ANTENNA TUNING UNITS

Introduction

This article is an abridged adaptation of a document published by LDG Electronics and is specifically intended to correct the misconception some amateur radio operators have over what an ATU actually does.

Theory of Operation

The theory underlying antennas and transmission lines is fairly complex, and in fact employs a mathematical notation called “complex numbers” that have “real” and “imaginary” parts. It is beyond the scope of this article to present a tutorial on this subject, but a little background will help you understand what your ATU is doing, and how it does it.

In simple DC circuits, the wire resists the current flow, converting some of it into heat. The relationship between voltage, current and resistance is described by the elegant and well-known “Ohm’s Law”, named for Georg Simon Ohm of Germany, who first discovered it in 1826. In RF circuits, an analogous but far more complicated relationship exists. RF circuits also resist the flow of electricity. However, the presence of capacitive and inductive elements causes the voltage in the circuit to lead or lag the current, respectively. In RF circuits this resistance to the flow of electricity is called “impedance”, and can include all three elements: resistive, capacitive, and inductive.

The output circuit of your transmitter consists of inductors (L) and capacitors (C) usually in a series/parallel configuration called a “pi network”. The transmission line can be thought of as a long string of capacitors and inductors in series/parallel, and the antenna is a kind of resonant circuit. At any given RF frequency, each of these can exhibit resistance, and impedance in the form of capacitive or inductive “reactance”.

The output circuit of your transmitter, the transmission line, and the antenna all have a characteristic impedance. For reasons too complicated to go into here, the standard impedance is about 50 ohms resistive, with zero capacitive and inductive components. When all three parts of the system have the same impedance, the system is said to be “matched”, and maximum transfer of power from the transmitter to the antenna occurs. While the transmitter output circuit and transmission line are of fixed, carefully designed impedance, the antenna presents a 50 ohm, nonreactive load only at its natural resonant frequencies. At other frequencies, it will exhibit capacitive or inductive reactance, causing it to have an impedance different from 50 ohms. When the impedance of the antenna is different from that of the transmitter and transmission line, a “mismatch” is said to exist. In this case, some of the RF energy from the transmitter is reflected from the antenna back down the transmission line, and into the transmitter. If this reflected energy is strong enough it can damage the transmitter’s output circuits. The ratio of transmitted to reflected energy is called the “standing wave ratio”, or SWR. An SWR of 1 (sometimes written 1:1) indicates a perfect match. As more energy is reflected, the SWR rises to 2, 3 or higher.

As a general rule, modern solid state transmitters must operate with an SWR of 2 or less. If your 50 ohm antenna is resonant at your operating frequency, it will show an SWR close to 1. However, this is usually not the case; operators often need to transmit at frequencies other than resonance, resulting in a reactive antenna and a higher SWR.

SWR is measured using a device called an “SWR bridge”, inserted in the transmission line between the transmitter and antenna. This circuit measures forward and reverse power from which SWR may be calculated (some meters calculate SWR for you). More advanced units can measure forward and reverse power simultaneously, and show these values and SWR at the same time.

The antenna tuner is used to cancel out the effects of antenna reactance. Tuners add capacitance to cancel out inductive reactance in the antenna, and vice versa. Simple tuners use variable capacitors and inductors; the operator adjusts them by hand while observing reflected power on the SWR meter until a minimum SWR is reached. Advanced automatic tuners add or reduce inductance and capacitance using either motorized variable LC components or relays to switch banks of fixed LC components. No tuner will fix a bad antenna. If your antenna is far from resonance, the inefficiencies inherent in such operation are inescapable; it's simple physics. Much of your transmitted power may be dissipated in the tuner as heat, never reaching the antenna at all. **A tuner simply "fools" your transmitter into behaving as though the antenna were resonant, avoiding any damage that might otherwise be caused by high reflected power.**

The Automatic Antenna Tuning Unit

The development of automatic antenna tuners incorporates a design that uses banks of fixed capacitors and inductors, switched in and out of the circuit by relays under microprocessor control. A built-in SWR sensor provides feedback; the microprocessor searches the capacitor and inductor banks, seeking the lowest possible SWR. Such tuners are a "Switched L" network consisting of series inductors and parallel capacitors. The inductors are switched in and out of the circuit by relays controlled by the microprocessor. An additional relay switches between high and low impedance ranges. The capacitors are connected to ground with the inductor relays. Another relay switches the entire capacitor bank to the input or output side of the inductor. This switching allows the ATU to automatically handle loads that are greater than 50 ohms (high setting) and less than 50 (low setting).

The SWR sensor is a variation of the Bruene circuit. This SWR measuring technique is used in most dual-meter and direct-reading SWR meters. The forward and reverse power sensors produce a calibrated DC voltage proportional to the forward and reverse RF power levels. These two voltages are read by analogue to digital converters in the microprocessor. Once in a digital format, they are used to calculate SWR in real time. The tuning routine first de-energizes the high/low impedance relay if necessary, then individually steps through the inductors to find a coarse match. With the best inductor selected, the tuner then steps through the individual capacitors to find the best coarse match. If no match is found, the routine repeats the coarse tuning with the high/low impedance relay energized. The routine then fine tunes the capacitors and inductors. The microprocessor then runs a fine tune routine that tries to get the SWR as low as possible.

Conclusion

On completing the tuning process, the antenna tuner presents the best possible matching transmission line/antenna combination to the output terminals of the transmitter. It has done nothing to improve the power radiation efficiency of the antenna itself. The non-radiated power is reflected back into the circuits of the antenna tuner where it is dissipated into the applicable circuit components.

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Acknowledgements:

1. LDG AT-7000 Automatic Antenna Tuner Manual, LDG Electronics, St Leonard MD, USA