Design of an Antenna Coupling Unit

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Here are some matters that need to be considered in designing your Antenna Coupling Unit. There is no such thing as an Antenna Tuning Unit, nowadays; the nearest thing was the adjustable-length trailing wire HF antenna laid out behind aircraft during WWII.

a. Zo of your txvr

Assume Zo is 50 ohm for solid-state finals. Valve jobs may be quite a bit higher – perhaps as high as 600 ohm. You will need to look at the txvr's nomenclature plate or in the Operator's Handbook to get this info.

b. Desired operational bands

Look at the harmonic relationships between the bands. Then look at the requirements for resonance in real wire – as you will see below, there are no real harmonic antennas that can be made from a single, un-trapped dipole that will map onto the amateur bands. Look at 80 m and 30 m, 40 m and 15 m, 18 m and 6m – all miss out by a bit, so an Antenna Coupling Unit [ACU] or a very tolerant txvr final PA is required.

The appropriate theoretical resonant length of a very thin ¼wave wire is 75/f m [f in MHz], when the antenna is a long way from any other possible electric field distorting matter. The open end of a ¼wave is at a very high impedance and so is easily affected by any objects at all; so, the antenna appears inductive. The usual correction is to shorten the antenna by 5%. If you use insulated wire, the dielectric coefficient of the insulation means that the antenna needs to be shortened a little further.

Let's just look at one of these harmonic operations. If we cut a thin, bare-wire dipole for 3.550 MHz [bottom end of the 80 m band], after all the corrections, each ¼wave leg should be 20.07 m. If we now excite this antenna with a 30 m signal at, say, 10.125 MHz, the first two ¼wave don't need shortening but the third does. So, the appropriate length for each of the first two ¼wave is 75/10.125 = 7.407 m, and the length for the third, because it has a free end, is 0.95 of this, ie, 7.037 m, giving a total of 7.047+7.047+7.037 = 21.131 m. So, our dipole cut for 80 m is too short for 30 m by about 5% and will be capacitive on 30 m.

This means that for multiband operation, an ACU is required.

In addition, for a fixed wire installation, the higher the harmonic on which you operate, the lower the radiation angle and the more radiation lobes there will be, ie, the radiation pattern will alter for each band.

c. PEP

For 400 W PEP from a 50 ohm PA, output Voltage is sq.rt.[PR] = sq.rt.20,000 V = 141 V.
400 W PEP from a 600 ohm PA → 490 V.
For 100W PEP, output Voltage from a 50 ohm PA is 71 V.
For 30 W PEP [or even CW], output Voltage from a 50 ohm PA is 35 V.

When using an SPC or Transmatch ACU, this Voltage determines the plate spacing of the input capacitor [C1 in the diagram below].

d. Maximum antenna length

The lower the frequency, the longer the antenna and the greater the height required for good propagation other than straight up [Near Vertical Incidence]. When multiband operation is required, the odd harmonics, ie 3x, 5x, 7x will have relatively low radiation resistance – in the 50 to 100 ohm range, while the even harmonics will face very high antenna radiation resistance – in the k ohm region. Makes having a balun at the feedpoint very difficult, because baluns work into fixed impedances. Almost demands open-wire, balanced feed line. Operate off-resonance and the antenna becomes reactive – means more correction required by the ACU. Operation below lowest resonance means that the impedance falls dramatically, especially over a good Earth.

e. Height of feedpoint

When the feedpoint for a dipole is a long way away from the Earth, the feedpoint radiation resistance approaches 72 ohm. When the feedpoint is at 0.18 wave from Earth, the radiation resistance is 50 ohm. Below 0.18 wave, radiation resistance falls almost uniformly to zero. Between 0.18 wave and infinity, the radiation resistance varies between 60 and 100 ohm. So, with a single dipole used as a multibander, the radiation resistance will be all over the place.

