Andrew G0RVM

Antenna Matching

An overview of some antenna terminology, the importance of impedance matching an antenna system and the highlighting of some common mis-truths.

Antenna Matching

Primer

Terminology

Terminology

- **Feed-point impedance** consists of:
  - **self impedance:**
    - impedance at feed-point of antenna when its located away from the influence of other conductors [a]
    - equal to feed-point voltage divided by feed-point current. When voltage and current in phase they cancel and impedance becomes purely resistive. [a] This is resonance
    - self-impedance consists of radiation resistance and the ohmic losses of the antenna structure. [h]
  - **mutual impedance**:
    - caused by conductive objects, inc ground, within antenna's reactive field. [a]
- Feed-point impedance is generally composed of either capacitive or inductive reactance in series with resistance. [a]

Terminology

- **Radiation resistance**
  - Power supplied to an antenna is dissipated by:
    - radiation (good loss)
    - heat losses in wires and nearby dielectrics (bad loss)
  - for both, dissipated power = I^2R
  - for radiation, R is a virtual resistance which could, theoretically, be replaced by a resistor of same value. This is radiation-resistance.
  - for heat losses R is real resistance
  - Losses due to heat are generally low in amateur antenna’s
  - Antenna’s are thus good radiators of electromagnetic waves.

All information, reference [a]

Terminology

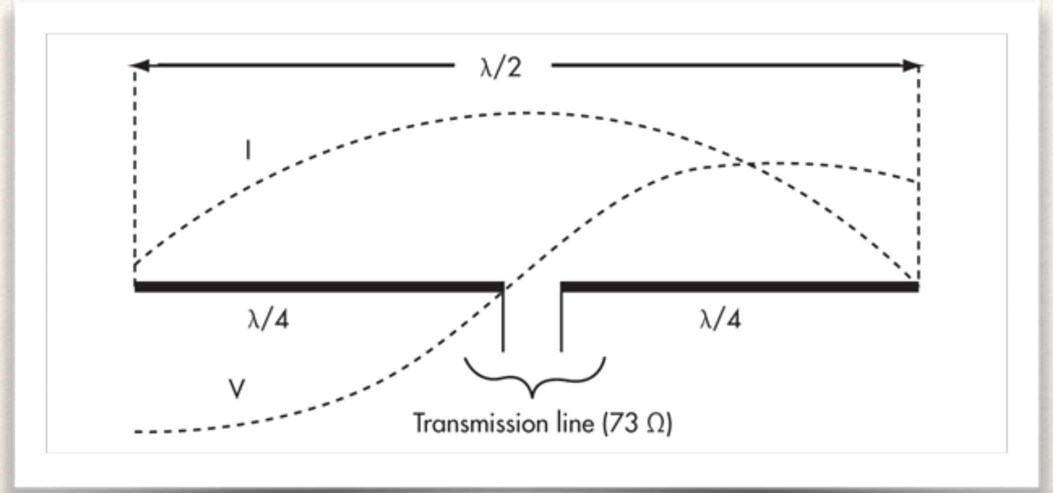
- **Counterpoise**
  - A network of suspended wires or metal screen used as a substitute for an earth/ground connection. [e]

