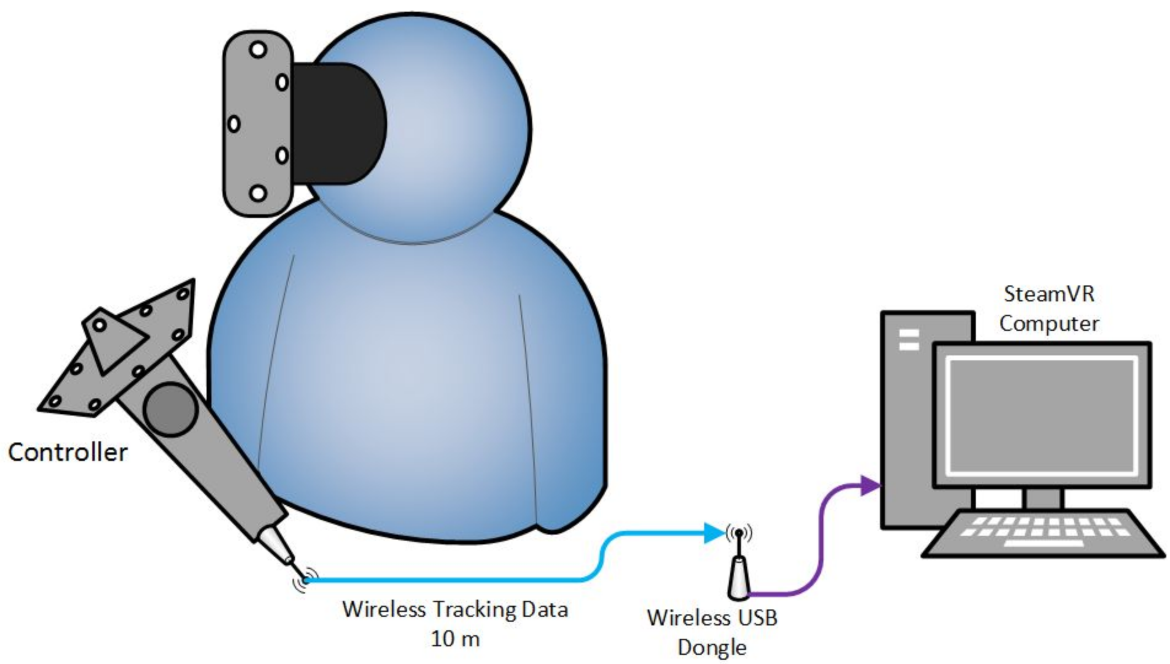
Antenna Design and RF Guidance

SteamVR™ Tracking

Introduction

In this document guidance is provided for RF antenna design goals for controllers for the SteamVR. In particular the needed antenna gain performance and RF transmitter power, that is part of the overall RF design for a VR controller is provided.

An RF link-budget has been created from a VR controller to a Steam Controller USB dongle. The communication protocol is Nordic's Enhanced Shockburst that operates in the 2.4 GHz ISM frequency band. The Steam Controller USB dongle is assumed to be installed in its provided external stand, and connected back to the SteamVR computer (see below) via its USB cable. A minimum antenna gain has been calculated for the VR controller, combined with any controller RF implementation losses, that is needed to close the data communications link at a set maximum distance of 10 meters.



In creating a RF link-budget there are a number of assumptions that have to be made. Understanding these assumptions is key to achieving the desired RF data link performance. This is because they are often intertwined with the calculating a minimum gain needed to form a stable data link. Thus changes to any of the following assumptions will invalidate the recommendations and guidance provided here.

Note that the following is intended to provide design guidance only. A device specific RF link-budget should be created for each unique VR controller design. These designs should be independently validated using measured antenna gain data from a VR controller device prototype or model. This includes the use of RF human phantom models for handheld, body worn, and head mounted controllers. The human body often reduces the realized antenna gain by a factor of 10 or more.

ShockBurst RF link-budget for VR Controllers

A link-budget is an estimation of the overall RF system performance and is used to examine the system level trade space, and to estimate how far the device can actually communicate. In this case, the distance is set at required maximum distance of 10 meters (approximately 32 feet). The other side of the link is with a SteamVR USB dongle. The end result of the link-budget analysis is a minimum required gain needed to close this link.

