Tuning the antenna with built in tuning features

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Introduction

Making a good RF antenna are by some considered a challenging part of a wireless product design. It required RF knowledge which is not common among general electrical design engineers and not widespread knowledge among software engineers either.

Radiocrafts has developed a process and the tools required to make this tuning process simple and straightforward in a way that a person with no RF experience can tune a 169MHz antenna to the final product.

This application note makes antenna design and antenna tuning available for non-RF engineers in general and describes how this is done with the built-in functionality of the RC1701HP-MBUS4 for 169MHz.

There are many Commercially-Off-The-Shelf (COTS) antennas in the market and many application notes showing reference antenna design. These antenna solutions are normally a very good starting point, but one major challenge is often seen. When using the COTS antenna or reference antenna in a real product, the environment around the antenna changes:

- The ground plane is smaller or larger or just different shape than reference design.
- There are objects/components close to the antenna
- Product enclosure is close to antenna
- Potting is close to antenna.

The effect of the changed surroundings is that the antenna performance will change and normally be degraded relative to the ideal COTS/reference design.

This application note does not intend to help design the original antenna, but it shows how the antenna tuning feature of the Radiocrafts modules will help in optimizing and tune the antenna in a real product in a few simple steps.

Background

This chapter describes some of the theory behind the antenna tuning. It requires some basic RF knowledge, but can be skipped if the reader wants to go straight to the tuning procedure.

Antenna tuning can be simplified to two separate parts.

- Make the antenna resonate at correct frequency (This maximize radiation)
- Match the antenna to the interfacing RF circuitry with lowest possible loss (This minimize mismatch loss due to reflection)

In the real world these are not completely separated items. Passive matching components will normally also have an effect on the resonance frequency of the antenna. Specifically if the matching is a T-network with serial components closest to the antenna (Figure 1). But in order to simplify the process it is smart to treat them as separated.

It is recommended to use a PI-matching network (Figure 2), and the rest of the document is based on this type of matching network. Normally just C1 and L1 need to be populated, but the third component is added to ensure possibility to cover all cases.
Figure 1. T-matching network

Figure 2. PI matching network
Test setup

In figure below (Figure 3) is shown the conceptual test setup. The setup consists of the product with the antenna to be tuned (Device under test - DUT), and a spectrum analyzer with a known reference antenna.

![Diagram of test setup](image)

*Figure 3. Principle test setup*

The DUT needs to be able to transmit and RF signals that cover the target frequency band plus frequencies slightly over and under the selected frequency. This is possible with the Radiocrafts module RC1701HP-MBUS4. The module is set in test mode ‘7’ which is equal to a frequency sweep mode. See MBUS user manual for details.

The spectrum analyzer can be a low cost PC based solution (RTL SDR) like AirSpy, or a full blown state-of-the-art spectrum analyzer from companies such as Rohde & Schwartz / Keysight.

The reference antenna can be a broadband antenna or an antenna dedicated to the frequency band of operation.

The spectrum analyzer shall be setup with a span covering the complete TX sweep range (20 MHz for RC1701HP-MBUS4), with max hold, minimum sweep time possible, and resolution bandwidth of typical 100 kHz.

By enabling the antenna tuning feature in Radiocrafts module (TX sweep test function) the spectrum analyzer gives a plot showing the signal strength vs frequency. (See Figure 4)

The plot contains some key information:

- Which frequency has the highest signal strength
- If the frequency with the highest signal strength is lower than the intended operating frequency, then the antenna is tuned too low in frequency.
- If the frequency with the highest signal strength is higher than the intended operating frequency, then the antenna is tuned too high in frequency
At the start of the tuning it is wise to also test a known good unit in the same setup. A good reference is the Radiocrafts development board with a dev kit antenna (Figure 5). This is well cantered in frequency and has a good signal level at the operating frequency.

Ideally, the tuning should be done in an echo free RF chamber (Anechoic Chamber) where the signal levels are calibrated. But due to high cost this is often difficult as the tuning process can take several hours. Many of the commercial design are done without out such chamber, but if a perfect result is required, then it is best to do this tuning in an anechoic chamber.

