Implementation of Antenna Switching Diversity and Its Improvements over Single-Input Single-Output System

by

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Abstract

This dissertation study the effectiveness of antenna switching diversity for orthogonal frequency division multiplexing (OFDM) systems such as in IEEE 802.11. One of the ways to exploit the multiple antenna configurations is to use antenna switching diversity. Antenna switching diversity is used in wireless systems to combat the effect of fading, as we can combine multiple independent copies of the same signal into a total signal with high quality. In this work, we implement and compare the performance of two systems, antenna switching diversity system and single-input single-output (SISO) system. We firstly study the performance of the antenna switching diversity system as we increases the number of antennas compared to the performance of signal-to-noise ratio (SNR) or gain of the system. The performance of antenna switching diversity is studied on several difference configurations such as receive diversity where there are multiple receive antennas, and transmit diversity where the there are multiple transmit antennas. The study is performed on eight (8) antenna switching, on either the transmit or receive side. The implementation of antenna switching diversity system shows that there are definite improvement on signal-to-noise ratio (gain) value compared to single-input single-output system signal-to-noise ratio (gain).

Acknowledgments

I would like to thank my supervisor, Prof. Amir K. Khandani, for his valuable guidance and support throughout the course of my graduate studies. His passion towards research and care for his student have made this work possible. I would also like to thank my colleagues at CST lab for their insightful discussions and supports.

I would like to thank my family for their unconditional love and belief in me. My parents and brother, with your endless supports and love that you have provided throughout.

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Chapter 1

Introduction

In wireless communications system, Orthogonal Frequency Division Multiplexing (OFDM) is a promising choice due to its high data rate transmission capability and high bandwidth capability. This is shown as OFDM has been implemented on wireless local area network (WLAN) standards such as IEEE 802.11a/b/g/n [1-4]. OFDM in Multiple-input-multiple-output (MIMO) systems is a good approach to satisfy the demand for higher data rate requirement for applications such as video transmission and streaming.

Multiple-input-multiple-output (MIMO) systems are those that have multiple antenna elements at both the transmitter and receiver [5]. The multiple antennas in MIMO systems can be exploited in two different ways, the creation of a highly effective antenna diversity system and the use of multiple antennas for the transmission of several parallel data streams to increase the capacity of the system.

Antenna diversity is used in wireless systems to combat the effects of fading. When multiple, independent copies of the same signal are available, we can combine them into a total signal with high quality [6]. The different signal copies are linearly combined, i.e., weighted and added. The resulting signal at the combiner output can then be demodulated and decoded in the usual way.

The optimum weights for this combining are matched to the wireless channel [maximum ratio combining (MRC)]. If we have N receive antenna elements, the diversity order, which describes the effectiveness of diversity in avoiding deep fades, is N; in other words, the diversity order is related to the slope of the signal-to-noise ratio (SNR) distribution at the combiner output. The multiple antennas also increase the average SNR seen at the combiner output. When the channel is known to the transmitter, we can again “match” the multiple transmitted signal copies to the channel, resulting in the same gains as for receiver diversity. If the channel is unknown at the transmitter, other strategies, like delay diversity or space-time-coding, have to be used. In that case, we can gain high diversity order, but not improvement of average SNR. The logical next step is the combination of transmit and receive diversity. It has been demonstrated that with Nt transmit and Nr receive antennas, a diversity order of NtNr can be achieved [7]. A MIMO system can thus be used for a high-quality transmission of a single data stream even in challenging environments.

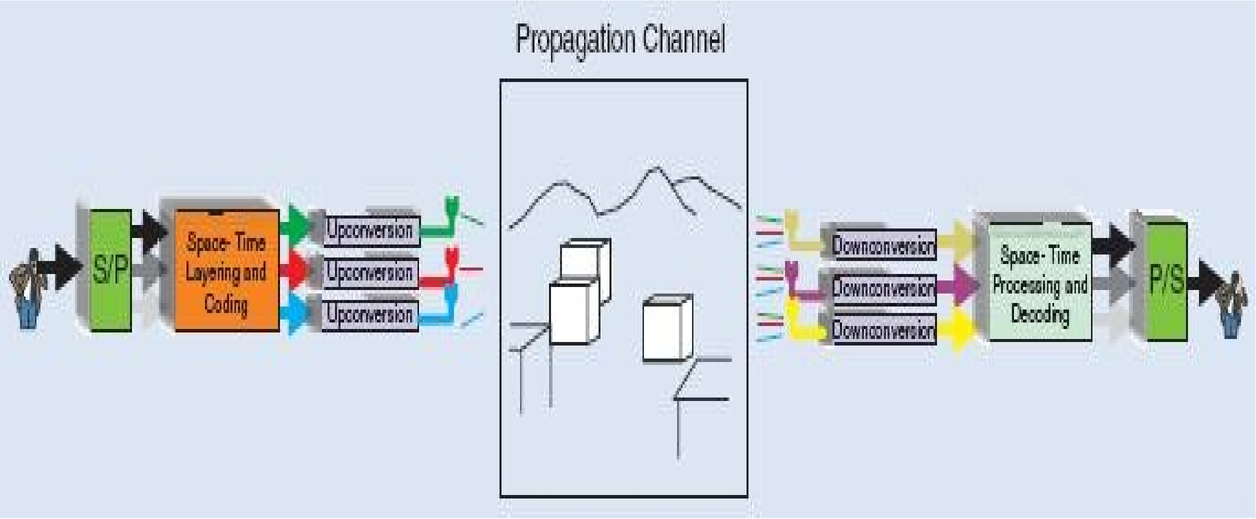

Figure 1.1: Principle of Spatial Multiplexing

An alternative way of exploiting the multiple antenna elements is the so-called “spatial multiplexing” [8] or “BLAST” [9] approach. The principle of this approach is sketched in Figure 1. Different data streams are transmitted (in parallel) from the different transmit antennas. The multiple receive antenna elements are used for separating the different data streams at the receiver. We have Nr combinations of the Nt transmit signals. If the channel is well-behaved, so that the Nr received signals represent linearly independent combinations, we can recover the transmit signals as long as Nt ≤ Nr . The advantage of this method is that the data rate can be increased by a factor Nt without requiring more spectrum.

1.1 Antenna Selection for MIMO

The drawback of any MIMO system is the increased complexity, adding more antenna means the RF elements are more expensive. Optimum selection algorithm have a complexity $\binom{N}{L}$. However, fast selection algorithm do exist that have much lower complexity and perform almost as well as full-complexity systems. There is great interest in so called hybrid-solution schemes, where the “best” L out of N antenna signals are chosen, down converted, and processed. This reduces the number of required RF chains from N to L, and, thus, leads to significant savings. The approach is called “hybrid selection / maximum-ratio-combining”

(H-S / MRC) or sometimes it also called “generalized selection combining”, If they are used for spatial multiplexing, the scheme is called “hybrid selection / MIMO” (H-S / MIMO). In this work, we use eight (8) as the number of N and we will choose one (1) best antenna signal as the number of L. Therefore we are choosing the best antenna out of eight antenna signals.

1.2 Contribution of Thesis

In this thesis, we work on antenna selection of multiple antennas system. We want to establish channel between pair of antennas in 802.11 standard and select the pair to operate in the channel with the best (highest SNR) gain for that particular pair of TX/RX antennas. After we had determined the best available pairings, we were able to perform various antenna selection experiments such as transmit and receive antenna selections, the effect of line of sight on antenna selection, and the effectiveness of adding antennas on gain improvement.

The goals are to find the characteristic of antenna selection system, the improvement over adding more antennas to choose from, the performance of implementing antenna selection on different side, and the benefit of adding more antennas compared to the improvement of the SNR (gain) values.

1.3 Organization of Thesis

The organization of this thesis is as follows. In Chapter 2, we explore previous work done in antenna selection method particularly in OFDM MIMO system. Chapter 2 begin with the performance of Single Input Multiple Output system and then the performance of MIMO system benefiting from antenna selection. In Chapter 3, the antenna selection system is introduced along with some explanations of selecting the antenna and the setup of the experiments. In Chapter 4, we show our experiment result and data that we have gathered. We investigated different number of antenna selections experiment and their findings. Lastly, in Chapter 5 we discuss the summary of the thesis and future work that can be done.

Chapter 2

Performance of Antenna Selection on Multiple Antenna System

We will discuss some previous work on the performance of antenna selection on multiple antenna system. We can see the block diagram of antenna selection system model of Molisch and Win [6] in Figure 2.1. A bit stream is sent through a vector encoder and modulator. The encoder converts a single bit stream into Lt parallel streams of complex symbols. Subsequently, a multiplexer switches the modulated signals to the best Lt out of Nt available antenna branches. For each branch, the signal is multiplied by a complex weight u whose actual value depends on the current channel realization (weight are set to unity if the channel is unknown to the transmitter). Antenna selection retains the diversity degree, compared to the full-complexity system, for both linear diversity systems with complete channel knowledge and space-time coded systems.

The signal is then sent over the channel, we will then have a matrix H which is the gain matrix of Nr x Nt size. The components of the matrix are the individuals gain from each transmit antenna to the corresponding receive antenna. For experiments that we performed, the switch in Figure 2.1 will choose the best corresponding gain of the transmit and receive antenna pair.

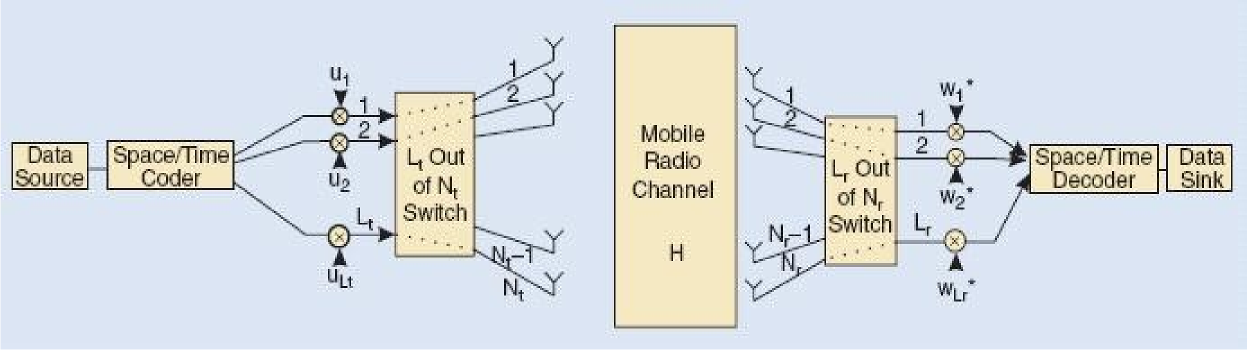

Figure 2.1: Block diagram of the system

The system will send the signal from one transmit antenna and switch trough all the receive antenna until all the gain matrix is entered. It will then change transmit antenna until all the components of gain matrix are scanned.

2.1 Performance of Single Input Multiple Output System

It is well known that the output SNR of maximum ratio combining is just the sum of the SNRs at the different receive antenna elements. For H-S/MRC, the instantaneous output SNR of H-S/MRC looks deceptively similar to MRC

$$\gamma_{\text{H-S/MRC}} = \sum_{i=1}^{L} \gamma_{(i)} \qquad (2.1)$$

The big difference to MRC is that the $\gamma(i)$ are the ordered SNRs, i.e., $\gamma(1) > \gamma(2) > \cdots > \gamma(N)$. This leads to a different performance, and poses new mathematical challenges for the performance analysis. Specifically, we have to introduce the concept of "order statistics" [10]. Note that selection diversity (where only one out of N antennas is selected) and MRC are limiting cases of H-S/MRC with $L = 1$ and $L = N$, respectively.

In general, the gain of multiple antennas is due to two effects: "diversity gain" and "beamforming gain." Diversity gain is based on the fact that it is improbable that several antenna elements are in fading dip simultaneously; the probability for very low SNR is thus decreased by the use of multiple antenna element. The beamforming gain is created by the fact that (with MRC) the combiner output SNR is the sum of the antenna SNRs. Thus, even if the SNRs at all antenna elements are identical, the combiner output SNR is larger, by a factor L, than the SNR at one antenna element.

The differences between MRC and antenna selection schemes:

a. Antenna selection provide good diversity gain, as they select the best antenna branches for combining. The diversity order obtained with antenna selection is proportional to N not to L.

b. However, antenna selection do not provide full beamforming gain. If the signals at all antenna elements are completely correlated, then the SNR gain of H-S/MRC is only L, compared to N for an MRC scheme.

The complexion of ordering the branches: we can alleviate this problem by transforming the ordered-branch variables into a new set of random variables. It is possible to find a transformation that leads to independently distributed random variables (termed 'virtual branch variables'). When the average branch SNRs are not equal, it can be shown that the virtual branch variables are conditionally independent. The combiner output SNR can be expressed in terms of i.i.d virtual branch variables, which simplifies the performance analysis of the system.

Channel estimation errors do not decrease the capacity significantly if the SNR of the pilot tones is comparable to, or larger than, the NR during the actual data transmission. We can also note that for the opposite scenario, when there are multiple antenna elements at transmitter and only one antenna at the receiver, the same principles can also be used (MISO). If transmitter has perfect channel state information (CSI), it can select transmit weights that are matched to the channel.

2.2 Performance of Multiple Input Multiple Output System

2.2.1 Diversity

Transmitter performs antenna selection, while the receiver uses all available signal and thus performs MRC. Also valid if it is the receiver that perform the antenna selection. It is well known that any diversity system with CSI at the transmitter achieves an effective SNR that is equal to the square of the largest singular value of the channel matrix. For a diversity system with antenna selection, we have to consider all possible antenna combinations. Each chosen set of antenna elements leads to a different channel matrix, and, thus, a different effective SNR. The antenna selection scheme finally chooses the matrix associated with the largest effective SNR.

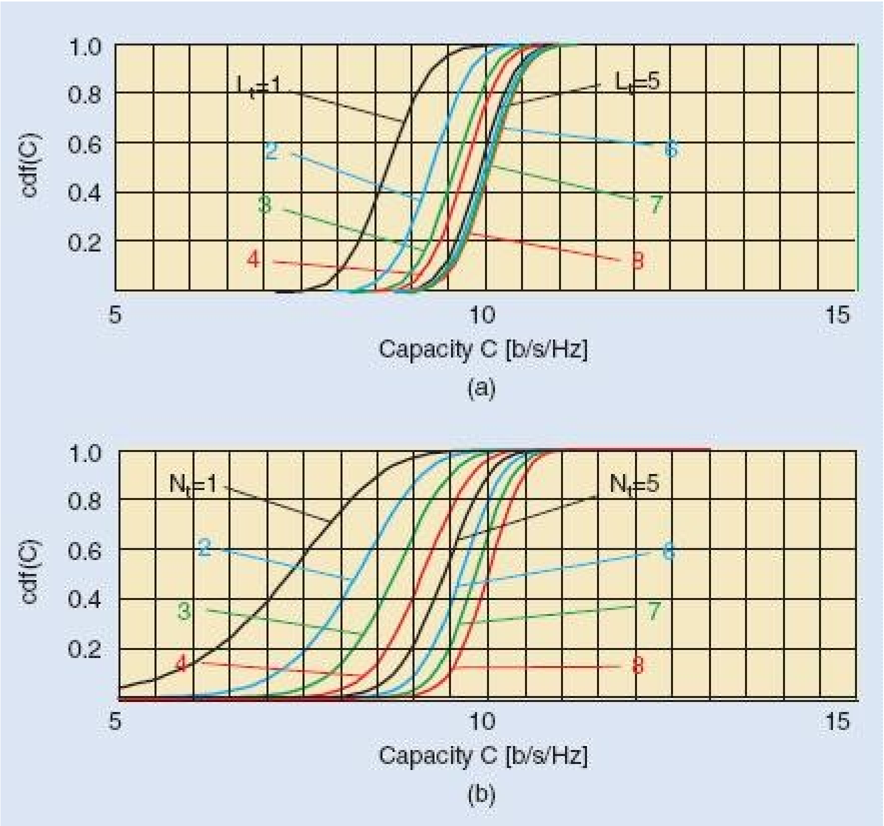

Figure 2.2: Comparison graph of Capacity of H-S/MRT with Nr=2, Nt=8 and different Lt

Vs

Capacity of pure MRT, Nr=2, Change values of Nt

It can be seen by comparing both graphs that, for a smaller number of RF chains, the H-S/MRT scheme is much more effective than a pure MRT scheme (for the same number of RF chains), both in terms of diversity order (slope of the curve) and ergodic capacity. No diversity gain can be achieved by multiple antenna elements in correlated channels, and all gain is due to beamforming.

2.2.2 Spatial Multiplexing

For spatial multiplexing, different data streams are transmitted from the different antenna elements; in the following, we consider the case where the transmitter (TX), which has no channel knowledge, uses all antennas, while the receiver uses antenna selection [11].

Similar to the diversity case, each combination of antenna elements is associated with its own channel matrix H. (H is created now striking Nr − Lr rows from H because the selection occurs at the receiver.) However, the quantity we wish to optimize now is the information-theoretic capacity:

$$C_{\text{H-S/MIMO}} = \max_{S(\underline{\tilde{H}})} \left(\log_2 \left[\det \left(\underline{I}_{N_r} + \frac{\overline{\Gamma}}{N_t} \underline{\tilde{H}}\underline{\tilde{H}}^{\dagger} \right) \right] \right) \qquad (2.2)$$

where I_{Nr} is the Nr × Nr identity matrix.

Let us first discuss from an intuitive point of view under what circumstances H-S/MIMO makes sense. It is immediately obvious that the number of parallel data streams we can transmit is upper-limited by the number of transmit antennas. On the other hand, we need at least as many receive antennas as there are data streams in order to separate the different data streams and allow demodulation. Thus, the capacity is linearly proportional to min(Nr , Nt) [12]. Any further increase of either Nr or Nt while keeping the other one fixed only increases the system diversity, and consequently allows a logarithmic increase of the capacity. But we have already seen in the previous section that hybrid antenna selection schemes provide good diversity. We can thus anticipate that a hybrid scheme with $Nr \geq Lr \geq Nt$ will give good performance.

Figure 2.3 shows the cdf of the capacity obtained by Monte Carlo simulations for Nr = 8, Nt = 3, and various Lr . With full exploitation of all available elements, a mean capacity of 23 b/s/Hz can be transmitted over the channel. This number decreases gradually as the number of selected elements Lr decreases, reaching 19 b/s/Hz at Lr = 3. For $Lr < Nt$, the capacity decreases drastically, since a sufficient number of antennas to spatially multiplex Nt independent transmission channels is no longer available.

Correlation of the fading leads to a decrease in the achievable capacity (compare the decrease in diversity discussed earlier). This fact can be combined with well-known results for capacity of full-complexity MIMO systems in correlated channels [13] to give bounds of the capacity. The optimum transmit correlation matrix is derived in [14]. Phase transformation [15],

[16], or beam selection [17] improve the performance in correlated channels. Also, the combination of constellation adaptation with subset selection is especially beneficial in correlated channels [18].

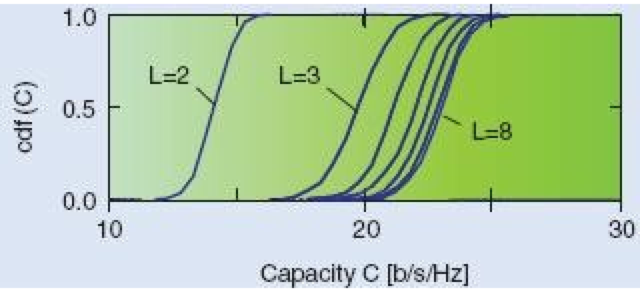

Figure 2.3: Capacity for a spatial multiplexing system with Nr=8, Nt=3, SNR = 20dB and Lr = 2,3,...,8

It also turns out that for antenna selection and low SNRs, diversity can give higher capacities than spatial multiplexing. This somewhat surprising result was proved in [19] . For small SNRs, the capacity with spatial multiplexing is

$$C_{\mathrm{H-S/MIMO}} \approx \frac{\gamma}{N_t \ln(2)} \sum_{i=1}^{L_r} \sum_{j=1}^{L_t} \left| \underline{\tilde{H}}_{ij} \right|^2 \qquad (2.3)$$

whereas for diversity it is

$$C_{\mathrm{H-S/MRC}} \approx \frac{\gamma}{N_t \ln(2)} \sum_{i=1}^{L_r} \left| \sum_{j=1}^{L_t} \underline{\tilde{H}}_{ij} \right|^2 \qquad (2.4)$$

In other words, the difference between the two expressions are the cross terms that appear for the diversity case. By appropriate choice of the antennas, the contribution from the cross terms to the capacity is positive, so that CH−S/MRC can be larger than CH−S/MIMO . Similar results also hold in the case of strong interference [20].

2.2.3 Antenna Selection Algorithms

The only mechanism for a truly optimum selection of antenna elements is impractical. Hence there are simplified selection algorithms, most of them are intended for systems where the selections is done at only one link end. The simplest algorithm is the one based on the power of the received signals. For the diversity case, this algorithm is quite effective. However, for spatial multiplexing, this approach breaks down. The capacity loss can be significant. This happens because receiver goal is to separate the different data streams, hence it is not good to use the signals from two antenna with high correlation, even if both have high SNR.

The alternative class of algorithm: Suppose there are two rows of the H that are identical, we can delete either of these two rows. If the power of the two rows are different, we delete the row with lower power. We can have channel matrix H whose rows have minimum correlation and maximum powers.

2.2.4 Effect of Nonidealities

Low-Rank Channels

Previously we assume that the channel is i.i.d complex Gaussian or exhibits some correlation at the transmitter and/or receiver. However, in all of those cases, the channel matrix is full-rank and the goal of the antenna selection is to decrease complexity, while keeping the performance loss as small as possible. The antenna selection can increases the capacity only compared to the case of equal power allocation for all antennas. It cannot increases the capacity compared to the waterfilling approach.

Frequency Selective Channel

In frequency selective channels, the effectiveness of antenna selection is considerably reduced. Different set of antenna elements are optimum for different (uncorrelated) frequency bands. Therefore, in the limit that system bandwidth is much larger than the coherence bandwidth of the channel, and if the number of resolvable multipath components is large, then, all possible antenna subsets become equivalent.

This can also be interpreted that such a system has a very high diversity degree, so that any additional diversity from antenna selection would be ineffective anyway. For Moderately frequency-selective channels, antenna selection will still give significant benefits.

Channel Estimation Errors

Various type of errors:

a. Erroneous choice of the used antenna elements

b. Errors in the transmit weights

c. Errors in the receive weights

The errors in the transfer function are assumed to have a complex Gaussian distribution with certain SNRpilot, which is the SNR during the transmission of the pilot tones. SNRpilot of 10dB is still tolerable loss of capacity (less than 5%). Below that level, the capacity start to decrease significantly. Another type of error can be caused by a limited feedback bit rate (for feeding back CSI from the receiver to the transmitter in a frequency duplex system).

Chapter 3

Antenna Selection System Setup

3.1 Experiment Equipments

In this section, we will explain the setup of the experiments where we gathered our data. We performed all of the experiments using Wireless open Access Research Platform (WARP[1]) which was designed at Rice University [21]. WARP board is a wireless platform that provide the ability to implement MAC/PHY development and to test the setup on real environment. Specifically, there are several parts that are important for our experiments such as Xilinx Virtex-II Pro FPGA, 2.4/5GHz Radio Board , Receive Antenna Board (switching board) and 10/100 Ethernet port.

In Figure 3.1 we can see the WARP board as such all of the important components for our experiments. Xilinx Virtex-II (noted on Figure 3.1 as A) Pro FPGA is the component in which the MAC protocols are written in C and transfered to embedded PowerPC cores, and also where the PHY protocols, using the Matlab Simulink, are implemented into the PFGA.

