a discussion on some of the principles and justifications behind the design of active receiving antennas

Ian Purdie's Amateur Radio Tutorial Pages

Active Receiving Antennas

BACK

An active antenna is sometimes used for receiving purposes in instances where a normal antenna would be impossible to accommodate in a physical sense. Such an antenna is sometimes called an aperiodic antenna other people refer to it as an antenna booster.

Because modern receivers now cover such a broad frequency range it is also desirable to have a broad band antenna. In this tutorial I will attempt to address some of the theoretical justifications for using such a booster antenna.

It must be borne in mind at all times that an active receiving antenna is quite capable of introducing more severe problems into a receiving system than those which it is intended to solve.

Consider now some theoretical basics where we might compare a one metre long whip with a standard quarter wave antenna in the amateur 40 metre band. I simply selected the 40 metre band purely on whimsy and the principles could still apply at 80 metres, the a.m. radio band or even at long wave 175 Khz (1700 metres).

Conveniently a standard 1/4 wave antenna at 40 metres would measure approximately 10 metres in length. Assuming a distant signal, when received on that antenna, had a field strength of 10 uV per metre it would induce in our 1/4 wave antenna an open circuit voltage of 100 uV. Again for convenience only we will assume a pipe diameter of 20 mm.

Now on our one metre whip the same signal would induce an open circuit voltage of 10 uV. Are you following me here? I haven't used any fancy maths yet but I'll introduce some useful formulae now. NOTE the terms "an open circuit voltage", that is VERY significant. Here we will assume a whip diameter of 3 mm.

Whip Antenna Capacitance

$$Ca = \frac{24.2\,h}{\log(2h/a) - 0.7353}$$

Fig 1.

Where Ca is the antenna capacitance (in pF), 'h' is the height and 'a' is the whip diameter, both measured in metres. NOTE the co-efficient 0.7353 becomes 0.615 if dimensions are measured in inches. Ca is an approximation, many other factors come into play.

Short Whip Antenna Radiation Resistance

$$Rr = 40\pi^2 \left(\frac{h}{\lambda}\right)^2$$

Fig 2.

Where Rr is the **short** whip antenna radiation resistance, 'h' is the height and λ is the wavelength. This formula assumes a short vertical whip over a perfectly conducting plane which does not occur in reality.

Open Circuit Voltage

Open circuit voltage is simply the electric field strength multiplied by the physical height, as one example a particular signal might have a field strength of say 10 uV per metre (10 uV/M) and if the antenna height was say 12 metres long this would give us an open circuit voltage of 120 uV.

Simply it's the multiplication of 10 uV/M times the length. Be quite clear on the topic of open circuit voltage because it becomes quite important to your continued understanding.

Visualise a vertical antenna sitting out in the yard, 12 metres tall and conveniently for us there is only one signal available, it has a strength of 10 uV/M giving a total signal voltage on the antenna **without any load attached** of 120 uV. Close the eyes and think about it.

When a load is attached and we want to take some power from this antenna then that's when the fun starts. If you don't understand the concept of **impedance** then go back to my inelegant, but readily understandable analogy NOW because without it you're going to labour after this and probably miss the point.

Comparison of Antennas

The quarter wave antenna (with 100 uV open circuit voltage) is well known to have a radiation resistance of around 30 ohms (I've used 36 ohms in my sums below) and, disregarding matching considerations if terminated in a traditional 50 ohm load would form a voltage divider action as in fig. 3. This is purely for illustrative and comparative purposes only, please understand that particular point.

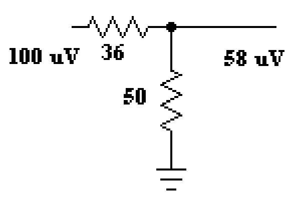

Fig 3.

In practice of course we would use ground radials and utilize matching techniques. How is the reduction in open circuit voltage worked out? Well consider this:

Vout = Vin **X** [RL / (Rr + RL)] **or;**

58 uV = 100 uV **X** [50 / (36 + 50)]

Let's look at our miserable one metre long whip which might be a few millimetres in diameter, we'll say for this exercise it is 3 mm diameter.

Using the formula above we get a Ca of about 12 pF (in practice it would most likely be more). At a nominal frequency of 7.5 Mhz the 12 pF reactance becomes a rough impedance of 1768 ohms in series with an insignificant Rr of much less than 1 ohm.

