REFERENCES

[1] F. E. Marx and L. P. Linde, “Theoretical analysis and practical implementation of a balanced DSSS transmitter and receiver employing complex spreading sequences,” *1996 IEEE AFRICON: 4th Africon Conference in Africa*, vol. I, pp. 402–407, September 1996.

[2] F. E. Marx and L. P. Linde, “DSP Implementation of a Generic DSSS Transmitter employing complex or binary spreading sequences,” *COMSIG: South African symposium on communications and signal processing*, pp. 75–80, November 1995.

[3] F. E. Marx and L. P. Linde, “DSP implementation of a generic DSSS transmitter,” *Elektron*, pp. 20–22, March 1996.

[4] L. P. Linde and M. P. Loẗter, “Spread-Spectrum Modulator and Method,” 17 January 1996. SA Patent no. 96/0355.

[5] R. E. Ziemer and R. L. Peterson, *Digital Communications and Spread Spectrum Systems*. USA: McMillan Publishing Co., 1985, 1985.

[6] R. C. Dixon, *Spread Spectrum Systems with Commercial Applications*. Wiley, third ed., 1994.

[7] J. K. Holmes, *Coherent Spread Spectrum Systems*. Wiley, 1982.

[8] R. De Gaudenzi and M. Luise, “Decision-Directed Coherent Delay-Lock Tracking Loop for DS-Spread-Spectrum Signals,” *IEEE Transactions on Communications*, pp. 758–765, May 1991.

[9] B. M. Popović, “Generalized chirp- like polyphase sequences with optimum correlation properties,” *IEEE Trans. on IT*, vol. 38, pp. 1406–1409, July 1992.

[10] M. P. Lötter and L. P. Linde, “Constant envelope filtering of complex spreading sequences,” *Electronics Letters*, vol. 31, pp. 1406–1407, August 1995.

[11] M. K. Simon, J. K. Omura, R. A. Scholtz, and B. K. Levitt, *Spread Spectrum Communications Handbook*. McGraw-Hill, 1994.

[12] S. Glisic and B. Vucetic, *Spread Spectrum CDMA Systems for Wireless Communications*. Artech House, Inc., 1997.

[13] R. L. Peterson, R. E. Ziemer, and D. E. Borth, *Introduction to Spread Spectrum Communications*. Prentice Hall, 1995.

[14] A. J. Viterbi, *CDMA: Principles of Spread Spectrum Communication*. Addison-Wesley, 1995.

[15] R. L. Pickholtz, L. B. Milstein, and D. L. Schilling, "Spread spectrum for mobile communications," *IEEE Transactions on Vehicular Technology*, vol. 40, pp. 313–322, May 1991.

[16] K. Raith and J. Uddenfeldt, "Capacity of digital cellular TDMA systems," *IEEE Transactions on Vehicular Technology*, vol. 40, pp. 323–332, May 1991.

[17] K. S. Gilhausen, I. M. Jacobs, R. Padovani, A. J. Viterbi, L. A. Weaver, and C. E. Wheatley, "On the capacity of a cellular CDMA system," *IEEE Transactions on Vehicular Technology*, vol. 40, pp. 303–312, May 1991.

[18] T. S. Rappaport, *Wireless Communications: Principles & Practice*. Prentice Hall PTR, 1996.

[19] W. C. Y. Lee, "Overview of cellular CDMA," *IEEE Transactions on Vehicular Technology*, vol. 40, pp. 291–302, May 1991.

[20] P. T. Brady, "A Statistical Analysis of On-Off Patterns in 16 Conversations," *Bell Syst. Tech. J.*, vol. 47, pp. 73–91, January 1968.

[21] J. G. Proakis, *Digital Communications*. McGraw-Hill, second ed., 1989.

[22] A. Lam and F. Ozlütürk, "Performance bounds for DS/SSMA communications with complex signature sequences," *IEEE Trans. on Comm.*, vol. 40, pp. 1607–1614, October 1992.

[23] D. V. Sarwate, "Bounds on crosscorrelation and autocorrelation of sequences," *IEEE Transactions on Information Theory*, vol. IT-25, pp. 720–724, November 1979.

[24] S. Boztas and P. V. Kumar, "Near-optimal 4ϕ sequences for CDMA," *University of Southern California, Technical Report*, vol. CSI-90-03-01, March 1990.

[25] M. P. Lötter, "A high capacity, micro-cellular, CDMA communication system employing complex spreading sequences," *Masters Thesis, University of Pretoria, South Africa*, March 1995.

[26] L. R. Welch, "A lower bounds on the maximum cross correlation of signals," *IEEE Transactions on Information Theory*, vol. IT-20, pp. 397–399, May 1974.

[27] V. M. Sidelnikov, "On mutual correlation of sequences," *Soviet Math. Dokl.*, vol. 12, pp. 197–201, 1971.

[28] D. V. Sarwate and M. B. Pursley, "Correlation properties of pseudorandom and related sequences," *IEEE Transactions on Information Theory*, vol. IT-68, pp. 593–619, May 1980.

[29] J. S. No and P. V. Kumar, "A new family of pseudorandum sequences having optimal correlation properties and large linear span," *IEEE Transactions on Information Theory*, vol. IT-35, pp. 371–379, March 1989.

[30] H. E. Rowe, "Bounds on the number of signals with restricted cross-correlation," *IEEE Transactions on Communications*, vol. COM-30, pp. 966–974, May 1982.

[31] P. V. Kumar and O. Moreno, "Prime phase sequences with periodic correlation properties better than binary sequences," *IEEE Transaction on Information Theory*, vol. IT-37, pp. 603–616, May 1991.

[32] P. V. Kumar and C. H. Liu, "On lower bounds to the maximum correlation of complex root-of-unity sequences," *IEEE Transaction on Information Theory*, vol. IT-36, pp. 633–640, May 1990.

[33] K. Kärkkäinen, "Code families and their performance measures for CDMA and military spread spectrum systems," *PhD Thesis, University of Oulu*, 1996.

[34] M. J. Sandhu, "Comparative Study of Complex Spreading Sequences for CDMA Applications," *Masters Thesis, University of Pretoria, South Africa*, 1999.

[35] I. Opperman and B. S. Vucetic, "Complex Spreading Sequences with Wide Range of Correlation Properties," *IEEE Trans. on Comm.*, vol. 38, March 1997.

[36] I. Opperman, P. Rapajic, and B. S. Vucetic, "Pseudo Random Sequences with Good Cross-Correlation Properties," in *International Symposium on Information Theory and Its Applications*, (Sydney, Australia), pp. 1001–1005, November 1994.

[37] I. Opperman, "Orthogonal Complex Valued Spreading Sequences with a Wide Range of Correlation Properties," *IEEE Trans. on Comm.*, vol. 45, November 1997.

[38] K. Feher, *Wireless Digital Communications: Modulation and Spread Spectrum Applications*. Prentice Hall PTR, first ed., 1995.

[39] F. M. Gardner, *Phaselock Techniques*. John Wiley & Sons, Inc., 1967.

[40] R. L. Pickholtz, D. L. Schilling, and L. B. Milstein, "Theory of spread-spectrum communications - a tutorial," *IEEE Transactions on Communication*, vol. COM-30, pp. 855–884, May 1982.

[41] S. Haykin, *Digital Communications*. Wiley, 1988.

[42] C. Liu and K. Feher, "$\pi/4$-QPSK Modems for Satelite Sound/Data Broadcast Systems," *IEEE Transactions on Broadcasting*, vol. 37, pp. 1–8, March 1991.

[43] K. Feher, "Modems for Emerging Digital Cellular-Mobile Radio System," *IEEE Transactions on Vehicular Technology*, vol. 40, pp. 355–365, May 1991.

[44] F. Davarian and J. T. Sumida, "A Multipurpose Digital Modulator," *IEEE Communications Magazine*, pp. 36–45, February 1989.

[45] H. Samueli and B. C. Wong, "A VLSI architecture for a high-speed all-digital quadrature modulator for digital radio applications," *IEEE JSAC*, vol. 8, pp. 1512–1519, October 1990.

[46] G. J. Saulnier, C. M. Puckette, R. C. Gaus, R. J. Dunki-Jacobs, and T. E. Thiel, "A VLSI Demodulator for Digital RF Network Applications: Theory and Results," *IEEE JSAC*, vol. 8, pp. 1500–1511, October 1990.