For instance, if you set up for 80 m, and put the feedpoint at 0.18 wave, Za = 50 ohm. How about operating this antenna at 160 m? radiation resistance may be as low as 20 ohm.
Now, try it on 40 m – radiation resistance is about 5 k ohm. [even harmonic]
Try 30 m, the antenna is now at 0.54 wave, and the radiation resistance is about 70 ohm.
Try 20 m, again about 5 k ohm.
And so on.

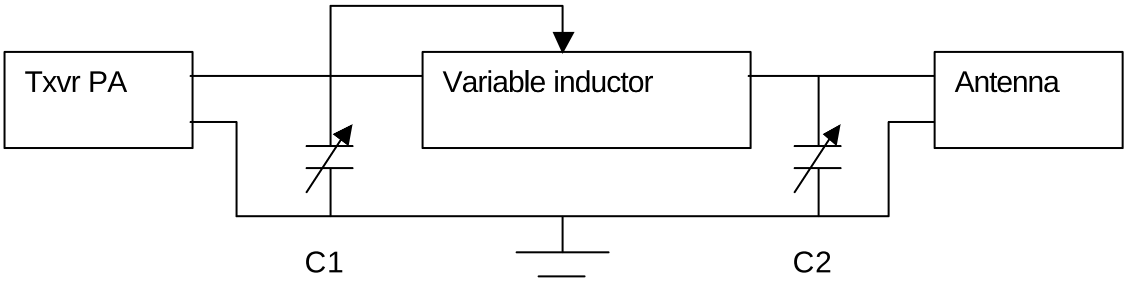
When the antenna radiation resistance is 100 ohm, the VSWR is 2:1, and the maximum Voltage at the antenna feedpoint for 400 W is about 282 Vrms. That requires relatively small spacing in the final tuning capacitor of an SPC or a Pi matcher [C2 in the diagram below]. Allow about 1 kV per mm – spacing needs to be 0.40 mm – a bit over 0.016".

When the antenna radiation resistance is 5 k ohm, the VSWR is 100:1, and the Voltage at the feedpoint is about 14,100 Vrms. That requires a lot of spacing in the final tuning capacitor of an SPC or a Pi matcher – spacing needs to be 20 mm – a bit over a 3/4".

So, it might be better, if you want both 80 m and 40 m capability, to use a trapped dipole. [See article in Oct 2004 AR for calculating size of trap inductor and length of dipole sections.] This antenna will work well on the odd harmonics of the 80 m antenna and the odd harmonics of the 40 m antenna, too, → 80, 40, 30, 15, 10 and 6 capability – pity about 20 m. Alternately, start with a 40 m trapped dipole – you do the maths for capability – this will start as a dipole whose total length is about 20 m. At worst, the VSWR may get to 4:1, meaning an antenna feedpoint Voltage of 560 Vrms and final ACU capacitor plate spacing of 0.80 mm, or about 32 thou [about 1/32"].

How does the Transmatch work?

Assume an unbalanced Pi configuration.



The two capacitors, C1 and C2, act as impedance splitters and conjugate matchers. Imagine the two Cs disconnected from ground – they are now in series and have an L is parallel – ie, we have a parallel LC resonant tank. Our aims are to adjust this tank for

1. resonance;
2. impedance match; and
3. conjugate match.

So, we have three variables, and the better transmatch units therefore have three controls – but you can't allocate one control to each required adjustment – it requires some backing and forthing.

If the two capacitors are both about 200 pF maximum and the inductor is about 20 uH maximum, the lowest resonant frequency will be 1/2pi sq.rt.[LC], ie, about 3.55 MHz. [Note: the two capacitors are in series and so count as 100 pF in the formula.]

And this will work if both the txvr and antenna are 50 ohm. What happens if the antenna is about 20 ohm resistive? [eg, operating on 80m with the dipole of 20 m length] The ratio of C1 to C2 will need to be 50:20; ie, set C2 at maximum capacity and C1 at 40%, or about 80 pF. However, the tank is no longer resonant at 3.55 MHz – it's resonant at more like 4.93 MHz. What you can see here is the normal thing that happens with this kind of ACU – you need to be able to switch in more capacitance to match the lower frequencies effectively. In this case, it would be useful to be able to switch in about 500 pF in parallel with C2; the Voltage rating for 400 W operation would need to be at least 500 V, though preferably several kV to allow for lightning strikes. On that point, a good ACU would have something like a 2.5 mH inductor across C2 as a path for such problems – the impedance of 2.5 mH at the lowest frequency of operation [80 m] will be about 56 kohm, so it will have negligible effect on the operation of the ACU.

