Detailed Design

Senior Design I

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Introduction:

In the detailed design, everything that is required to build the model is described. Layout drawings, dimensions, and specifications are included for each part in the system. These details have been obtained from the manufacturers. Additionally, a bill of materials has been created, listing each essential part. Necessary calculations for the final design are also included at this point. These include weight, battery, and distance considerations. A full model is displayed, showing each component fitting together on the quadcopter. Safety considerations are also discussed, and finally the product lifecycle is described in detail.

Layout Drawings:

Turbo Ace Matrix-S-FPV:

Figure 7.1: The Matrix S-FPV. Gathered from the TurboAce website.

- Dimensions Wingspan (including propellers): Diagonal=1110mm, Front=1000mm, Back=935mm
- Dimensions Operating Position (including propellers): W=760mm, L=760mm, H=130mm
- Wind Tolerance: Class 5

(I*nformation for the quadcopter came from turboace.com Matrix S-FPV overview).*

5.8GHz 600mW Tx Relay:

Figure 7.2: The 5.8GHz relay

- Dimensions (LxWxH): L=50mm x W=23mm x H=15mm
- Weight (Grams): 18g
- Supply Voltage: 6-25V (2S-6S LiPo)
- Power Consumption: 3W

(*Information from ImmersionRC.com)*

Duo5800 v3 Diversity A/V Rx Link:

Figure 7.3: The 5.8 GHz Link

- Dimensions (LxWxH): L=88mm x W=105mm x H=25mm
- Weight (Grams): 202g
- Not on quadcopter

(*Information from ImmersionRC.com)*

R-1000 TELEMETRY RECEIVER:

Figure 7.4: The VHF receiver

- Dimensions: 6.1" (15.5cm) high, 2.6" (6.6cm) wide, 1.5" (3.8cm)
- Weight: 12.4oz. (352 g)

(Information from R-1000 TELEMETRY RECEIVER OPERATING MANUAL)

Black Velcro Cable:

Figure 7.5: The Velcro straps for the VHF receiver

- Unit Weight: 0.30 lbs
- Size: 3/4 x 12"

(Information from ULINE)

Hosa BNC to BNC Cable:

Figure 7.6: BNC cable for VHF Receiver to antenna

- Weight: 4.8 oz
- Length 3’

(Information from Sweetwater)

SMA Male on RG58C/U to SMA Female Bulkhead Cable:

Figure 7.7: SMA cable for 5.8 GHz link

- Operating Temperature: 80 ºC
- Length: 1’

(Information from fieldcomponents.com)

RA-2AK VHF Antenna:

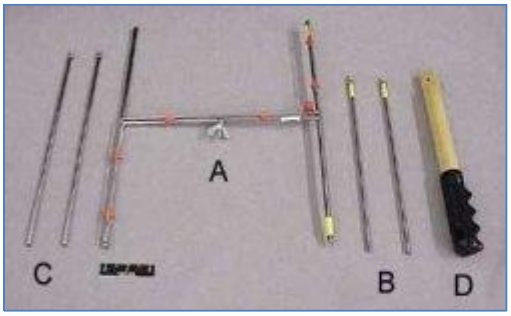


Figure 7.8: The VHF Antenna

- Length: 1.5'
- Width: 3'

(Information from Telonics.com)

Bill of Materials:

Figure 7.9 shows the flow diagram for the components (1-6) which create subsystems (7-9) and finally with all subsystems built and interfacing on the quadcopter the final design (10) is realized. Table 7.1 shows a break down each device cost organized by subsystem.

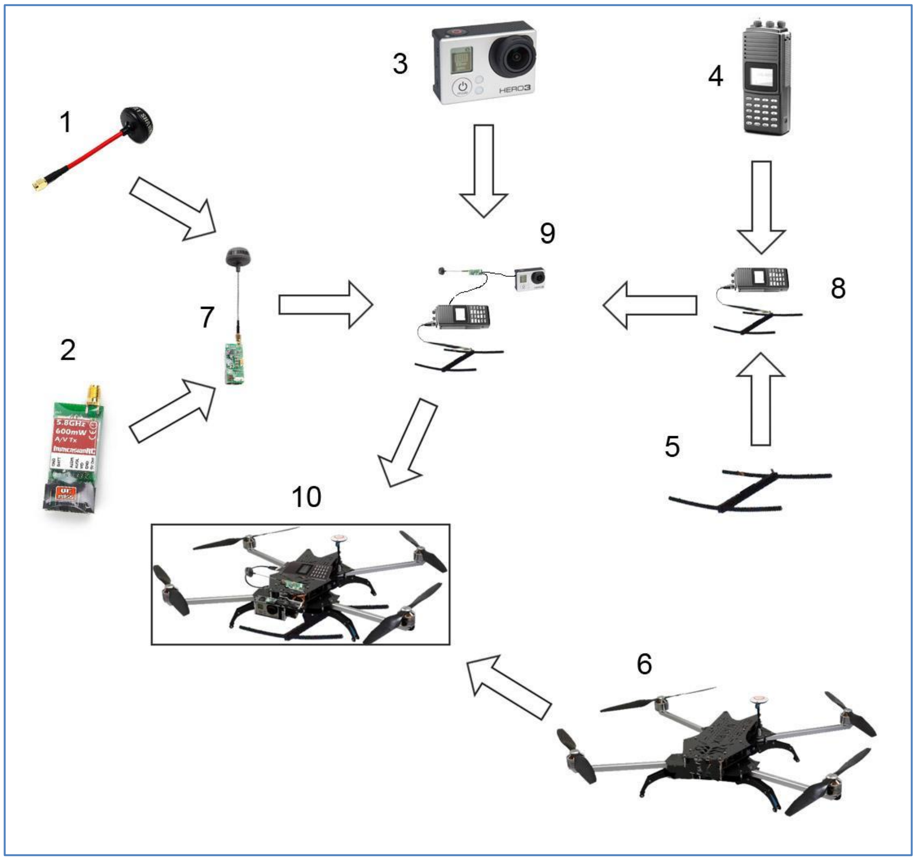


Figure 7.9: Flow diagram showing all of the individual parts, subsystems and final design.