[47] C. Liang, J. H. Jong, W. E. Stark, and J. R. East, "Nonlinear amplifier effexts in communication systems," *IEEE Trans. on Microwave Theory and Applications*, vol. 47, pp. 1461–1466, August 1999.

[48] G. Zhou, "Analysis of spectral regrowth of weakly nonlinear power amplifiers," *IEEE Comm. Letters*, vol. 4, pp. 357–359, November 2000.

[49] K. Feher, *Wireless Digital Communications: Modulation and Spread Spectrum Applications*. Prentice Hall PTR, first ed., 1995.

[50] L. P. Linde and F. E. Marx, "Multi-Dimensional Spread Spectrum Modem, South African Complete Patent no 2000/2645, 30 January 2002."

[51] L. P. Linde and F. E. Marx, "Multi-Dimensional Spread Spectrum Modem, United States Complete Patent no 6744807, 1 June 2004."

[52] Telecommunication Industry Association, *TIA/EIA Interim standard: Mobile station-base station compatibility standard for dual-mode wideband spread spectrum cellular system TIA/EIA/IS-95*, July 1993.

[53] ETSI Secretariat, Valbonne France, *Universal Mobile Telecommunications Systems (UMTS); UMTS Terrestial Radio Access UTRA; Concept Evaluation: Technical Report 101 146 (1997-12)*, UMTS 30.06 version 3.0.0 ed., 1997.

APPENDIX A

UNIQUE COMBINATION SEQUENCE RESULTS

Unique combinations of the real and imaginary parts of the complex spreading sequences are used as defined by

$$C_{r_1 comb} = C_{r_1} - C_{i_1} \tag{A.1}$$

$$C_{i_1 comb} = -C_{r_1} - C_{i_1} \tag{A.2}$$

and is shown in Figure A.1. The real and imaginary parts of the root-of-unity filtered complex spreading sequence 1 and 6 of length, $L = 121$, and samples per chip, $spc = 8$, are depicted in Figures A.1 and A.4, while the real vs. imaginary parts of sequence 1 and 6 are shown in Figures A.2 and A.5, respectively. The power spectral densities (PSD) for sequence 1 and sequence 6 are shown in Figures A.3 and A.6, respectively.

The same for complex spreading sequence 6

$$C_{r_6 comb} = C_{r_6} - C_{i_6} \tag{A.3}$$

$$C_{i_6 comb} = -C_{r_6} - C_{i_6} \tag{A.4}$$

and is depicted in Figure A.4.

A.1 AUTOCORRELATION FUNCTION

The sequence $\{s_k\}$ of length L has periodic AC function, $R_{ss}[l]$, given as:

$$R_{ss}[l] = \sum_{k=0}^{L-1} s[k] \cdot s^*[k+l]_{mod\,L} \tag{A.5}$$

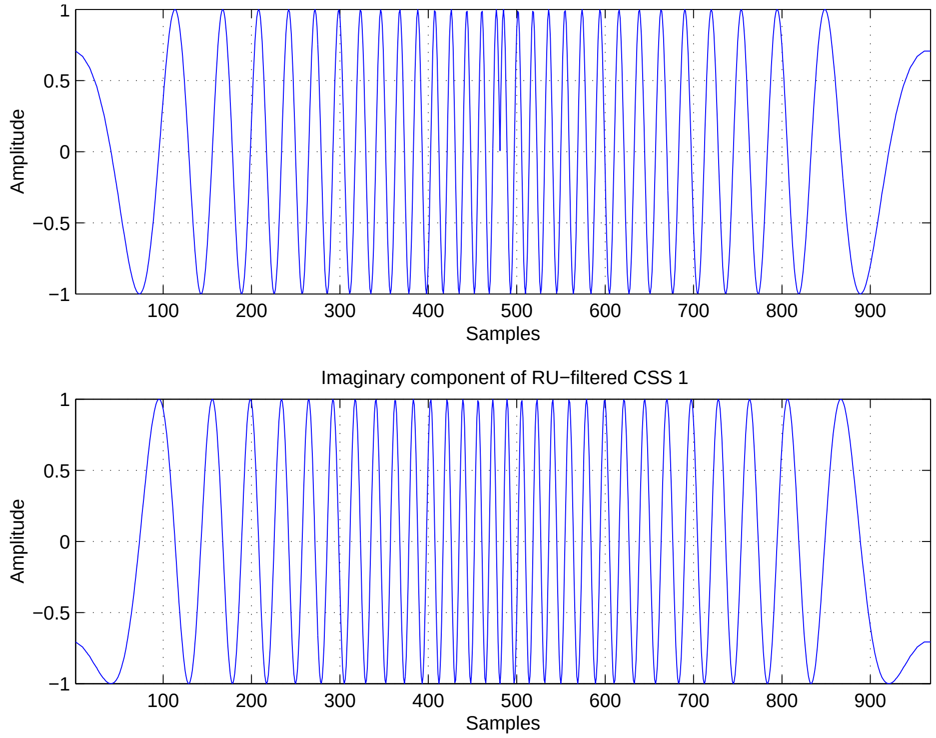


FIGURE A.1: The Real, (a), and Imaginary, (b), part of the unique combination of CSS 1. $(L = 121, RUfiltered, spc = 8)$

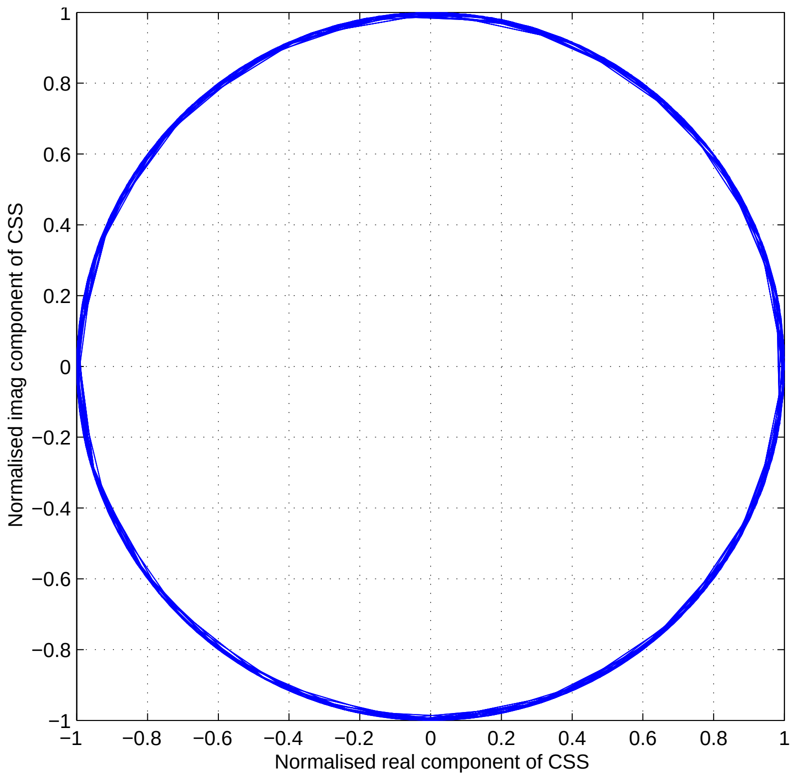


FIGURE A.2: Real vs. Imaginary part of unique combination of complex spreading sequence 6. $(L = 121, RUfiltered, spc = 8)$