Antenna Matching

Primer

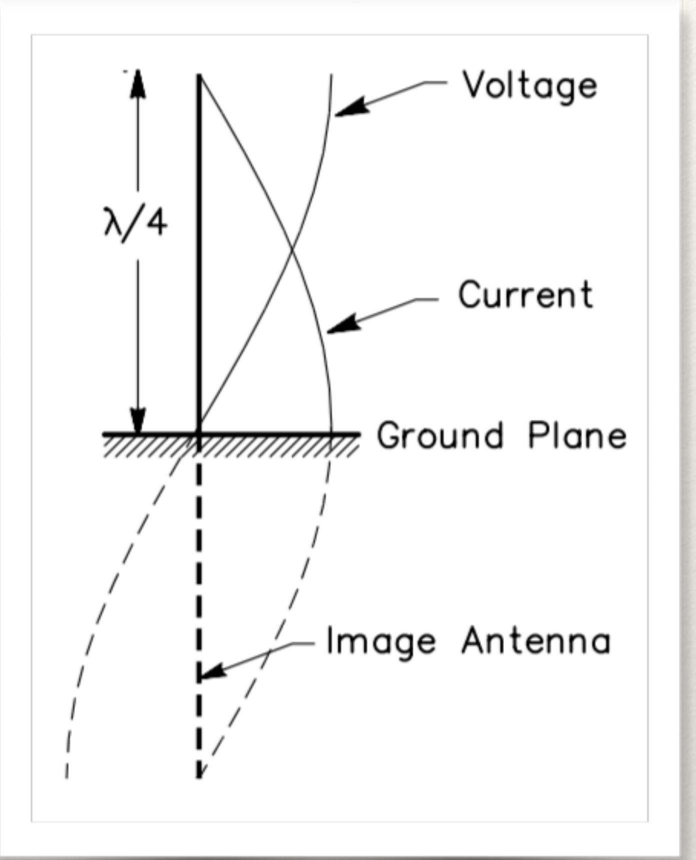
Three basic antennas

The Dipole



- Full-size, half-wave, centre-fed dipole is a fundamental type of antenna.
  - i.e. it forms the basis of many other designs.
- Theoretically thin wire dipole will have approx. 73Ω self-impedance at resonance. Real-world wire dipole is closer to 65Ω. Can be easily coupled to radio's and coax.[g]
- But very rarely is ~65Ω achieved due to other factors…

The Ground Mounted Monopole



- A 1/2 wave dipole can be ground mounted and reduced to just one 1/4 wave vertical element. Neat, however…
- The other 1/4 wave section is still needed but the ground is used as missing half
- But the ground is very, very lossy!
- Without elaborate grounding systems efficiency is not likely to exceed 50% of a 1/2 wave dipole and will likely be much less [a]
- Typical feed-point impedances at resonance are in the range 30 - 40Ω [a]

The Mobile Monopole

- Typically a shortened 1/4 wave monopole using vehicle body & chassis as a counterpoise
- Antenna's are small and significantly less efficient that a full-sized equivalent. The largest single factor is Ground loss. [d]
- Mounting is key to minimising loss:
  - excellent bonding to body and chassis is essential
  - the lower the mount the more current is forced to flow through very lossy ground under the vehicle
  - the more metal under the antenna the better. Hence central roof mounting is often the least inefficient location.
- At resonance, self-impedances can vary significantly depending upon frequency and can be from as low as 1Ω to 40Ω for an efficient installation. [g] Add other losses and the feed-point impedance can be almost anything. Every installation is different.
- Matching the 50Ω transceiver to the feed-point is essential to achieve optimum efficiency.

Primer Summary

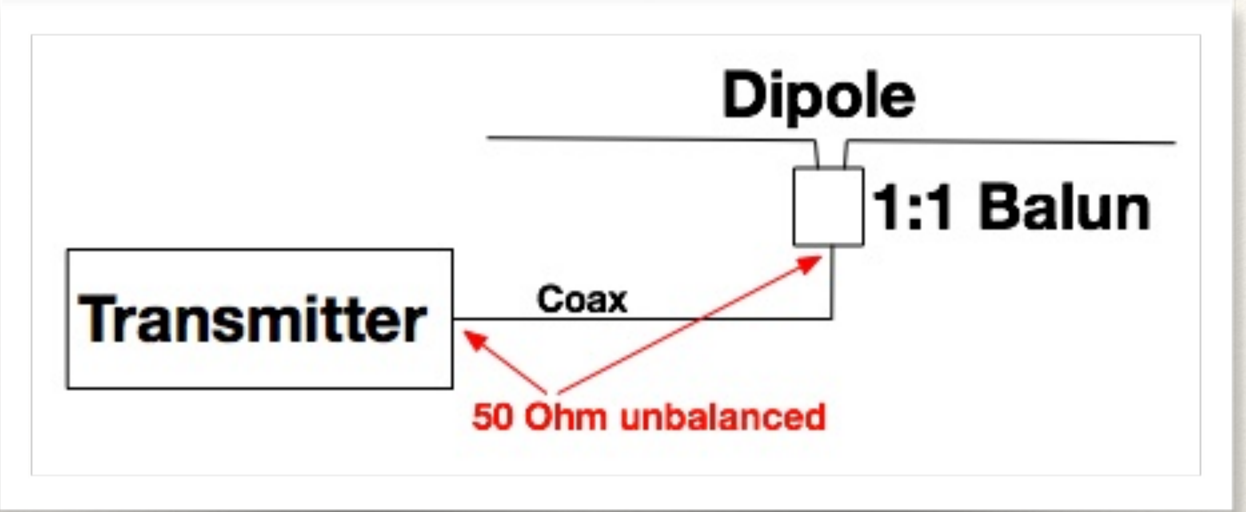
- We have seen:
  - three common antenna’s based upon the Dipole
  - that feed-point impedance can vary substantially for an antenna at resonance.
- We know that:
  - maximum power transfer occurs between impedance matched components in the antenna system. Jacobi’s law [j] & [e]
  - that modern amateur transceivers aggressively reduce Tx power on detection of moderate reflected power. e.g. 1.5:1