Table 7.1: Cost analysis for the wildlife tracking system

10	**Wildlife Tracking System**	
9	**Video/Audio Relay Subsystem**	
8	**VHF Subsystem**	
4	R-1000 TELEMETRY RECEIVER	$695.00
5	RA-2AK VHF Antenna	$50.00
	Hosa BNC to BNC Cable	$6.99
7	**Relay Subsystem**	
1	SpiroNET Omni - 5.8GHz CP Antenna	$39.99
2	5.8GHz 600mW Tx Relay	$69.00
	SMA Male on RG58C/U to SMA Female Bulkhead Cable:	$30.74
3	GoPro Hero 3 Camera	$399.99
6	Turbo Ace Matrix-S-FPV	$3,847.95
	Ground System (not pictured)	
	Duo5800 Diversity A/V Rx	$239.00
	Total Cost	$5,378.66

Purchased Component Specifications:

Turbo Ace Matrix-S-FPV Specifications:

- Dimensions Wingspan (including propellers): Diagonal=1110mm, Front=1000mm, Back=935mm
- Dimensions Operating Position (including propellers): W=760mm, L=760mm, H=130mm
- Dimensions Folded Position (including propellers): W=295mm, L=780mm, H=110mm
- Dimensions Motor to Motor: Diagonal=725mm
- Maximum Payload Capacity: Gimbal + Camera + Accessories = 3.5LB, Gimbal+Camera+Accessories+8000mah Battery=6.2LB
- Maximum Optimal Payload Capacity: Gimbal + Camera + Accessories = 2.5LB, Gimbal+Camera+Accessories+8000mah Battery=5.2LB
- Matrix Weight without Payload/Battery: 4.8LB
- Typical Operating Weight with Hero3: Matrix+Gyrox-3+VTX& Power (5.33LB)+ Hero3 (.17LB) +VTX+8,000mah Battery (2.5LB) = 8LB
- Typical Operating Weight with Sony NEX 5R: Matrix-E+Gyrox-5R+VTX&Power (5.5LB) + NEX-5R+Lense (1LB), 8,000mah Battery (2.5LB) = Total: 10LB
- Motors: Diameter=42mm, Height=35mm
- ESC: 40 amp
- Propellers: 2xCW & 2xCCW, 15" Extra Robust Carbon Fiber Constructions, Dual Position Mount
- Flight Time: Matrix + 22,000mah 6S Battery + Brushless Gyrox-3 Gimbal + Hero 3/3+ = 40-42 min

- Flight Time: Matrix + 2x 10,000mah 6S Battery + Brushless Gyrox-3 Gimbal + Hero 3/3+ = 38-40 min
- Flight Time: Matrix + 16,000mah 6S Battery + Brushless Gyrox-3 Gimbal + Hero 3/3+ = 36-38 min
- Flight Time: Matrix + 10,000mah 6S Battery + Brushless Gyrox-3 Gimbal + Hero 3/3+ = 26-29 min
- Flight Time: Matrix + 8,000mah 6S Battery + Vibration Isolation Carbon Plates + Hero 3/3+ = 27-30 min
- Flight Time: Matrix-S + 8,000mah 6S Battery + Brushless Gyrox-3 Gimbal + Hero 3/3+ = 22-25 min
- Flight Time: Matrix-E + 8,000mah 6S Battery + Brushless Gyrox-5R Gimbal & Sony NEX-5R = 12-15 min
- Transmitter & Receiver Recommendation: 2.4GHz, Minimum 6-Channels, Optimal 7-Channels or more
- Standard Distance Operations: 300 to 500 feet (Using Walkera Devo 10 & Most Other Name Brand Transmitters)
- Long Distance Operations: 4,224 feet (.8miles) to 6,336 feet (1.2miles) (Using Spektrum DX8/DX18 & Futaba 14SG)
- FPV Recommendation: 5.8GHz Video Transmitter & Video Receiver + Monitor or Goggles
- Wind Tolerance: Class 5
- Aluminum Case Dimensions: L=935mm, W=410mm, H=145mm

(*Information for the quadcopter came from turboace.com Matrix S-FPV overview).*

5.8GHz 600mW Tx Relay:

- 600mW (27dBm, +/- 1dBm) of clean output power
- SMA Antenna connector, with supplied 5.8GHz Rubber-duck antenna
- Frequencies: 5740, 5760, 5780, 5800, 5820, 5840, 5860MHz
- Not affected by 2.4GHz R/C radios
- Dimensions (LxWxH): L=50mm x W=23mm x H=15mm
- Weight (Grams): 18g
- Supply Voltage: 6-25V (2S-6S LiPo)
- Power Consumption: 3W

(*Information from ImmersionRC.com)*

Duo5800 v3 Diversity A/V Rx Link:

- A/V receiver with diversity antenna inputs
- GS-Link for single-cable connection to a groundstation
- Frequencies: 5740, 5760, 5780, 5800, 5820, 5840, 5860MHz
- NexWaveRF technology, for double-range
- Not affected by 2.4GHz, or UHF R/C radios
- Dimensions (LxWxH): L=88mm x W=105mm x H=25mm
- Weight (Grams): 202g

