Application Note AN-001: *Range Extension using NuWaves' NuPower^{TM} Xtender^{TM} Bidirectional Power Amplifiers*

Introduction

This application note covers the basics of RF propagation, the effects of fading, multipath, and other phenomena on communication range, modulation types, and how to improve digital link distances using NuWaves' NuPower^{TM} Xtender^{TM} line of bidirectional PA's. While the first method considered by most systems engineers to improve link range is to use high gain directional antennas, many situations preclude their use. For unmanned aircraft systems (UAS) and other airborne platforms, the use of large or complex high gain antenna systems can be impractical. Omni-directional antennas are often the best antenna solution, but these antennas have low gain figures. In these situations, more RF output power from the radio is necessary to extend the link distance. This application note explores the use of bidirectional PAs for communications range extension.

Figure 1. NuWaves' NuPower^{TM} Xtender^{TM} features 10 W of RF output power and a 3.5 dB noise figure.

Radio Performance

Many radios on the market today come with a variety of options including programmable bandwidths, RF power settings, and modulation type. Usually the bandwidth and modulation settings are based on the application data throughput requirements (i.e., higher data throughput requires more complex modulation schemes, which requires greater bandwidth). The RF power setting is dependent upon the desired link quality and link distance. For most users, the RF power this is set to the maximum setting for ensured link reliability. The maximum output power of these radios can provide 0.6 to 2 watts (W) of RF power, providing solid performance over for short distances. However, the link suffers significantly at longer ranges due to the low power output – especially when higher data rates are desired. When longer range and high data rates are needed, the user has two options: improve the antenna system, or utilize an RF PA.

UAS Application Example

Consider the communications link between a manned aircraft and a UAS. Both aircraft are equipped with dipole antennas of approximately 2.15 dBi gain. The data link requirements are to provide at least 2.5 Mb/s for video streaming and UAS command and control. The frequency of operation is S-Band at 2.4 GHz. With the bandwidth set to 10 MHz and using BPSK ¾ modulation, the radios provide a data throughput of 4.5 Mb/s using 802.11g standards to allow for some margin. The radios chosen provide 2 W of RF output power and utilize a time-division multiple access (TDMA) channel access scheme. The radio receivers provide good sensitivity with a noise figure (NF) of 5 dB.

The link distance between the aircraft is calculated from the transmit power, antenna gains, the free space RF propagation path loss, and receiver sensitivity. As the distance between the aircraft increases, the signal weakens due to the increasing path loss. The receiver sensitivity is a function of bandwidth, modulation type, minimum signal to noise ratio (SNR) and NF. The minimum SNR for 802.11g signals is 9 dB, as provided in the IEEE 802.11 standard. For a signal bandwidth of 10 MHz, the thermal noise floor -104 dBm. By adding the noise figure of the receiver to the thermal noise floor, the noise floor of the receiver is -99 dBm. To determine the minimum discernable received signal strength, the minimum SNR value is added to the receiver noise floor value, for a signal strength of -90 dBm.

A plot of received signal strength versus distance is shown in Figure 2. The graph shows that the link is closed at up to 6 nautical miles (nmi). The caveat however, is that this analysis is based on ideal free space path loss, which does not take into account any losses due to propagation through the atmosphere or the effects of multipath. Systems engineers apply additional margin for high link reliability, terrestrial land based losses, multipath effects, and other factors. This additional margin is known as fade margin.