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[1] http://warp.rice.edu/

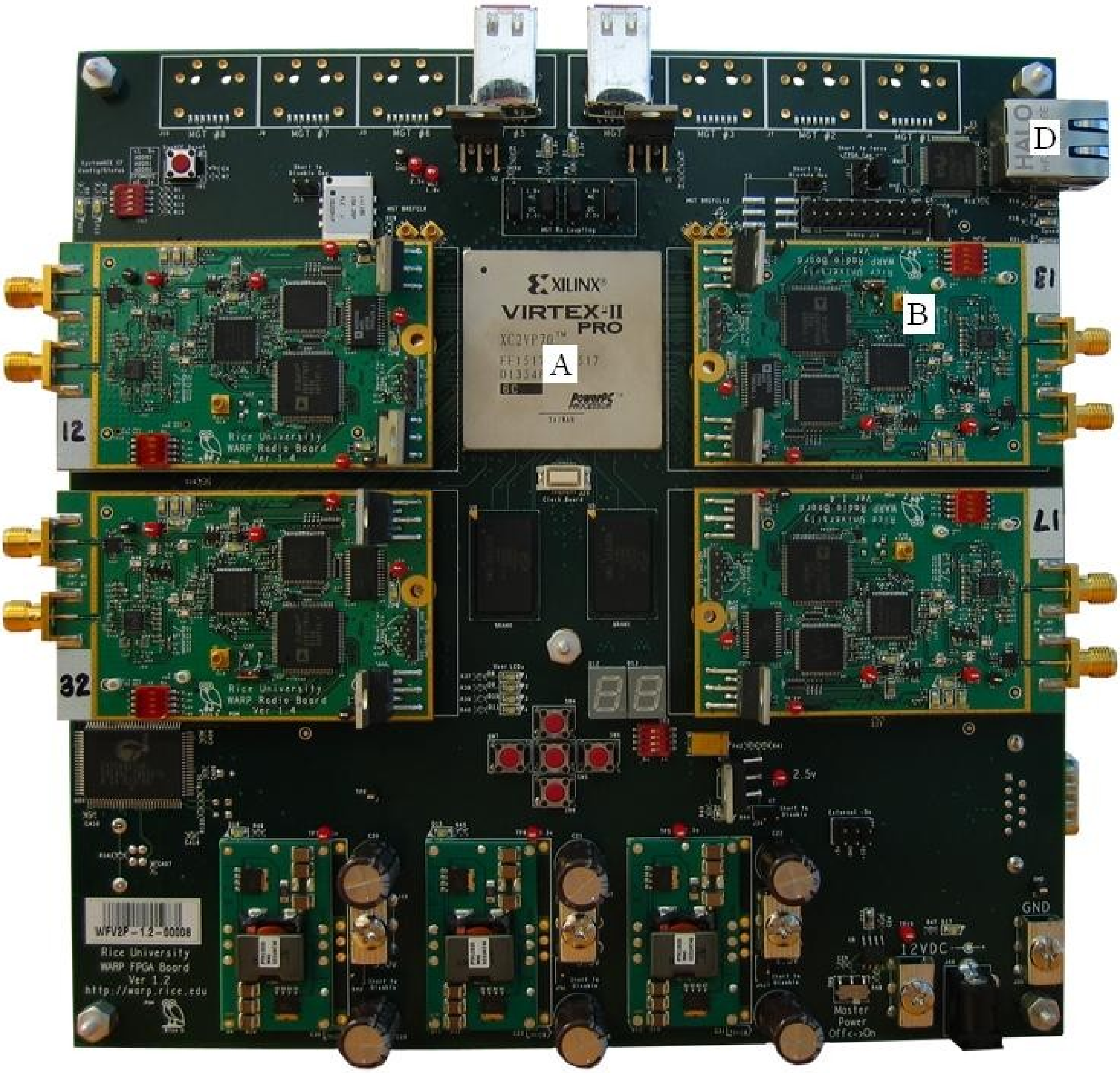

Figure 3.1: WARP Board

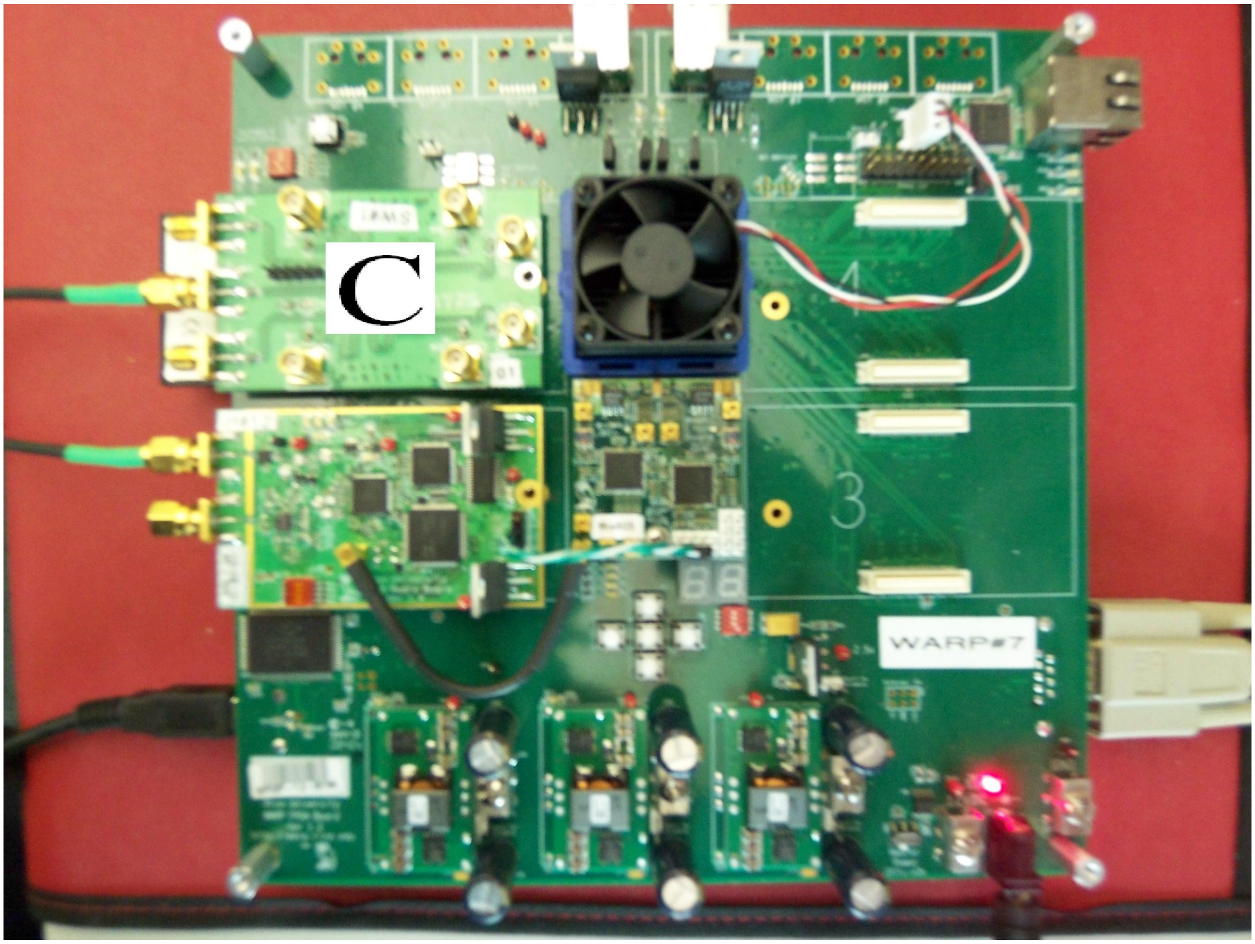

Figure 3.2: WARP Board with Switching Board

The Radio Board (noted on Figure 3.1 as B) is the component where we transmit and receive the signal through the wideband applications such as OFDM. The Receive Antenna Board (noted on Figure 3.2 as C) is the switching board where all of the antennas are connected and the selected antenna can pass through. The Ethernet port (noted on Figure 3.1 as D) is the interfaces to the wired internet where the original and destination of the data are connected.

In addition, there are other equipments that are needed for this experiment such as antennas, ethernet cables, and computers. It is self explanatory, that we use the antennas (Figure 3.3) to transmit and receive the signal. The ethernet cables are used for connection from the computers to the WARP board. Meanwhile, the computers are the source of the data (on the transmit side) and also the destination of the data (on the receive side) where we can see the data that we had sent.

Figure 3.3: Antenna

3.2 Experiment Setup and Antenna Selection Process

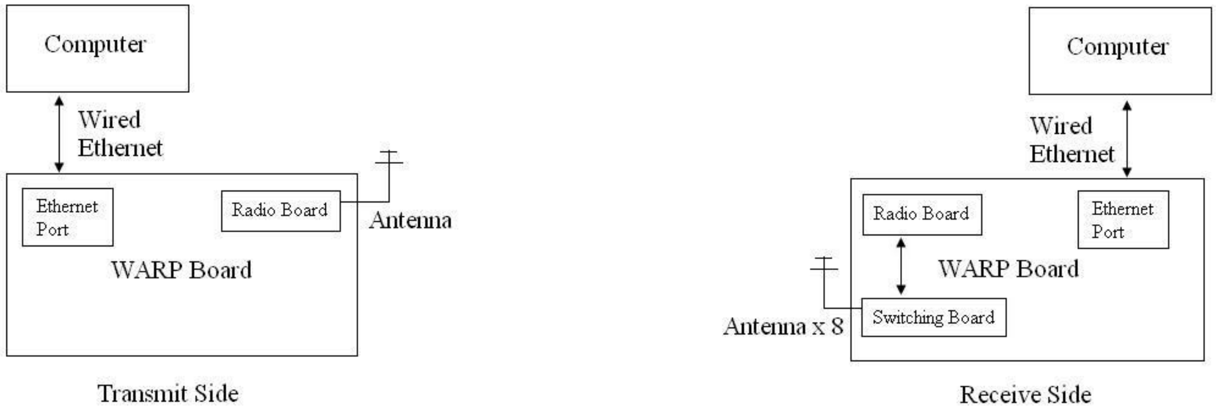

Figure 3.4: Equipment Setup in Antenna Selection Experiment

In order to clarify the directions flow of the signal, Figure 3.4 show the equipment setup of antenna selection on the receive side. The computer on the transmit side send the data through the wired ethernet to the WARP board using the ethernet port. After the data is processed through the WARP board, the radio board can send the signal through wireless channel using the antenna. On the receive side, the switching board will assist the process of selecting the best antenna gain follow by selecting that particular antenna and pass through the signal to the radio board. The radio board will then process it through the WARP board where the data will then be sent to the computer using the ethernet port. In SISO configuration, the switching board is skipped and we connect the antenna directly to the radio board. It can also be noted that we can do the antenna selection on the transmit side with the same principles, where the switching board will be connected to the transmit side.

The MAC/PHY protocols are similar to IEEE 802.11 that operates at channel 11 of 2.4GHz band with Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The over-the-air system bandwidth is 10MHz with a sampling rate of 40MHz. There are 64 subcarriers (52 data subcarriers with 4 pilot subcarriers) in OFDM symbols and supports BPSK, QPSK, and 16-QAM modulation schemes. We implemented the OFDM Reference Design of Rice University [21] and added our antenna selection scheme on the project.

The antenna selection process is quite simple, as we scan through all of the available antennas and then choose the best available one. The selection code is written on C as part of the MAC protocols, we send signal to the switching board to select an antenna and then note the signal gain of that particular antenna. We performed this procedure until we gathered the gain for all of the antennas. We will then choose the best available antennas and stop scanning for a period of time as the same antenna is used for receiving data. The scanning process will be performed periodically to maintain the best gain.

Chapter 4

Antenna Selection Experimental Results and Performances

4.1 Receive Switching Diversity of 1 x 8 System

In this experiment we examined the changes and fluctuation of individuals antenna gain over time. We investigated by implementing a 1 by 8 system with 1 transmit antenna and 8 receive antennas. The receive antennas scan through the signal sent by the transmit antenna, and using the switching board to change from one antenna to another. The result of the experiment shows the changes of individual antenna gains over time. Each antenna gather the gain changes and the best gain of all eight antennas is chosen to be the best antenna. The switching gain is the best antenna's gain as we are choosing the best antenna from the eight receive antennas.