(*Information from ImmersionRC.com)*

R-1000 TELEMETRY RECEIVER:

- Selectivity: 6dB down @ ± 1.2 kHz, 60dB down @ ± 2.2 kHz
- Receive Mode: CW

- Antenna Impedance: 50 ohms
- Antenna Jack: Standard BNC (BNC female)
- Power Requirements: 4.8vdc (4 ea. "AA" Ni-cad or NiMH rechargeable
- batteries), or 6.0vdc (4 ea. "AA" Alkaline batteries),
- or 9-16vdc from supplied 110vac wall or
- cigarette lighter charger
- Current Drain: 160ma at maximum audio output
- Dimensions: 6.1" (15.5cm) high, 2.6" (6.6cm) wide, 1.5" (3.8cm)
- deep, less knobs
- Weight: 12.4oz. (352 g) with supplied NiMH rechargeable
- batteries
- Headphone Jack: Top Mounted 3.5mm (1/8") mono headphone jack

(Information from R-1000 TELEMETRY RECEIVER OPERATING MANUAL)

Black Velcro Cable Ties:

- Dimensions: Width- Slotted End: 3/4" Narrow End: 1/2"
- Material: Polypropylene hook, Nylon loop

(Information from ULINE)

Hosa BNC to BNC Cable:

- Type: Video/Word Clock
- Connector: Male BNC to Male BNC
- Length: 3'

(Information from Sweetwater)

SMA Male on RG58C/U to SMA Female Bulkhead Cable:

- RG Type:58C/U
- Conductor: 20 AWG 19/32 Tinned Copper
- Insulation: Solid Polyethylene
- Nom. Core O.D.: 0.115 in
- Shielding: Tinned Copper
- Jacket: Non-Contaminating PVC -Type 11A
- Nom. O.D.: 0.199 in
- UL Style: 1354
- Nom. Attenuation:
    - 1.4 dbl/100 ft at 10 MHz
    - 4.1 dbl/100 ft at 50 MHz
    - 5.3 dbl/100 ft at 100 MHz
    - 8.2 dbl/100 ft at 200 MHz
    - 12.6 dbl/100 ft at 400 MHz
    - 20.0 dbl/100 ft at 900 MHz
    - 24.0 dbl/100 ft at 1000 MHz
- Nom. Velocity of Propagation: 83%
- Nominal Capacitance: 16.2 pF/ft
- Nominal Impedance: 50 ohms
- Operating Temperature: 80 ºC
- Frequency: 1ghz

(Information from fieldcomponents.com)

RA-2AK VHF Antenna:

- Frequency Ranges: 148-152 MHz, 150-154 MHz, 158-162 MHz, 164-168 MHz, 168-172 MHz, 170-174 MHz, 216-220 MHz
- Gain: 4 dBd
- Front to Back Ratio: 10 dB
- Connector: BNC female
- Reception Radiation Pattern:

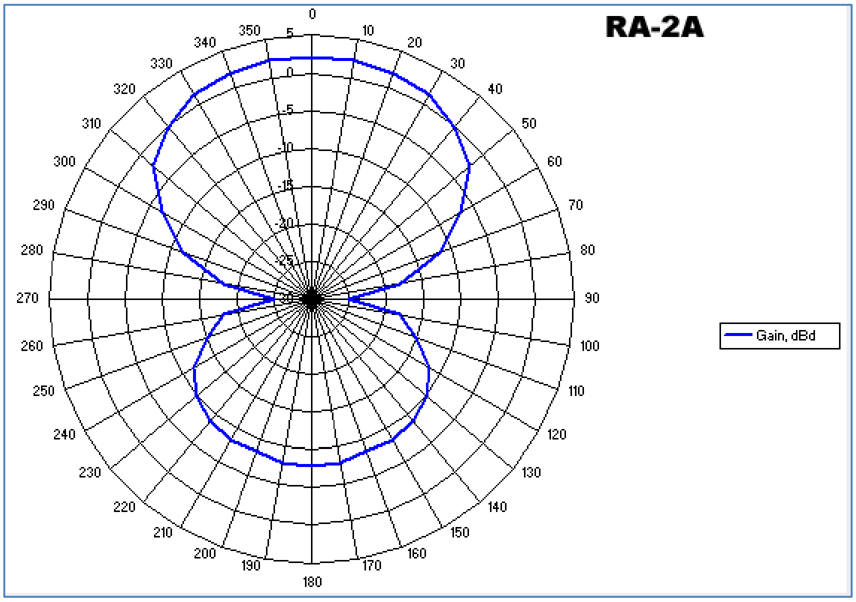


Figure 7.10: Reception radiation pattern of RA-2AK VHF Antenna)
(Information from Telonics.com)

Detailed Design:

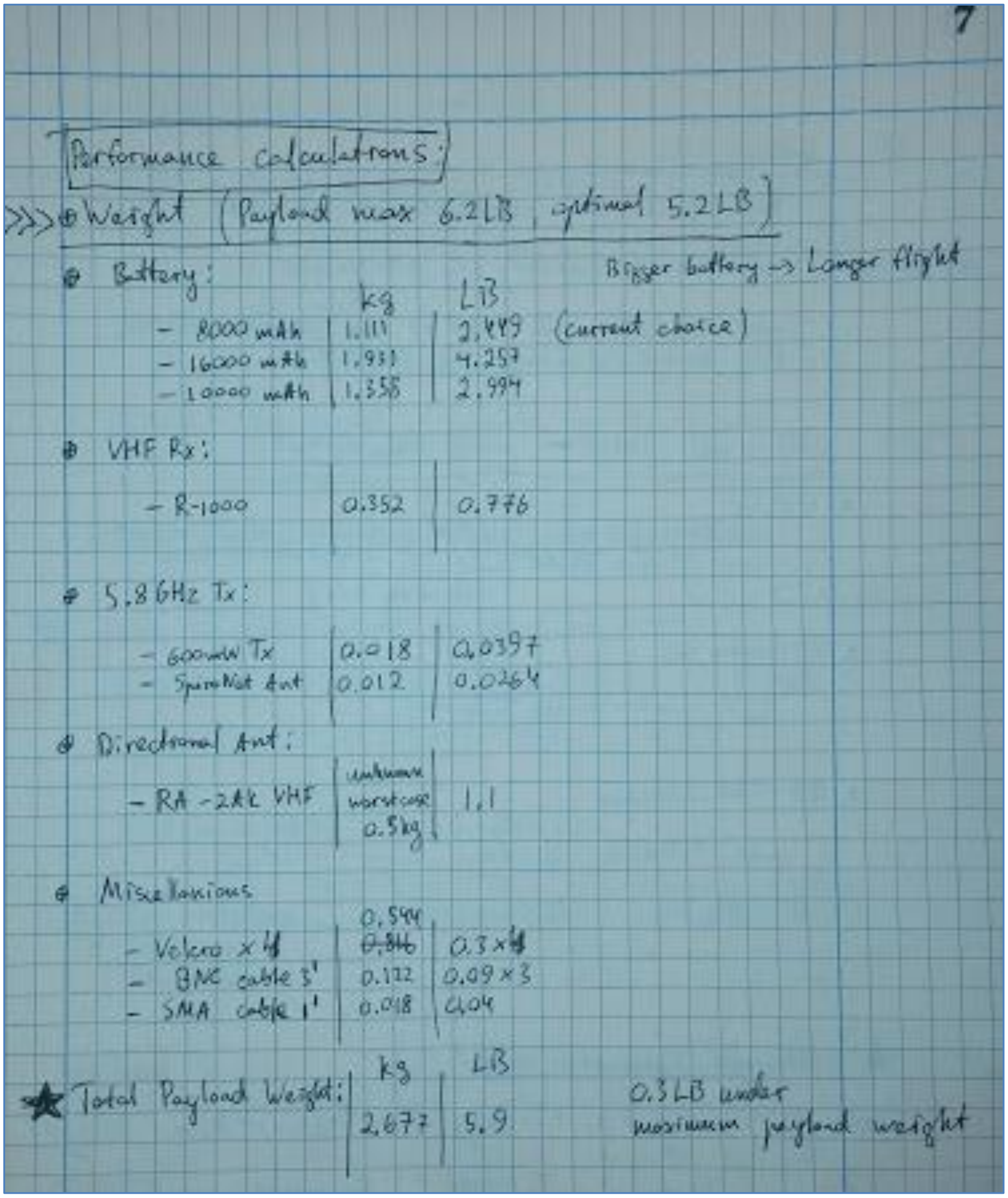
This section contains:

- Calculations
- System model
- Safety considerations

Calculations:

The following images show calculations conducted in order to verify that level 1 requirement are theoretically satisfied. These calculations are preliminary, final calculations will be done in Mathcad and provided with the final report. Level 1 requirements verified:

- Tracking distance above 2km Maximum payload weight 6.2LB
- Flight time equal or above 30 minutes



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Performance calculations:

>>> Weight (Payload max 6.2LB, optimal 5.2LB)

Battery: Bigger battery -> Longer flight

	kg	LB	
- 8000 mAh	1.111	2.449	(current choice)
- 16000 mAh	1.931	4.257	
- 10000 mAh	1.358	2.994	

VHF Rx:

- R-1000	0.352	0.776

5.8GHz Tx:

- 600mW Tx	0.018	0.0397
- SpiroNet Ant	0.012	0.0264

Directional Ant:

- RA-2AK VHF	unknown worstcase 0.5kg	1.1

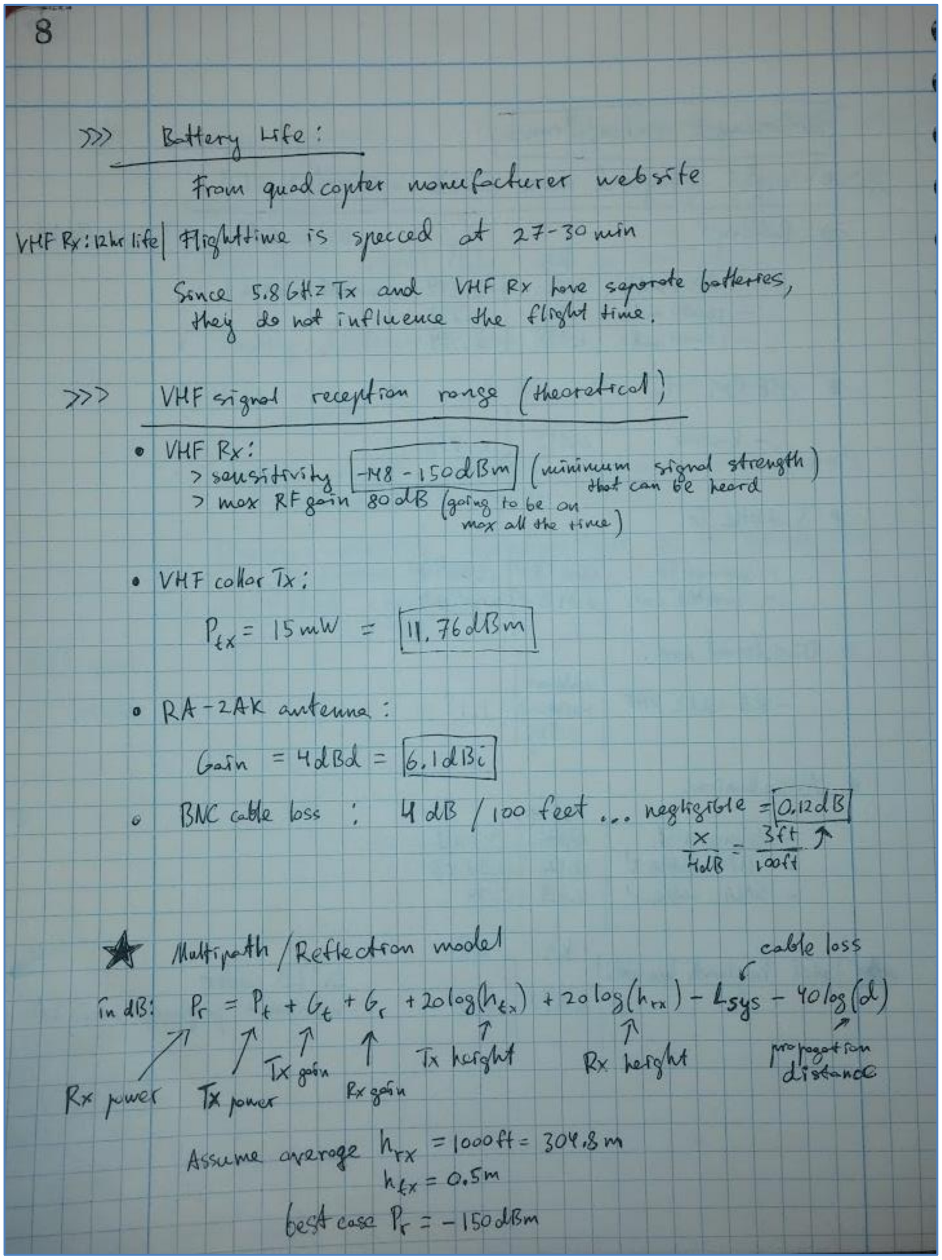
Miscellanious

- Velcro x 4	0.544 ~~0.846~~	0.3 x 4
- BNC cable 3'	0.122	0.09 x 3
- SMA cable 1'	0.018	0.04

	kg	LB	
★ Total Payload Weight:	2.677	5.9	0.3LB under maximum payload weight

Figure 7.11: Payload weight calculations.

We could not obtain information for the H-directional antenna weight, worst case scenario if it weighs 1.1 LB, overall weight is 5.9LB which is 0.3 less than the maximum limit.



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>>> Battery Life:

From quadcopter manufacturer website

VHF Rx: 12hr life | Flighttime is specced at 27-30 min

Since 5.8GHz Tx and VHF Rx have separate batteries, they do not influence the flight time.

>>> VHF signal reception range (theoretical)

- VHF Rx:
  - > sensitivity $\boxed{-148 - 150\,dBm}$ (minimum signal strength that can be heard)
  - > max RF gain 80 dB (going to be on max all the time)
- VHF collar Tx:

  $P_{tx} = 15\,mW = \boxed{11.76\,dBm}$
- RA-2AK antenna:

  $Gain = 4\,dBd = \boxed{6.1\,dBi}$
- BNC cable loss : 4 dB / 100 feet ... negligible $= \boxed{0.12\,dB}$

  $\frac{x}{4\,dB} = \frac{3\,ft}{100\,ft}$

★ Multipath / Reflection model

in dB: $P_r = P_t + G_t + G_r + 20\log(h_{tx}) + 20\log(h_{rx}) - L_{sys} - 40\log(d)$