Antenna Matching

Antenna

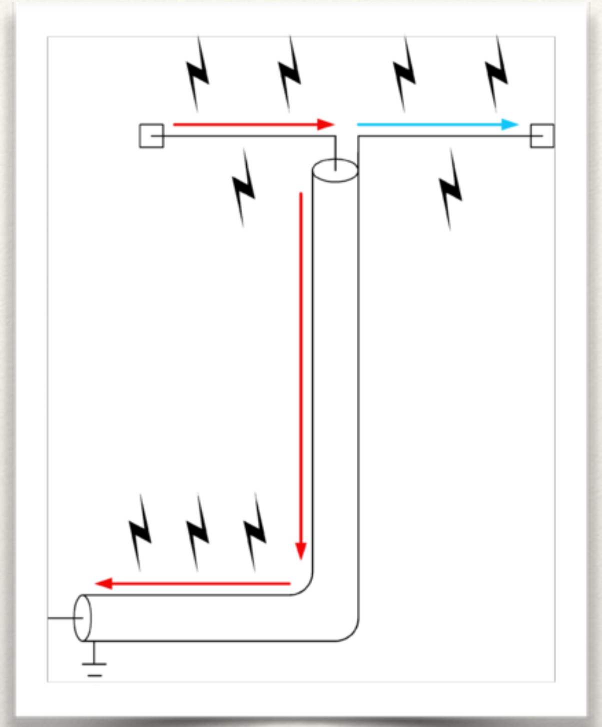
Matching

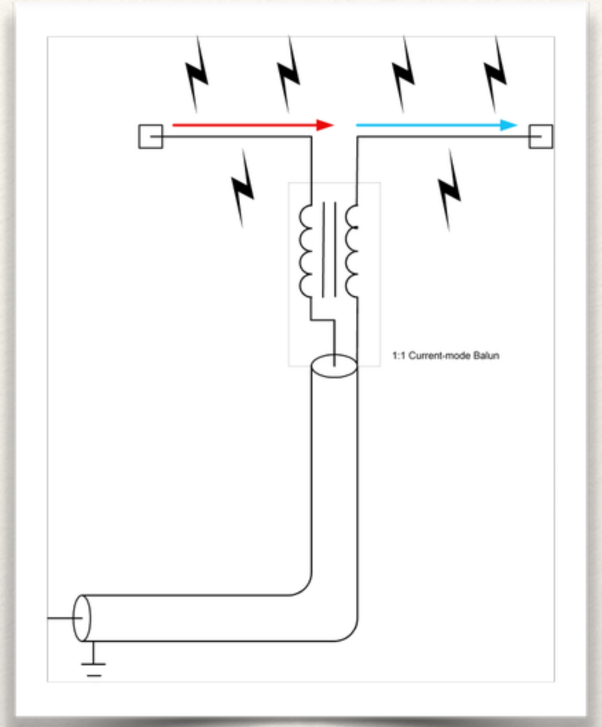
A Simple Setup



- A simple amateur system is a transceiver feeding a full-size, half-wave dipole using coax and a balun.
- Assuming that the dipole is at least a 1/4 wave above ground and the feed-point impedance around 60Ω, 50Ω is sufficiently close to 60Ω that mismatch is negligible thus no impedance matching interface is required.
- We have an efficient antenna system with minimal unwanted losses!
- But what is that balun thing? Its adding unwanted loss, yes? True but…