For best results, place the DUT and reference antenna in the same position every time and do not change anything in the environment that can influence the radio signal. Rotation of the product is also important not to change. Make sure that there are minimal changes in the surrounding environment. Anything that includes metal in the room needs to stay in the same position during the tuning process.
Work flow

Below is illustrated the process of tuning the antenna (Figure 6). Note that there is an option to go back and fine tune antenna length also after the matching is done. The first step is to tune the length of the antenna and the second step is to tune the matching network.

![Figure 6. Tuning process]
Tuning options

When tuning the antenna the designer has two adjustable items to work with
- Adjust antenna length
- Adjusting matching component.

Adjusting the antenna length is the first and the key step to optimizing the antenna. This is very straight forward for any wire, helical or PCB trace antenna.

The principle is simple:
Reducing antenna length tune the antenna to higher frequency and extending antenna length will reduce the resonance frequency of the antenna.

Matching the antenna is a bit more complex than adjusting the antenna length, as it has a two dimensional tuning range.
The recommended process is this:
• Start by adding a large inductor to ground, close to the antenna. L1 in the PI network in figure 2 (See the example below for values)
• Reduce the inductor value step by step, and monitor radiated power vs inductor value.
• The value of the inductor when it the radiated power peaks at the desired frequency is the value to use in the design.

Many times the short inductor alone is creating acceptable matching
If a short inductor did not improve the radiated power, you could try with short capacitor, but note that it is very rare that a short capacitor has a positive effect. Start with small capacitor value and increase the value step by step.

If the short inductor did help, a combination of short inductor and series capacitor C1 can be tested.
- Adjust one and one component
- Go in small steps as large steps can easily detune significantly
- Alternate which component to adjust value on.
- They work together and cannot be optimized individually.
Example: 169 MHz helical antenna
The above description is general. Below is shown an example of a 169 MHz antenna and tuning of this.
A space limited 169 MHz antenna can be a helical antenna of height 50 mm, diameter 10-12 mm and wire length 750-800mm. This would typically be mounted vertical on a ground plane. Such antenna is shown below (Figure 7).

For such an antenna a short inductor (L1) of 100 nH to 10 nH might be a good match. Start with 100 nH and reduce while evaluating results. A wire wound inductor of 0603 or 0805 size (e.g. LQW series from Murata) is recommended due to lower loss. For this specific antenna a series capacitor (C1) is not expected.

Evaluating the measurements
When evaluating the plot from the spectrum analyzer there are 3 points to notice.
- Peak frequency.
- Height (signal strength) of peak
- How narrow the peak is

The peak frequency is normally related to the resonance frequency of the antenna. Figure 8 below shown an antenna that is tuned to a too low frequency, which means that the antenna is too long. The intended
operational frequency of this antenna is 169.4375 MHz (center of plot). We see that this antenna will radiated 2 dB less on operational frequency than it could.

Increasing the antenna length with 1 cm shows an increase of the resonance frequency of the antenna (Figure 9)

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**Figure 8. Antenna too low resonated**

**Figure 9. Antenna curve after length adjustment**
The flatness of the curve give information about how broadband the antenna is. But a flat curve also indicate that matching is not optimal. When adding and tuning on L1, it is expected that antenna curve has a more narrowband and higher peak, By making L1 too small the antenna curve will still be a narrow peak, but the peak level will start to drop. Figure 10 show an antenna with L1 and Figure 11. Antenna curve after optimizing L1 Figure 11 shows the same antenna with L1 at 47 nH. The peak output power has increased by 1.5 dB, but also note that the peak frequency is also shifted slightly. This can be compensated by going back to antenna length adjustment.

**Figure 10.** Antenna curve with less peak but wider bandwidth

**Figure 11.** Antenna curve after optimizing L1
Network Analyser tuning

An alternative approach is to use a network analyzer. This helps evaluate VSWR and is often a principle used in literature. However in a practical approach this method has limitation.

- It requires very costly instruments
- If not calibrated correctly and to the correct physical point it will give wrong results
- The coaxial connection of to the board influence the antenna itself.

This method is not within scope for this application note.

A guide to this process is given here: [https://www.tek.com/blog/5-easy-steps-antenna-matching-vector-network-analyzer](https://www.tek.com/blog/5-easy-steps-antenna-matching-vector-network-analyzer)
Document Revision History

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