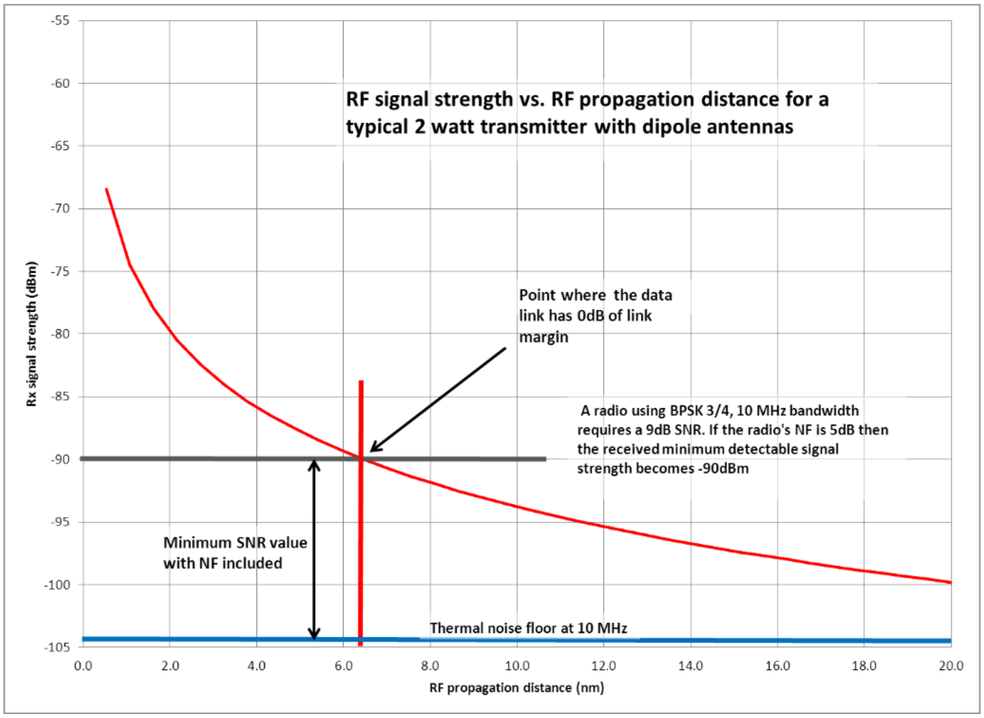

Figure 2. A 2 W radio under ideal conditions can achieve link distances of over 6 nmi.

For more realistic analysis, fade margin is considered. Assume that the application requires a data link reliability of 95%. For line-of-sight communications, the Rayleigh distribution function is used to determine the fade margin. From Table 1, the fade margin is 10 dB for a link reliability, or time availability, of 95%. The graph in Figure 3 shows the difference in free space path loss between the idea case and the addition of the 10 dB fade margin. The results are dramatic – the addition of the fade margin decreased the link distance to 2 nmi, for a loss of 4 nmi over the ideal case.

Table 1. Rayleigh Fading Model Time Availability vs. Fade Margin

Rayleigh Fading Model	
Time Availability (%)	Fade Margin (dB)
90	8
95	10
99	18
99.9	28
99.99	38
99.999	48

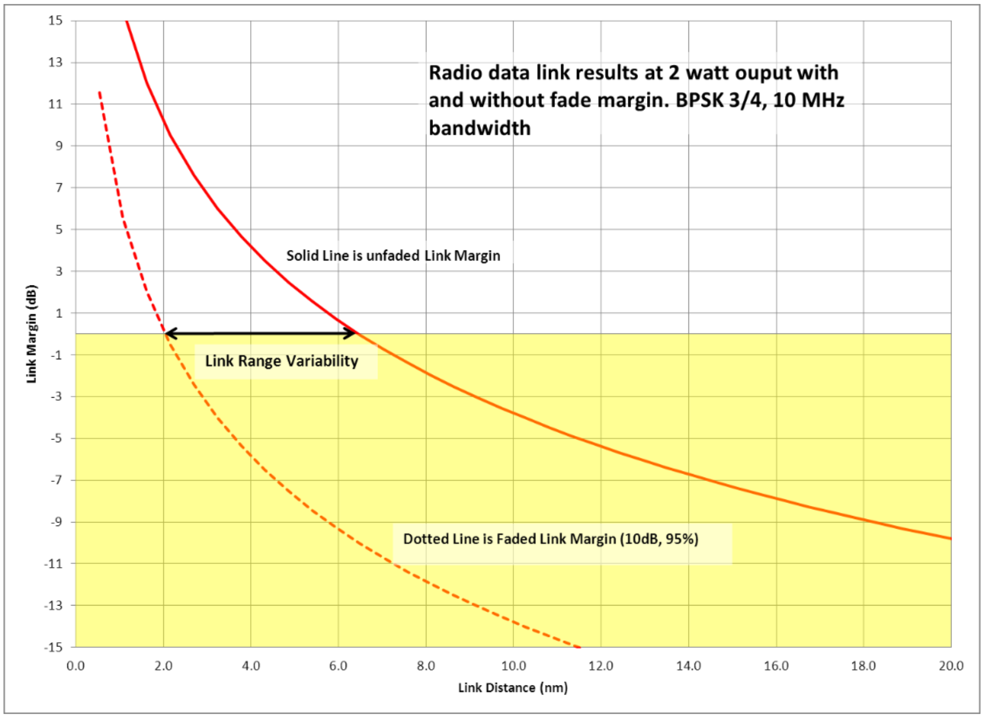

Figure 3. A 2 W radio, considering a realistic RF environment based on the Rayleigh Fade Model, achieves a link distance of only 2 nmi