Now, if the antenna feedpoint resistance were 100 ohm, C1 would need to be increased to about 400 pF.

In both these cases, the inductor, C1 and C2 would need to be adjusted, though the inductor might not need much adjustment at the lowest frequency. In some designs, you will find an additional fixed inductor that can be switched in series with the adjustable one to increase flexibility of operation at the lower frequencies. Note that the variable inductor should be shorting – otherwise it acts like a transformer and can generate extremely high Voltages that may flash over and cause permanent damage as well as frightening the cat.

If you choose to operate on a frequency for which your antenna is not resonant, the feedpoint impedance will be partly reactive. You will mostly use C2 to adjust for this reactivity – commonly referred to as 'conjugate matching'. That is why you will often find C2 labelled as 'Load'. But, in reality, it's also involved in tuning. Actually, true conjugate matching means that the resistive and reactive components are all accounted for in order to get maximum power out of the PA for that particular drive level [See Maxwell, in QEX, May-June, 2001].

Now, you should be starting to get the general hang of designing an ACU.

Choosing capacitors

If you are going to be operating at 30 W, then ordinary broadcast band tuning capacitors will be quite satisfactory. An advantage of these is that they are usually about 365 to 400 pF per section. Multi-gang capacitors allow you to switch several gangs in parallel to get a suitable range of adjustment at the lower frequencies; use switches whose switching parts are quite far apart so you don't get arcing under conditions of high VSWR. Choose variable capacitors that have very low resistance connections between the rotor and the frame or the sliding contactors. You may wish to dismantle the capacitors before putting them into service and clean them as per the article in Oct 2004 AR. The only modification to the reassembly instructions I would give is to use an electrically conducting and oxidation-resistant grease between the sliding contacts and in the ball bearings, eg, Almanox®. Avoid silicone-based greases and cleaning compounds – they may prevent oxidation but they also prevent conduction.

Even up to 400 W, quite moderate plate spacing is OK for C1. However, if there is a possibility of moderately high VSWR and power, then C2 needs to have quite wide plate spacing.

Finding inductors

The thing you may get hung up on is the variable inductor. The ways around this problem are many. Look in other people's junk boxes, ask at your local club, or roll your own. The first one you make could be wound on white plastic pipe and have taps to which you attach a clip-lead – just make sure that you don't adjust the tap while transmitting – you could get quite an instantaneous and unpleasant surprise. Later on, you may find a colleague who can lathe-cut a helical spiral on the outside of the plastic former to ensure the wire doesn't shift as it heats when you go for high power or high VSWR. At resonance, there are high currents circulating between the capacitors and the inductor. Consequently, the wiring between these components may need to carry up to 10 times the expected transmission current – use braided wire to reduce the series inductance and resistance – dc and RF. Don't forget that the two capacitors are in series.

Rather than provide all the answers, I'll let you find the formula for the inductance of an air-cored inductor. Use very thick wire because any resistance is in series with the radiation resistance of your antenna and therefore reduces the power reaching your antenna. Further, as the frequency increases, skin effect becomes more noticeable, ie, the effective conducting part of the wire gets thinner and so the effective RF resistance increases. The better inductors use thick-silver-plated wire because silver has higher conductivity than copper.

Hey, it’s Boxing Day already

When you come to put all this in a box, think of using plywood for a start – it’s a good insulator – however, it does allow capacitance of your hand to interfere, particularly at the higher frequencies. If you plan to make your ACU fit in a metal box, be careful of sharp points in your wiring that could be the start points for high Voltage arcing. You may also need to look very carefully at the connections to your capacitors.