
Development of an Electrostatic Energy Harvester for Implantable Devices

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University of Liège - School of Engineering and Computer
Science

Development of an Electrostatic Energy Harvester for Implantable Devices Annexe

An Autonomous Approach to Powering Medical Implants

Supervisor: Dr. Jean-Michel Rédouté

Master's thesis completed in order to obtain the degree of
Master of Science in Electrical Engineering

by George Irabor

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Appendix A

Full Program Implementation

```
1
2
3
4     /* USER CODE BEGIN Header */
5 /* USER CODE END Header */
6 /* Includes
   -----*/
7 #include "main.h"
8
9 /* Private includes
   -----*/
10 /* USER CODE BEGIN Includes */
11 #include <stdio.h>
12 #include <string.h>
13 #include <stdbool.h>
14 /* USER CODE END Includes */
15
16 /* Private typedef
   -----*/
17 /* USER CODE BEGIN PTD */
18 // Enumerate system states
19 typedef enum {
20     INVESTMENT,
21     HARVESTING,
22     REIMBURSEMENT,
23     RECOVERY
24 } SystemState;
25 /* USER CODE END PTD */
26
27 /* Private define
   -----*/
28 /* USER CODE BEGIN PD */
```

```

29 #define ADC_BUF_LEN 79 //Recovery phase buffer
30 #define MAX_CAP_THRESHOLD 3000 // Set based on observed values
31 #define MIN_CAP_THRESHOLD 200 // Set at 200 to switch just
    before reaching the maximum
32 #define EPSILON 20 // Small buffer to prevent frequent
    toggling near threshold values
33 // #define SAMPLES 5 // Number of samples for averaging
34
35 /* USER CODE END PD */
36
37 /* Private macro
    -----*/
38 /* USER CODE BEGIN PM */
39 /* USER CODE END PM */
40
41 /* Private variables
    -----*/
42 ADC_HandleTypeDef hadc1;
43 DMA_HandleTypeDef hdma_adc1;
44
45 TIM_HandleTypeDef htim2;
46 TIM_HandleTypeDef htim16;
47
48 UART_HandleTypeDef huart2;
49
50 /* USER CODE BEGIN PV */
51 uint16_t adc_buf[ADC_BUF_LEN];
52 volatile uint16_t maxValue;
53 volatile uint16_t maxVal;
54 volatile uint16_t HarvestVoltage;
55 volatile uint32_t smoothedValue;
56 SystemState system_state = RECOVERY; // Initial state
57 uint32_t adcValues[SAMPLES];
58 uint8_t sampleIndex = 0;
59 bool bufferFull = false;
60
61 /* Variable to report ADC analog watchdog status: */
62 /* RESET <=> voltage into AWD window */
63 /* SET <=> voltage out of AWD window */
64 volatile uint8_t ubAnalogWatchdogStatus = RESET; /* Set into
    analog watchdog interrupt callback */
65 /* USER CODE END PV */
66
67 /* Private function prototypes
    -----*/
68 void SystemClock_Config(void);
69 static void MX_GPIO_Init(void);
70 static void MX_DMA_Init(void);
71 static void MX_USART2_UART_Init(void);

```

```

72 static void MX_TIM2_Init(void);
73 static void MX_TIM16_Init(void);
74 static void MX_ADC1_Init(void);
75 /* USER CODE BEGIN PFP */
76 /* USER CODE END PFP */
77
78 /* Private user code
   -----*/
79 /* USER CODE BEGIN 0 */
80 void MicroDelay(uint16_t microseconds)
81 {
82     __HAL_TIM_SET_COUNTER(&htim16, 0); // if htim16 is the timer
           instance
83     __HAL_TIM_ENABLE(&htim16);
84     while (__HAL_TIM_GET_COUNTER(&htim16) < microseconds);
85     __HAL_TIM_DISABLE(&htim16);
86 }
87
88 void GeneratePulse(void) {
89     // Start ADC conversion
90     HAL_ADC_Start_DMA(&hadc1, (uint32_t*)adc_buf, ADC_BUF_LEN);
91     HAL_GPIO_WritePin(GPIOA, GPIO_PIN_6, GPIO_PIN_SET); //Connect
           Op amp output to ADC
92     HAL_GPIO_WritePin(GPIOA, GPIO_PIN_7, GPIO_PIN_SET); // Start
           charging the capacitor
93
94     //Start the ADC and take many samples with the DMA
95     MicroDelay(10); // Charge for a very short time
96     //Check the values and choose the largest value
97     HAL_GPIO_WritePin(GPIOA, GPIO_PIN_7, GPIO_PIN_RESET); //
           Discharge the capacitor
98     // Stop ADC conversion
99
100     HAL_ADC_Stop_DMA(&hadc1);
101     HAL_GPIO_WritePin(GPIOA, GPIO_PIN_6, GPIO_PIN_RESET);
           //disconnect Op amp output to ADC
102     processData();
103     HAL_Delay(500); //Delay before sending the next pulse
104
105 }
106
107 void processData() {
108     maxVal = 0;
109     for (int i = 0; i < 38; i++) {
110         if (adc_buf[i] > maxVal) maxVal = adc_buf[i];
111     }
112     uint16_t max = 1 + ((maxVal - 1200) * (1000 - 1)) / (1800 -
           1200); //Values set based on observed maximum and minimum