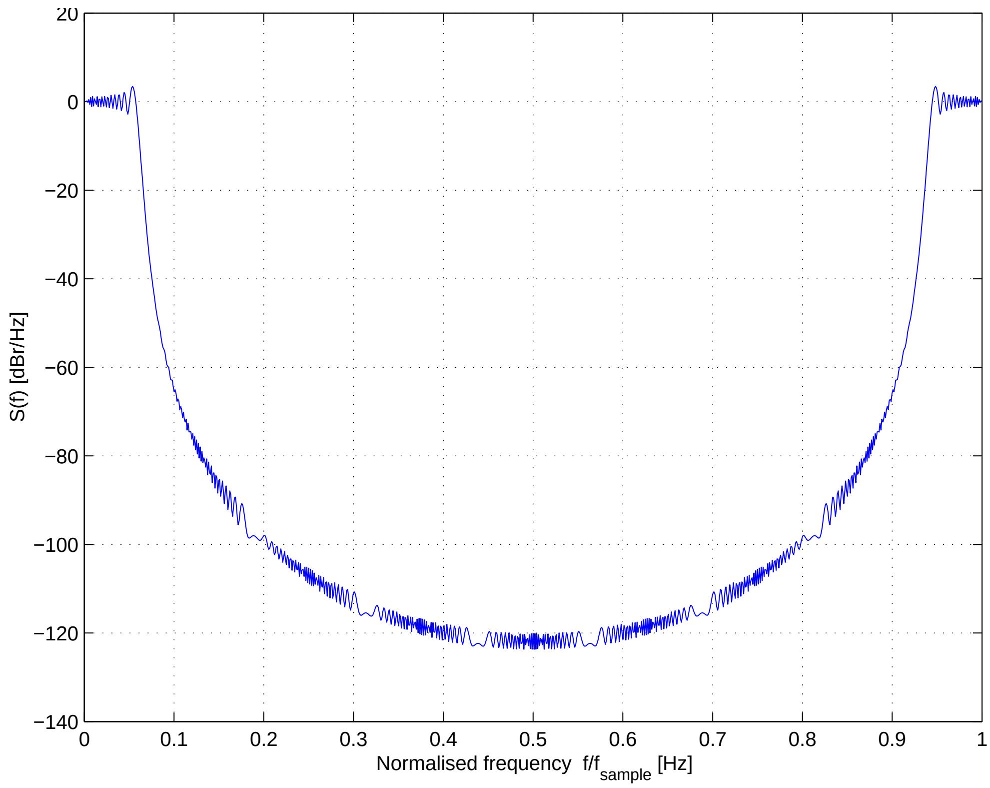


FIGURE A.3: Power spectral density (PSD) of unique combination of complex spreading sequence 1. $(L = 121, RU filtered, spc = 8)$

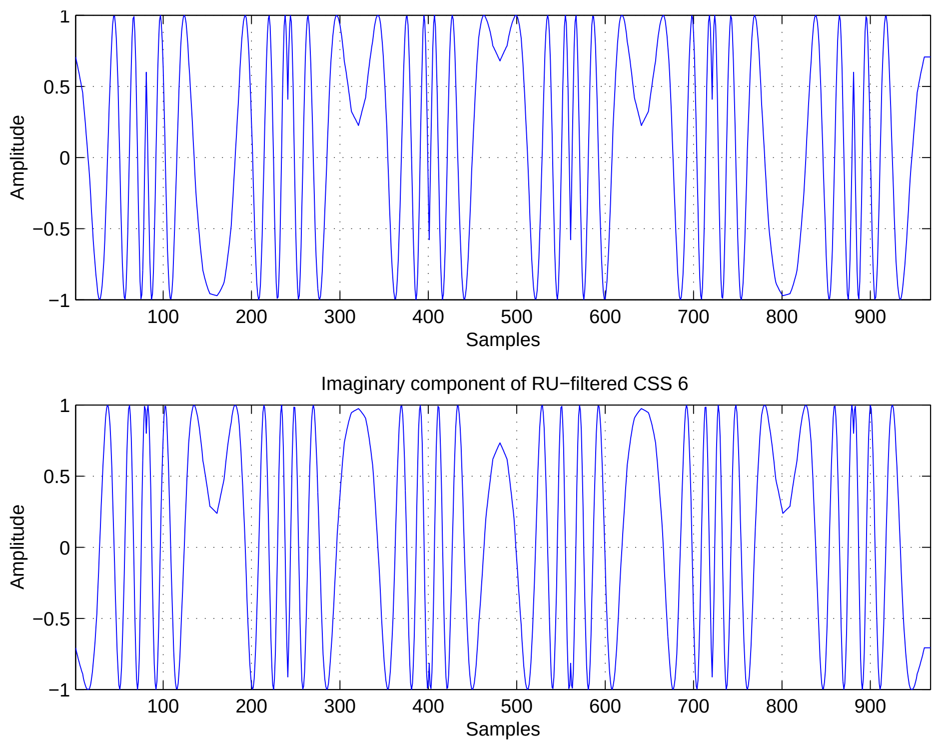


FIGURE A.4: The Real, (a), and Imaginary, (b), part of unique combination of CSS 6. $(L = 121, RU filtered, spc = 8)$

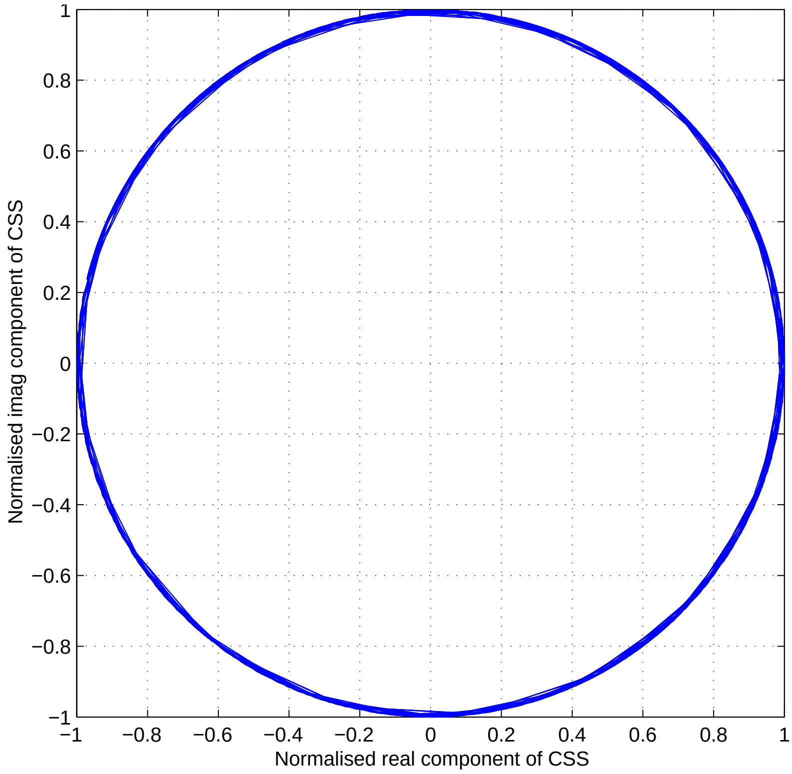


FIGURE A.5: Real vs. Imaginary part of unique combination of complex spreading sequence 6. $(L = 121, RU filtered, spc = 8)$

where * denotes the complex conjugate, the index $[k + l]$ is computed modulo L, and the time shift is l.

Thus for the ZC sequences, the periodic AC function is:

$$R_{ss}[l] = \sum_{k=0}^{L-1} W_L^{\frac{k(k+1)}{2}} \cdot W_L^{\frac{-(k+l)_{mod\, L}\, ((k+l)_{mod\, L}+1)}{2}} \tag{A.6}$$

for $q = 0$ and L odd.

The periodic AC functions for the ZC sequences 1 and 6, for a length of 121, can be seen in Figures A.7, A.8 and Figures A.9, A.10, respectively.

For a sequence s_k of length L the aperiodic AC function is defined as:

$$R_{ss}[l] = \int_{-\infty}^{\infty} s[l] \cdot s^{*}[t + l]\, dl \tag{A.7}$$

where * denotes the complex conjugate and the time shift is l.