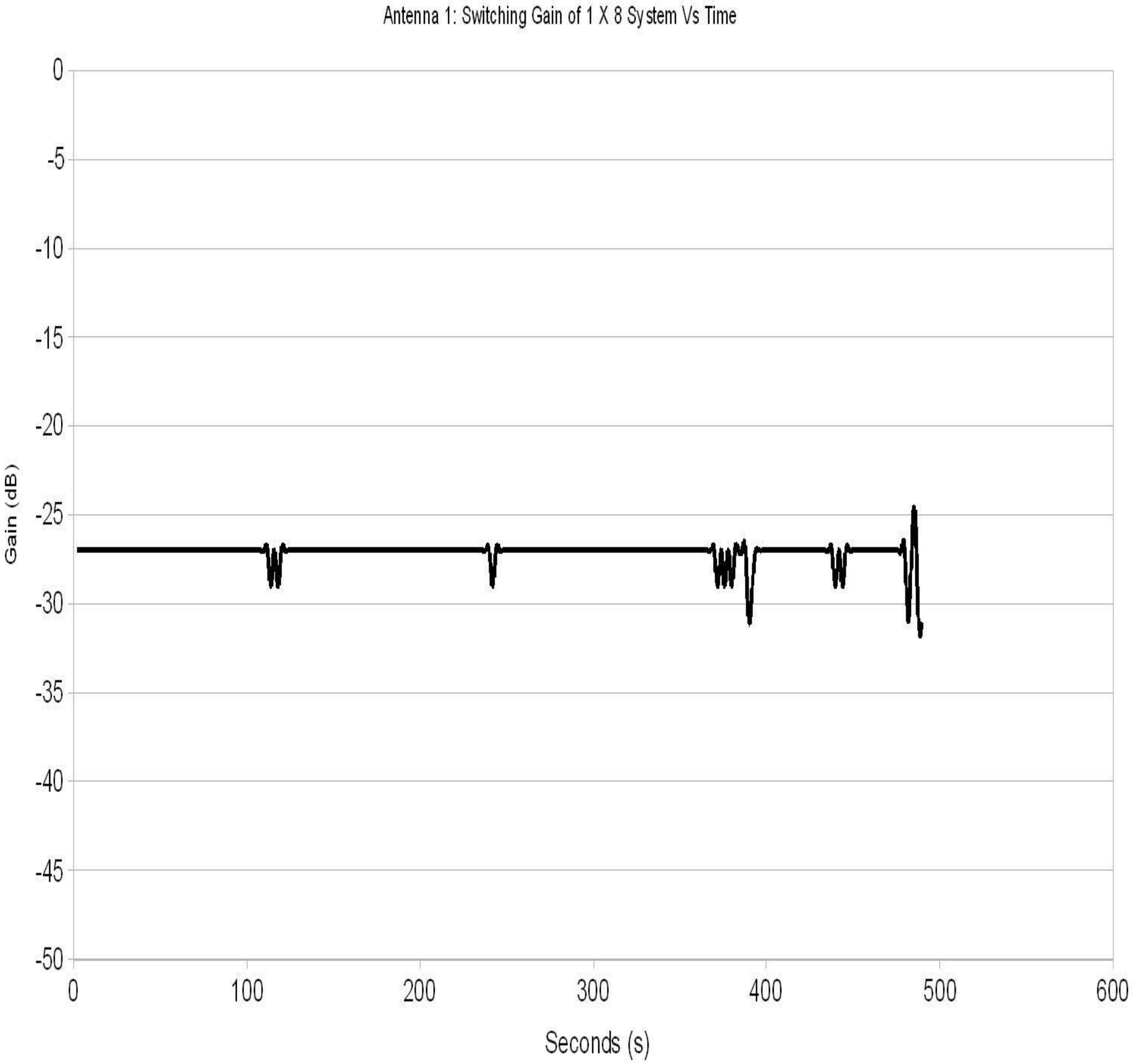

Figure 4.1: Antenna 1 Switching Gain of 1 x 8 System Vs Time

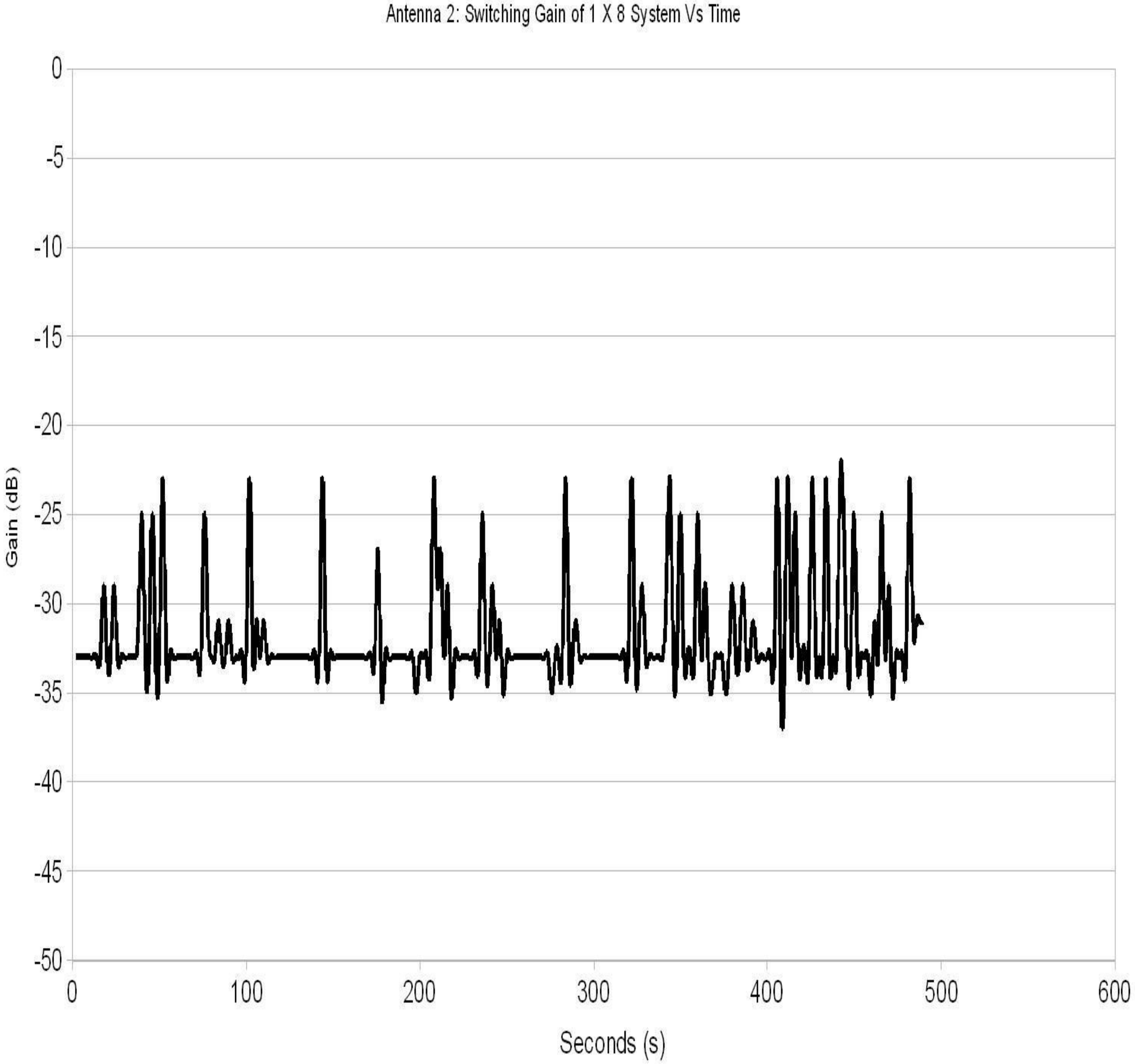

Figure 4.2: Antenna 2 Switching Gain of 1 x 8 System Vs Time

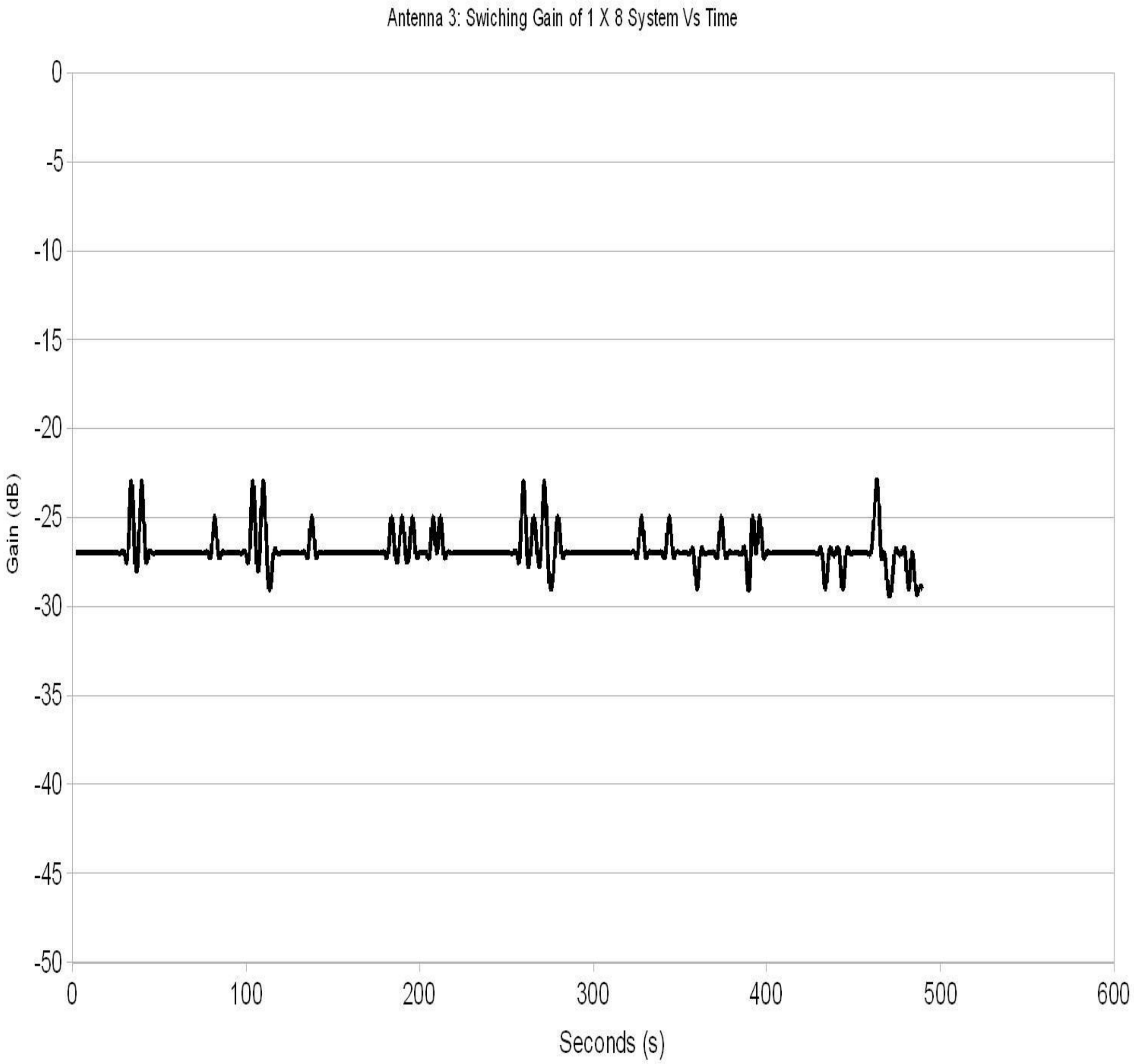

Figure 4.3: Antenna 3 Switching Gain of 1 x 8 System Vs Time

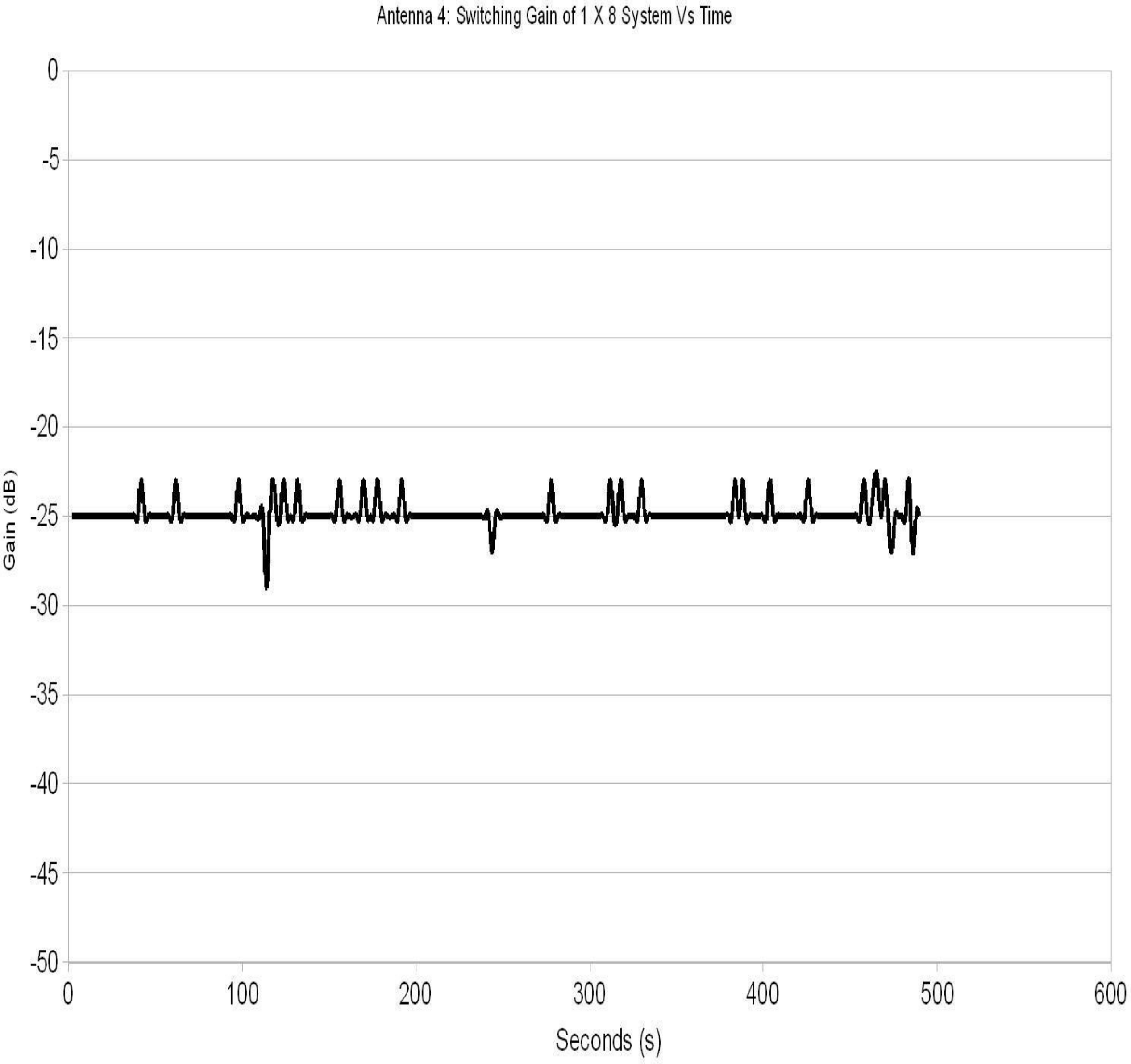

Figure 4.4: Antenna 4 Switching Gain of 1 x 8 System Vs Time

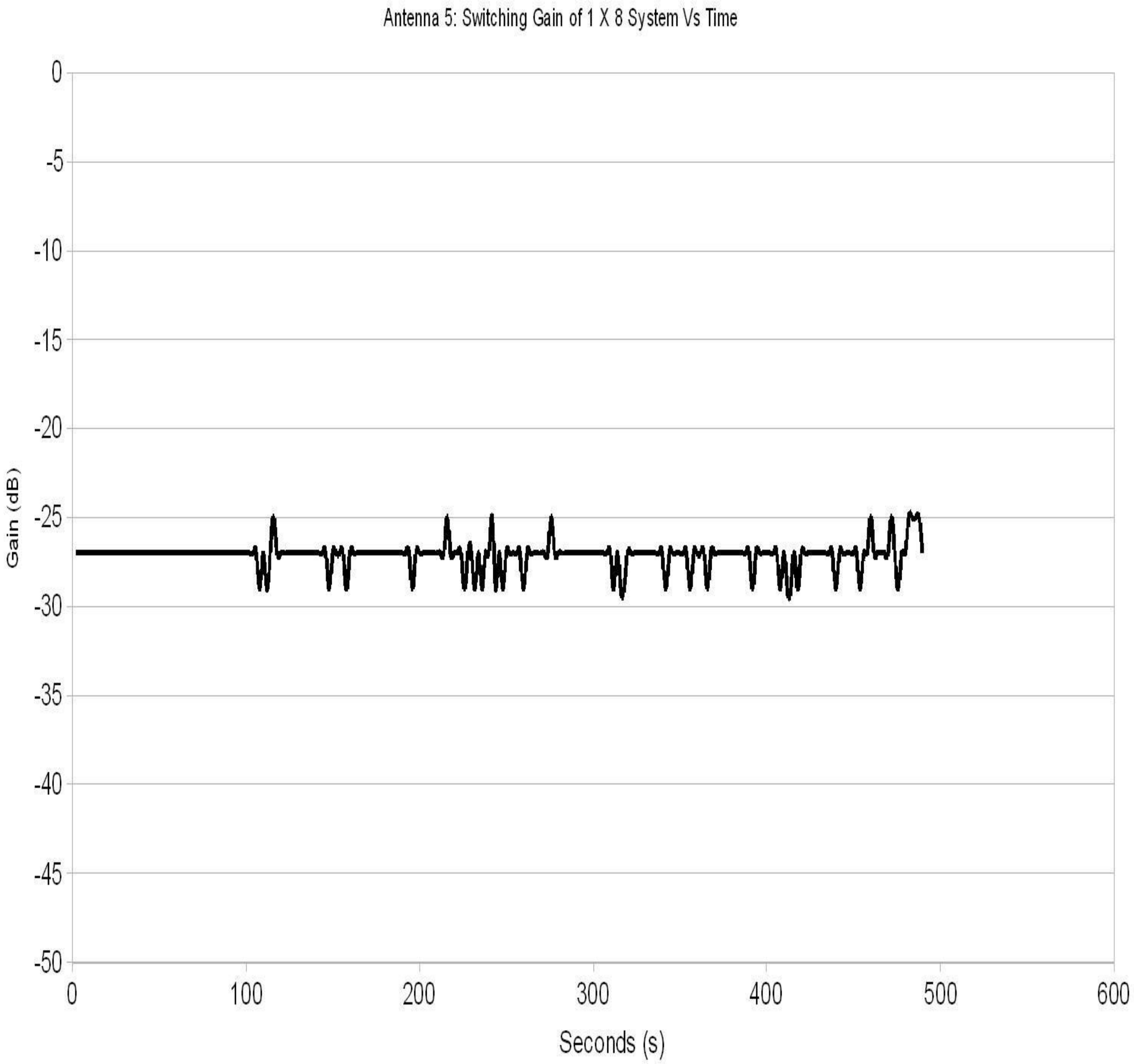

Figure 4.5: Antenna 5 Switching Gain of 1 x 8 System Vs Time

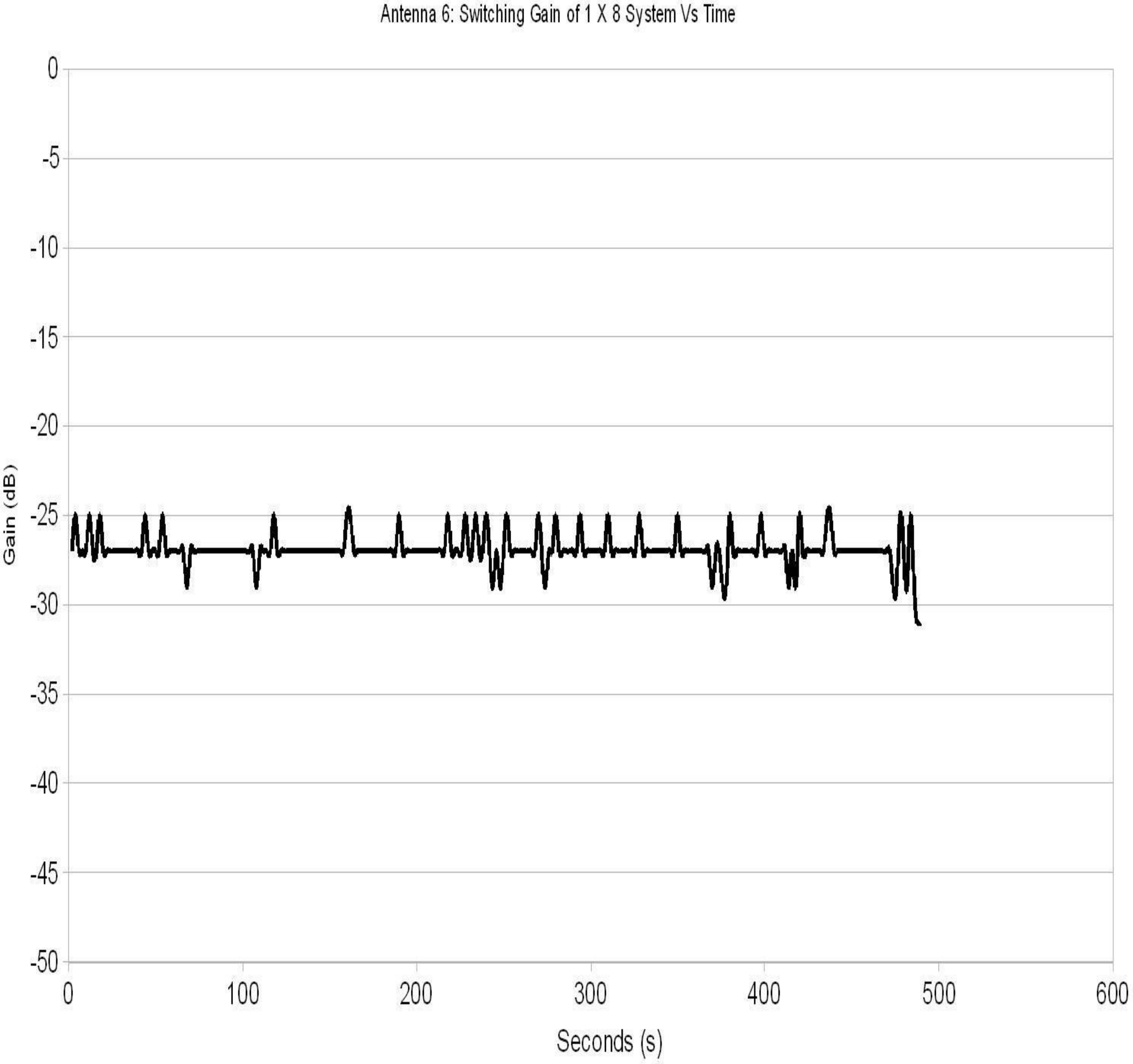

Figure 4.6: Antenna 6 Switching Gain of 1 x 8 System Vs Time

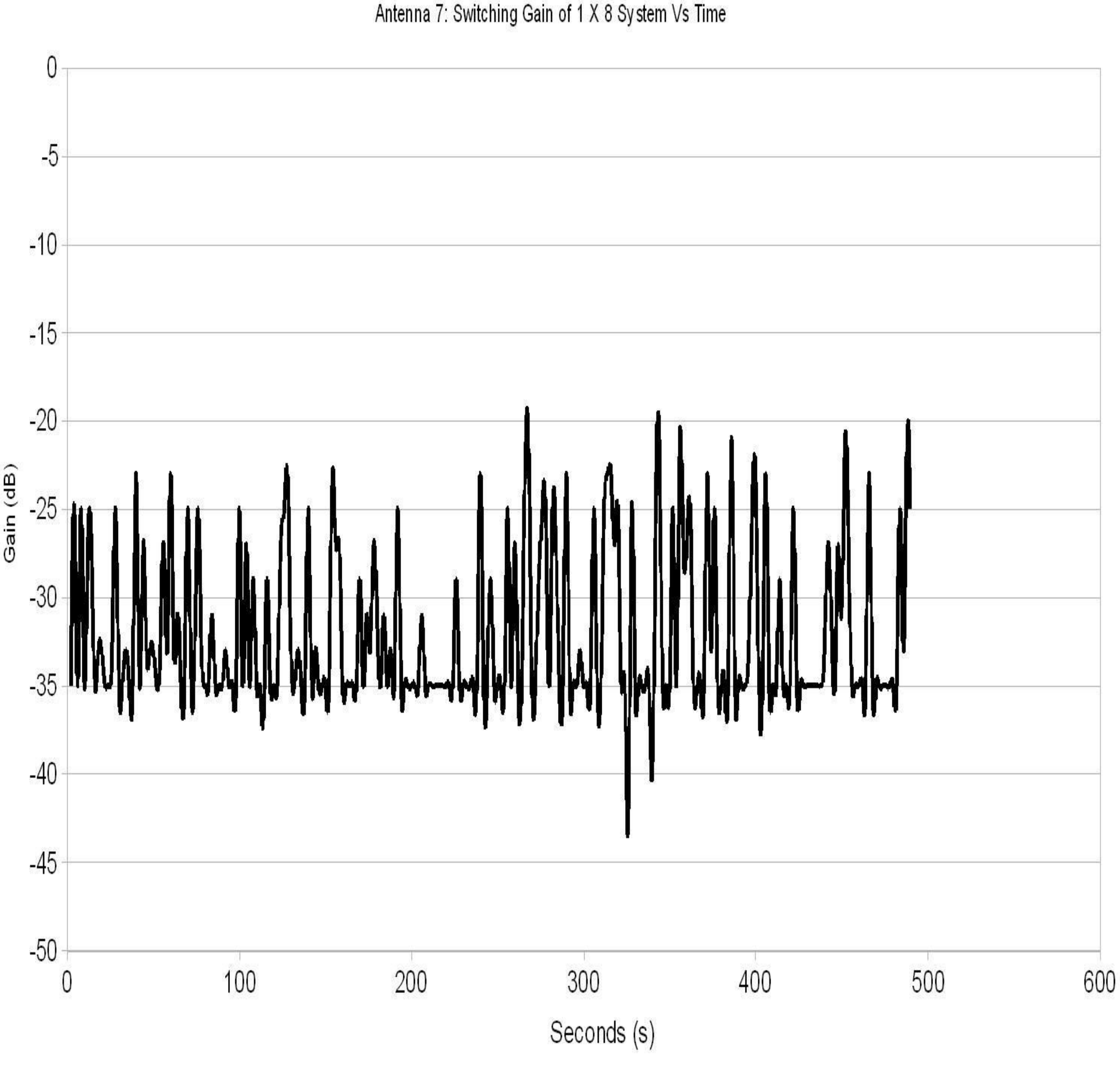

Figure 4.7: Antenna 7 Switching Gain of 1 x 8 System Vs Time

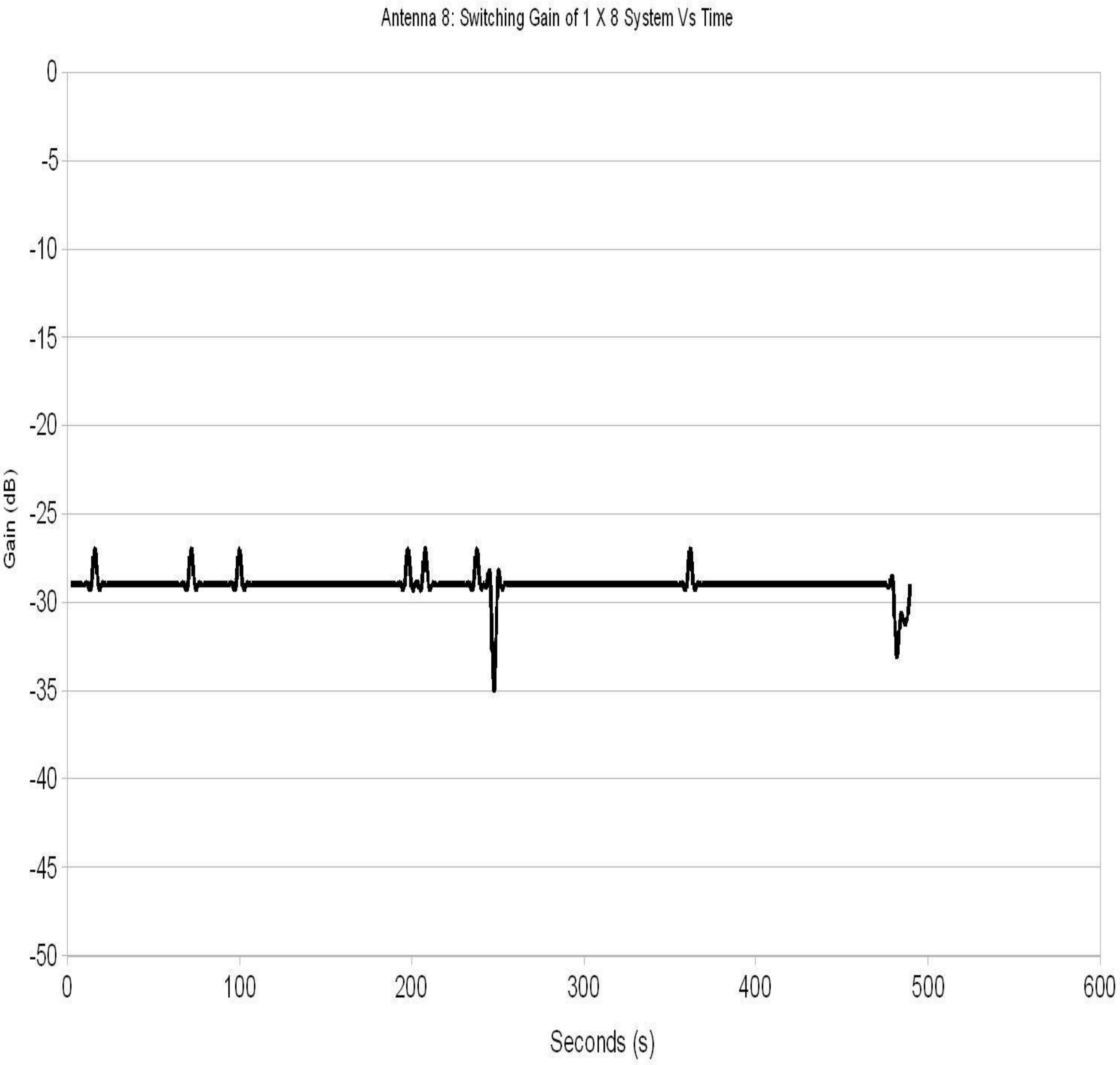

Figure 4.8: Antenna 8 Switching Gain of 1 x 8 System Vs Time

The individual antenna gains can be seen on the figures above, each plot shows the individual gain of the antenna. As we examine the plot further, we can point out some interesting observations that we can see. The fluctuation of individual gain are generally pretty small. The gain only changes a few dB lower or higher from the previous gain. This result are expected since the gain should not fluctuate too rapidly.

However there are two antennas that provide rapid fluctuation of individual gain. Antenna 2 and 7 shows the gain fluctuate at a faster rate. This result happens since the location of antenna are placed on the obstruction from the transmit antenna. The fluctuation happens since the signal was not received at a constant high gain, hence, there were drops in gains as we sent the signal.

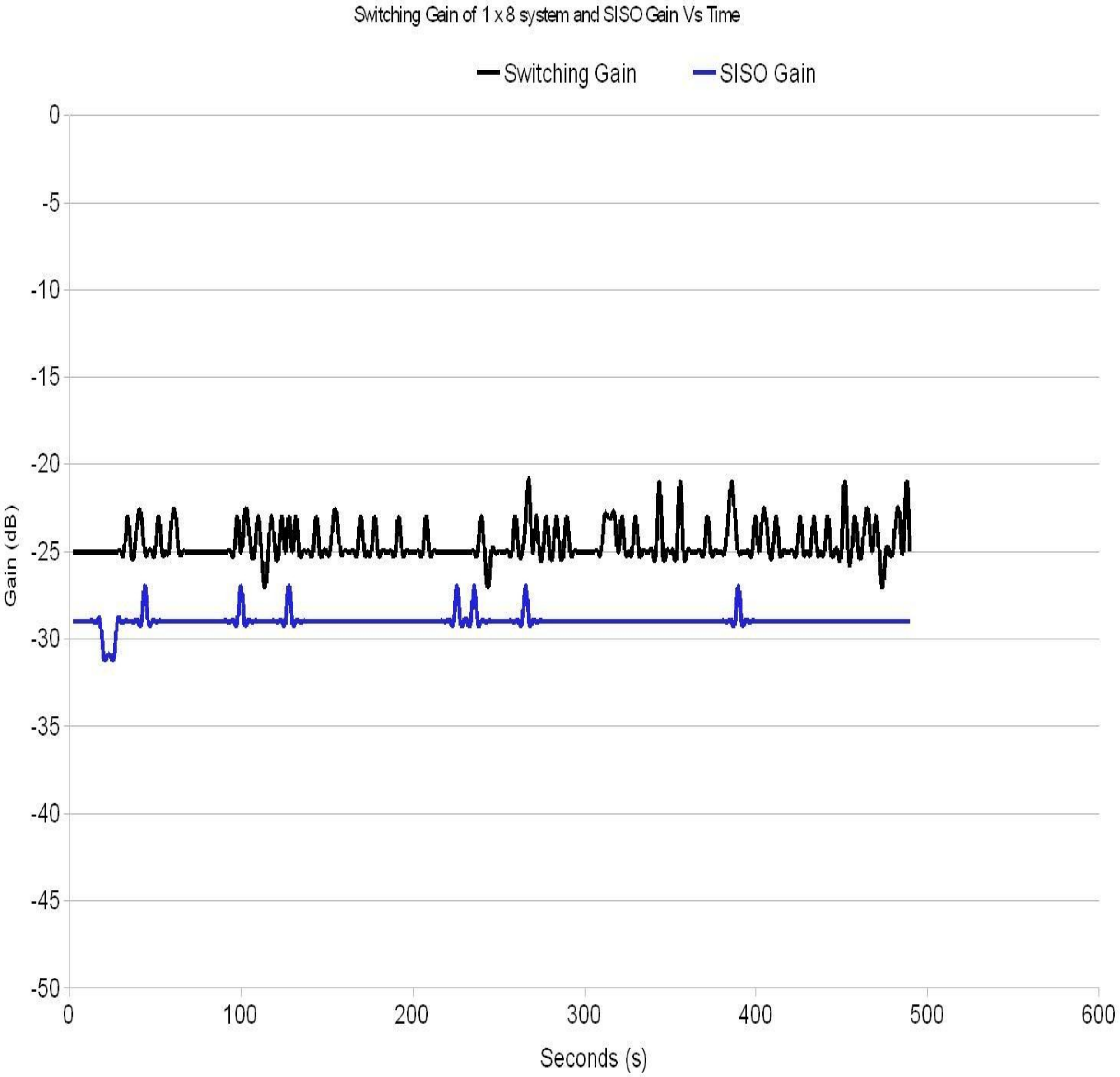

Figure 4.9: Switching Gain of 1 x 8 System and SISO Gain Vs Time

In Figure 4.9 above, we see the result of the switching gain as it provides the best available antenna gain. This means at a particular time, the system will scan through all the available antennas and choose the best available gain. Since the individual antenna gain do not fluctuate too often, the switching of antenna also will not occur too often. This is possible because the higher gain will most likely be provided by the same antenna most of the time (antenna A). However with the antenna switching, when the signal of that antenna (antenna A) dipped lower, gain of another antenna (antenna B) might be better and the system will then switch and used another antenna (antenna B) to get a better gain. Even though switching antenna might not happen to often, however the scan through all the antenna gains will still be performed periodically.

