Foxhunt Variable Attenuator

Background

In the summer of 2020, hams in our area were desperate for something, ANYTHING to do while faced with COVID-19 restrictions on group gatherings. Two clubs, the Woodbridge Wireless and Ole Virginia Hams got together and sponsored a fox hunt activity that could be safely held outdoors.

Although I'd never participated in a foxhunt, I did have prior work experience in basic direction-finding systems using antennas and receivers. Figuring that I'd be "a natural" for this event, I thought I'd have no problems finding the hidden fox. Instead, I failed; miserably. In my haste to get my handheld radio and antenna ready, I had forgotten to borrow a step attenuator from the laboratory at work. Instead of being able to attenuate the strongest signals, I had to rely on peaks and nulls in the antenna pattern to determine bearings. Unfortunately, multipath reflections due to the suburban surroundings caused so much confusion in finding the signal, that I basically got trapped in chasing "ghost" signals.

After licking my wounds, I decided to explore attenuator options. I considered purchasing a step attenuator but was put off by the price. I considered building a traditional switched step attenuator but concluded that the size and weight wasn't ideal for quickly attenuating and homing in on signals. I did research the frequency-offset attenuators, which were inexpensive, but read about their limitations of high insertion loss and problems with intermodulation products overwhelming handheld radios. In the end, I chose a different approach and built my own attenuator, optimizing the design for the way I thought best for operating in the field.

Design Goals

I wanted to come up with a design that was optimized for useability as well as performance. My criteria were:

- Battery operation with low current drain for long (multi-hour) duration hunts.
- Avoid the size and weight of conventional step attenuators that use toggle or slide switches.
- Avoid the inherent ("baseline") insertion loss and poor noise/intermodulation performance of mixer-based systems that rely on a diode and 4MHz offset oscillator to place the signal at the skirts of the radio's IF filter.
- Allowed immediate tuning to the 3rd harmonic of the VHF fox transmitter signal without having to disconnect in-line equipment.
- Support a "wearable" form factor that made operation of the antenna hassle-free while listening to the radio and/or watching the signal strength display.

Block Diagram

I investigated various RF attenuator ICs on the market and found that most of them were too expensive for the hobby market. Some were analog voltage-controlled, and others were digitally controlled, but they covered frequency ranges far beyond what was needed for simple VHF/UHF fox hunting.

Instead, I found low-cost PIN attenuator ICs, typically used in consumer products like satellite receivers and cable TV boxes, as viable alternatives that would cover the desired frequency range. To avoid the baseline insertion loss of the PIN attenuator, I found low-cost CMOS RF switches that would allow the attenuator path to be bypassed when not in use. This allows the antenna and receiver to operate normally until attenuation is needed. To control the RF switches, CMOS logic gates are used to generate the complementary control signals. The PIN attenuators can operate at voltages as low as 9V, so I settled on using a 9V battery as the power source and used a low quiescent current voltage regulator to generate the 5V needed for the CMOS gates.

The attenuation curve for a single PIN attenuator is shown in Figure 1. The internal diagram for a single RF switch is shown in Figure 2. The complete variable attenuator block diagram is shown in Figure 3. It should be noted that, although there are ports labeled “ANT” and “RX”, the design is reciprocal. This means that the “ANT” and “RX” connections can be swapped with no change in performance.

Schematic Diagram

The schematic diagram of the attenuator is shown in Figure 4. The schematic was drawn using the free version of DipTrace. Since the potentiometer has only one integral switch used to select the bypass mode of operation, I didn’t want to add a separate switch just to control ON/OFF functionality. When the attenuator is not in use, the 9V battery is disconnected.

PCB Layout

The PCB layout of the attenuator is shown in Figures 5 and 6 and was also drawn using DipTrace. Since I wanted to support a “wearable” form factor, I found a Hammond plastic enclosure with belt clip that would accommodate the PCB and battery. The PCB is a simple two-sided board design on FR4 laminate. To maximize inter-stage shielding, readily available RF shields were used to contain the two identical attenuator/switch sections. The assembled attenuator is shown in Figure 7.