In discrete time notation the aperiodic AC function can be expressed as:

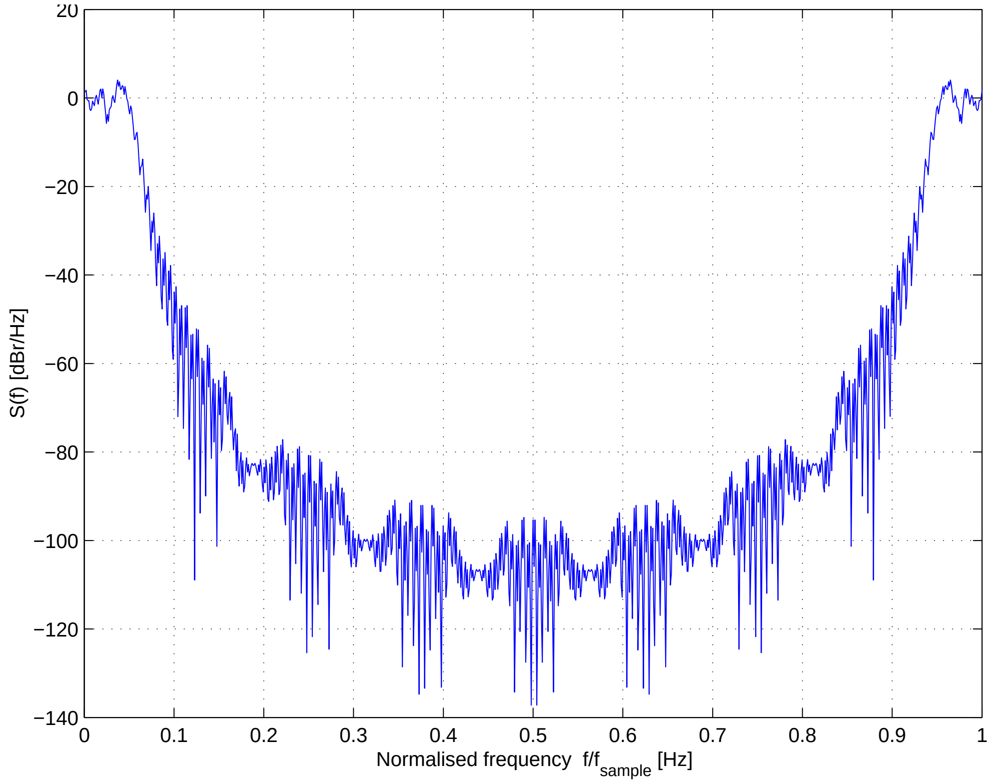


FIGURE A.6: Power spectral density (PSD) of unique combination of complex spreading sequence 6. $(L = 121, RU filtered, spc = 8)$

$$R_{ss}[l] = \begin{cases} \sum_{k=0}^{L-1-l} s[l] \cdot s^*[k+l] & ; 0 \leq l \leq L-1 \\ \sum_{k=0}^{L-1+l} s[k-l] \cdot s^*[k] & ; 1-L \leq l < 0 \\ 0 & ; \mid l \mid \geq L \end{cases} \tag{A.8}$$

For ZC sequences the aperiodic AC function is:

$$R_{aa}[l] = \begin{cases} \sum_{k=0}^{L-1-l} W_L^{\frac{k(k+1)}{2}} \cdot W_L^{\frac{-(k+1)(k+l+1)}{2}} & ; 0 \leq l \leq L-1 \\ \sum_{k=0}^{L-1+l} W_L^{\frac{(k-l)(k-l+1)}{2}} \cdot W_L^{\frac{-k(k+l)}{2}} & ; 1-L \leq l < 0 \\ 0 & ; \mid l \mid \geq L \end{cases} \tag{A.9}$$

for $q = 0$ and L odd.

The aperiodic AC functions for the ZC sequences 1 and 6, for a length of 121, can be seen in Figures A.11, A.12 and Figures A.13, A.14, respectively.

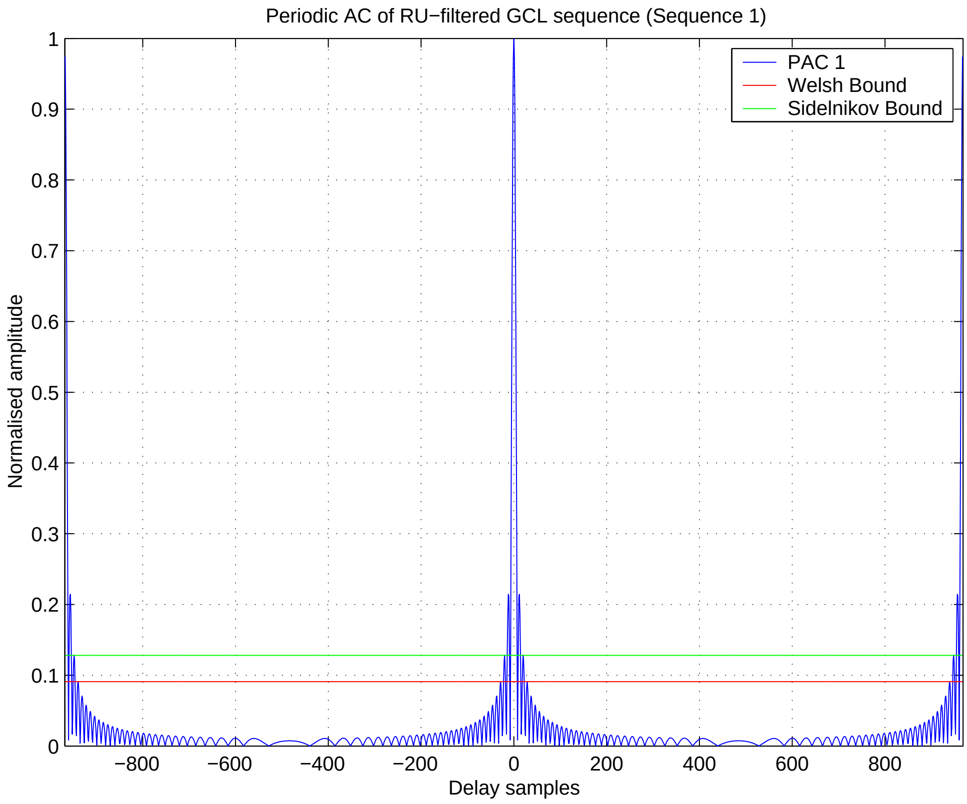


FIGURE A.7: Periodic Auto Correlation (PAC) function of unique combination of complex spreading sequence 1. $(L = 121, RU filtered, spc = 8)$

A.2 CROSSCORRELATION FUNCTION

The CC function shows the correspondence between two signals at different time shifts. The periodic CC function between any two sequences s_k and u_k, both of length L, is defined as:

$$R_{su}[l] = \sum_{k=0}^{L-1} s[k] \cdot u^*[(k+l)_{modL}] \tag{A.10}$$

where $*$ denotes the complex conjucate, the index $(k + l)$ is computed modulo L, and the time shift is l.

Thus for the ZC sequence the periodic CC function is:

$$R_{ab}[l] = \sum_{k=0}^{L-1} W_{L_a}^{\frac{k(k+1)}{2}} \cdot W_{L_a}^{\frac{-(k+l)_{modL}((k+l)_{modL}+1)}{2}} \tag{A.11}$$

for $q = 0$ and L odd.

The periodic cross correlation functions between spreading code number 1 and 6 are shown in Figures A.15 and A.16.

The aperiodic CC function between any two sequences s_k and u_k, both of length L, in discrete time notation is defined as:

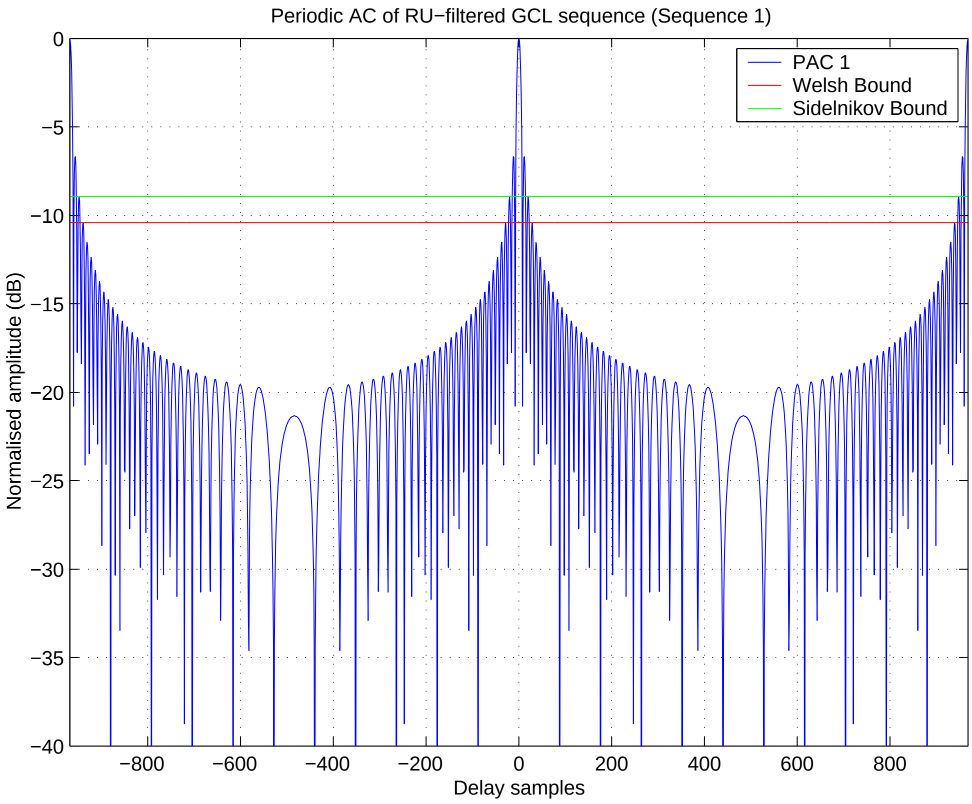


FIGURE A.8: Periodic Auto Correlation (PAC) function of unique combination of complex spreading sequence 1 in decibels. $(L = 121, RU filtered, spc = 8)$

$$R_{su}[l] = \begin{cases} \sum_{k=0}^{L-1-l} s[l] \cdot u^*[k+l] & ; 0 \leq l \leq L-1 \\ \sum_{k=0}^{L-1+l} s[k-l] \cdot u^*[k] & ; 1-L \leq l < 0 \\ 0 & ; \mid l \mid \geq L \end{cases} \tag{A.12}$$

where * denotes complex conjugate and the time shift is l.

For the ZC sequences the aperiodic CC function is

$$R_{ab}[l] = \begin{cases} \sum_{k=0}^{L-1-l} \; W_{L_a}^{\frac{k(k+1)}{2}} \cdot W_{L_b}^{\frac{-(k+1)(k+l+1)}{2}} & ; 0 \leq l \leq L-1 \\ \sum_{k=0}^{L-1+l} \; W_{L_a}^{\frac{(k-l)(k-l+1)}{2}} \cdot W_{L_b}^{\frac{-k(k+l)}{2}} & ; 1-L \leq l < 0 \\ 0 & ; \mid l \mid \geq L \end{cases} \tag{A.13}$$

The aperiodic cross correlation functions for the ZC sequences are depicted in Figures A.17 and A.18.

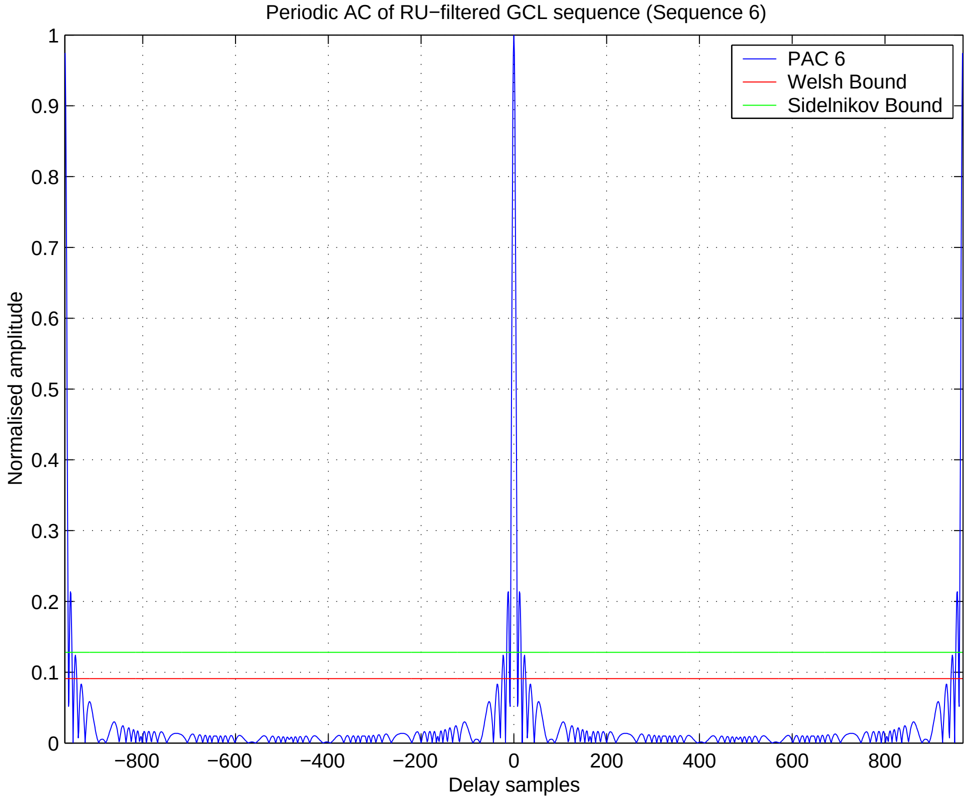


FIGURE A.9: Periodic Auto Correlation (PAC) function of unique combination of complex spreading sequence 6. $(L = 121, RU filtered, spc = 8)$

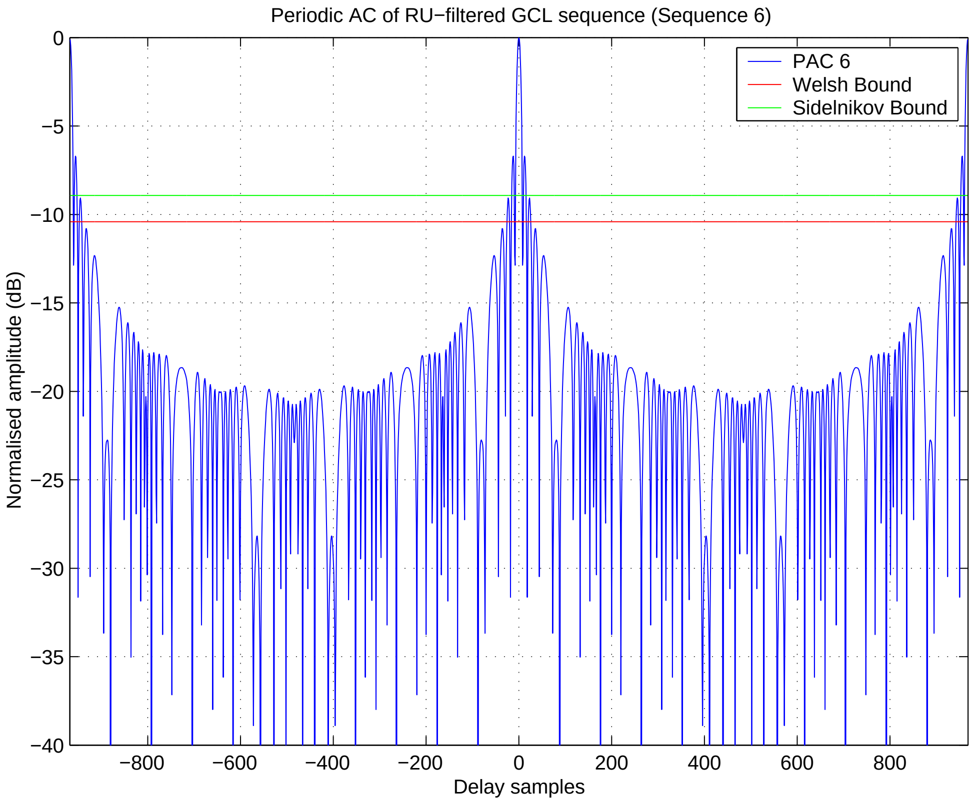


FIGURE A.10: Periodic Auto Correlation (PAC) function of unique combination of complex spreading sequence 6 in decibels. $(L = 121, RU filtered, spc = 8)$