Also in Figure 4.9, we can compare the result of switching gain with Single Input Single Output (SISO) gain. As we can see the switching gain (the higher line) provide better overall result compared to SISO gain (lower line). We also finds that the mean value of switching gain is -24.46 dB while the mean value of SISO gain is -28.99 dB. This shows that switching gain provide on average 4.54 dB improvement than SISO gain.

4.2 Transmit Switching Diversity of 8 x 1 System

The next experiment we conducted was a transmit switching diversity where instead of having 8 receive antennas, as we had on section 4.1, we have 8 transmit antennas. This provide an 8 x 1 system with 8 transmit antennas and 1 receive antenna. The switching board is located on the transmit side, where we are sending the signal using the best available transmit antenna. The principles are the same as the transmit side will have the information to choose the best antenna out of 8 available antennas. The decisions of choosing antenna is determined by the receive gain we get on the receive side. The receive gain is the gain corresponding to using each transmit antenna. The scan is performed and the best available antenna can then be determined. Therefore there is information being sent from the receive side to the transmit side to help decide the best transmit antenna, this information is performed by a computer that is connected to both the receive and transmit side.

On Figure 4.10 below, we see the result of switching gain in an 8 x 1 system and its comparison to SISO gain. The SISO gain (lower line) shown at a similar mean value as the previous experiment. In this experiment, we obtain a mean value of -28.73 dB. While the result of the switching gain show a mean value of -23.64 dB. This results does not differ much from an 1 x 8 system as the switching gain provide an improvement of 5.09 dB on average.

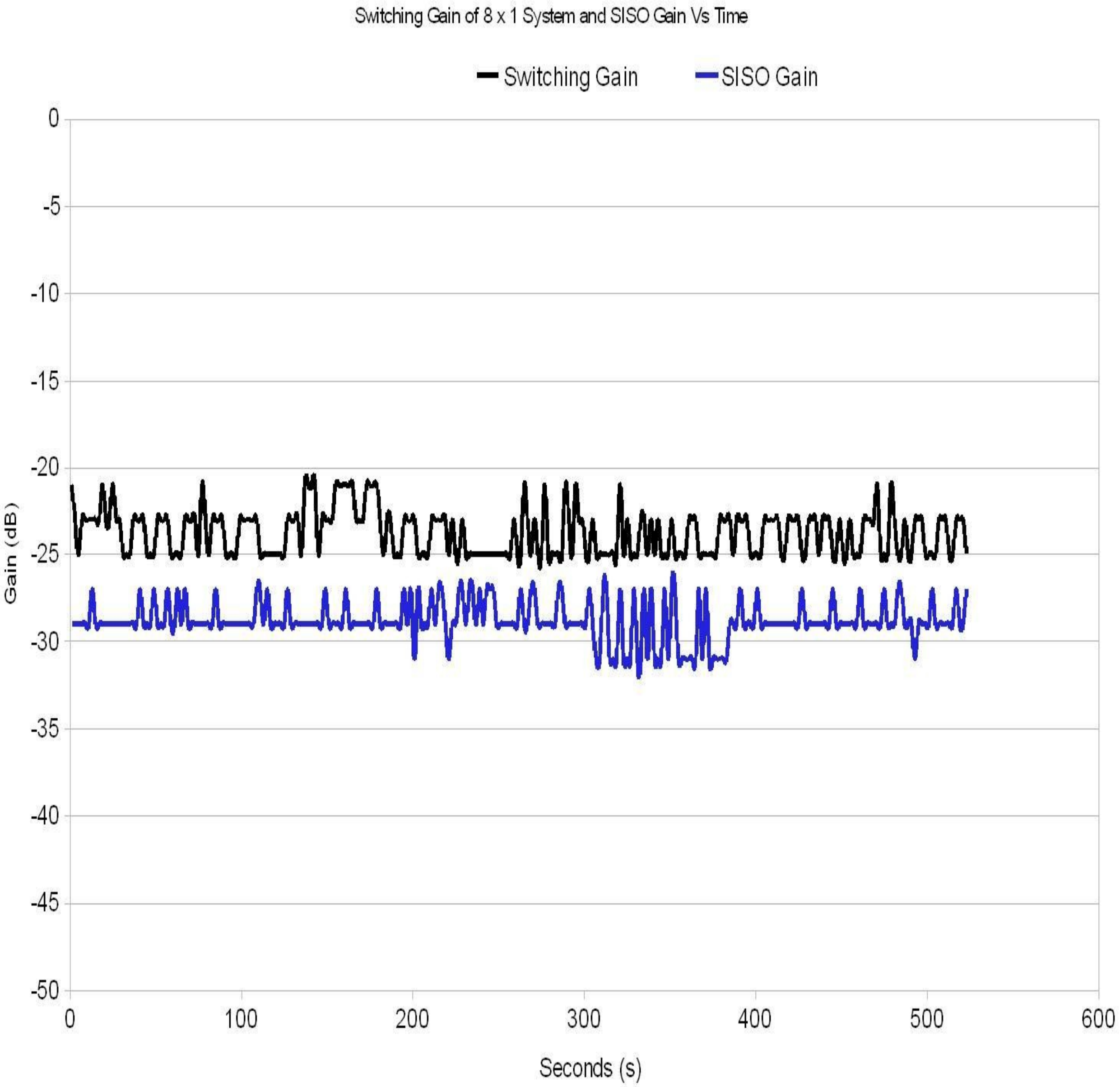

Figure 4.10: Antenna 1 Switching Gain of 1 x 8 System Vs Time

We can see that both transmit and receive side switching will provide a significant improvement. The improvements shown are at similar value of more than 4.5 dB improvement. There are both 8 possible antenna pairing in both transmit and receive system, hence we are choosing the best out of the eight pairing. The probability of having a low gain on all 8 pairing is small, therefore we can maintain higher gain by using the switching gain. This experiment show that we can use the antenna switching on both the transmit or receive side as both will provide similar improvement.

4.3 Switching Diversity with Line of Sight

This experiment will show the switching gain diversity with Line of Sight (LOS). The setup is the same as section 4.1. There are 8 receive antennas and 1 transmit antenna. This experiment is set with a clear line of sight from transmit antenna to the receive antennas. This is basically another try of 1 x 8 setup with a clear line of sight. We will see what improvement we can get by using line of sight on this setting and whether the individual antenna gains can provide a high overall switching gain in the end.

