LF Tuning Meter for the 136kHz Band

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When adjusting the tuning and matching components of an LF antenna, it is extremely useful, if not essential, to have some way of indicating the impedance mismatch at the antenna feed point. One way of doing this is to use an SWR bridge, as is usually done at HF, but this only indicates the magnitude of mismatch, so adjustment is still a matter of trial and error. For a long time I have used a dual-trace ‘scope to display the voltage and current waveforms at the feed-point (see the “Scopematch” article in the LF Handbook) The antenna loading coil can then be tuned so that voltage and current are in phase (ie. the load is resistive), and then the tapping point of the impedance matching transformer adjusted so that V/I = 50Ω. This makes tuning the antenna very quick and straightforward to do, but does need an oscilloscope; OK if you have one in the shack anyway, but not very convenient for /P operation! This LF tuning meter was conceived to perform the same function, but to be a simple, self-contained unit requiring no additional power supply. The tuning meter contains two meters – An RF voltmeter and ammeter, and a phase meter. The voltmeter/ammeter is used to determine the magnitude of the load impedance (V/I), while the phase meter indicates if the load is resonant (voltage and current in phase), inductive (+ve phase; voltage leads current), or capacitive (-ve phase, voltage lags current). The complete circuit is shown in figure 1 below.

RF Voltmeter/Ammeter

The RF voltage is measured by a simple diode rectifier voltmeter (D11, D12), driven from a divide-by-21 capacitive voltage divider. A toroidal current transformer T3 is used with another rectifier (D7 – D10) to measure current. “Hi” (300V, 6A) and “Lo” (100V, 2A) voltage and current ranges are provided, which makes the meter usable over a range of about 20W to 200W(Lo range) or 200W to 1.8kW(Hi range) transmitter power. The voltage and current scales are chosen so that the voltage scale is 50 times the current scale FSD. Therefore, with a 50Ω load connected, the same deflection is seen on the meter scale when the meter is switched between voltage and current measurement. This means the operator can immediately see if the load is matched to 50Ω (V/A readings equal deflection), greater than 50Ω (V>A), or less than 50Ω (V<A), without performing any mental arithmetic, and also without requiring any additional device to calculate and display the resistance.