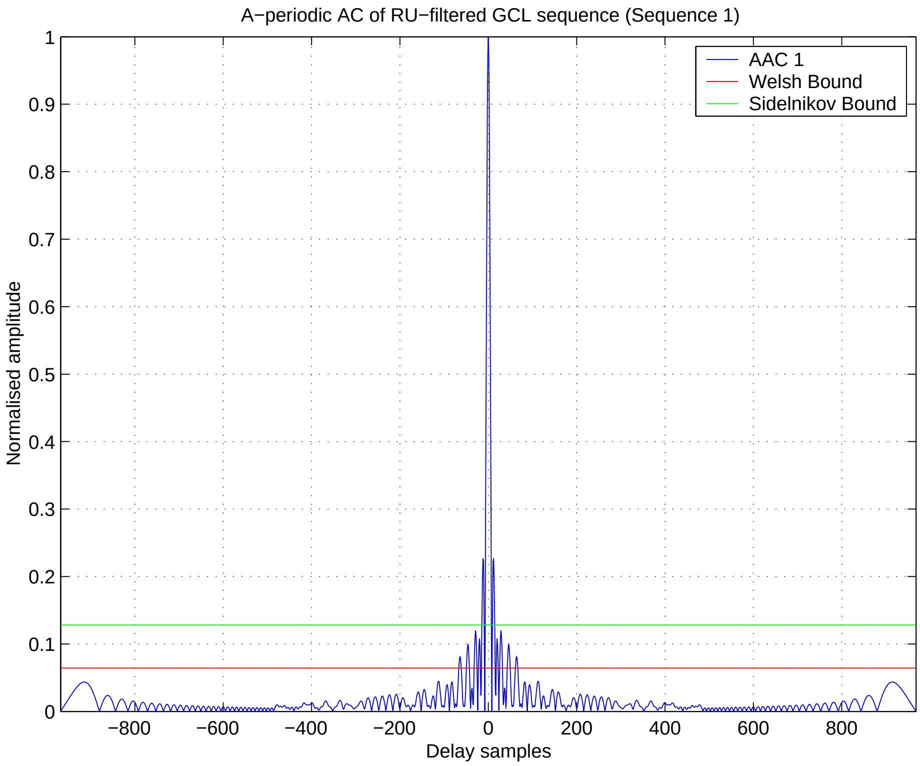


FIGURE A.11: Aperiodic Auto Correlation (AAC) function of unique combination of complex spreading sequence 1. $(L = 121, RU filtered, spc = 8)$

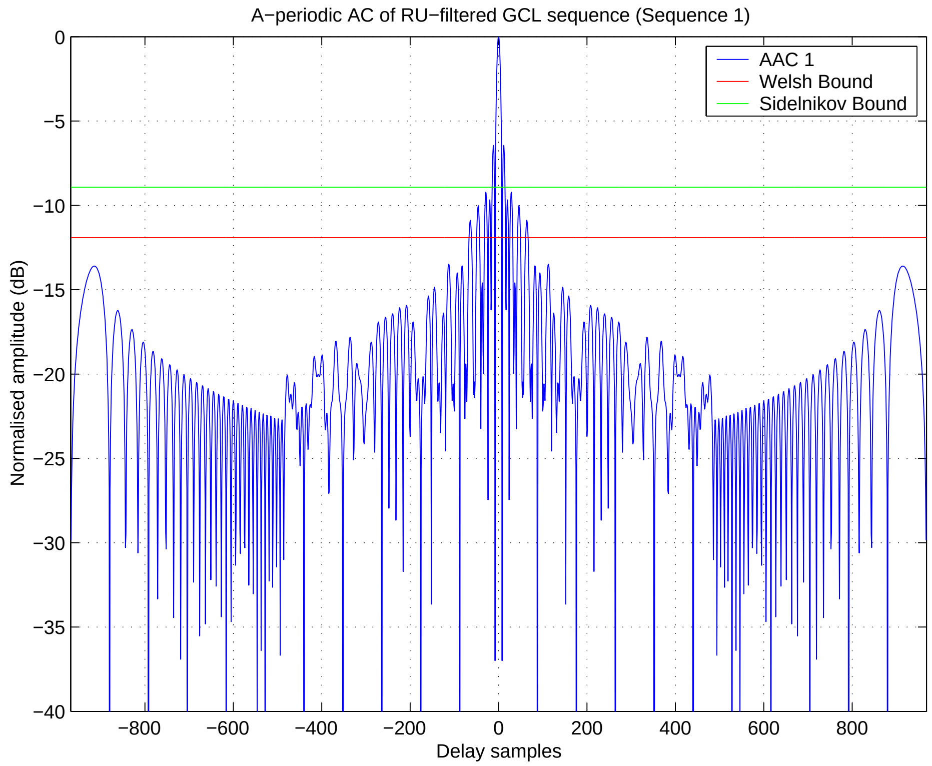


FIGURE A.12: Aperiodic Auto Correlation (AAC) function of unique combination of complex spreading sequence 1 in decibels. $(L = 121, RU filtered, spc = 8)$

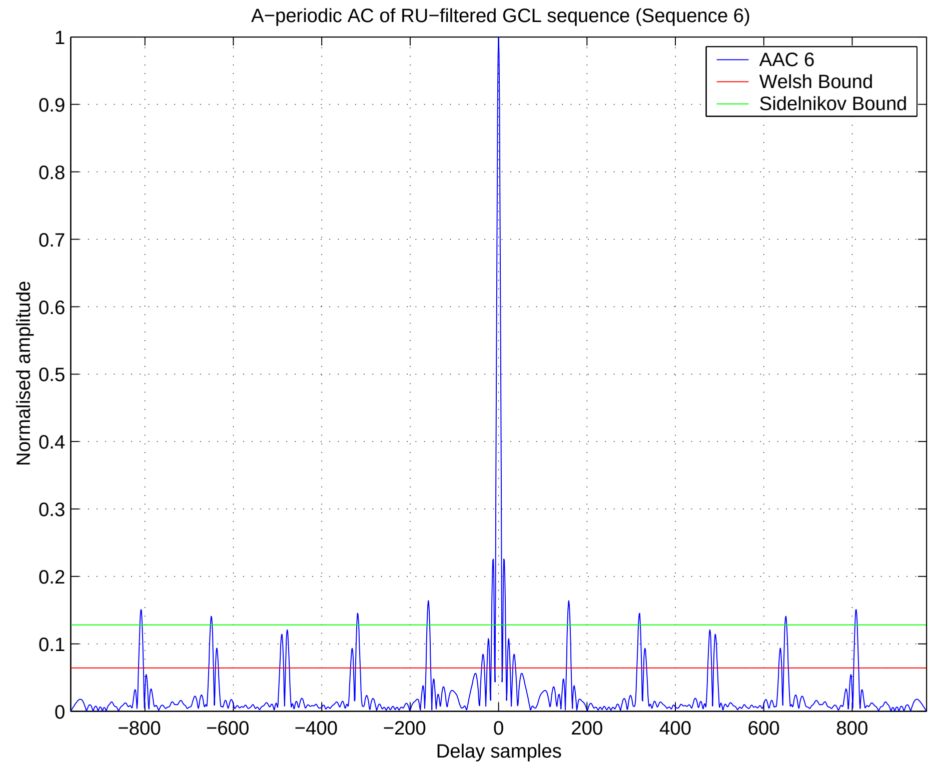


FIGURE A.13: Aperiodic Auto Correlation (AAC) function of unique combination of complex spreading sequence 6. $(L = 121, RU filtered, spc = 8)$