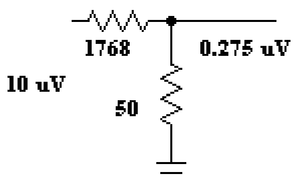

Fig 4.

Consider again,

Vout = Vin **X** [RL / (Z + RL)] **or;**

0.275 uV = 10 uV **X** [50 / (1768 + 50)]

Essentially the 50 ohm load becomes almost a **short circuit** to the signal. Now I can assure you I have taken a considerable number of liberties here in the name of simplicity but the picture I have demonstrated is pretty much the real world situation.

In fact if you want to play around with receiving antennas I'd suggest you thoroughly digest this lesson as set out above because it should prove sobering (no pun intended).

Role of the Active Receiving Antenna

Now here is the general justification of an active antenna. If a high impedance load is connected to our one metre whip instead of the 50 ohm dead short then our calculations proceed as follows.

Assuming we use a field effect transistor as the amplifying device. The circuit configuration will be a source follower. A source follower exhibits high input impedance and relatively low output impedance. It also has a voltage LOSS.

This voltage loss (without going into a lot of theory) is about 10% BUT the power gain is almost infinite.

That statement will cause a great deal of confusion so consider this (purely hypothetical), if the input to our source follower is 10 uV into an impedance of 100,000 ohms (nominal for illustrative purposes) the input power taken by the FET is E^2 / R which by way of calculation is 1 X 10^{-15} watts.

The output delivered to a 200 ohm (nominal for illustrative purposes) load would be 90% of the input voltage (10% loss) or 9 uV and E^2 / R which by way of calculation is 4.05 X 10^{-13} watts **or** 405 times the input power **or** a power gain of 26 dB.

That is the role of the active device in this antenna. Simple!, well NO, there are quite a number of problems involved here. Firstly all FETS have some inherent input capacitance and this is one of the limiting problems. Assume a possible input capacitance of about 5 pF and a real world one meter whip having a capacitance of say 25 pF including holder, feed connection etc. Oh dear here comes that fink voltage divider action again.

The FET driving voltage is:

Vin / [1 + (Ct / Ca)]

where Ct is the FET input capacitance (5 pF) and Ca is the antenna capacitance (all up 25 pF). If our one meter whip produces our former 10 uV open circuit voltage then the FET driving voltage is: 10 uV / [1 + (5 pF / 25 pF)] or 8.3 uV.

This reduction in voltage is nothing to become paranoid about because subsequent amplification will quite readily make up the difference. BTW the FET source follower configuration used here is sometimes considered to be an impedance converter.

Noise considerations

The first critical issue is one of S / N ratio. Assuming we are using a fairly good FET it should not degrade the overall noise performance of the receiving system. Below say 15 Mhz this is rarely an issue.

In the example of the quarter wave antenna and a 10 uV/M signal, external noise levels might be 1 uV/M.

These noise levels would include QRN (natural noise) and QRM (man made noise, such as my computer is presently doing to a nearby receiver). The noise is a constant ratio compared to received signal.

Whether we use a full quarter wave antenna or a physically short whip, the signal level and the noise level are going to be both proportional to physical length. The only consideration is whether the output signal level is going to be below the inherent receiver noise.

Limitations

So far you might imagine we could get away with an active receiving antenna as small as 50 mm in height (by the way it has been experimentally built). Unfortunately several vexing problems jump in our way. Don't discard the idea of an active receiving antenna because of them but be aware of the potential limitations. Some of these are:

1. Compromise of Receiver Dynamic Range:

Dynamic range might generally be described as the ratio of the level of strong out-of-band signals to the level of the weakest acceptable desired signal. An active receiving antenna is very broad band by nature and by virtue of its design. Indeed that often is the principle goal. Unfortunately it will also likely compromise the dynamic range of an otherwise excellent receiver because ALL signals present on the antenna are amplified equally.

I spoke earlier of signal levels of 10 uV/M, QRP-CW (low power morse code) enthusiasts wouldn't consider that much of a challenge. BUT with a broad band antenna don't be surprised to encounter signal levels of VOLTS per metre (not micro volts) from nearby transmitters especially strong stations in the A.M. radio band.