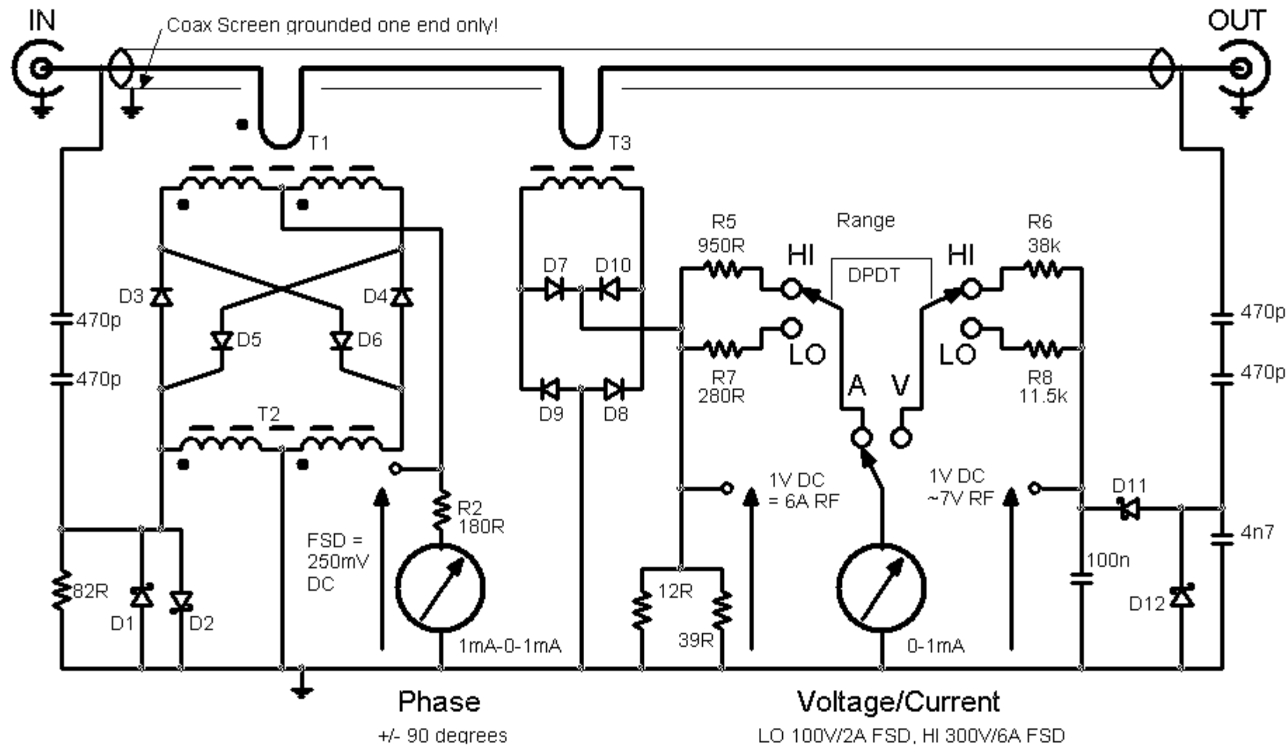

Figure 1 Tuning meter circuit diagram

Phase Meter

A classic technique to measure the phase difference between two signals is first to phase shift one signal by 90^0, then clip the signals to a constant amplitude square wave (to make the measurement independent of signal amplitude) and apply the signals to the inputs of a balanced mixer. With square wave signals applied to the mixer, the output consists of a DC level with a voltage proportional to the phase difference over the range -90^0 to $+90^0$. For the tuning meter, one input signal is a sample of the transmitter output voltage from a potential divider. The other input is a sample of the transmitter output current from a current transformer. This system provides a nice phase measurement, but gets quite complicated. However, in practice we only need to determine if the phase is zero, positive or negative, so we can accept reduced measurement accuracy in exchange for drastically reduced complexity. In this circuit, the voltage is sampled by the network consisting of 2 x 470pF capacitors and the 82 ohm resistor shunted by a pair of back-to-back Schottky diodes, D1,D2. This provides a reasonably square waveform of fairly constant amplitude over a wide power range, phase shifted by 90^0. This signal is applied to a balanced diode mixer (D3 – D6), which is driven by a sample of the load current obtained from the current transformer T1. Although the current driving the mixer varies widely, it is sufficient to saturate the mixer over a wide range also, so quite a wide variation of transmitter power does not affect the mixer gain greatly. The DC output from the mixer is measured by a centre-zero meter to indicate the phase. Since the mixer output is zero when voltage and current are in phase, there is very little error in the indication of zero phase shift over a wide power range – in the prototype unit, zero degrees phase was accurately indicated with transmitter powers between 20W and 1200W – at power levels below about 20W, there is a substantial reduction in meter deflection when the load impedance is inductive or capacitive, but the sign of the phase reading is still correct, which is all that is required for tuning an antenna. At 1W level, the zero phase reading is still only in error by a few degrees.

Components and Construction

The prototype tuning meter is shown in figure 2 – the part numbering below corresponds to the circuit diagram in figure 1.

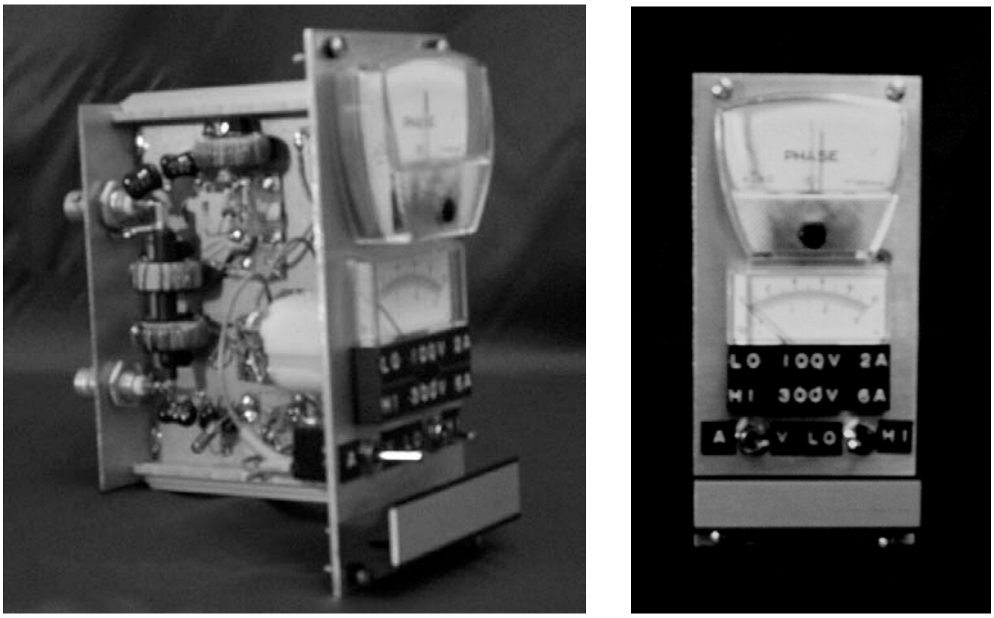

Figure 2 – Prototype tuning meter – the mechanical design is to fit a "Eurocard" rack; it measures about 130mm x 130mm x 60mm overall.

The clipping diodes D1, D2 are BAT85 Schottky switching diodes, and limit the input signal to about 500mV pk-pk, ie. less than the forward voltage drop of the junction diodes used in the mixer. 1N5819 small Schottky rectifier diodes also worked well, with slightly lower Vf, which reduces the DC output from the mixer somewhat. RF-type Schottky and germanium diodes will not work well in this application – their current-carrying capability is too small.