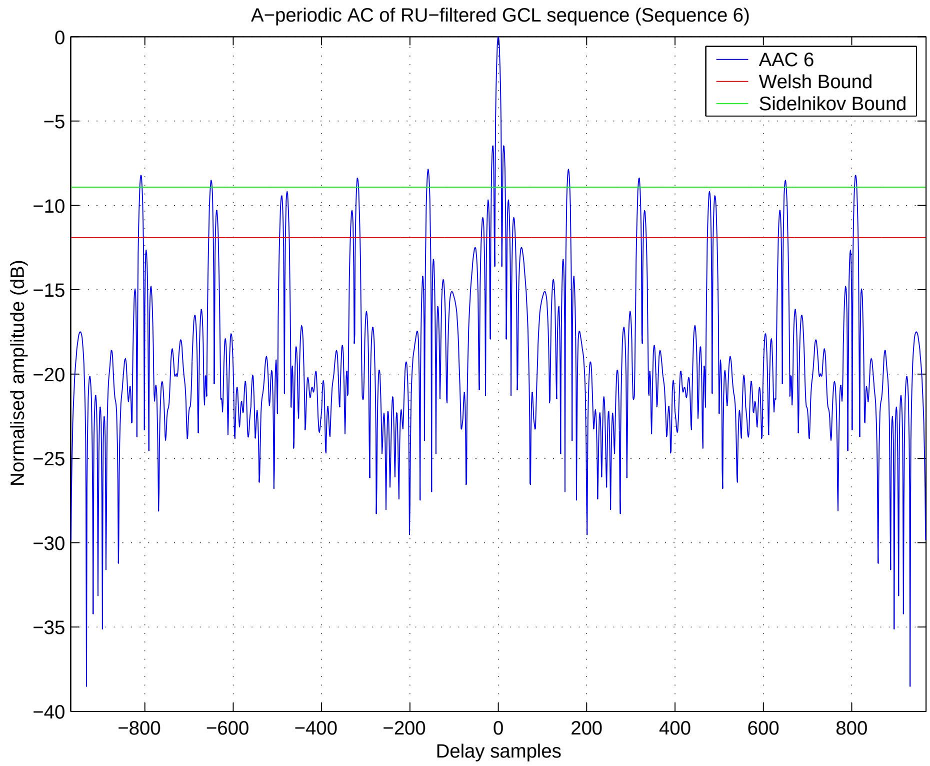


FIGURE A.14: Aperiodic Auto Correlation (AAC) function of unique combination of complex spreading sequence 6 in decibels. $(L = 121, RU filtered, spc = 8)$

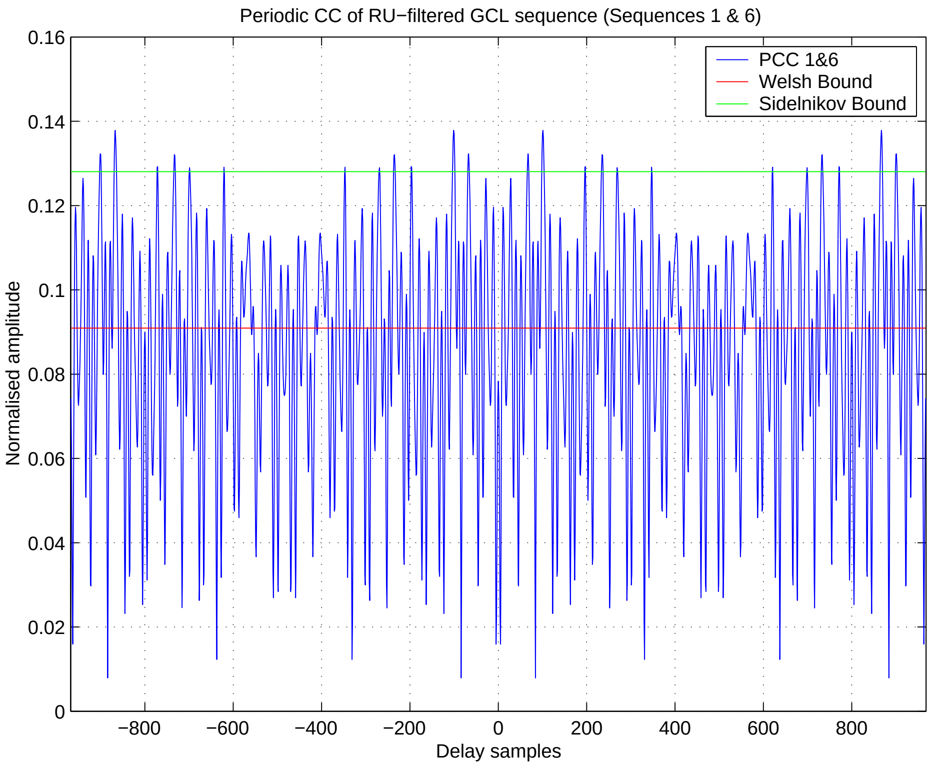


FIGURE A.15: Periodic Cross Correlation(PCC) function between unique combinations of complex spreading sequences 1 and 6. $(L = 121, RU filtered, spc = 8)$

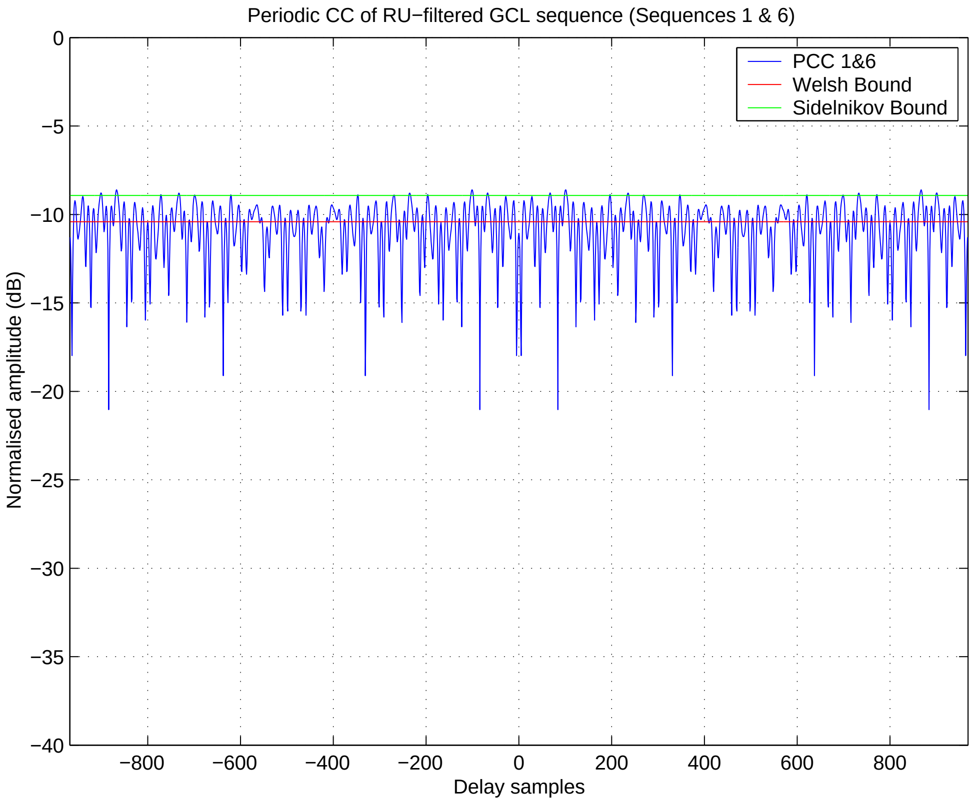


FIGURE A.16: Periodic Cross Correlation(PCC) function between unique combinations of complex spreading sequences 1 and 6 in decibels. $(L = 121, RU filtered, spc = 8)$

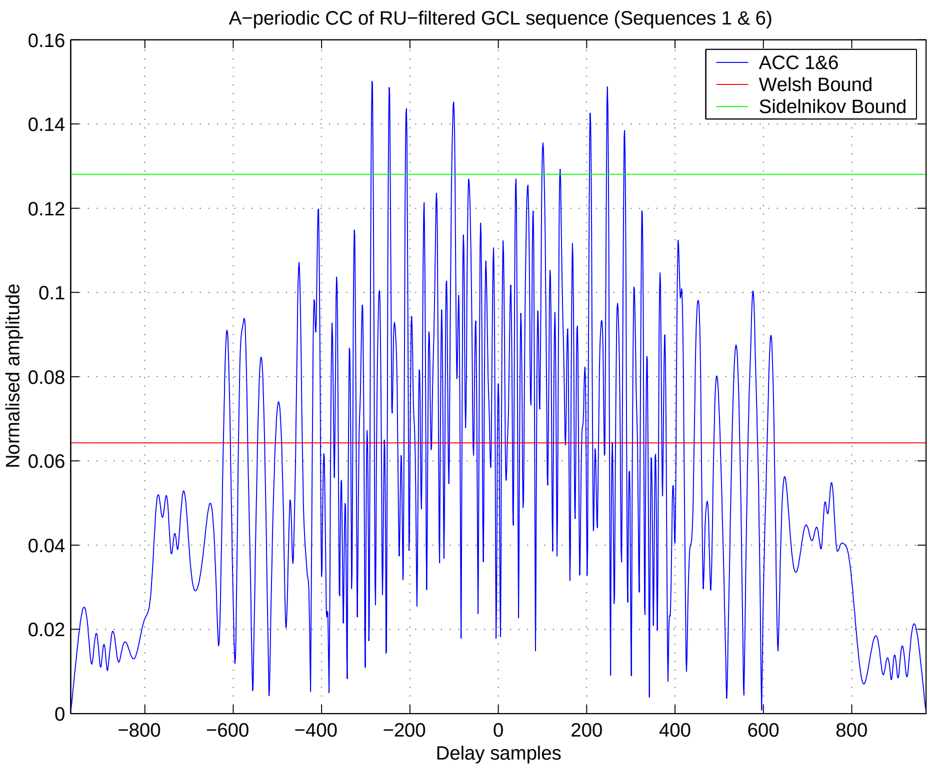


FIGURE A.17: Aperiodic Cross Correlation(PCC) function between unique combinations of complex spreading sequences 1 and 6. $(L = 121, RU filtered, spc = 8)$