Rx power

Tx power

Tx gain

Rx gain

Tx height

Rx height

cable loss

propagation distance

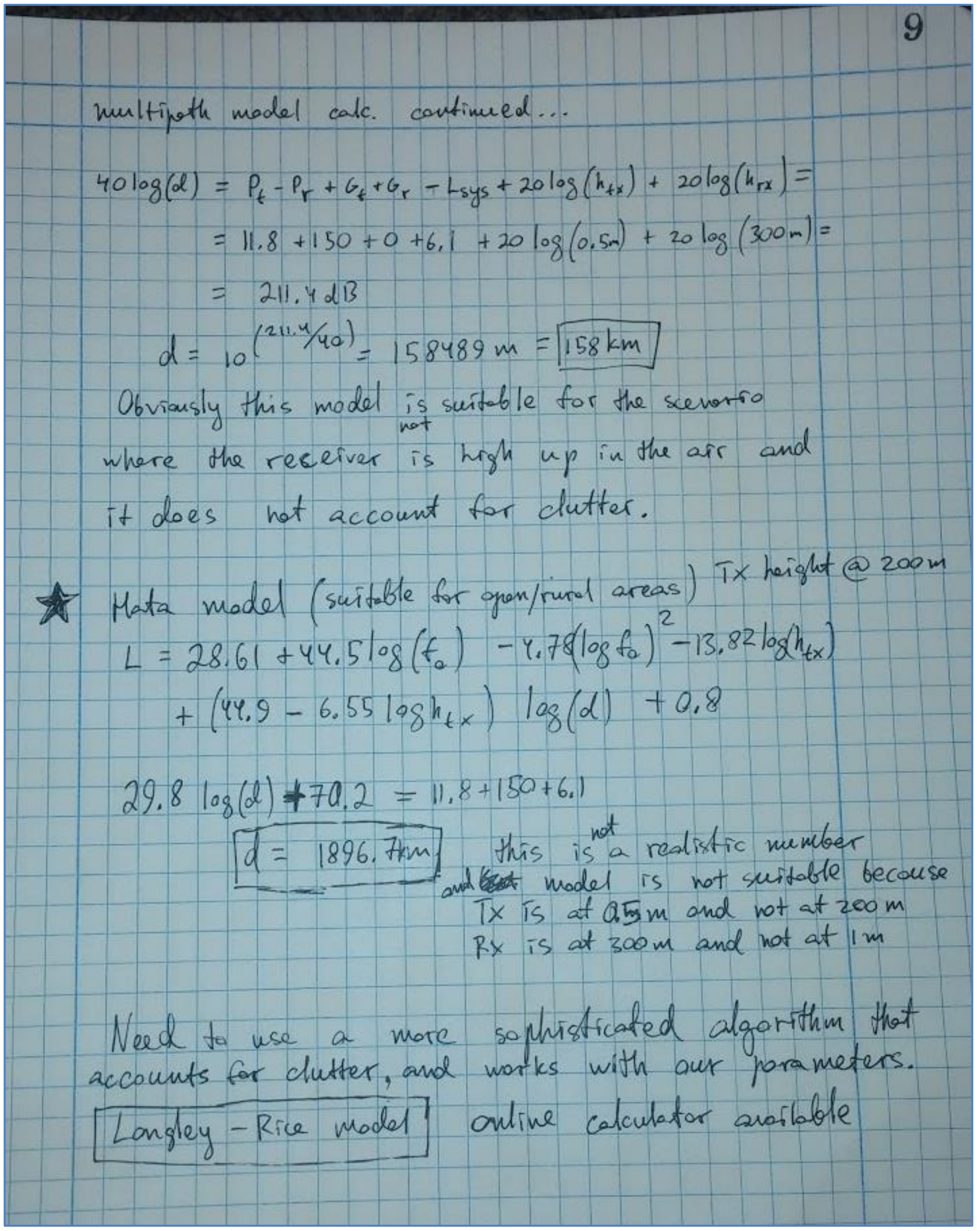
Assume average $h_{rx} = 1000\,ft = 304.8\,m$

$h_{tx} = 0.5\,m$

best case $P_r = -150\,dBm$

Figure 7.12: Battery life calculations were unnecessary since VHF/5.8GHz radios are independently powered.

The quadcopter manufacturer provides information on average flight time based on the payload weight. For our payload the flight time is 27-30 min, which is very close to the requirement of 30 min. First part of signal reception range is also included here.



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multipath model calc. continued...

$$40\log(d) = P_t - P_r + G_t + G_r - L_{sys} + 20\log(h_{tx}) + 20\log(h_{rx}) =$$

$$= 11.8 + 150 + 0 + 6.1 + 20\log(0.5m) + 20\log(300m) =$$

$$= 211.4\,dB$$

$$d = 10^{(211.4/40)} = 158489\,m = \boxed{158\,km}$$

Obviously this model is not suitable for the scenario where the receiver is high up in the air and it does not account for clutter.

★ Hata model (suitable for open/rural areas) Tx height @ 200m

$$L = 28.61 + 44.5\log(f_c) - 4.78(\log f_c)^2 - 13.82\log(h_{tx})$$

$$+ (44.9 - 6.55\log h_{tx})\log(d) + 0.8$$

$$29.8\log(d) + 70.2 = 11.8 + 150 + 6.1$$

$$\boxed{d = 1896.7km}$$

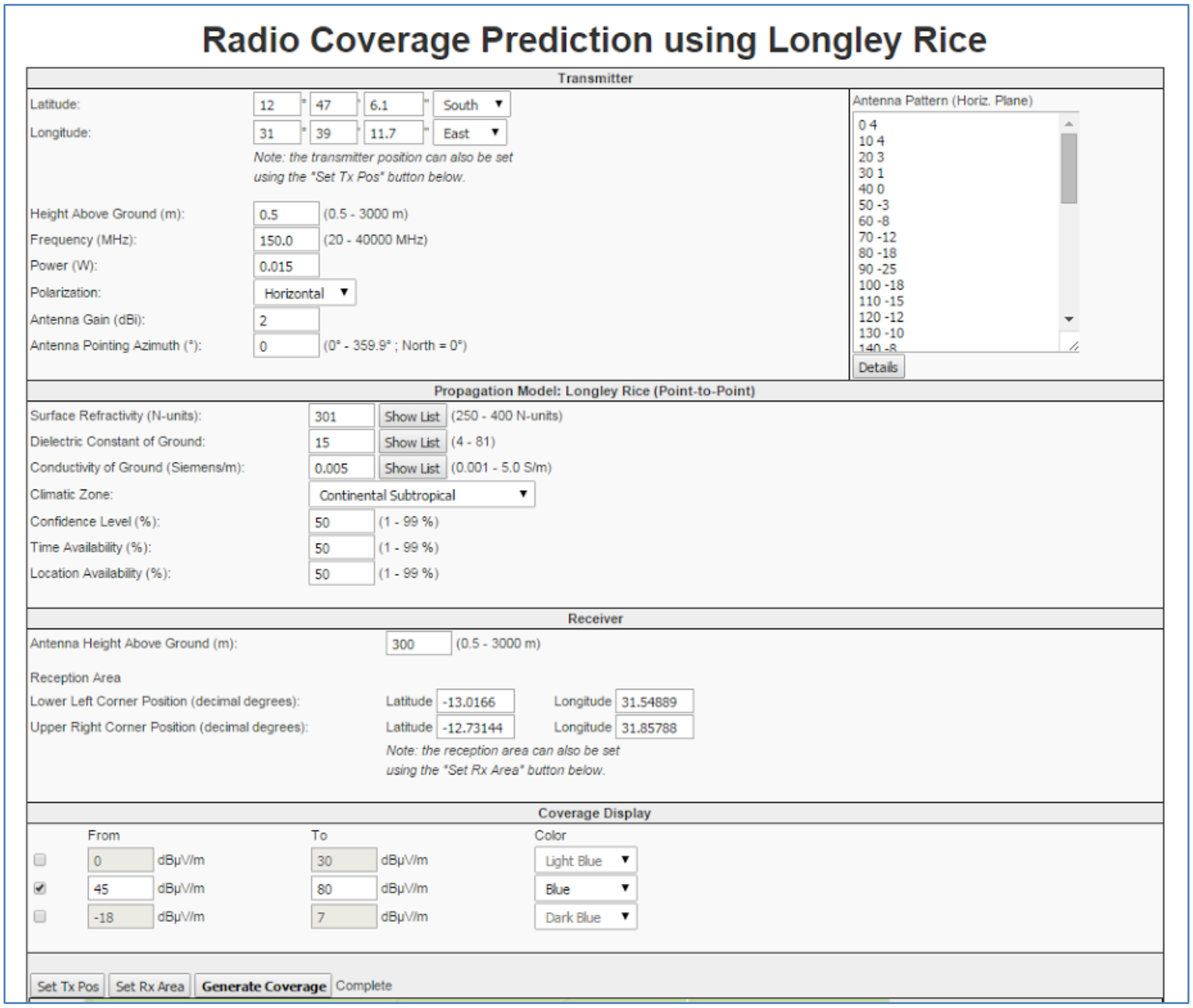
this is not a realistic number and ~~that~~ model is not suitable because Tx is at 0.5m and not at 200 m Rx is at 300m and not at 1m