Range Extension

As distance increases, the signal strength decays by 6 dB for each doubling of the distance. By the same relationship, every 6 dB increase in SNR doubles the link distance. SNR is improved by increases the signal strength, through an increase in transmit output power, as well as by decreasing the NF of the receiver. ***NuWaves' Xtender^{TM} bidirectional PA provides both***.

To illustrate the range improvement, the Xtender^{TM} bidirectional PA is added to both aircraft. The Xtender^{TM} PA features 10 W of class AB RF power and a low NF of 3.5 dB. The increase in SNR of the system leads to an improvement factor of 2.75 over the non-amplified 2 W radio link: approximately 18 nmi of link distance for the ideal case, and 6 nmi for the Rayleigh Fade Model, as shown in Figure 4.

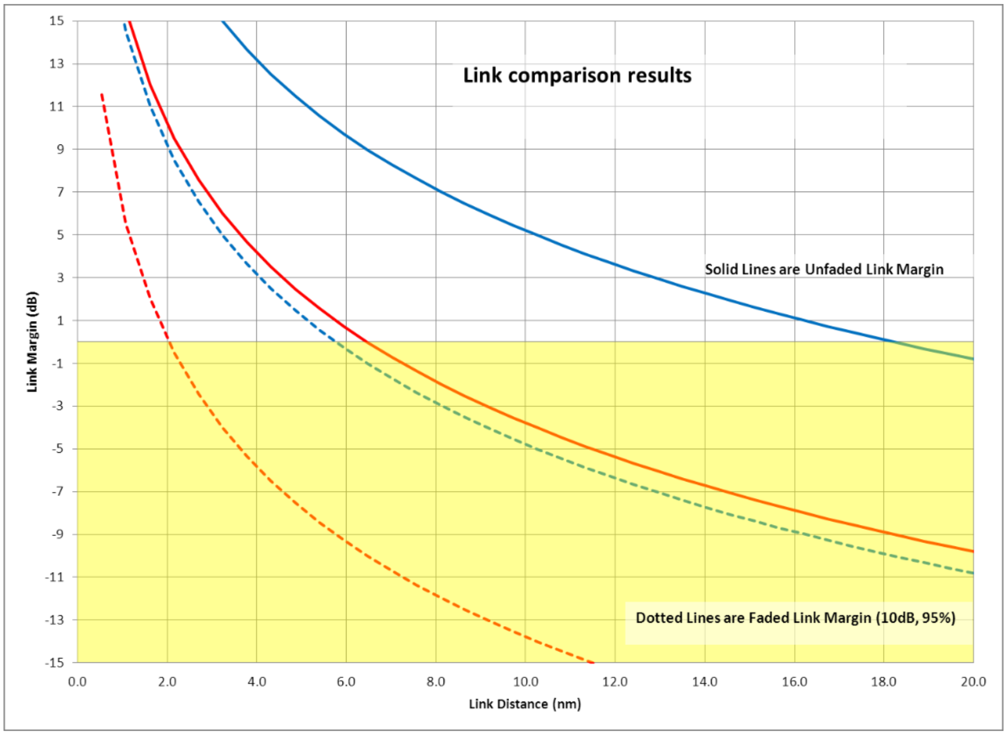

Figure 4. A comparison of the non-amplified 2 W radio to the 2W radio with the NuWaves' Xtender^{TM} bidirectional PA shows a significant improvement in range through the use of the PA. The range is increased by a factor of 2.75.

Laboratory Testing Results

Two 802.11 based radios were tested on the bench with and without Xtender^{TM} PAs to verify the analysis provided above. To simulate the free space path loss, RF attenuators were used to control the signal levels between the radios. Data throughput was monitored for both TCP and UDP data packets.

The system noise figure was determined by taking the difference of the calculated received signal strength over the thermal noise floor for a 10 MHz bandwidth (the calibrated SNR, or “Cal SNR” in the tables below) and the SNR reported by the radios. The noise figure of the radio alone was found to be 6 dB, and the radio plus the Xtender^{TM} was found to be 3.6 dB.

