.

The impedance analyzer shall be calibrated before each use (short circuit calibration: @100kHz, series measurement mode, Z-phase angle mode; open circuit calibration: @1MHz, parallel measurement mode, Z-phase angle mode). Warm-up time for most impedance analyzers is 20-30 min. Reference the instruction manual provided with the impedance analyzer for details.

6.0. TUNING

1. Reference drawing R4.301238, page 2. Determine the RWL connections (third column) based on the FWO (simplified schematic) or the chosen value of C1 (see chapter 4.0 on calculating C1 in case of customer tuning). For example, if the capacitance C1 needs to be 2000pF and you have one of models 301238.0003 or 301238.0004 no connections are needed for the capacitor part. If you have one of models 301238.0001 or 301238.0002, connect studs A and B with a rigid link. If wire links are needed, keep them as short as possible.
2. Disconnect yellow lead connecting stud EQUIP on the protective unit and stud E1 on the inductor unit.
3. Disconnect ground lead (black) from stud E2 on the inductor unit.
4. Determine the value of the inductance L1 either by calculating it as shown in chapter 4.0 or estimate it from Table 2. See FWO (simplified schematic) for the value of CC in case of in-factory tuning. Choose the closest value if the exact value of the coupling capacitor is not shown in Table 2. For example if the coupling capacitor is 5.5nF, you can choose either 5nF or 6nF as coupling capacitor, so inductance L1 could be either 650uH or 760uH.
5. Reference drawing R4.301237, page 1. Determine the RL connections (fourth column) based on the FWO (simplified schematic) or the calculated value of L1 (see chapter 4.0 on calculating L1 in case of customer tuning). Always choose a combination with the least number of connections. For example, if the inductance L1 needs to be 250uH and you have model 301237.001 no connections are needed for the inductor part (see fourth line: 80-270uH, RL connections: none). If you have model 301237.0002, one solution would be to connect studs 2 and 3 with a red wire link (see third line: 135-500uH, RL connections: 2-3), but a better solution is the one in the fourth line (130-400uH, RL connections: none). If two neighboring studs need to be connected (for example: 2 to 3) use rigid links. If wire links are needed, use red wire and keep the wire as short as possible. Determine which studs need to be connected to the connection points E1 and E2. For instance, for model 301237.0001 and 250uH, connect stud 5 to stud E1 or E2 (whichever is closer) and stud 6 to the

remainder of E1 or E2. Use red wire and keep it as short as possible.

6. Loosen the set screws on the fine tuning knob (there are four at 90 degrees apart).
7. Make sure the hardware on every stud is tightened properly.
8. Set the impedance analyzer in series L-R mode. Set the frequency to the cut-off frequency $f_{cut\text{-}off}$ (see FWO for in-factory tuning). Connect the measuring leads to the E1 and E2 studs of the inductor unit.
9. Determine the value of the inductance L1 form Table 2 for the value of the coupling capacitor CC. See FWO (simplified schematic) for the value of CC in case of in-factory tuning. Use linear interpolation if the exact value of the coupling capacitor is not shown in Table 2. For example if the coupling capacitor is between 5 and 6 nF, the inductance L_1 will be $L_1 = 650\mu H + (760\mu H - 650\mu H)\cdot(CC[nF]-5)$, so for 5.4nF you will get $L_1 = 650\mu H + (760\mu H - 650\mu H)\cdot(5.4-5) = 694\mu H$ and for 5.7nF you will get $L_1 = 650\mu H + (760\mu H - 650\mu H)\cdot(5.7-5) = 727\mu H$. Note that this is only an estimated value, the final value will be set later.
10. Turn the fine tuning knob until the analyzer reads the value of L1 determined in the previous step.
11. Connect with a yellow lead stud EQUIP on the protective unit and stud E1 on the inductor unit.
12. Reconnect ground lead to stud E2 on the inductor unit.
13. Open ground switch (see drawing R4.301236, page 2).
14. Connect a low dissipation capacitor (for instance polyester or similar capacitor) having the value of the coupling capacitor CC to the line side bushing.
15. Connect a low-inductance resistor between the E1 and E2 terminals of the IMT having the same nominal resistance than the coaxial side impedance (R_C). See FWO (simplified schematic) for the value of R_C in case of in-factory tuning.
16. Set the impedance analyzer in series L-R mode. Set the frequency to the cut-off frequency $f_{cut\text{-}off}$ (see FWO for in-factory tuning). Connect the measuring leads to the free end of the capacitor simulating CC and to the grounding stud of the line tuner (see component view drawing for location of the ground stud).
17. Calculate the return loss based on the inductance and resistance reading of the

impedance analyzer and the following formula:

$$R_{loss} = 20 \cdot \log \frac{\sqrt{(R + R_L)^2 + (2 \cdot \pi \cdot f_{cut-off} \cdot L)^2}}{\sqrt{(R - R_L)^2 + (2 \cdot \pi \cdot f_{cut-off} \cdot L)^2}}$$

where R_{loss} is the calculated return loss, R and L are the resistance and inductance readings on the analyzer, R_L is the line side impedance and $f_{cut\text{-}off}$ is the cut-off frequency.

18. If the return loss needs to be adjusted (it is either less than specified or one wants to reduce it in order to achieve exactly the specified return loss at the cut-off frequency) turn the fine tuning knob about a quarter turn, take another set of readings on the analyzer and recalculate the return loss. Repeat this step until the desired return loss is achieved.
19. Fix the fine tuning knob with the four set screws.