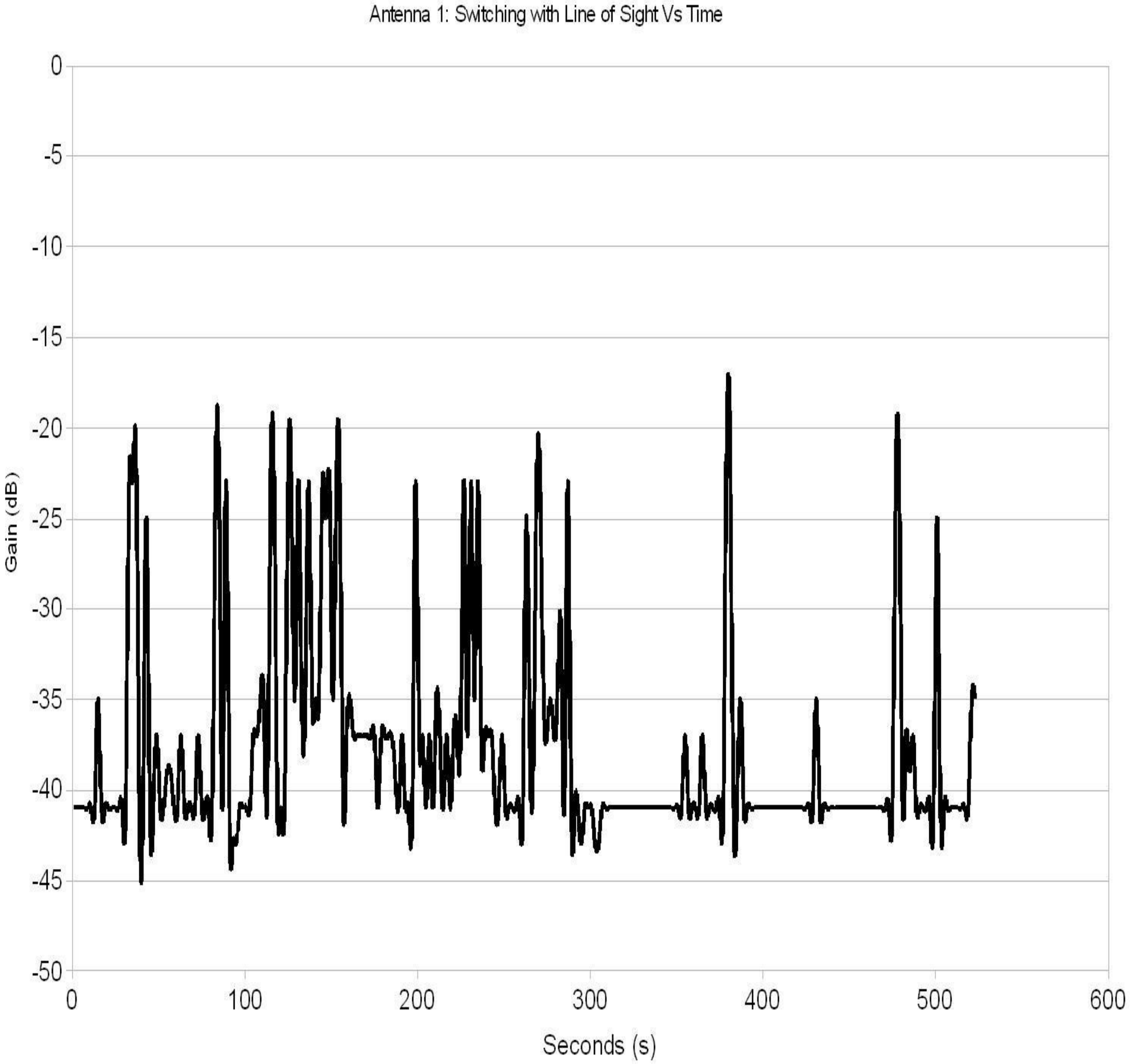

Figure 4.11: Antenna 1 Switching Gain with Line of Sight Vs Time

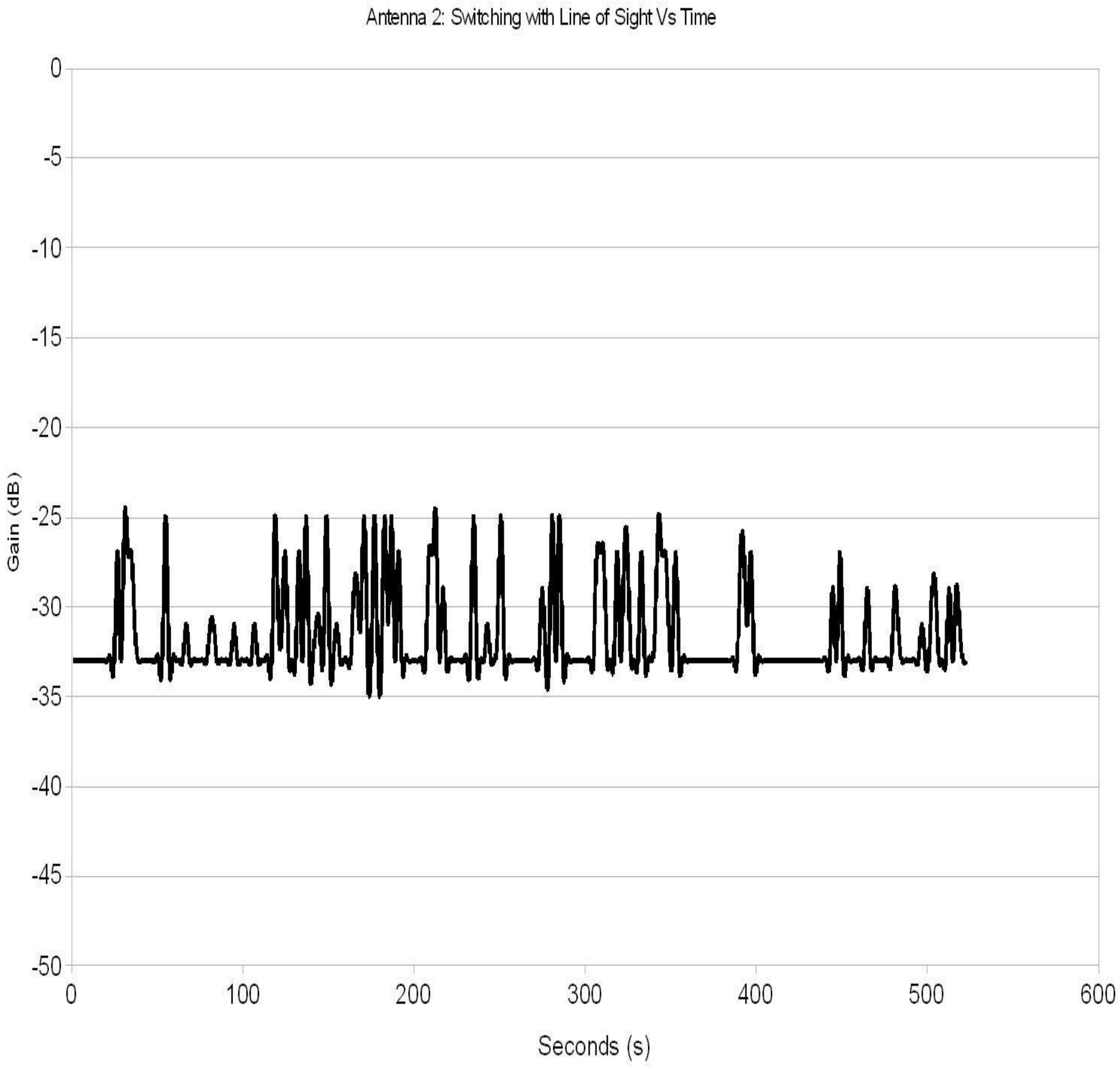

Figure 4.12: Antenna 2 Switching Gain with Line of Sight Vs Time

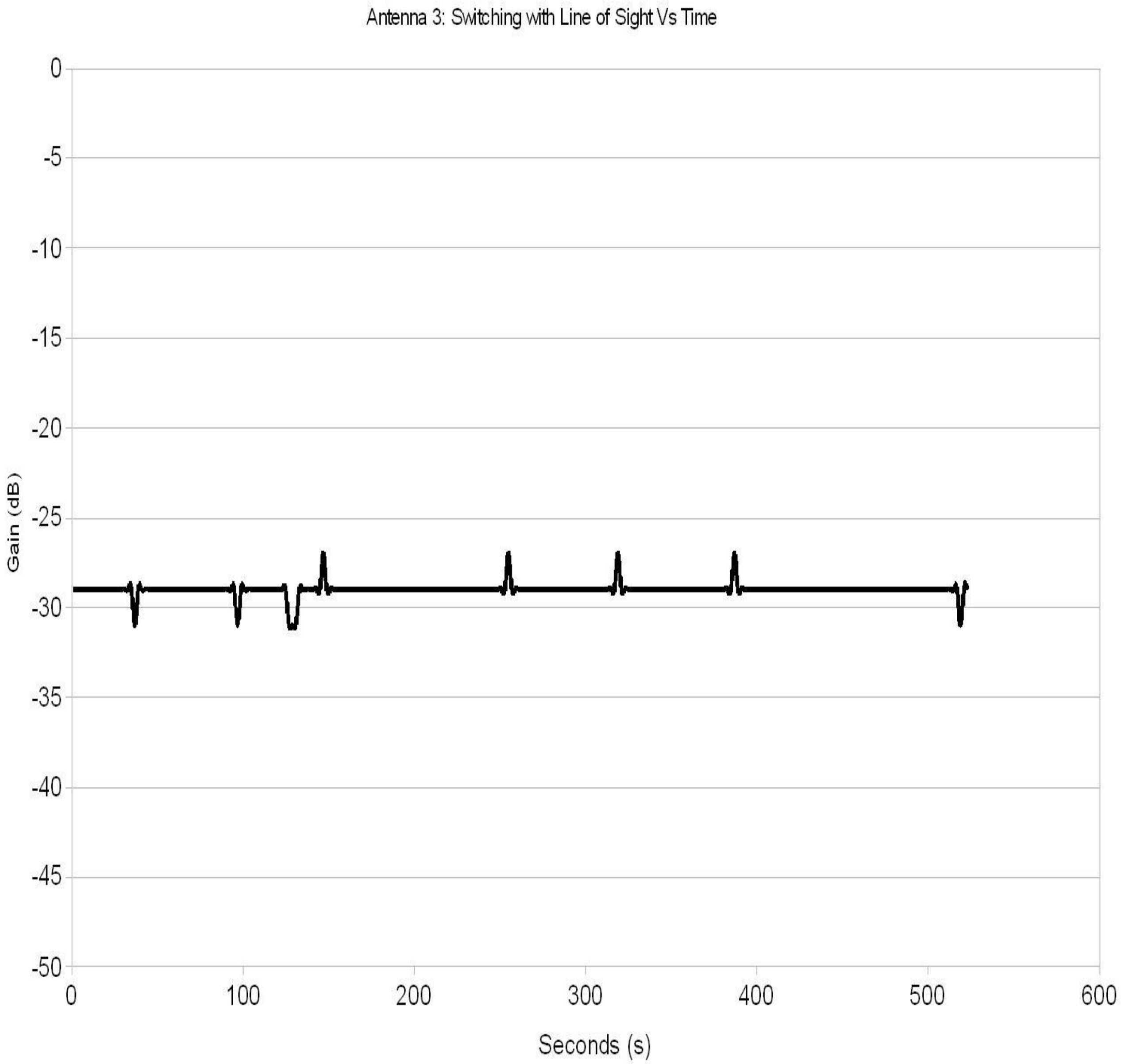

Figure 4.13: Antenna 3 Switching Gain with Line of Sight Vs Time

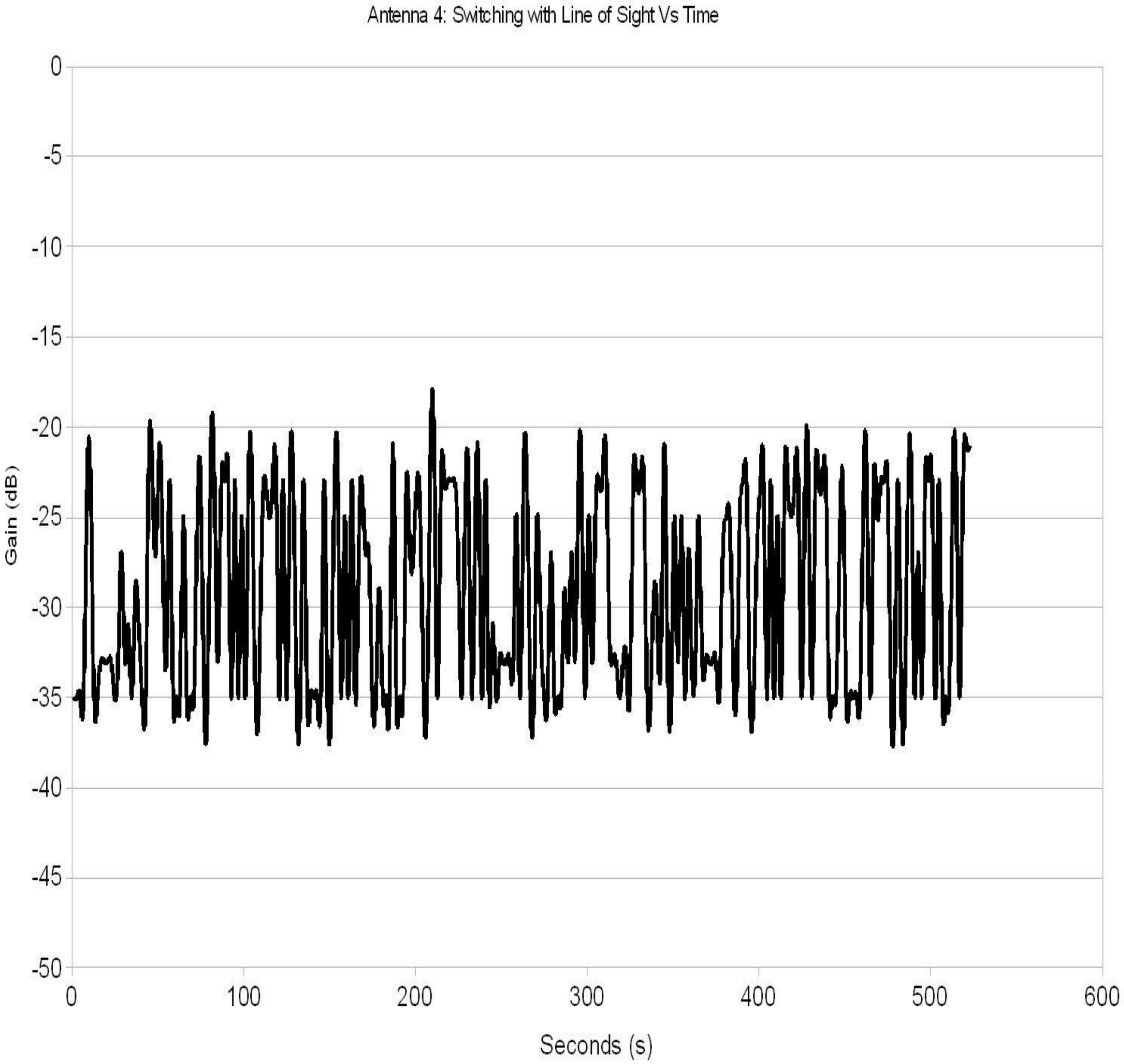

Figure 4.14: Antenna 4 Switching Gain with Line of Sight Vs Time

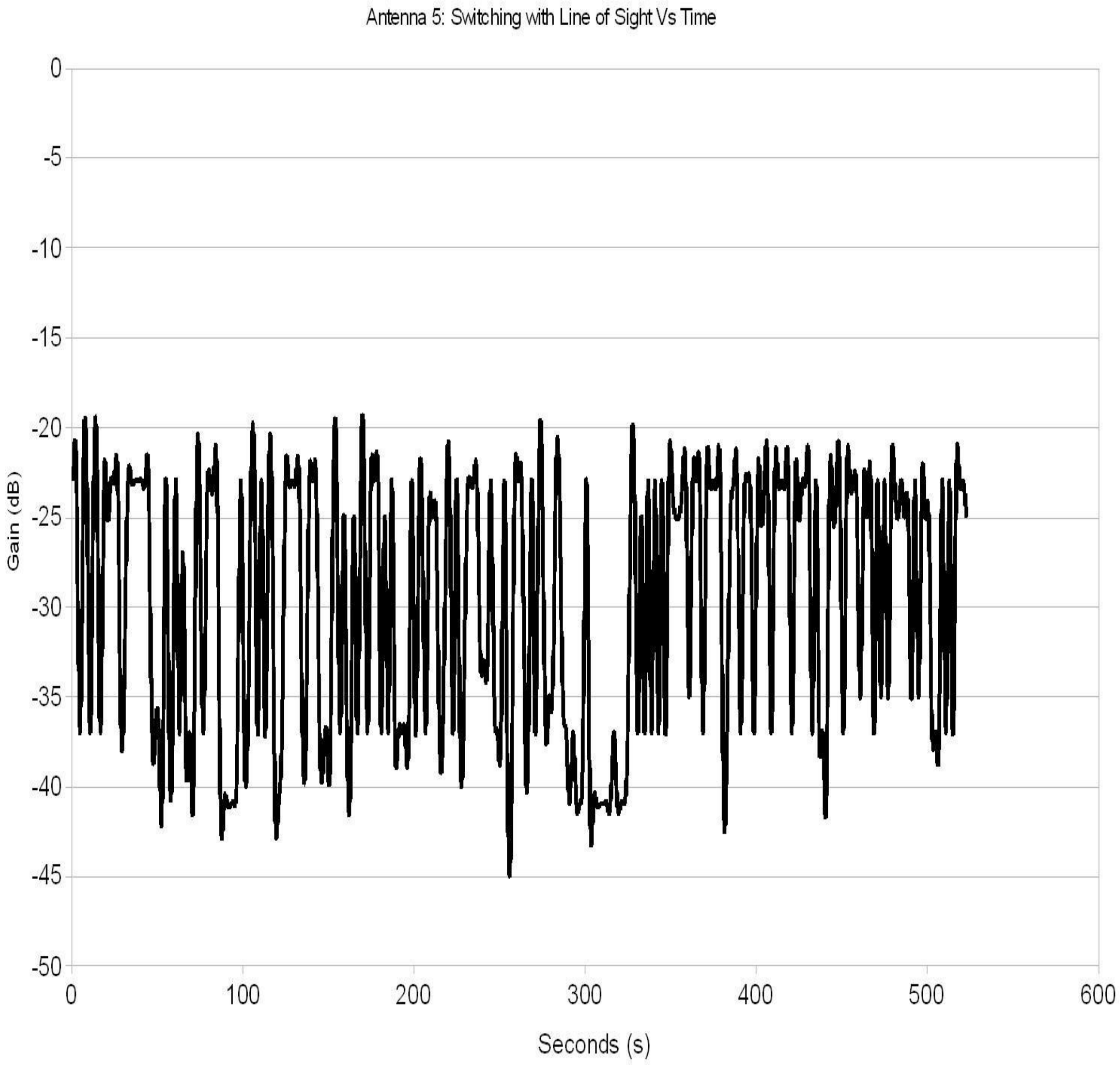

Figure 4.15: Antenna 5 Switching Gain with Line of Sight Vs Time

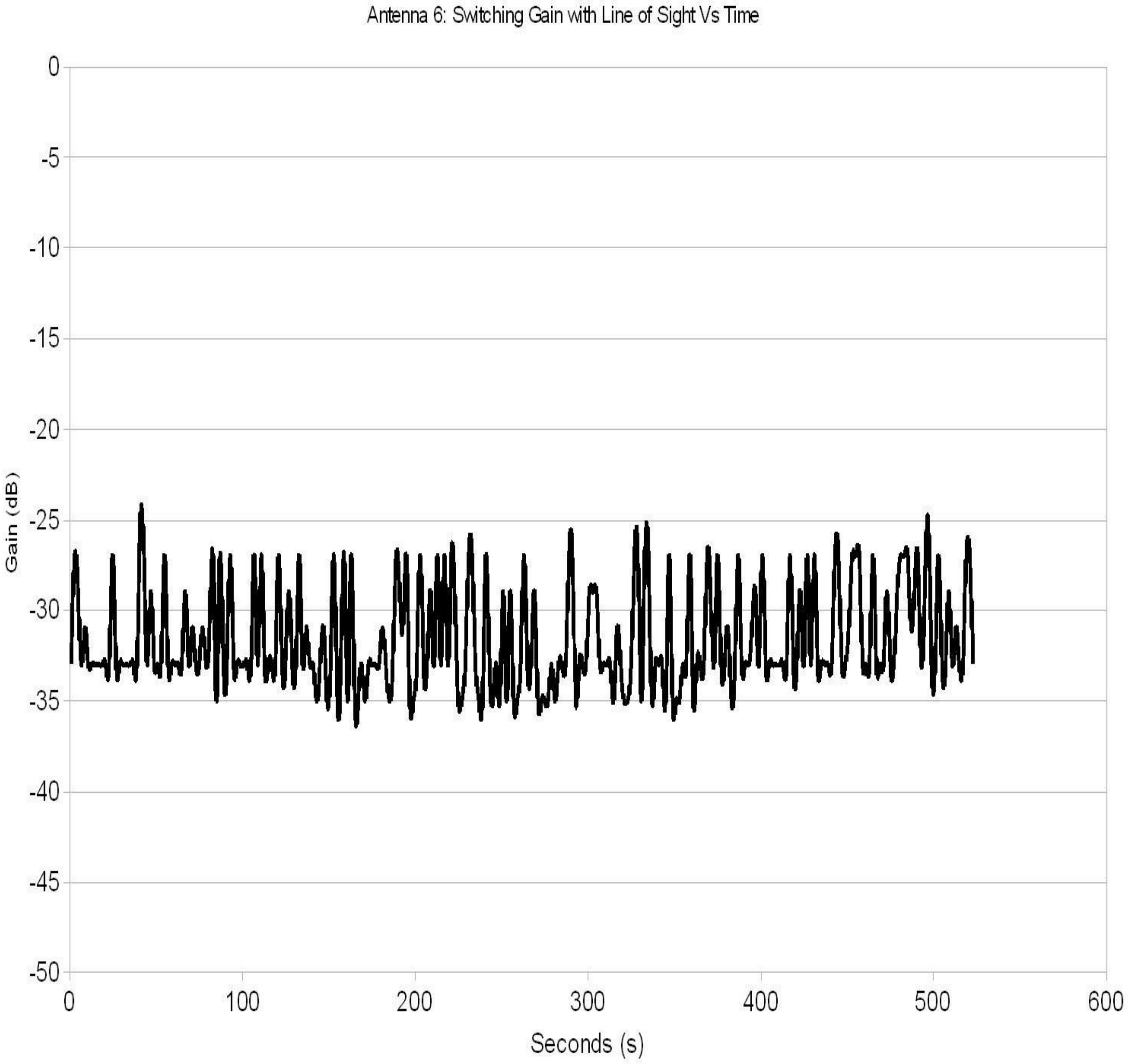

Figure 4.16: Antenna 6 Switching Gain with Line of Sight Vs Time

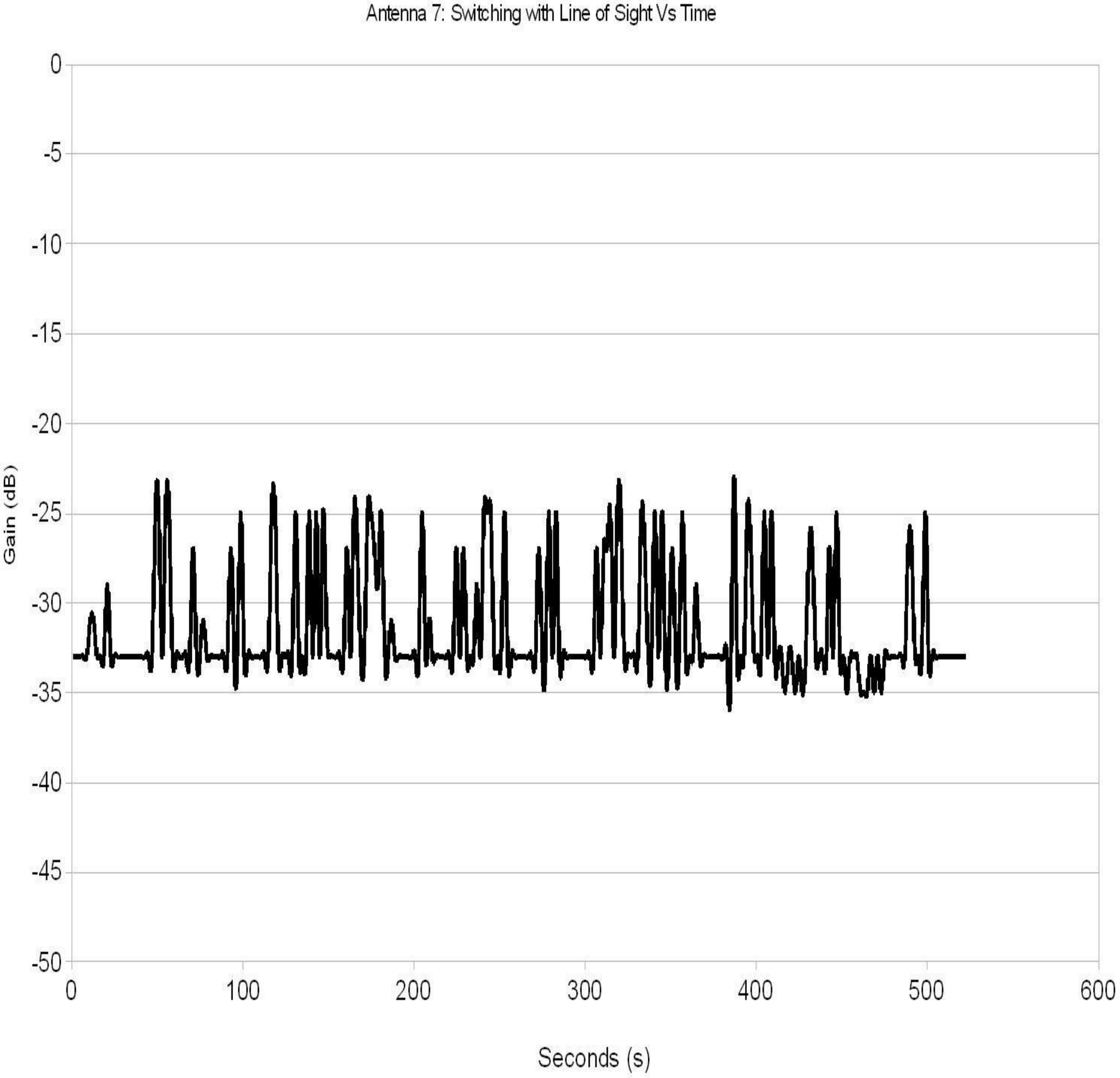

Figure 4.17: Antenna 7 Switching Gain with Line of Sight Vs Time

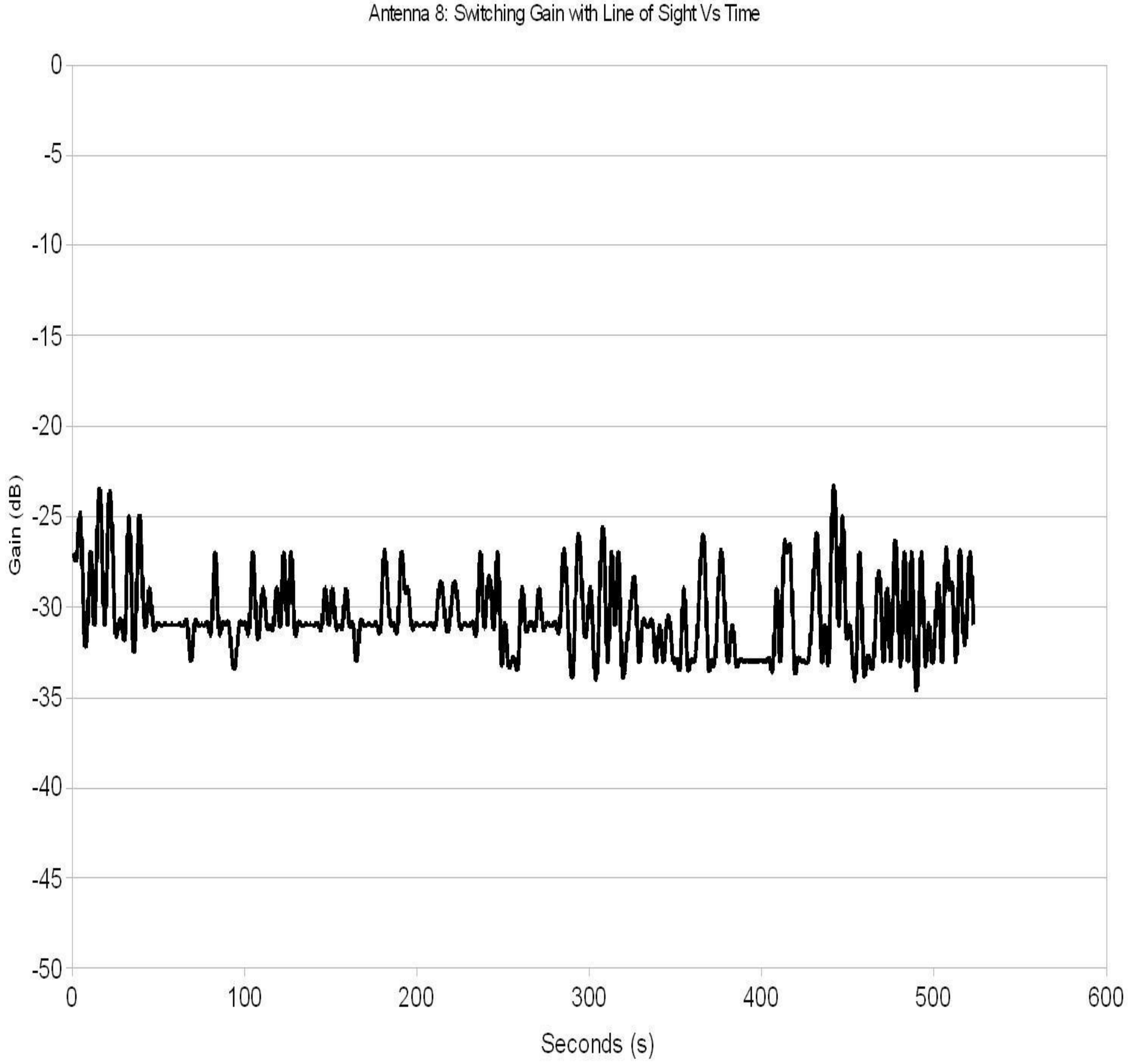

Figure 4.18: Antenna 8 Switching Gain with Line of Sight Vs Time

The individual gain shown above changes more rapidly compare to the individual gain in section 4.1. This happen due to the environments where the test is performed. The rapid changes in the individual antennas however should not make the switching gain to suffer since there are eight antennas to choose and the probability of all antennas in a low gain is still pretty low. Furthermore, the individual gain still able to reach a gain of -24 dB or higher, the problem that happens is that each individual antenna can not maintain a high gain at a longer time and drop for the next time period. As we see each individual antenna gain, there are 5 antennas in particular that can contribute in maintaining the overall switching gain to be high. Antenna number 1, 2, 4, 5 and 7 have reach a high gain, with antenna switching we should be able to use a combination of these antenna to maintain a high gain in the overall switching gain.

In Figure 4.19 below, we show the result of switching gain with line of sight compared to SISO gain. As we can expect by now, the SISO gain (lower line) has a mean value of -28.99 dB. The mean value of the switching gain (higher line) with line of sight is calculated to be -23.7 dB. This show an improvement of 5.29 dB on average. These results does not changes much from the result we gathered on section 4.1. Even though each individual gain changes so rapidly, however by implementing antenna switching we are able to maintain the high gain value and substitute the drop in gain with another pairing of antenna.

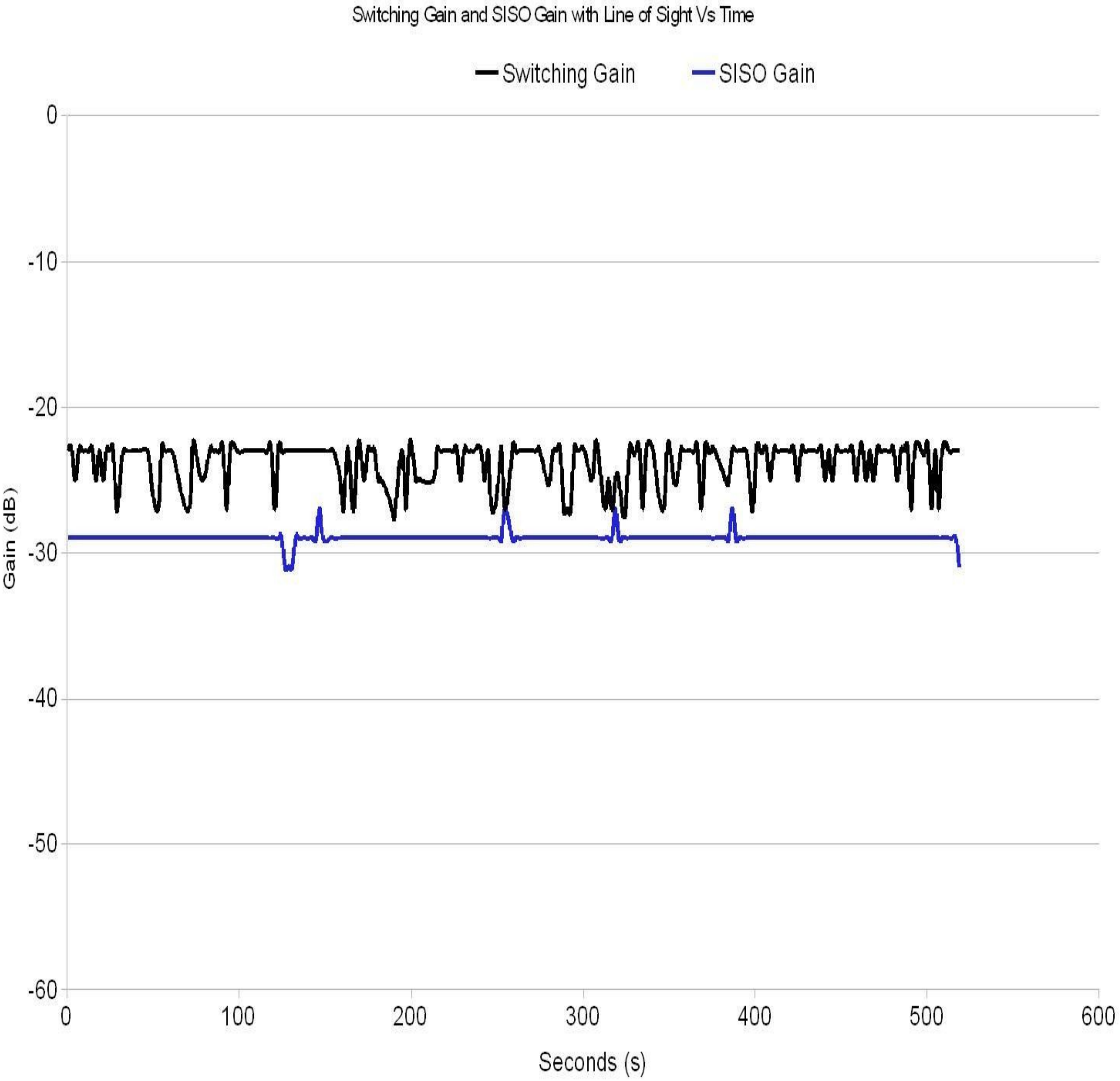

Figure 4.19: Switching Gain and SISO Gain with Line of Sight Vs Time

4.4 Switching Diversity with No Line of Sight

In this section, we will discuss the improvements of implementing antenna switching diversity with no line of sight in particular to be compared with SISO setup. The setup and location of antennas on the experiment are identical to section 4.3. We are still using the same 1 transmit antenna and 8 receive antennas configuration. However, in this experiment, we put an obstruction between the transmit and receive antennas. The obstruction is placed in order to create no line of sight between the transmit and receive antennas.

In the individual antenna gain plots shown below (Figure 4.20 to Figure 4.27) there are several interesting results that we found. Almost all of the antennas have lower gain value from previous experiment results. Antenna number 1, 2, 5 and 7 in particular have their individual gain dropped significantly. These result of individual gain are completely different from what we have found in section 4.3, where those antennas can provide most of the best gains pairings. The gain value of these antennas are very low that they are at the same level as when these antennas do not receive any signal from the transmit antenna. All of these antennas have individual gain that is lower than -40 dB and mean gains that is lower than -42 dB. Antenna number 3 and 8 have a better level of individual gain than -40 dB, but still lower than the level we usually see for individual gain without obstruction. These antenna have mean gains that is lower than -32 dB.