Need to use a more sophisticated algorithm that accounts for clutter, and works with our parameters.

$\boxed{\text{Longley - Rice model}}$ online calculator available

Figure 7.13: Signal reception range calculations continued.

Multipath/reflection model is not suitable since it does not account for clutter. hata model is not suitable since it assumes the Tx is higher than the Rx. It is the opposite in our case. We were recommended to use the Longley-Rice model. It accounts for clutter and works for various Rx/Tx heights. The calculations were done in an online calculator, since the algorithm is too sophisticated to be done on paper.



Radio Coverage Prediction using Longley Rice

Transmitter

Latitude: 12 ° 47 ' 6.1 " South

Longitude: 31 ° 39 ' 11.7 " East

Note: the transmitter position can also be set using the "Set Tx Pos" button below.

Height Above Ground (m): 0.5 (0.5 - 3000 m)

Frequency (MHz): 150.0 (20 - 40000 MHz)

Power (W): 0.015

Polarization: Horizontal

Antenna Gain (dBi): 2

Antenna Pointing Azimuth (°): 0 (0° - 359.9° ; North = 0°)

Antenna Pattern (Horiz. Plane)

```
0 4
10 4
20 3
30 1
40 0
50 -3
60 -8
70 -12
80 -18
90 -25
100 -18
110 -15
120 -12
130 -10
140 -8
```

Propagation Model: Longley Rice (Point-to-Point)

Surface Refractivity (N-units): 301 (250 - 400 N-units)

Dielectric Constant of Ground: 15 (4 - 81)

Conductivity of Ground (Siemens/m): 0.005 (0.001 - 5.0 S/m)

Climatic Zone: Continental Subtropical

Confidence Level (%): 50 (1 - 99 %)

Time Availability (%): 50 (1 - 99 %)

Location Availability (%): 50 (1 - 99 %)

Receiver

Antenna Height Above Ground (m): 300 (0.5 - 3000 m)

Reception Area

Lower Left Corner Position (decimal degrees): Latitude -13.0166 Longitude 31.54889

Upper Right Corner Position (decimal degrees): Latitude -12.73144 Longitude 31.85788

Note: the reception area can also be set using the "Set Rx Area" button below.

Coverage Display

	From		To		Color
☐	0	dBµV/m	30	dBµV/m	Light Blue
☑	45	dBµV/m	80	dBµV/m	Blue
☐	-18	dBµV/m	7	dBµV/m	Dark Blue

Figure 7.14: Parameters chosen for the calculations.

Unfortunately the tool is not flexible enough to estimate maximum range, but it provides a propagation map instead.