The link-budget is basically an accounting of the RF power delivered from a transmitting (in this case) VR controller to/from the SteamVR USB dongle's radio. Inputs into the RF Link-Budget are numerous and include:

- VR controller's transmitter power. This has been set to 0 dBm as part of the RF system trade space.
- RF losses getting the RF energy from the VR radio output to its transmitting antenna.
- The VR controller's antenna gain. This is booked in the budget with any of the RF losses added as mentioned above.
- The distance between the transmitter and receiver. This is the largest "loss" factor in the data link. For the VR system this distance has been set to a required maximum distance 10 meters.
- The SteamVR USB dongle's antenna gain. This is based on measured RF antenna gain performance of this device.
- RF losses from the SteamVR USB dongle receive antenna to its radio input. This was obtained via measurement of this dongle when connected via its external dongle stand.
- The sensitivity of the SteamVR USB dongle receiver radio to detect signals and close the data link.
- RF noise present at the receiver. There are many sources, and RF noise is always a factor. In this case the typical noise floor used in these analysis has been increased from -95 dBm to -89 dBm to account for an additional 6 dB of RF noise due to the VR equipment in operation. This includes the potential for co-channel interference, adjacent channel interference, and other potential 2.4 GHz ISM band RF interference sources. This is based on RF engineering judgement and not a actual measurement.
- The Signal to Noise Ratio (SNR) requirement to close a 1 Mbps Enhanced Shockburst link. This value has been determined using a Bit Error Rate (BER) of 0.01% while, for comparison, the classic BlueTooth standard link is 0.1% BER. A tougher BER case is being used for this link analysis. This is because the VR system is more susceptible to lag due to dropped packets, and its negative impact the user experience.
- RF engineering experience, assumptions, and judgment to account for the unknown used in interpreting the results and setting of the environmental inputs and margins.

In a typical RF link-budget some of these inputs are easily obtained from specification sheets for the radio chip in the device. Some inputs come directly from regulations and other specifications. As mentioned, the antenna gain and RF losses for the SteamVR USB dongle was obtained from measured data of its antenna. The amount of RF losses between the radios and the antennas comes from experience and/or test data as well. As mentioned in the list above some entries are set by the use case, for example the distance of 10 meters.

Finally, there is the large factor of RF engineering experience and judgment. This involves what assumptions are to be used and makes sense for the analysis. It is also knowing where to draw the line as to what is acceptable and valid in the link-budget. This is required because one cannot account for all the possible loss mechanisms between devices. Further judgment is required in this process as trying to design to the worst case performance and environmental factors is cost prohibitive and would always result in an unfunctional system. Items in the link-budget that rely on this judgment are the use of the -89 dBm noise floor, and the use of the average of the measured gain of the SteamVR USB dongle mounted in its external stand. (+2.18 dBi).

Judgement also includes a healthy amount of skepticism, but is balanced by RF engineering experience to know exactly where to draw an acceptable performance limit. This is often expressed as "margin." This judgement comes into play when examining the Signal to Noise Ratio, or SNR, at the receiver. The SNR is the amount of power of the transmitted signal above the environmental noise present at the input of the receiver. An Enhanced Shockburst uses the same Gaussian Frequency Shift Keyed (GFSK) encoded signals that standard Bluetooth links use. The goal link speed is then set at 1 Mbps data rate, utilizing a 1 MHz channel width, and with a Bit Error Rate (BER) of 0.01%. From communications theory the encoding needs a minimum SNR requirement of 11.4 dB to work. Achieving the required SNR at distance is almost always the limiting factor in most wireless data links. Finally a +6 dB SNR margin is added to the SNR requirement for a given data rate to also account for the unknowns in the noise environment at the receiver.