The mixer diodes D3 – D6 are a matched quad of 1N4148s. Matching is critical so that a significant error does not occur in the zero-phase reading. Fortunately, this can be easily done using the "diode check" range on most digital multimeters. Pick several diodes from the same production batch – usually if you buy some diodes, they come on tape "bandoliers", and you can be pretty certain they come from the same batch. Check the forward voltage drop of each diode with the multimeter, taking care that they are all at an equal temperature by only touching them with the meter leads, and doing the job reasonably quickly. Pick the 4 diodes with the closest matching V_f, which should be within a few millivolts of each other. Diodes selected at random can easily have V_f differing by 50mV or more, which will result in large phase measurement errors. I tried this matching procedure with batches of 1N4148, 1N914 and 1S44 switching diodes, all with satisfactory results in the phase meter circuit. D7 – D10 can also be 1N4148 or other small switching diodes – matching is not critical. D11 and D12 are BAT85 Schottky diodes for low forward voltage drop – germanium signal diodes should also work well. Note that D3-D6 are connected as a "rat-race", but D7-D10 are in a bridge rectifier connection.

The 470pF capacitors must be stable and withstand the full RF output voltage from the transmitter. Silver-mica units were used. The 4.7nF was polystyrene. The transformers are all wound on some high-permeability ferrite cores about 22mm diameter of unknown origin, probably from a pulse transformer in a SMPS. They have A_L of about 4000nH/t, and permeability is about 5000. The RS components 232-9561, 212-0910 and numerous others should be suitable. Power handling is not important, but if lower permeability material is used, the reduced inductance could cause problems with unwanted phase shifts. The winding details are as follows:

T1: Primary is RG58 coax passing through core. Secondary 2 x 25t Bifilar 0.3mm enamelled Cu .
T2: 2 x 50t bifilar 0.25mm enamelled Cu.
T3: Primary is RG58 coax passing through core. Secondary 50t 0.5mm enamelled Cu.

The coax links the input and output sockets, and T1 and T3 are threaded on to the coax in the usual SWR-bridge style. Make sure you ground one end only of the coax braid!

The meters and range-setting resistors will depend on what you have in the junk box, and what transmitter power it is to be used with. I had a 1mA-0-1mA meter marked "phase", so I used it for the phase meter… meters of higher sensitivity can also be used by increasing the value of R2. The resistor value should give full-scale deflection of the meter with a mixer output of around 250mV, but this will vary slightly with different diodes and so on – accuracy is not critical, however, since we are mainly just interested in the sign of the phase. Similarly, for the voltmeter/ammeter section, I had a 1mA meter with 0-3 and 0-10 scales available, so the voltage and current scales used reflect this and the range of transmitted power I expect to be using. R5 and R7 set the current scales, and can be calculated from $R = (I_{RF}/I_M)/6$, where I_{RF} is the full-scale RF current, I_M is the full-scale meter current in amps. The meter coil resistance must be subtracted from this (50Ω for the particular meter used). The voltage range resistors R6 and R8 are given approximately by $R = (0.134 \times V_{RF} - 1)/I_M$, where V_{RF} is the full-scale RF voltage. If facilities are available to calibrate the voltage and current ranges, presets could be used instead of fixed range setting resistors. "Hi" and "Lo" ranges were provided to extend the useful power range of the unit; this is obviously not necessary if a fixed transmitter power is to be used. The rectifiers, particularly the voltage-sensing rectifier, become less accurate at low power levels due to the effect of finite diode forward voltage drop, but at the 20W level, the error in the prototype was less than 5%. If the unit were to be used with a QRP transmitter, it would be a good idea to change the division ratio of the capacitive potential divider to supply a higher signal voltage to the rectifier.

Testing and Use

With the unit connected between a transmitter and non-reactive dummy load, the phase meter should read zero within a few percent of FSD for power levels of a few watts or greater. Small errors can be trimmed out using the mechanical zero adjustment on the meter. With the transmitter set to a low power output, connect a capacitor of about 22nF in place of the dummy load. With about 30V or more RF voltage from the transmitter (but with output kept low enough not to damage transmitter or capacitor!), the phase meter should read close to negative full scale – adjust R2 if required. If the meter reads positive instead of negative phase, this can be corrected by reversing the connections of the secondary of T1, or by reversing the meter connections. The voltage and current ranges can also be checked and adjusted – it is not vital that the readings have high absolute accuracy, but the range setting resistors should be adjusted so that the meter deflection is the same when the meter is switched between V and A with a 50Ω load connected, since this makes it easy to tell whether the antenna is correctly matched, as explained previously.

In use, select the "Hi" or "Lo" range to suit the power level in use. Apply some transmitter power to the antenna, and note the phase meter reading. If the phase is negative (capacitive), increase the loading coil inductance, and reduce the inductance if the phase is positive (inductive). When zero phase is obtained, switch between "V" and "A" ranges. The ratio V/I is the resistance – if it is greater or less than 50Ω, as indicated by the meter deflections not being equal, adjust the matching transformer, loading coil or whatever matching system you are using as appropriate. If the "V" deflection is greater than the "A" deflection, adjust to give a reduced load resistance; if "V" is less than "A", adjust for a higher load resistance.

Revision – A and V markings on meter range switch in fig 1 were interchanged – corrected 30/4/03