Many years ago I was fooling around with a basic crystal set tuned to a local A.M. station. I had a ferrite rod antenna which was tuned with a variable capacitor. NO external antenna was connected but I did have my high impedance oscilloscope attached to the ferrite rod. I was astounded to see a perfect A.M. signal of nearly 20V P/P.

2. Cross Modulation Distortion:

This occurs when the modulation (e.g. music) of an unwanted strong signal is transferred to a wanted weak signal (e.g. voice). I only highlighted those particular examples to give you an extreme understanding.

3. Inter modulation Distortion (IMD)

Receivers with many active devices, especially a receiver which has as the first active device an active receiving antenna, will frequently react in ways that do not always agree with theory. IMD is a complex problem.

In the case of an active receiving antenna you must also consider that the active device is capable of functioning as a mixer. I could give you pages of mathematics indicating trignomatic identities involving the production of a number of components with difference frequencies.

One definition (for our purposes) might be: "IMD - occurs in any non linear device (our FET) when driven by a complex signal having more than one frequency (our broad band antenna signals of - from 10 Khz up to 300 Mhz or more). The resultant signals (our output) become distorted".

As **only one** example, the possible effects of the A.M. radio band on an active antenna:

Signal (A) 900 Khz; Signal (B) 1500 Khz; - both at a field strength of 1000 uV/M (easily common) and finally our desired Signal (C) 3900 Khz - it's a lowly 10 uV/M signal.

A possible mixing action in our FET (they make good mixers) might be;

2 X Sig (A) + Sig (B) = Sig (C) **0r**

(2 X 1500) + 900 = 3900 Khz

considering the high levels of A and B and the low level of desired signal C what hope do you think you have recovering C signal? Hey and I've only mentioned two interferers and only ONE mathematical combination from around millions of available signals and a hell of a lot of possible mathematical combinations. Want to weep?

What to do?

Well don't slash you wrists or go and play on the freeway, consider why you really wanted an active antenna in the first place. Was it because someone told you they were the "ants pants"? Do you have space limitations?

If you live on acres somewhere then I would be hard pressed to imagine why you would even consider an active antenna. On the other hand if you live in an apartment and have decided the way to go for you is monitoring LF bands then an active antenna is all you may be able to consider.

If however you were a keen short wave listener then I'd certainly consider trying to unobtrusively lay as much small gauge insulated wire around the bottom of skirting boards, beneath carpets, throughout rooms as you could possibly lay. Consider all solutions, the cheaper the better.

An active receiving antenna is not necessarily restricted to a short whip. I've seen them used in conjunction with both tuned and untuned loops particularly on the V.L.F. AND L.F. bands.

Because they are tuned loops don't think they are necessarily selective. Anyone who has waded through my tutorials on L.C. Filters has seen that myth blown out of the water, or more correctly, put into proper perspective.

Go back to the basics. What was the original goal? If you can lay out as much wire as possible, the odds are any impedance mismatch could be accommodated with a relatively inexpensive simple tuner.

You might still incur some losses but they are often tolerable.

Update 17th November, 1999

I have asked a colleague who also happens to be a professional, world renowned antenna engineer to critically review all I have written above - his reply:

Ian,

You did a good job of presenting the challenges inherent in an amplified antenna for receiving, but your general conclusion may be overdrawn. The negatives generally apply to those overpriced and under engineered units sold to the unsuspecting SWL. I might have presented the ideas more as challenges toward better engineering. For example, variable gain amplifiers can reduce the problem without overwhelming the receiver dynamic range. Pre filtering for the bands or band segments of interest can reduce spurious responses from strong out-of-filter signals. Also, the local noise pick-up can be variable, depending on its source and polarization. But those are just my ways and not to be imposed on others.

The only definite change I would suggest is in the schematics of the input circuit equivalents. The reactance should not be shown with a resistor symbol, since the junction shows a vector driven value, not just a series pick-off value.

I prefer a larger antenna myself, but the field of small antennas is a challenging one and SWL's need to know how to sort of duds from the potentially useful items on the market or what they would need to do to build one of the things in a way that has a chance of working.

Hope this is useful.

-73-

That's all folks. **Please email me.**

BACK

http://my.integritynet.com.au/purdic/

URL: http://my.integritynet.com.au/purdic/activeantenna1.htm

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