The inputs and needed gain results from the link-budget is shown in the table below:

Watchman NRF52 ShockBurst (GFSK) SNR Link Budget

Inputs				
Tx Power (dBm)	Ant Gain (dB)	Distance (m)	Noise Floor (dBm)	SNR Margin Limit (dB)
0	-9.4	10	-89	6

	Output			
	BER	SNR Requried	SNR	SNR Margin
Link	0.10%	9.8	17.4	7.60
	0.01%	11.4	17.4	6.00
	0.0001%	13.5	17.4	3.86

The assumed, and set values, are in some of the yellow “input” blocks. The inputs for the VR controller's transmit power, antenna gain, plus any RF implementation losses, is in the yellow input block for Tx Power and “Ant Gain” respectively. The dongle’s antenna gain is set at a fixed +2.18 dBi and is not shown in the above table.

The resulting outputs are in the green boxes below for various BER links. As mentioned before a BER of 0.01% has been chosen.Stop light bullets in the SNR Margin blocks (SNR Computed - SNR Required) of green, yellow, or red indicate the predicted health of the data link. A green bullet represents a good link, yellow bullet is for a marginal link, and red is a non-functional link.

The output of the link-budget analysis was found by adjusting the “Ant Gain” input entry representing a VR controller’s antenna gain, and any implementation loss. The output is that the “Ant Gain” needs to be -9.4 dB or better. At this level of gain, the data link will close with a SNR margin of 6 dB for a 0.01% BER, and a SNR margin of 7.6 dB for a 0.1% BER data link. A very marginal link is established for a BER of 0.0001% with a SNR margin of only 3.86 dB.

The interpretation of this result and the resulting design guidance for VR controller antennas is discussed next.

Guidance for RF and Antenna Performance

The following guidance is based on the result of the link-budget that shows that a combination of 0 dBm transmitter power and a minimum gain of -9.4 dB. The two are interlinked as a higher antenna gain allows for a one to one dB reduction in transmit power and vice versa. However it is not recommended to have a lower antenna gain, as the SteamVR USB dongle’s minimum transmitter power is also 0 dBm. This enables a symmetric link between the two devices.

The gain figure includes any implementation losses in the RF path from the radio to the antenna. Examples of additional losses would include the use of an RF cables, lossy transmission lines, connectors, etc. It also represents installed gain where the antenna is placed in the full controller design and not in a stand alone configuration.

Note that the USB dongle that the VR controller is being connected to has a meandered monopole or Inverted-F antenna (IFA) that provides a mix of antenna polarizations: the 3D spacial direction of the electric RF field as it moves through the air. Idealy the VR controller gain should also provide a mix of antenna polarizations. This avoids the potential case when two communicating antennas have orthogonal polarizations, or are cross polarized. Whis this occurs the two antennas are blind each other's signals. A potential familiar analogy is how polarized sunglasses block light reflections from surfaces. When antenna polarizations are not aligned it leads to a loss. This can be booked in the link-budget as a polarization loss. Thus the -9.4 dB guidance also would include any strong RF polarization loss from the controller's antenna to the dongle. An example is an ideal monopole or dipole. In this case an additional 3 dB of gain should be added, resulting in a -6.4 dBi as the design guidance for very linearly polarized antennas in the controler.

The gain, RF losses, and transmit power limit of -9.4 dB holds for all of the possible direct line of sight viewing angles between the controller’s antenna and the SteamVR USB dongle. The worst case gain performance by orientation angle to the dongle over the frequency span should be used in determining if the controller’s antenna gain and RF performance is acceptable. The 6 dB SNR margin figure is used in part to accommodate variations in the USB dongle antenna pattern and mix of polarizations as the average gain from measured data has been used.

The gain figure should include any human body losses for handheld, worn, and head mounted controllers. The human body often reduces the realized antenna gain by 10 dB or more. This is critical when the line of sight path from the VR controller’s antenna to the SteamVR USB dongle is directly through any part of the human body.

Again the information provided here is intended to provide RF antenna and system design guidance only for VR controller designs. A device specific RF link-budget should be created for each unique VR controller design and specific to how it will exactly be used with the VR system. Changes to the assumptions used here will invalidate the recommendations provided. Antenna and RF designs should be validated by measuring the antenna pattern gain performance from early design prototypes. This validation should be also performed on the final design controllers as a final check before any mass-production of devices begins.