The free space range was derived from the amount of attenuation used between the two radios. In both the non-amplified and amplified cases, the free space range was very close to the predicted ideal case range calculated in the analysis above[1]. The radio only link distance was calculated to be approximately 6 nmi, and the results of the laboratory testing

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[1] The closed-loop test setup does not simulate fading, multipath, or other propagation phenomena. Therefore, the ideal free space loss calculations are the most representative for these tests.

showed a distance of 6 to 6.7 nmi (see Table 2). In the radio plus Xtender™ case, the calculated link distance was 18 nmi, and the results of the laboratory testing showed a distance of 17 to 19 nmi (see Table 3).

Table 2. Through testing the non-amplified 2 W radio, the theoretical maximum range of 6 nmi was confirmed.

												BW=>	10	MHz	
Freq (MHz)	2407		Tx Power (dBm)	33								NBW=	-104	dBm	
Atten. (dB)	Free Space Range (mi)	Free Space Range (nm)	Radio 1 SNR	Radio 2 SNR	Reported Average SNR (dB)	Radio 1 TCP	Radio 2 TCP	Average TCP Throughput (Mbits/S)	Radio 1 UPD	Radio 2 UDP	Average UDP Throughput (Mbits/S)	Rx Pin	Cal SNR	Difference (NF in dB)	Rx SNR
121	6.908	6.003	9.55	10.13	9.84	4.29	3.33	3.81	4.10	3.69	3.90	-88	16	6.16	10.06
122	7.751	6.736	9.21	9.09	9.15	3.20	2.94	3.07	3.56	2.97	3.27	-89	15	5.85	9.06
123	8.697	7.558	7.79	7.80	7.80	3.20	2.68	2.94	3.25	2.82	3.04	-90	14	6.21	8.06
124	9.758	8.480	7.17	7.75	7.46	2.67	2.30	2.49	2.74	2.23	2.49	-91	13	5.54	7.06
													average=>	5.94	dB

Table 3. With a NuWaves' Xtender™ Bidirectional PA added to the 2 W radio, the theoretical maximum range of 18 nmi was confirmed.

												BW=>	10	MHz	
Freq (MHz)	2407		Tx Power (dBm)	40								NBW=	-104	dBm	
Atten. (dB)	Free Space Range (mi)	Free Space Range (nm)	Radio 1 SNR	Radio 2 SNR	Reported Average SNR (dB)	Radio 1 TCP	Radio 2 TCP	Average TCP Throughput (Mbits/S)	Radio 1 UPD	Radio 2 UDP	Average UDP Throughput (Mbits/S)	Rx Pin	Cal SNR	Difference (NF in dB)	Rx SNR
130	19.470	16.919	9.46	11.70	10.58	4.44	3.08	3.76	4.30	3.11	3.71	-90	14	3.42	10.44
131	21.846	18.984	8.23	9.94	9.09	3.18	2.55	2.87	3.53	3.00	3.27	-91	13	3.92	9.44
132	24.512	21.300	7.63	9.69	8.66	3.11	2.13	2.62	3.39	2.09	2.74	-92	12	3.34	8.44
													average=>	3.56	dB

Summary

Low-power radio systems, though designed for short distance communications, can be an inexpensive and reliable means of communications over greater distances – especially when the application is small UAS platforms. To overcome the limitation of low output power, the integrator must choose the best antenna systems compatible with the platform, and a bidirectional RF PA. NuWaves' NuPower™ Xtender™ was designed for these applications, where small size, minimum weight, and efficient use of onboard power are critical factors. Contact NuWaves today to find the perfect solution for your range extension needs!

NuWaves Engineering is a premier supplier of RF and Microwave solutions for Department of Defense (DoD), government, and industrial customers. An RF engineering powerhouse, NuWaves offers a broad range of design and engineering services related to the development and sustainment of key communications, telemetry and electronic warfare systems, as well as a complete line of commercially available RF products. NuWaves' products include wideband frequency converters, high-efficiency and miniature solid state power amplifiers and bidirectional amplifiers, high intercept low noise amplifiers and miniature RF filters. NuWaves Engineering…Trusted RF Solutions™.

Contact Ryan Foster, Director of Product Solutions, at (513) 360-0800 ext. 154, or visit www.nuwaves.com for more information.