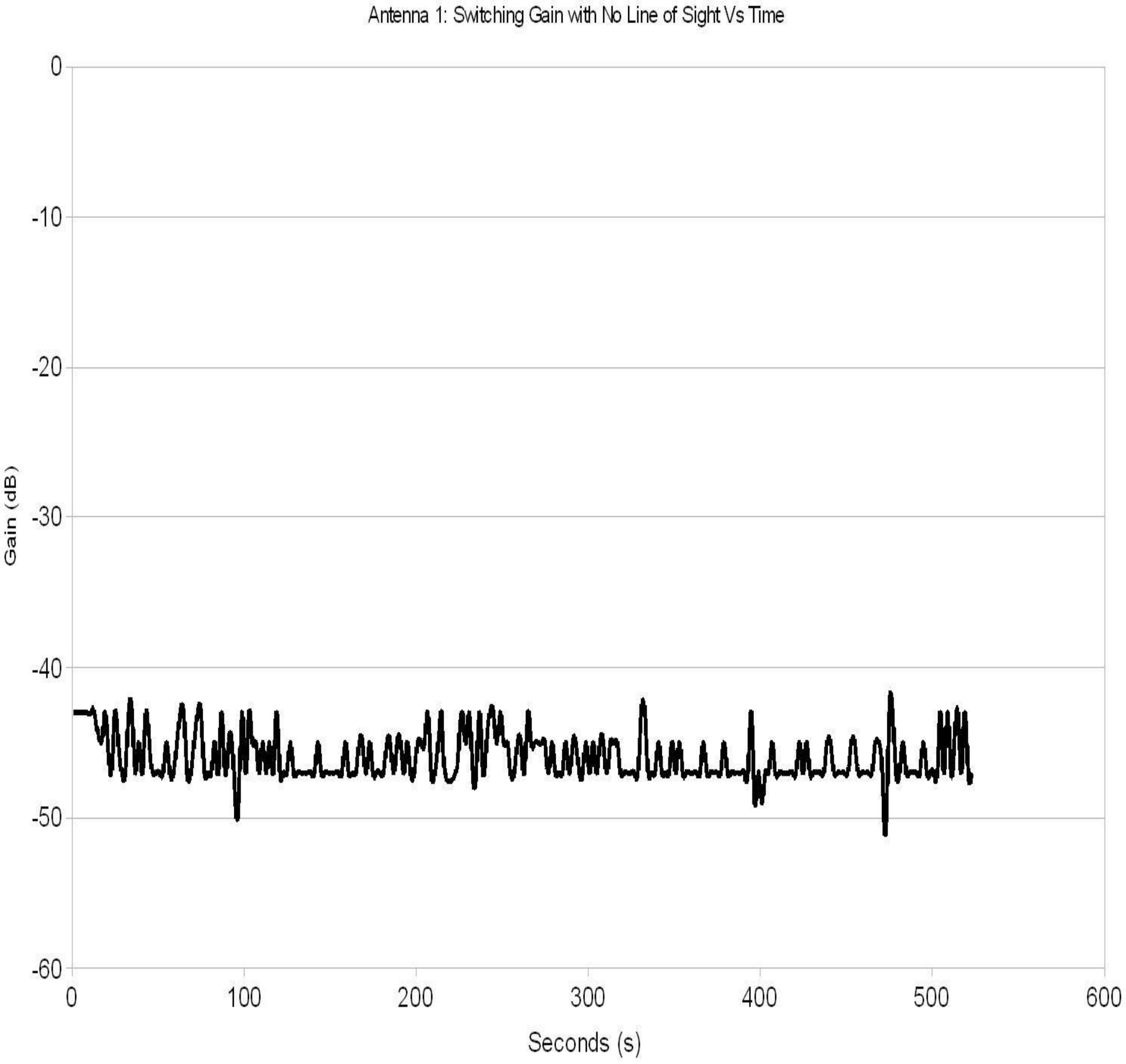

Figure 4.20: Antenna 1 Switching Gain with No Line of Sight Vs Time

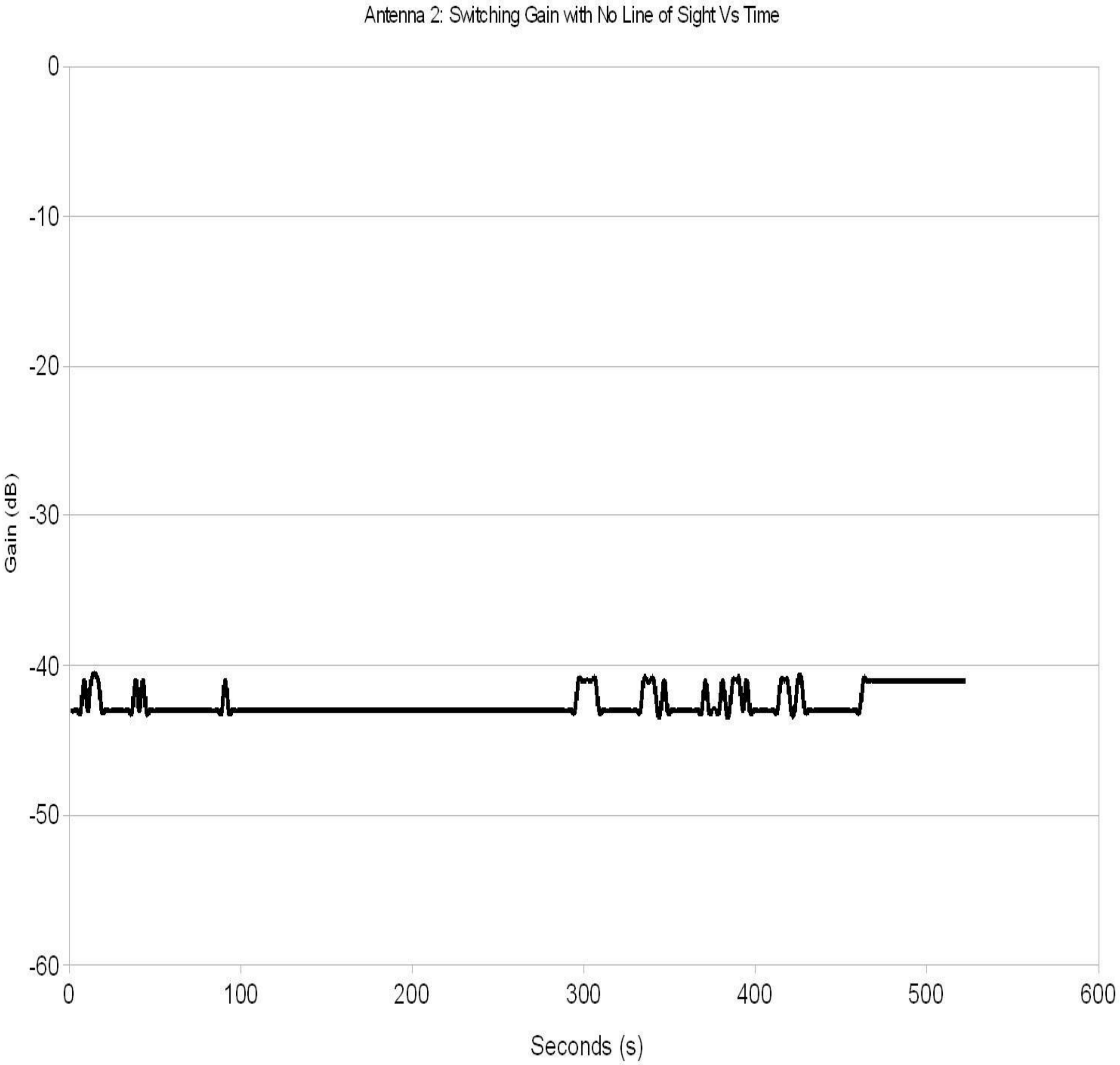

Figure 4.21: Antenna 2 Switching Gain with No Line of Sight Vs Time

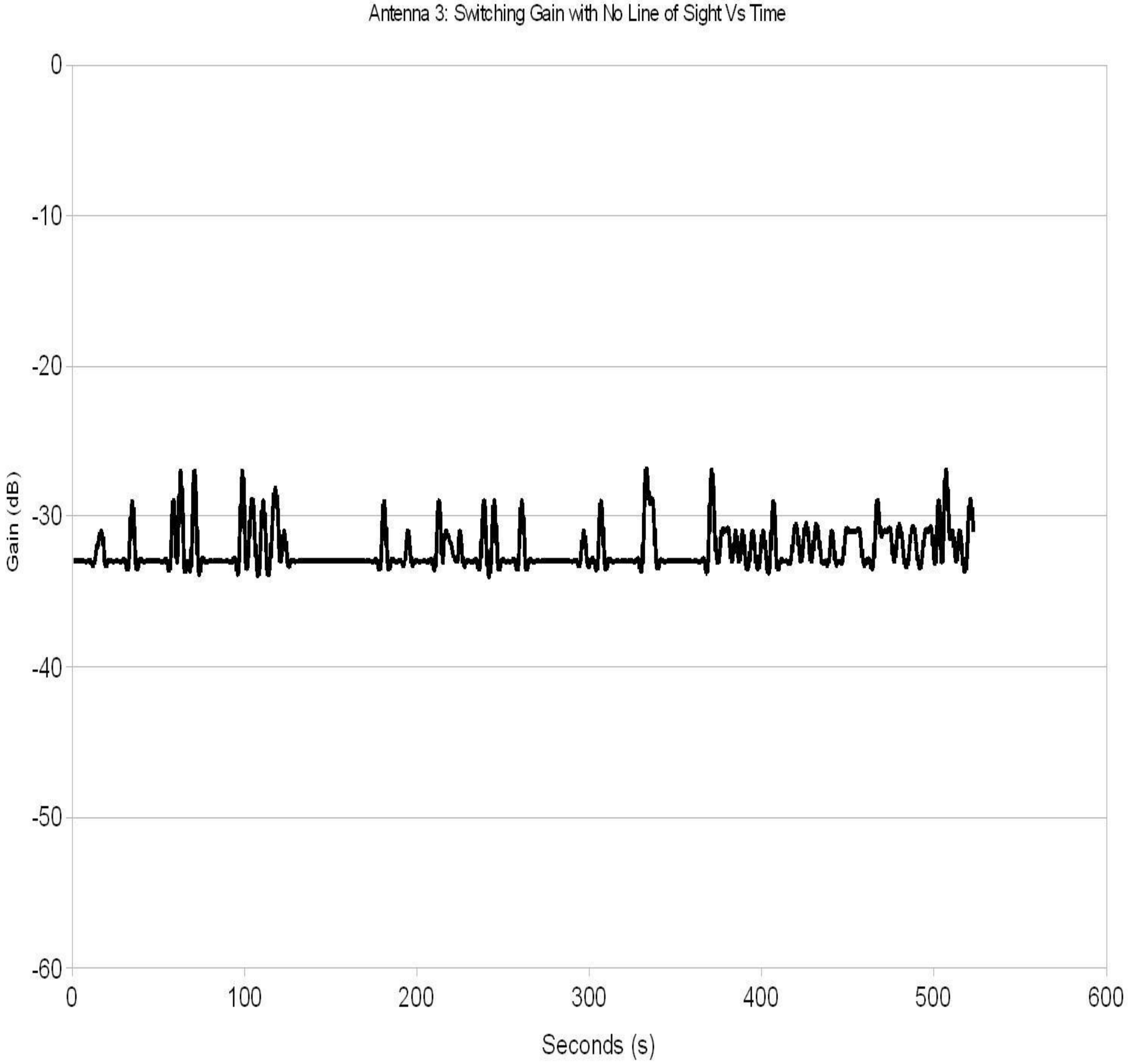

Figure 4.22: Antenna 3 Switching Gain with No Line of Sight Vs Time

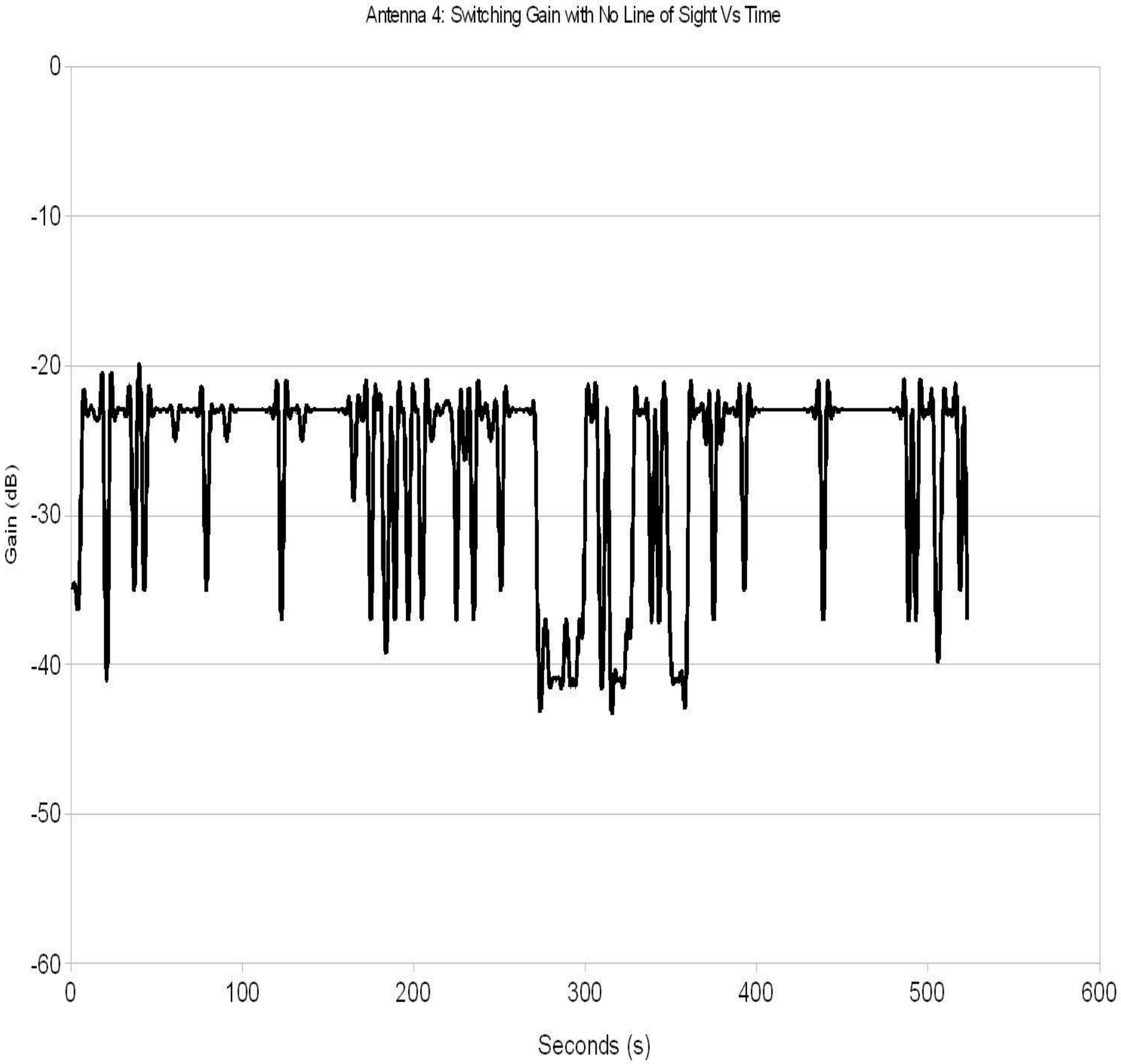

Figure 4.23: Antenna 4 Switching Gain with No Line of Sight Vs Time

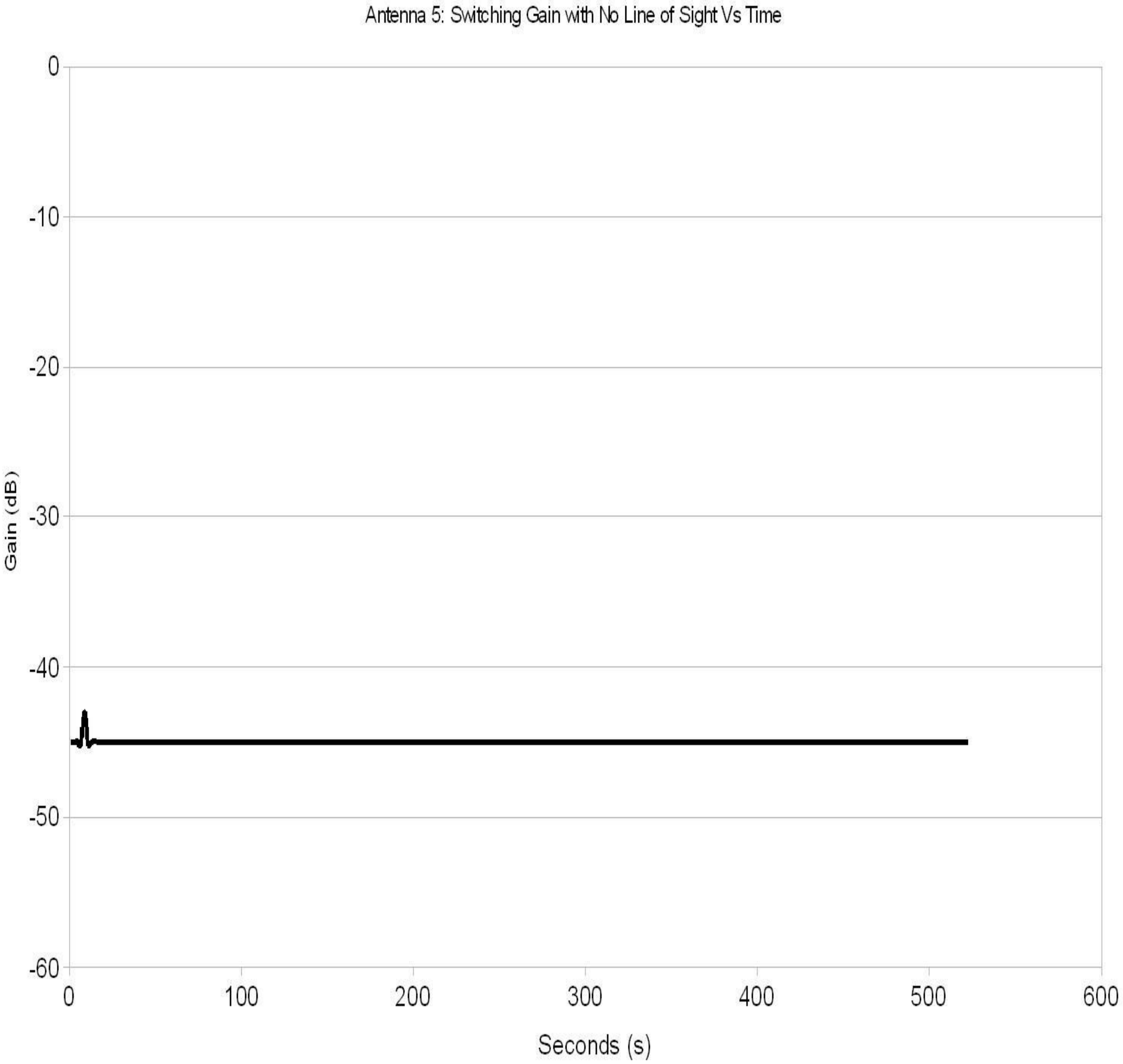

Figure 4.24: Antenna 5 Switching Gain with No Line of Sight Vs Time

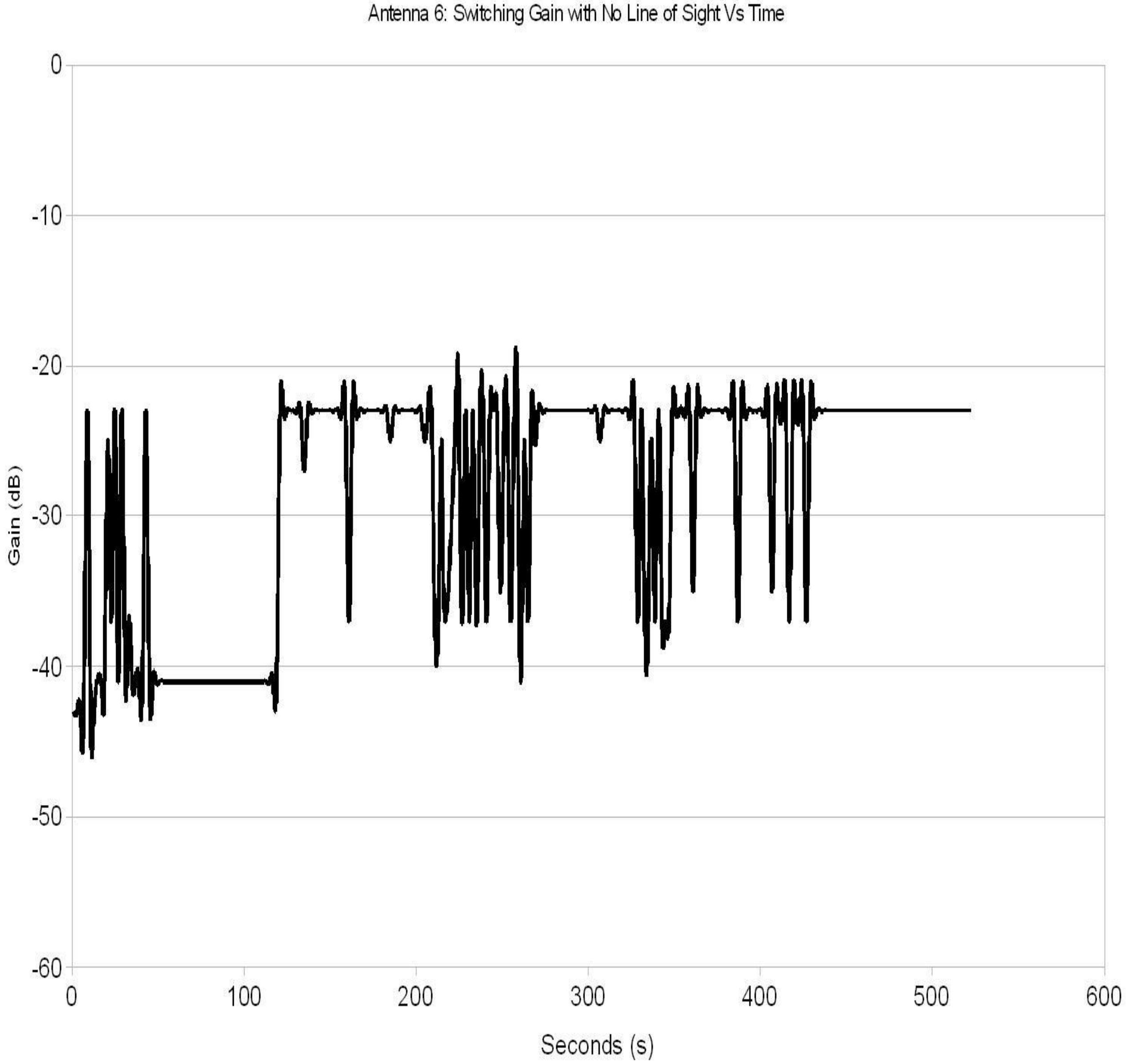

Figure 4.25: Antenna 6 Switching Gain with No Line of Sight Vs Time

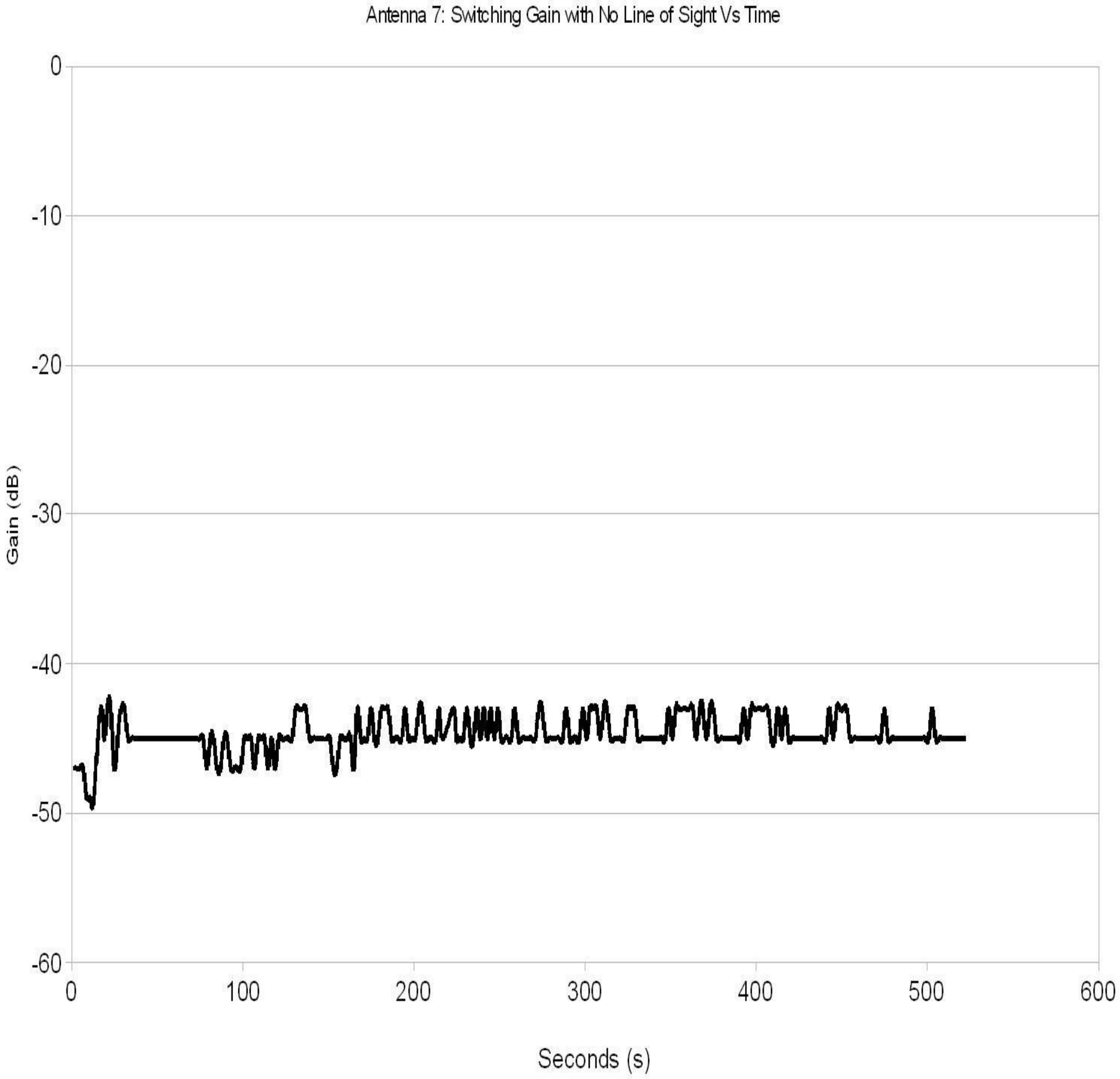

Figure 4.26: Antenna 7 Switching Gain with No Line of Sight Vs Time

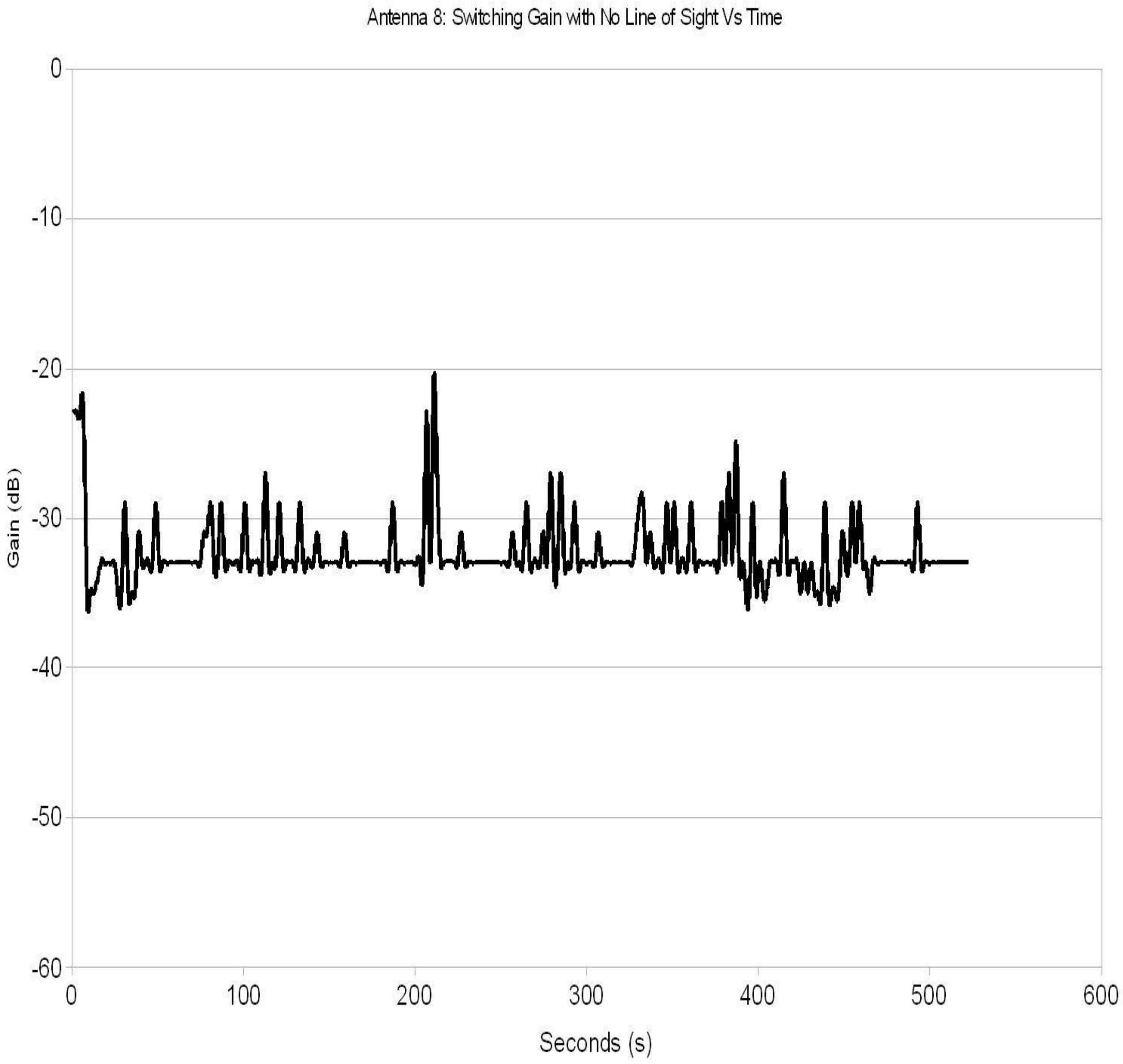

Figure 4.27: Antenna 8 Switching Gain with No Line of Sight Vs Time

The best individual gain that we get are from antenna number 4 and 6. These antennas did not contribute much on section 4.3 where there is line of sight. However without line of sight, these antennas become the best antennas available from the 8 antenna pairings. The individual gain themselves still have drops on certain time, however the antenna switching gain will be obtained from these antennas. The interesting observations we can see is that at the time where antenna 6 has a drop of gain for several seconds, antenna 4 can maintain the higher gain and vice versa. This will create an overall high gain when antenna switching is performed. Individually, antenna 4 have a mean gain of -24.77 dB, while antenna 6 have a mean gain of -25.55 dB.