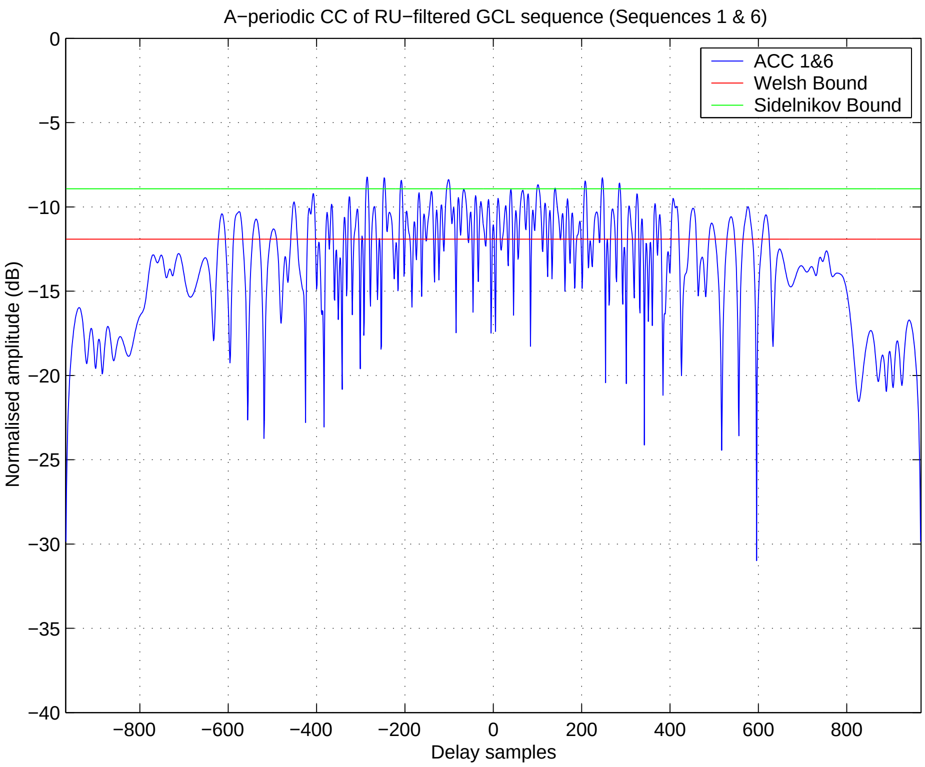
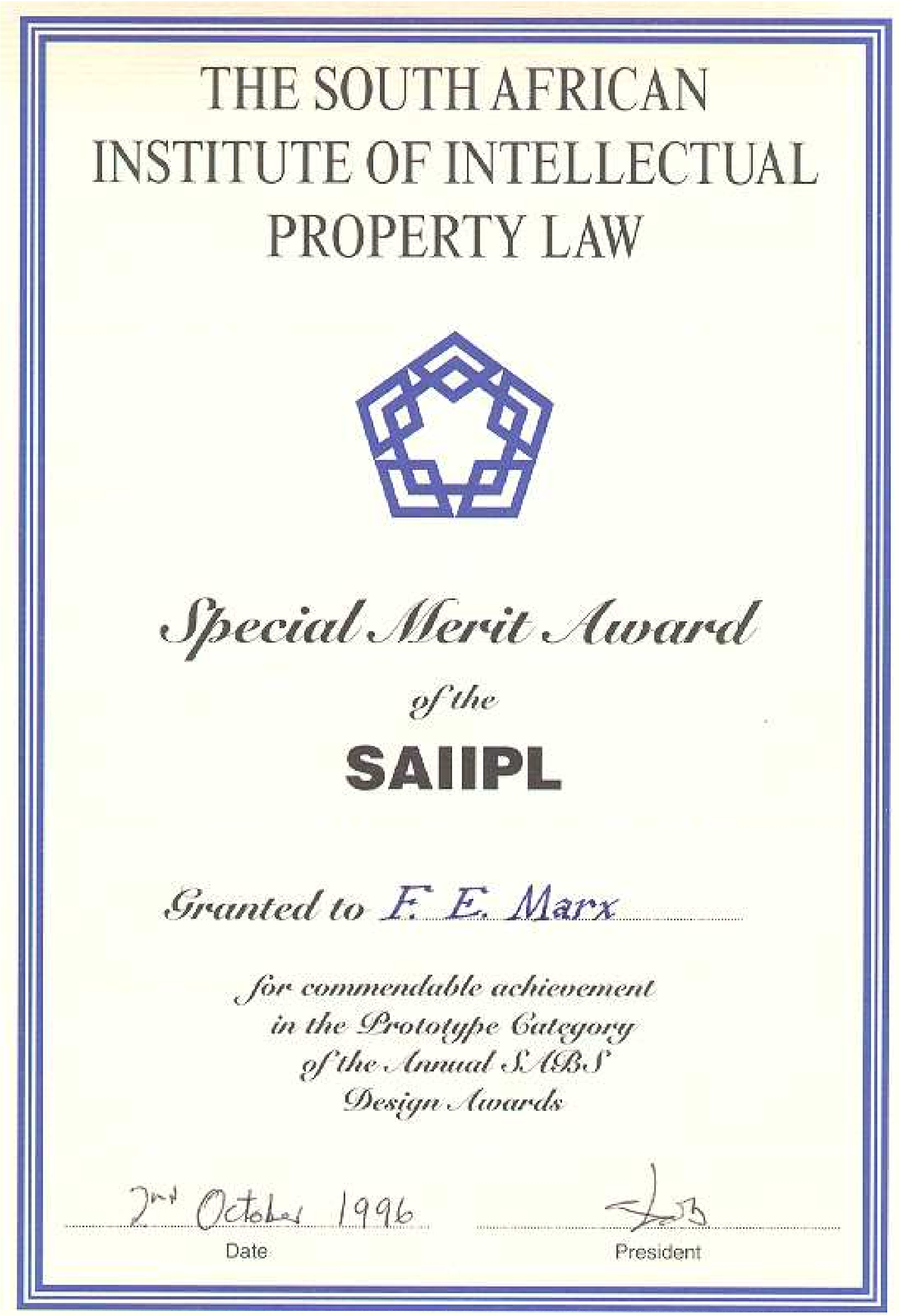


FIGURE A.18: Periodic Cross Correlation(PCC) function between unique combinations of complex spreading sequences 1 and 6 in decibels. $(L = 121, RU filtered, spc = 8)$

APPENDIX B

AWARDS RECEIVED DURING MASTERS DEGREE

- F.E. Marx and L.P. Linde, SABS design institute awards, 1996.
- F.E. Marx, Special Merit Award of the SAIIPL, 1996.
- L.P. Linde, D.J. van Wyk, B. Westra, F.E. Marx and W.H. Büttner, SABS design institute awards, 1997.



THE SOUTH AFRICAN INSTITUTE OF INTELLECTUAL PROPERTY LAW

Special Merit Award

of the

SAIIPL

Granted to F. E. Marx

for commendable achievement
in the Prototype Category
of the Annual SABS
Design Awards

2nd October 1996

Date

President

FIGURE B.1: Special Merit Award of the SAIIPL