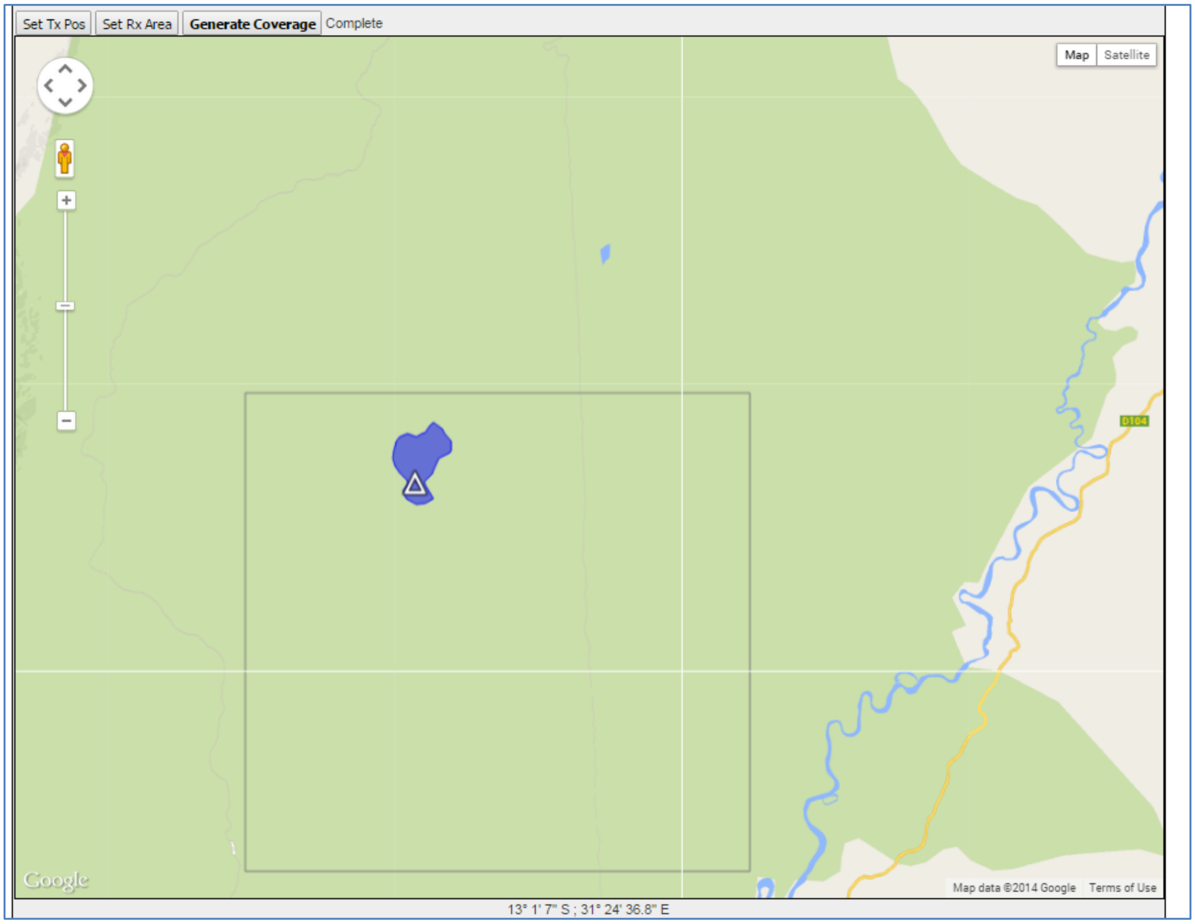


Figure 7.15: Shows the area that can be picked up by the directional antenna if the was coming from the triangle on the map.

The location was chosen in a Zambian national park (most of the research is done in Zambia). The maximum distance (directional antenna has to point head on at the Tx) was estimated at 2.5 miles (4km) using Google maps. This is twice the range required.

<u>Summary:</u>

Theoretically the system satisfies level 1 requirement and even greatly surpasses in regards of signal detection range. However RF propagation is very sensitive and may vary greatly due to small disturbances. If possible, field tests will have to be conducted at similar or close to similar research conditions in order to test the performance of the system.

System model:

Figure 7.16: Showing each individual part connected in the final configuration.

It can be seen in Figure 7.16 how the final design will look. The radio and antenna will be mounted at center mass above and below the quadcopter respectively to prevent flight issues that may be caused by adding the additional hardware. The A/V transmitter that will connect the antenna and video to the pilot will be mounted such that any signal interference with the control antenna and VHF antenna will be minimized. This will be connected to both the camera and radio outputs using a shielded SMA Cable also to prevent noise in the signal. Each device will be connected using Velcro so that they may be removed for storage and transportation.

Safety considerations:

There are a couple safety considerations that must be taken into account in this design. These safety concerns will be better understood once testing can be performed on the prototype. The first concern is the quadcopter blades. It may be necessary to include additional protection or shielding for these blades, but this is unlikely. Once the quadcopter is obtained, it can be determined whether or not this is a true concern. The second safety consideration will be unwanted RF frequency emission from the design. Again, once a prototype is built, this can be tested. It is unlikely that this will be a concern, but it should certainly be taken into consideration and fixed if found necessary. Other safety issues may be found during testing, but it is difficult to foresee many concerns at this point.

Product Lifecycle:

This product will begin in the development stage, then continue into a utilization and support stage and finally a decline stage. This group will spend basically all its time in the first stage, while the product will be in the hands of the client and users during the remaining stages.

In the development stage, all of the initial work to get the wildlife tracking system operational will be completed. This includes the preliminary design processes and background research. After this is complete, detailed design can be done, followed by a prototype model being built. Testing and revisions will be done on the prototype, at which point the final product construction can be completed.

In the utilization and support stage, the wildlife tracking system will be in the hands of the client and other users. The user will learn how to operate this system and utilize it in an effective and efficient manner. The user may or may not perform modifications to the design, based on individual preferences or ongoing improvements to the tracking process. The quadcopter design will be able to withstand countless iterations of being taken up into flight to track an animal. However, some maintenance will have to be periodically done on the product. Specifically, the quadcopter battery will need to be recharged after it is used. Other maintenance will include keeping the quadcopter clean, safe, and in good flying condition. Special care will have to be given to keep the blades, antennas, and other essential components free from damage.

The decline stage will be where the product is no longer effective. This may be due to a variety of reasons. Some component of the quadcopter design itself may fail after an extended life of usage. A solution to this would be to purchase a new quadcopter or defective part. The remainder of the good parts could be recycled and reused. The product would then re-enter the utilization and support stage after reassembly. A cheaper and better solution could also be developed sometime in the future, such as if GPS collars were made to be much less expensive than currently. This would deem the old VHF collars as obsolete, and the quadcopter solution would most likely be retired. In this case, the quadcopter and other components could still be recycled and used for other purposes.