In Figure 4.28 below, we can see the overall antenna switching gain compared to the SISO gain when there is no line of sight. The SISO gain (lower line) performance has dropped into a mean value of -32.11 dB. This value translate into a drop of at least 3 dB from the value when there is line of sight. As for the antenna switching gain result, we can see that the gain seems to be unaffected compared to value of antenna switching gain with line of sight. We achieve a mean of -23.08 dB for antenna switching gain which actually improve slightly from the previous experiments of antenna switching gain value.

This value is intriguing, especially since there are only two antennas that are available for switching as the rest of the antennas have lower value of gain. This result shows a significant improvements from SISO gain to antenna switching gain for experiment with no line of sight. The mean gain value difference is found to be 9.04 dB between SISO and antenna switching. The greater mean gain value difference create a greater advantage of implementing antenna switching for configuration with no line of sight.

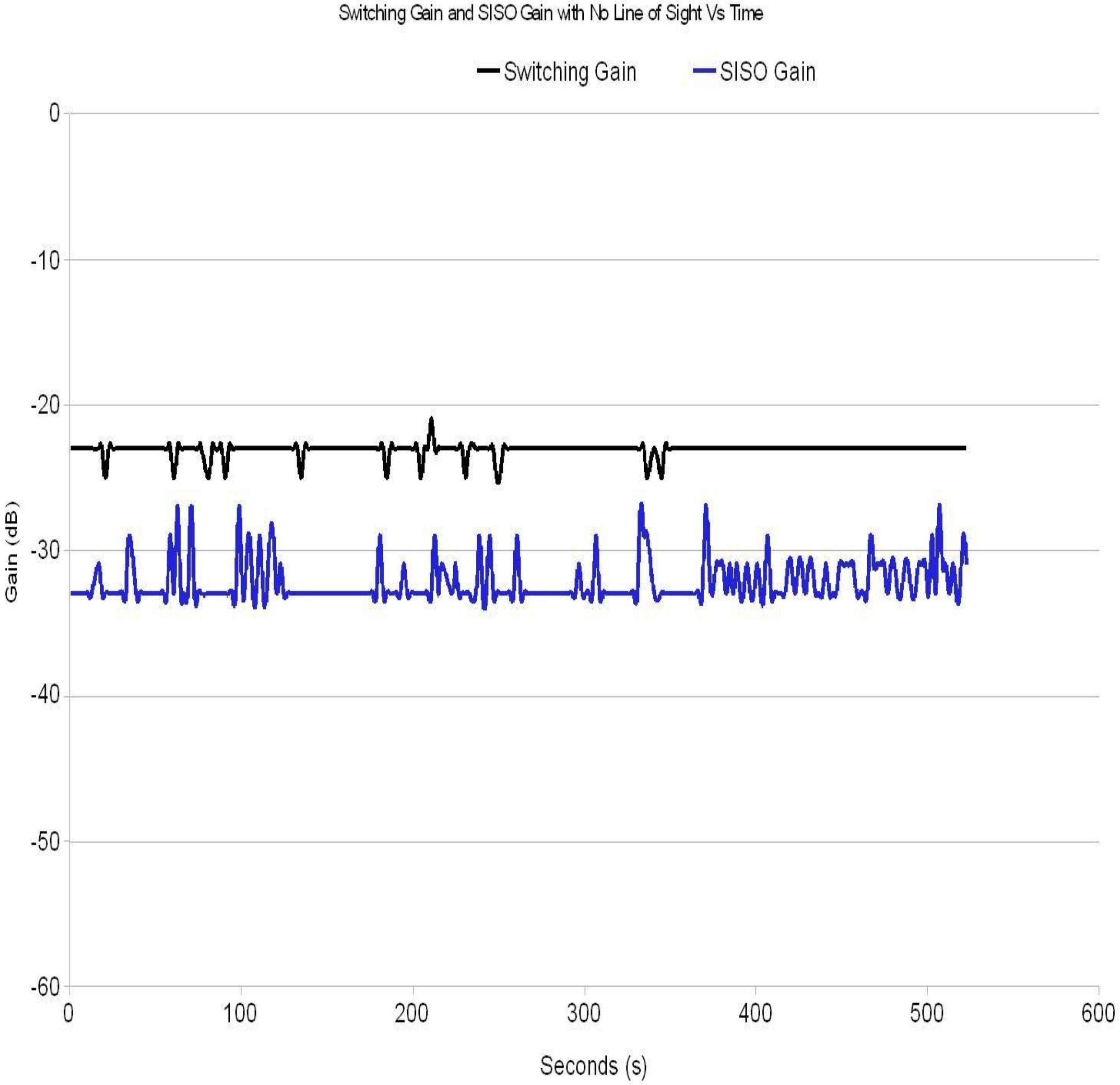

Figure 4.28: Switching Gain and SISO Gain with No Line of Sight Vs Time

4.5 Performance of Switching Diversity in Relation to Number of Antenna

In this section, we will discuss the effect that number of antennas have in the performance of antenna switching gain. We will see the changes in the overall gain as we increases the number of antenna used. We will start increasing number of receive antenna from one (SISO as we use one transmit antenna) until eight receive antenna.

In the individual plots as we see the on Figure 4.29 to Figure 4.36, the gain value does not differ too much specifically if we are comparing plots that only have one receive antenna difference. In other words, if we place two neighboring plots into one figure, there will be overlap in the gain value. This overlap means that the changes and improvements are only several dB difference in the mean gain measurements. There are more overlap when we are comparing higher number of antenna such as from eight to seven antennas than if we are comparing one to two antennas. This implies that the improvements at the higher number of antennas is smaller than at the lower number of antennas. Furthermore, if we are placing all eight gain values from the eight number of receive antennas into one figure, we will see much more overlap at the higher gain as this means that there are more gain at that higher gain (overlap of gain indicate that most of the gain value are at the same level). This also means that we can achieve a high level of gain without using all eight receive antennas, as lower number of antenna might suffice.