The Balun - a wee digression





- The radio is unbalanced
- The coax is unbalanced
- A dipole is a balanced antenna
- We don't want the coax shield radiating
- Radiating coax can place RF where we don't want it causing interference
- Thus we need to convert
- A 1:1 balun is not an impedance matching device

Tuning the Antenna

- When tuning an antenna, use an analyser and adjust for minimum reactance. i.e. resonance
- The antenna may exhibit minimum reactance at several quite different frequencies so keep an eye on DC resistance and check its in line with design expectations
- An antenna should always be tuned with the minimum amount of feeder necessary to separate you and the measuring equipment from the antenna
- An antenna cannot be tuned by adjusting for minimal SWR. At resonance, SWR is extremely unlikely to be the lowest value achievable
- Once adjusted to provide minimal reactance, the feed-point impedance is what it is. i.e. if its 100Ω its 100Ω! Now the 50Ω transceiver and coax impedance needs transforming to ensure a good match.

A Cautionary Note

- Two things to remember when tuning and matching antennas:
  - SWR / VSWR
    - there is a prevalent misconception that a low SWR indicates the antenna is tuned and thus the antenna system is *good* - Wrong
    - the antenna should never be adjusted to present minimal SWR at the transceiver
    - its very unlikely that the SWR measurement of an antenna at resonance will be minimal. i.e. 1:1
  - the term 'Antenna tuning unit' or ATU is a misnomer
    - it does nothing of the sort - it does not tune an antenna.

Coupling including the ATU

- We have seen that an antenna at resonance will most likely **not** have a feed-point impedance that is close to 50Ω
- But if we are to get maximum power transfer from/to the transceiver we need a 50Ω antenna system
- The solution? Match impedances in the antenna system where mismatch occurs. In a simple transceiver, coax, antenna system add capacitive / inductive components as needed at the antenna feed-point to transform 50Ω into the feed-point impedance.
- Not always practical, especially for a multi-band antenna.
- Including the correct coupling capacitance/inductance and tuning for resonance is especially important for mobile antenna's due to poor overall efficiency
- We can use an ATU to impedance match. If used - best placed at the antenna feed-point. However, this is problematic for a manual ATU! An auto ATU is a much better solution
- By using ATU the transceiver 'sees' a 50Ω antenna system and thus generates full Tx power. But nothing has changed on the antenna….
- I prefer the term 'coupler' as you are coupling the transmitter to the antenna system.

SWR - What is it anyway?

- SWR is an abbreviation of VSWR
- VSWR - Voltage Standing Wave Ratio
- Put simply, its a ratio of forward vs reflected power
  - i.e. at the point of measurement, the transmitted power vs that reflected from the load or antenna
- Where an impedance mismatch occurs in an antenna system power will be reflected.

SWR - Why do we care?

- A low SWR is an indication that the majority of forward power is being transferred to the antenna system
- SWR tells us nothing useful about the antenna system
- Transmitters don't like reflected power and aggressively reduce Tx power when its sensed.
- Actually a high SWR is not a bad thing. Power just bounces back and forth till its radiated or leaks out the coax! [i]

Conclusion

- Amateur stations are generally:
  - low power (compared to commercial)
  - use small antenna's
  - use antenna's in compromised environments.
- As such, its important we adjust antenna's correctly for resonance and impedance match where necessary to minimise unwanted losses
- Remember that an efficient transmit antenna system makes an efficient receiving system.
- Further information: See references

Antenna Matching

References

[a] - The ARRL Antenna Handbook, 21st Edition

[b] - The ARRL Handbook, 2009, 86th Edition

[c] - Practical Wire Antennas, RSGB, 2008 Edition

[d] - http://www.k0bg.com

[e] - Wikipedia

[f] - http://www.qsl.net/g3tso/Hombrew-Mobile%20Antennas.html

[g] - The Amateur Radio Mobile Handbook, Peter Dodd G3LDO

[h] - Telecommunications Engineer's Reference Book, Fraidoon Mazda

[i] - Understanding SWR by Example, Darrin Walraven, K5DVW, QST 2006

[j] - H.W. Jackson (1959) Introduction to Electronic Circuits, Prentice-Hall

Antenna Matching

The End