Theory of Operation

Since the attenuation range of one PIN attenuator is only about 50dB at the lowest frequencies of interest, I used two cascaded stages to ensure well over 60dB of attenuation control over the VHF/UHF frequency range. RF shields were employed to maximize isolation between the stages. Two RF switches were used in each stage to further increase the isolation when the PIN attenuators are active.

In reviewing the datasheet for the PIN attenuator IC, it became apparent that almost all the dynamic range was restricted to a limited control voltage range. Referring again to Figure 1, the steep curve between 1V and 2V shows that the attenuation varies primarily between these two points. To “spread out” the tuning range a bit further, I experimented in LTSpice with a few “linearizers” to extend the potentiometer’s rotation and prevent the attenuator from rapidly varying between the two attenuation extremes.

In a typical foxhunt scenario, the operator would keep the attenuator in the bypass mode most of the time. Once the signal is heard, the attenuator would be switched in and the potentiometer varied between the maximum and minimum attenuation settings to weaken the signal just enough to allow the antenna’s pattern to help determine the line of bearing. One fortuitous aspect of using PIN attenuators in this application is that maximum attenuation occurs at minimum current draw. Similarly, while in the bypass mode, the current consumption of the RF switches is also exceptionally low, allowing the circuit to operate for long periods of time during the hunt.

The attenuator operates from 50MHz to 2000MHz. The upper limit is determined by the performance of the RF switches. The lower limit is determined by the value of the DC blocking capacitors in the RF path. The frequency range can be extended downward by increasing the capacitance values.

Performance Data

Table 1 – Attenuator DC Power Consumption vs. operational state.

Mode	Current (mA) @ 9VDC
Bypass	0.5507
Full Attenuation	1.0517
Min. Attenuation	4.929

Table 2 – Attenuator RF insertion loss in the bypass mode and attenuation mode extremes.

Mode	VHF (144-148MHz)	UHF (420-450MHz)
Bypass	1.8dB	1.8dB
Full Attenuation	80dB	78dB
Min. Attenuation	13.5dB	13.6dB

Figure 8 shows the maximum attenuation vs. frequency over the VHF range, while Figure 9 shows the maximum attenuation vs. frequency over the UHF range. The input P1dB is greater than +10dBm; I was not able to measure the upper limit due to limitations in the vector network analyzer used.

Concept of Operation

The belt worn attenuator configuration is shown in Figure 10. Coaxial cables are used to connect the attenuator to the radio and the antenna. The antenna is held in the dominant hand, while the potentiometer is controlled by the non-dominant hand. The audio output of the radio is monitored with headphones or by turning up the speaker volume. As designed, the attenuator is belt worn. Clearly, other form factors and use-case scenarios can be chosen if the PCB layout or enclosure are modified.

Attenuator operation starts off in the bypass mode. When the signal is heard, the operator immediately rotates the potentiometer and switches into the attenuation mode. Rotating the potentiometer back and forth allows the operator to “ride” the attenuation while moving the antenna around for maximum audio output. It should be noted that the attenuation starts off at maximum and diminishes with clockwise rotation; this was a personal choice and is determined by the connections to the potentiometer’s terminals.

An Important Warning

The MASWSS0179 RF switch can handle a maximum RF input signal level of 0.5W without damage. I had considered adding PIN limiters to further protect the attenuator but decided against it to avoid the additional component costs. When using a handheld transceiver as the receiving device, it is **IMPERATIVE** that the operator prevent high transmit levels from being applied to the attenuator. Lowering the TX power level to the minimum setting is highly recommended. The easiest way to prevent accidental transmissions on a handheld is to enable the PTT lockout feature. On Baofeng radios such as the UV-5R (which do not have a PTT lockout capability), set the TX frequency to 0Hz.

Conclusion

The RF performance of the attenuator was a bit better than expected and should provide sufficient dynamic range for fox hunting. The PCB is physically larger than necessary but was sized to accommodate the mounting holes in the Hammond wearable enclosure. It would be possible to use a different enclosure, rework the PCB layout, and place the attenuator on the antenna boom, for example. I'm looking forward to testing the attenuator out during the next fox hunt!

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