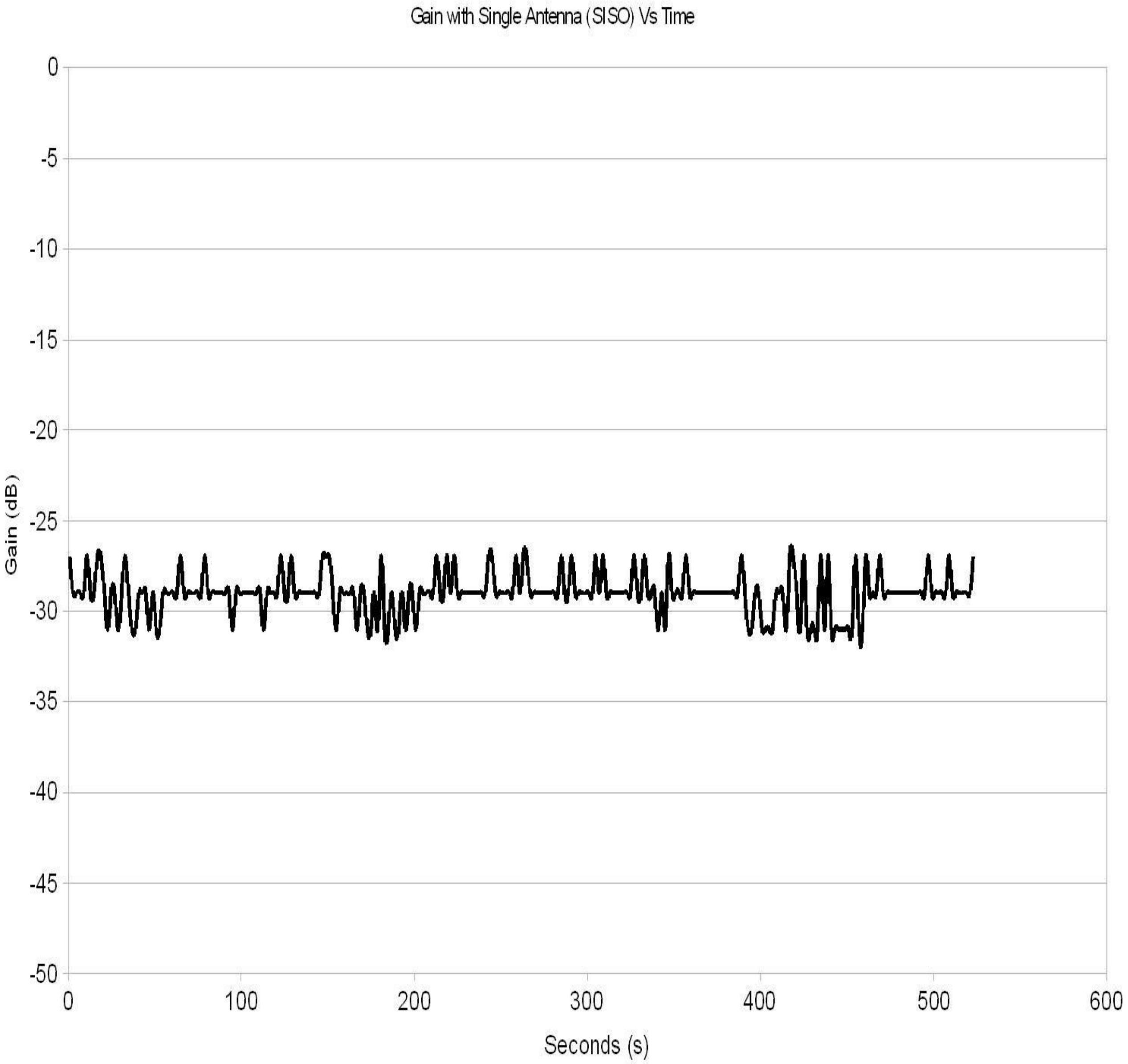

Figure 4.29: Gain with Single Antenna (SISO) Vs Time

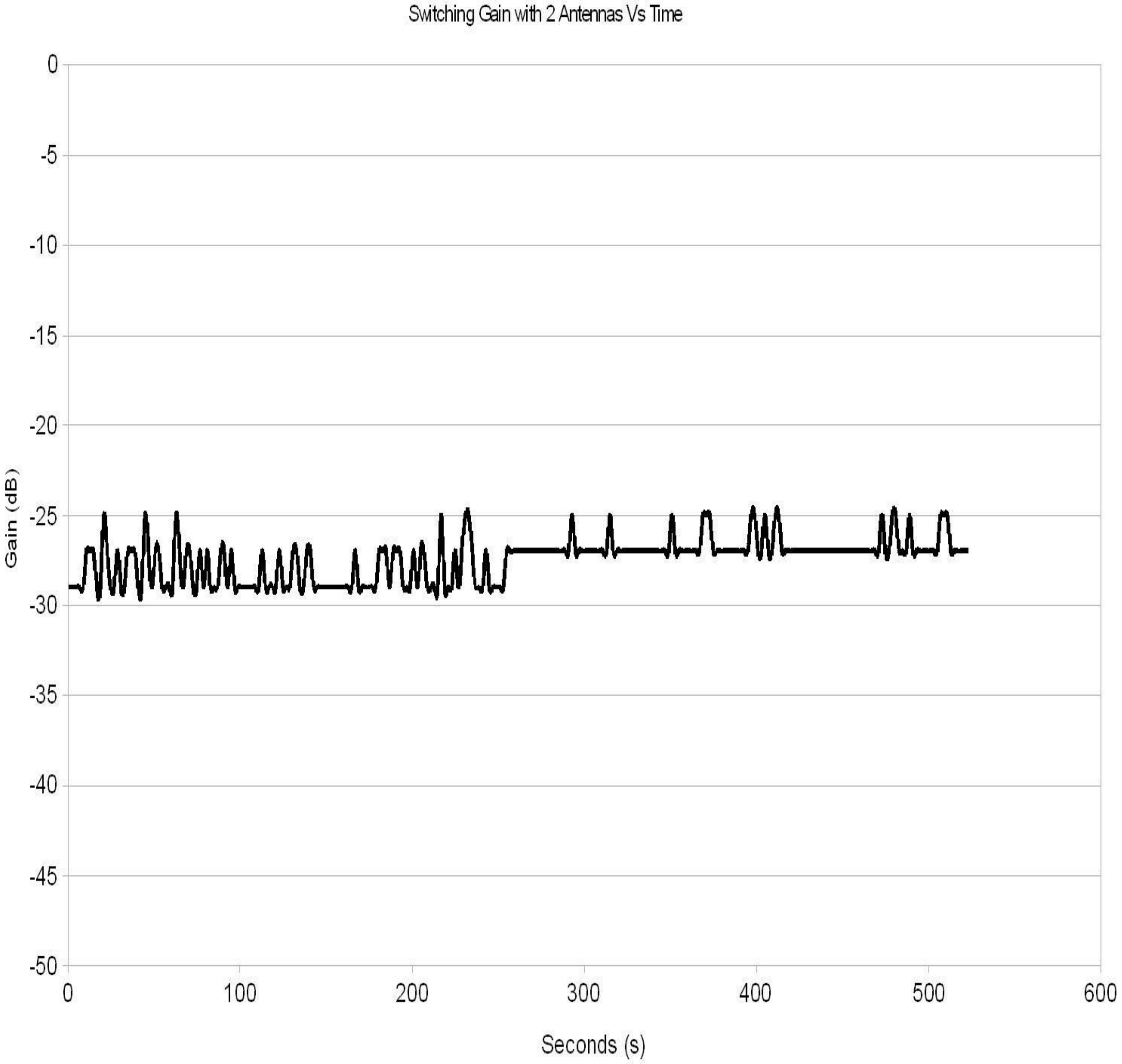

Figure 4.30: Switching Gain with 2 antennas Vs Time

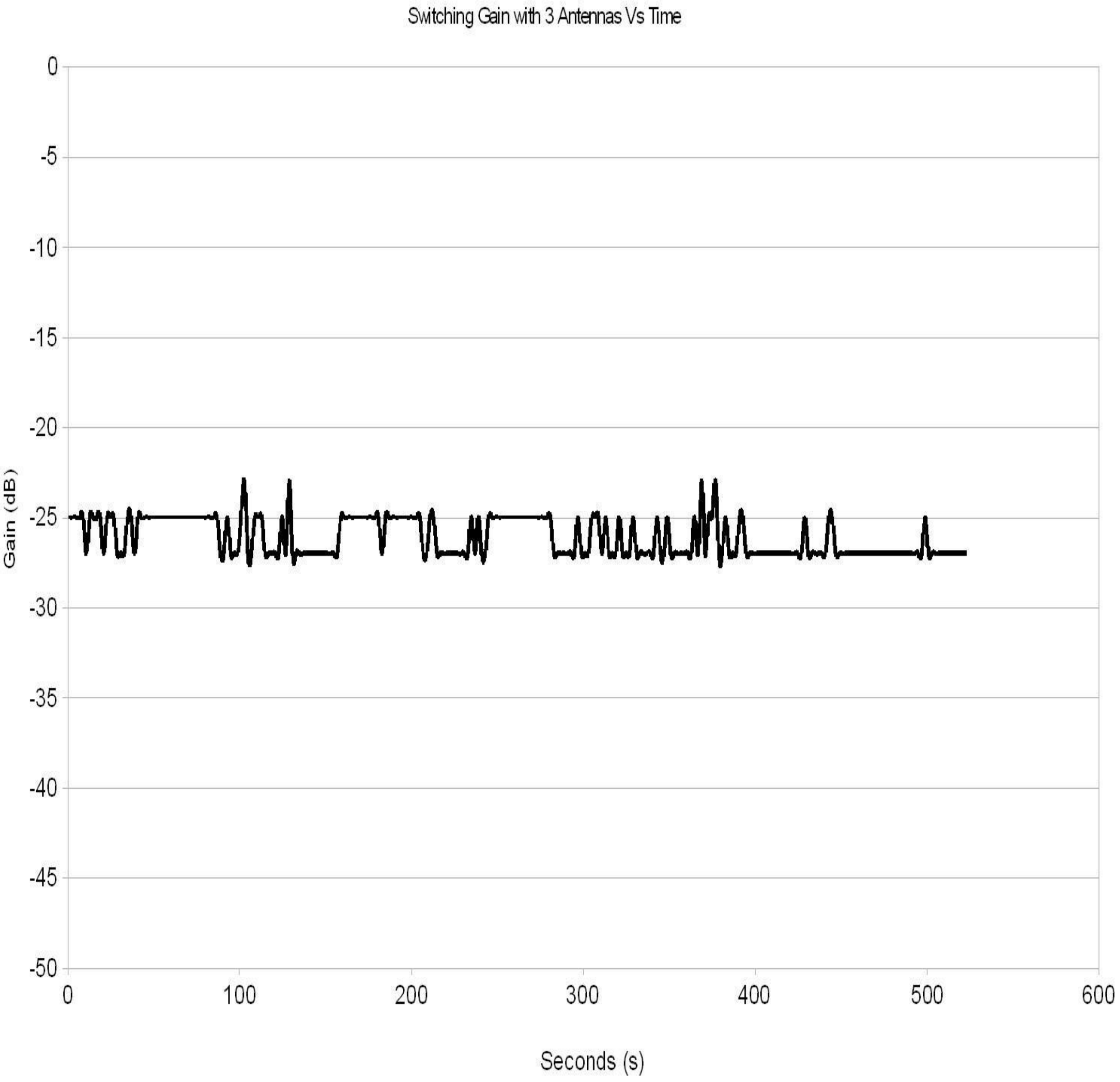

Figure 4.31: Switching Gain with 3 antennas Vs Time

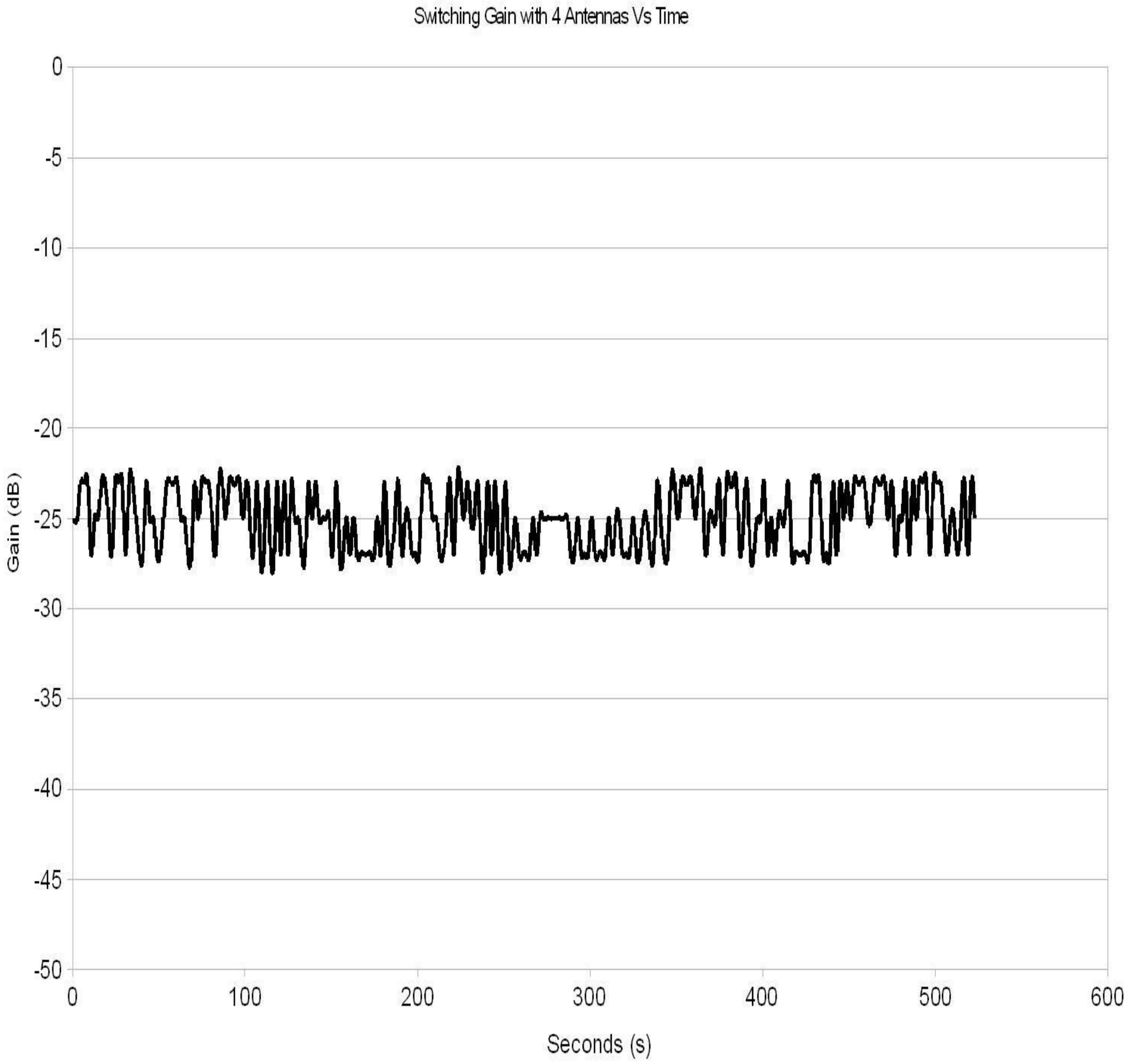

Figure 4.32: Switching Gain with 4 antennas Vs Time

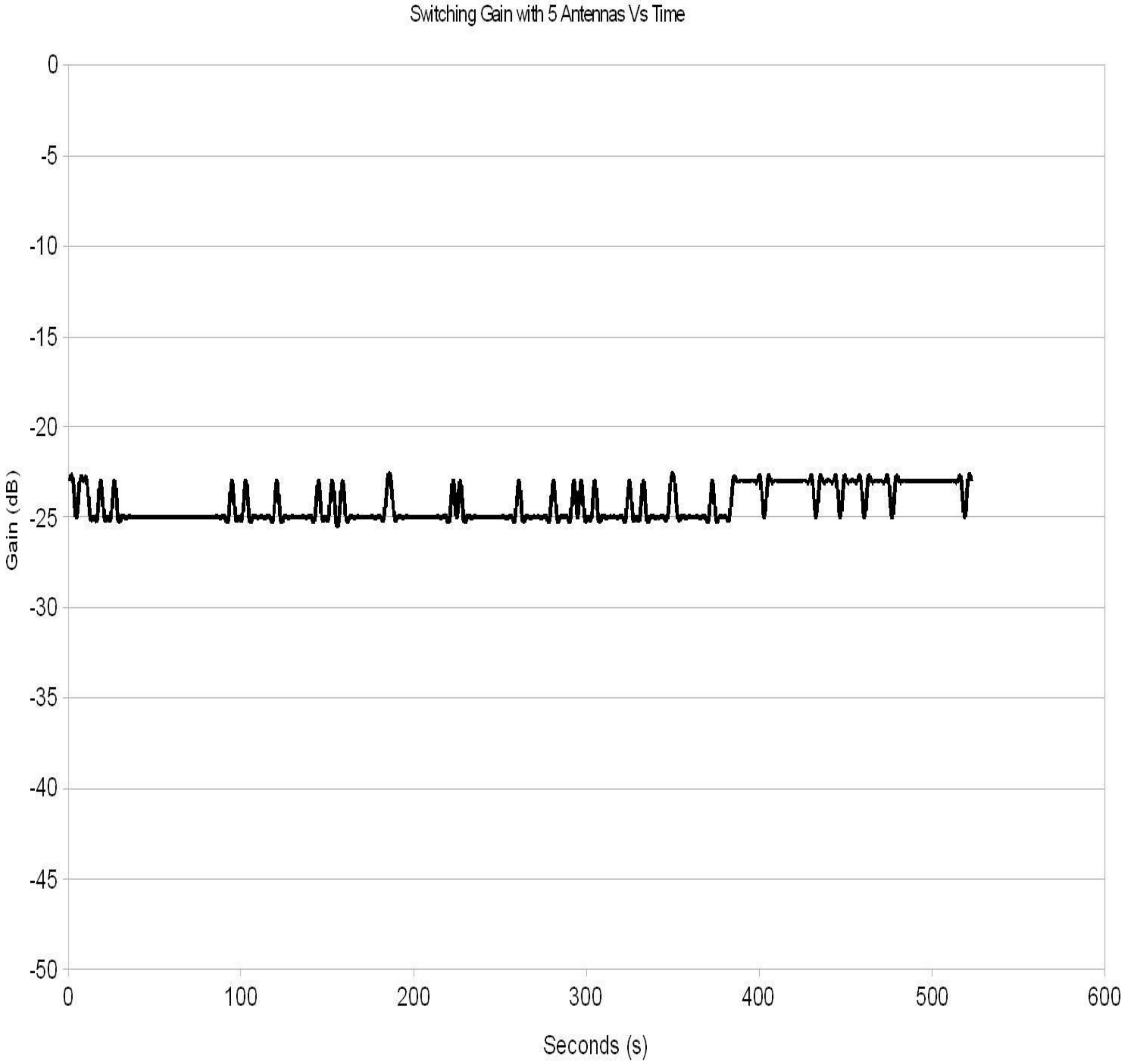

Figure 4.33: Switching Gain with 5 antennas Vs Time

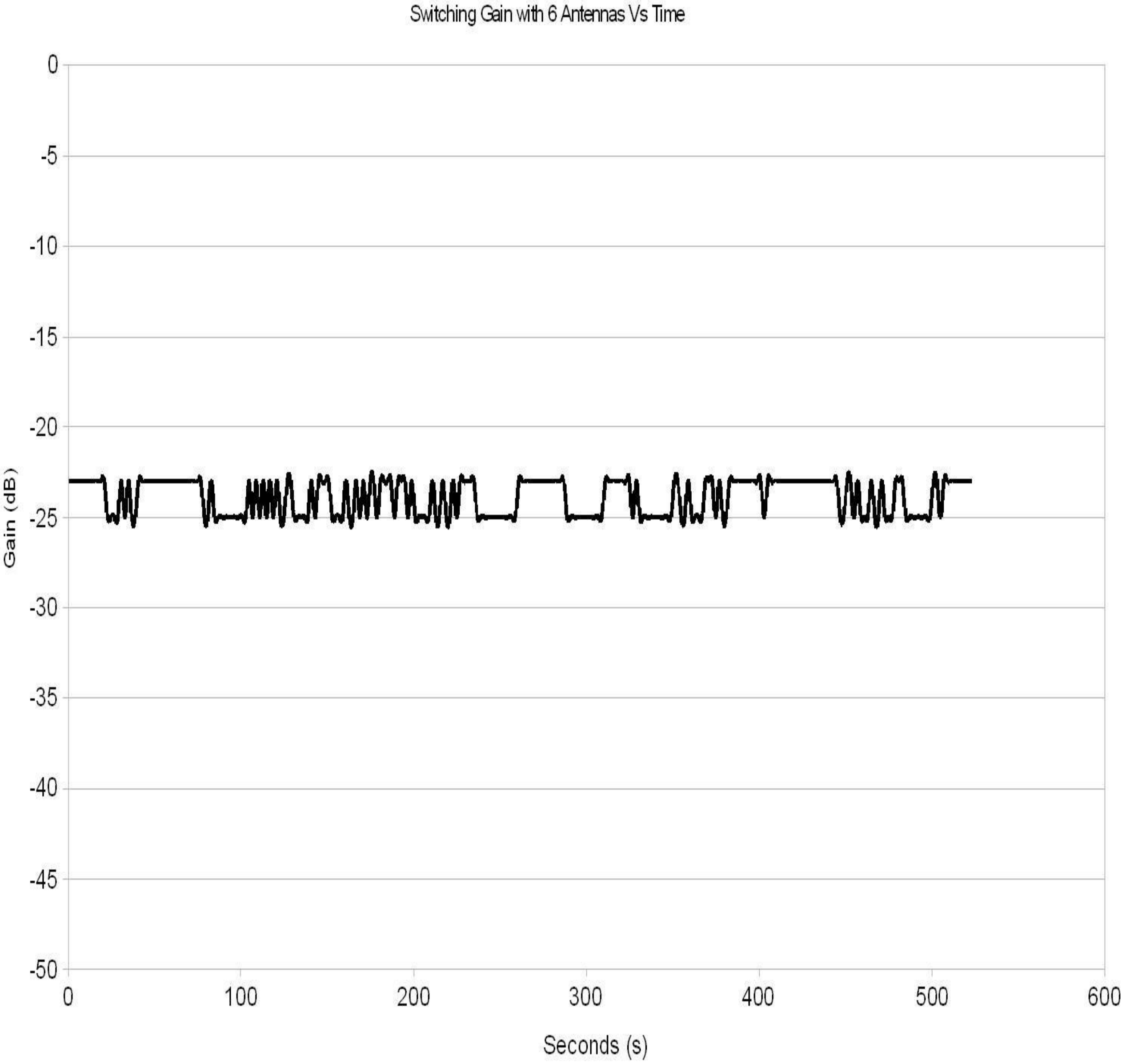

Figure 4.34: Switching Gain with 6 antennas Vs Time

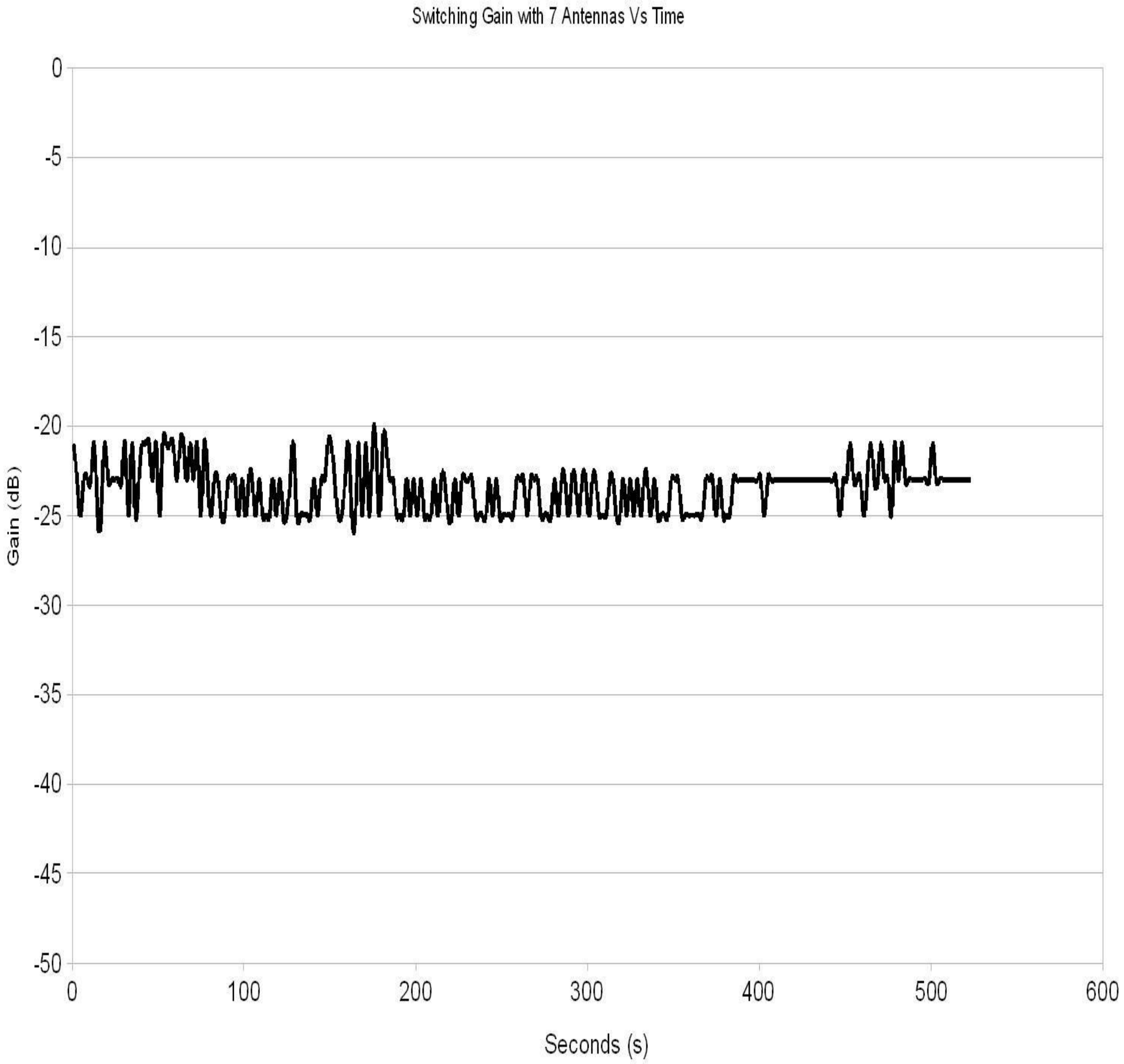

Figure 4.35: Switching Gain with 7 antennas Vs Time

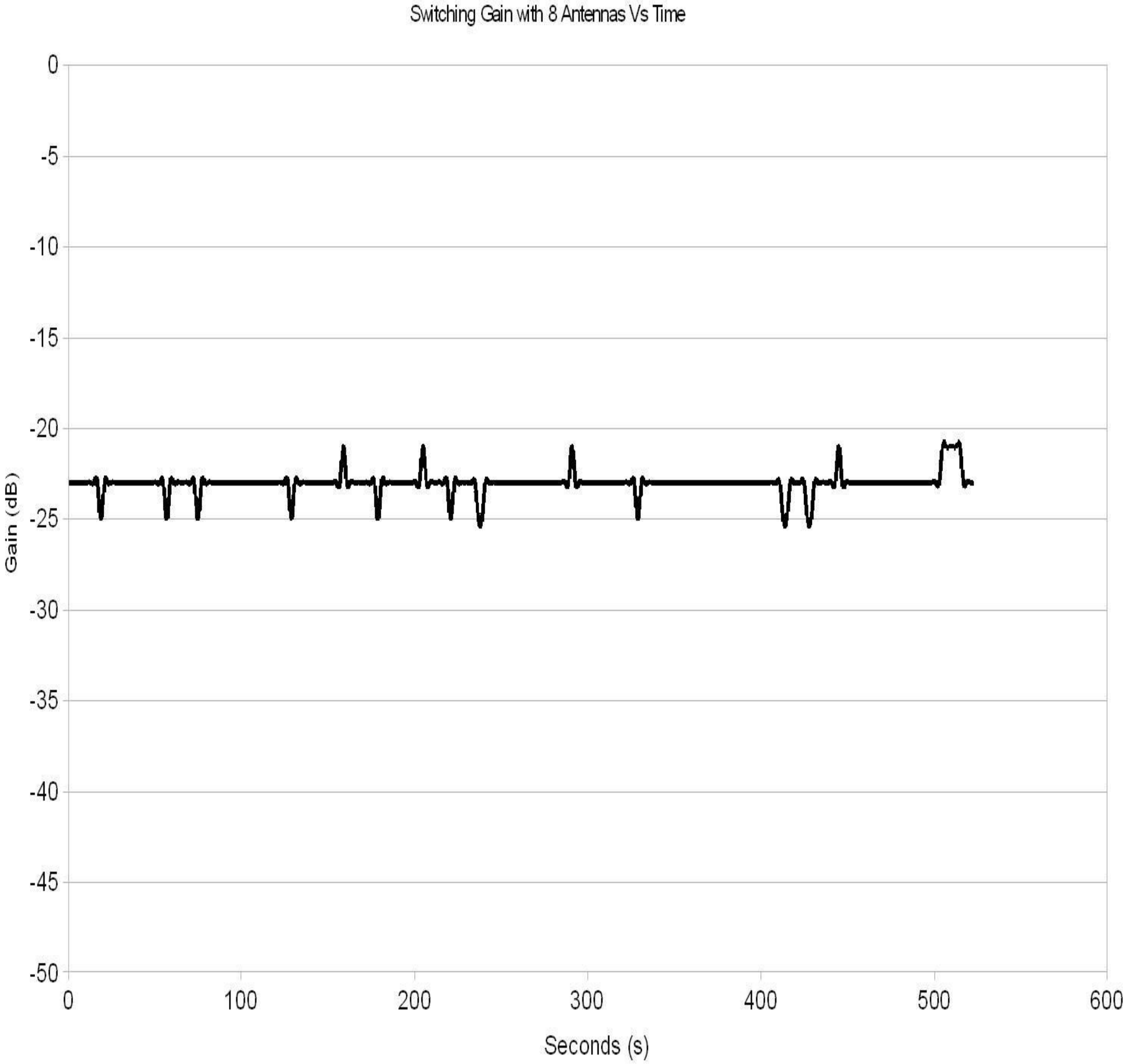

Figure 4.36: Switching Gain with 8 antennas Vs Time

Figure 4.29 above show the SISO gain result which is using one receive antenna. Similar to most SISO gain result we have before, the mean gain value is at -28.95 dB. The mean value gain improves as we start adding number of receive antenna. In Figure 4.30, we are using two antenna switching. The result show an good improvement of mean gain at -27.36 db, this represent and improvements of 1.59 dB from SISO gain.

Increasing the number of antenna furthermore, as we can see in when there are three and four antennas used, there are still overall mean gain improvement. The mean antenna switching gain with three and four antennas is at -26.04 dB and -24.87 dB respectively. This show an improvement of more than 1 dB from the previous antenna switching mean gain. As the difference from two to three antennas is at 1.32 dB while the difference from three to four antennas is at 1.17 dB.

Table 4.1 Mean Gain and Number of Receive Antenna

# Receive Antenna	Mean Gain
1	-28.95 dB
2	-27.36 dB
3	-26.04 dB
4	-24.87 dB
5	-24.25 dB
6	-23.83 dB
7	-23.34 dB
8	-23.00 dB

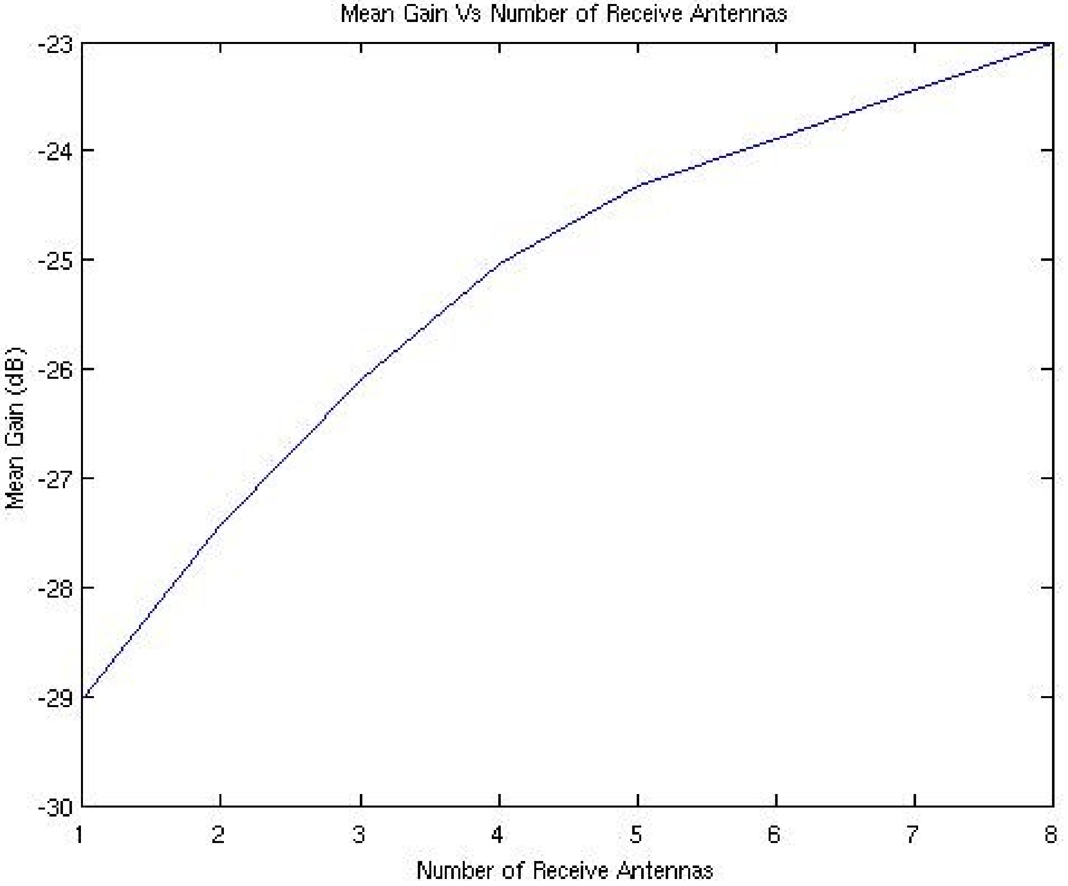

Figure 4.37: Mean Gain Vs Number of Receive Antennas

As we keep adding more number of available antennas, we see that the improvement on the mean gain becomes smaller. With five antennas we have the switching mean gain at -24.25 dB, and it improves to -23.83 when we have six antennas. The next two switching means gain value are at -23.34 dB and -23.00 dB when there are seven and eight switching antenna respectively.

These value of mean gains and its corresponding number of receive antenna can be seen on Table 4.1 and also on Figure 4.37 above. In the mean value gain that we gathered, we have calculated that as we keep adding number of receive antennas the improvement become smaller. After four number of receive antennas, there are slight improvements for every antenna added. These value of improvement are below 1 dB of mean gain. From four to five antennas, we have an improvement of 0.62dB. While above that, we have an improvement of 0.34 to 0.49dB of mean gain every time we add another antenna.

In this section, we have discussed the effectiveness of adding receive antenna and their relation with the mean gain that they provide. There are smaller improvement as we add more antenna into the system. As the value of individual gain we obtained, we can reach the high gain at -23 dB or above with four receive antennas or more. Therefore the improvements after four antennas are not as great as the lower number of antennas.

The antenna switching mean value for different number of receive antenna also shows similar observations. The mean gain with five antennas is at -24.25 dB, this value is similar to the value of overall antenna switching mean gain that we have on the previous sections. This says that by using five antennas, we might achieve the similar performance as using eight antennas. The different value of mean gain when there are eight antennas can be caused by the environment aspects such as location of walls, movements in the room, and objects on the room. In other words, from the experiments that we have done on previous sections, the mean gain value that we can achieve by using eight antenna switching is at -24 dB level or better. Therefore since we can achieve the similar value of mean gain by using five antennas, the performance is similar when there are additional antennas.

The advantages of having eight antennas is that there is a lower chance of having low switching gain, since we have more antenna to scan and provide possible antenna pairings. As there is a smaller probability that all eight antennas will have low gain, therefore the best gain will most likely be a high gain. In other words, the value of using more antennas is sustainability that we have to keep a high gain. The more antennas we have, the less chance of having all antennas with low gain hence maintaining an overall high antenna switching gain.

Chapter 5

Conclusion and Future Work

Antenna switching diversity is an excellent method to exploit the use of multiple antenna system. We are able to select the best gain of all the antennas, hence providing the best available pairing of antennas. This attribute is an attractive advantage especially since we can provide improvements of gain over SISO with the use of smaller number of antenna elements than MIMO. Smaller number of antenna elements means less RF elements which will decrease complexity of the system and save cost.

In this work, we had discussed several experiments related to antenna switching diversity. We performed the 1 x 8 antenna switching which is switching in the receive side, 8 x 1 antenna switching with the switching on the transmit side, antenna switching with line of sight and antenna switching with no line of sight. In addition, we also did experiment to see the effect of adding multiple antennas on the performance and improvement of antenna switching gain.

We focus our observations to the value of antenna switching gain over time as the performance measurement. Table 5.1 below show the result of our antenna switching experiments with their mean gain value and improvements. We can see that the result of implementing antenna switching in either receive or transmit side are very similar. Both of them provided good antenna switching mean gain and similar improvements of mean gain.

The result we have on our next experiments show some interesting observations. We compared the performance of antenna switching on antenna with line of sight and with no line of sight. The result show that line of sight does not affect the performance of antenna switching mean gain. However the improvements of mean gain compare to SISO mean gain is much more on antenna with no line of sight. This means that system with no line of sight get more benefit in using antenna switching diversity.

Table 5.1 Experiment Results of Antenna Switching Mean Gain and Their Improvements

Experiment	**Antenna Switching Mean Gain**	**SISO Mean Gain**	**Improvement of Mean Gain**
1 x 8 Antenna Switching	-24.46 dB	-28.99 dB	4.53 dB
8 x 1 Antenna Switching	-23.64 dB	-28.73 dB	5.09 dB
Line of Sight Antenna Switching	-23.70 dB	-28.99 dB	5.29 dB
No Line of Sight Antenna Switching	-23.08 dB	-32.11 dB	9.04 dB

We also found that the improvements on mean gain value decreases as we add more antennas into the switching system. This means that the mean gain value improves further from one to two antennas than the mean gain improvement from seven to eight antennas. There are small differences on mean gain improvement after four antennas which means we can reach similar mean gain value with five antennas as we can with eight antennas. The benefit of having more antennas are higher probabilities of reaching the high mean gain value (high mean gain value is higher than or equal to -24.5 dB).

Some of future research, the performance of switching system when we have a combination of transmit and receive antenna switching diversity. Other ideas is to choose the best two or more antenna values and combine them using combining method such as Maximum Ratio Combining (MRC). Another, the performance of the system when we use other scanning method of switching such as only start scanning the antenna when the gain value drop a certain threshold instead of periodically.

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