```

```

114     if (max <= 0){
115         max = 0;
116     }
117
118     maxValue = max;
119     if (maxValue > 4000){
120         maxValue = 9999; //For Debugging
121     }
122
123 }
124
125
126
127 void Update_GPIO_States(SystemState state) {
128     switch (state) {
129         //System states for use on the PCB directly. They are unused
130         //here as the PCB design is not optimal
131         case RECOVERY:
132             //HAL_GPIO_WritePin(GPIOB, GPIO_PIN_0, GPIO_PIN_RESET);
133             //HAL_GPIO_WritePin(GPIOB, GPIO_PIN_7, GPIO_PIN_RESET);
134             break;
135         case INVESTMENT:
136             //HAL_GPIO_WritePin(GPIOB, GPIO_PIN_0, GPIO_PIN_SET);
137             //HAL_GPIO_WritePin(GPIOB, GPIO_PIN_7, GPIO_PIN_RESET);
138             break;
139         case HARVESTING:
140             //HAL_GPIO_WritePin(GPIOB, GPIO_PIN_0, GPIO_PIN_SET);
141             //HAL_GPIO_WritePin(GPIOB, GPIO_PIN_7, GPIO_PIN_RESET);
142             break;
143         case REIMBURSEMENT:
144             //HAL_GPIO_WritePin(GPIOB, GPIO_PIN_0, GPIO_PIN_RESET);
145             //HAL_GPIO_WritePin(GPIOB, GPIO_PIN_7, GPIO_PIN_SET);
146             break;
147     }
148 }
149 //Function to smooth out ADC values
150 uint32_t getSmoothedValue(uint32_t newValue) {
151     adcValues[sampleIndex] = newValue;
152     sampleIndex++;
153     if (sampleIndex >= SAMPLES) {
154         sampleIndex = 0;
155         bufferFull = true;
156     }
157
158     uint32_t sum = 0;
159     uint32_t count = bufferFull ? SAMPLES : sampleIndex;
160     for (uint8_t i = 0; i < count; i++) {
161         sum += adcValues[i];

```

```

162
163     return sum / count; // Return the average
164 }
165 /* USER CODE END 0 */
166
167 /**
168  * @brief The application entry point.
169  * @retval int
170  */
171 int main(void)
172 {
173     /* USER CODE BEGIN 1 */
174
175     /* USER CODE END 1 */
176
177     /* MCU
178      Configuration-----*/
179
180     /* Reset of all peripherals, Initializes the Flash interface
181      and the Systick. */
182     HAL_Init();
183
184     /* USER CODE BEGIN Init */
185     /* USER CODE END Init */
186
187     /* Configure the system clock */
188     SystemClock_Config();
189
190     /* USER CODE BEGIN SysInit */
191     /* USER CODE END SysInit */
192
193     /* Initialize all configured peripherals */
194     MX_GPIO_Init();
195     MX_DMA_Init();
196     MX_USART2_UART_Init();
197     MX_TIM2_Init();
198     MX_TIM16_Init();
199     MX_ADC1_Init();
200     /* USER CODE BEGIN 2 */
201
202
203     /* USER CODE END 2 */
204
205     /* Infinite loop */
206     /* USER CODE BEGIN WHILE */
207     while (1)
208     {

```

```

209     switch (system_state) {
210         case RECOVERY:
211
212             HAL_GPIO_WritePin(GPIOB, GPIO_PIN_5,
213                 GPIO_PIN_RESET); //Keep reimbursement closed
214             HAL_GPIO_WritePin(GPIOA, GPIO_PIN_12,
215                 GPIO_PIN_SET); // Switch for charging the
216                 capacitor
217             HAL_GPIO_WritePin(GPIOA, GPIO_PIN_9,
218                 GPIO_PIN_SET); // Measurement is enabled
219
220             GeneratePulse();
221             HAL_GPIO_WritePin(GPIOA, GPIO_PIN_12,
222                 GPIO_PIN_RESET); // Switch for charging the
223                 capacitor
224             if (maxValue <= (MIN_CAP_THRESHOLD + EPSILON)) {
225                 HAL_GPIO_WritePin(GPIOA, GPIO_PIN_9,
226                     GPIO_PIN_RESET); // Isolate measurement
227                     circuit
228                 HAL_GPIO_WritePin(GPIOA, GPIO_PIN_6,
229                     GPIO_PIN_RESET); //Disconnect Opamp from
230                     ADC to prevent damage
231                 system_state = INVESTMENT;
232             }
233             break;
234
235         case INVESTMENT:
236
237             HAL_GPIO_WritePin(GPIOA, GPIO_PIN_7,
238                 GPIO_PIN_SET); // Start biasing capacitor
239             HAL_Delay(50); // Ensure full charge
240             HAL_GPIO_WritePin(GPIOA, GPIO_PIN_12,
241                 GPIO_PIN_RESET); // Isolate capacitor
242             HAL_GPIO_WritePin(GPIOA, GPIO_PIN_7,
243                 GPIO_PIN_RESET); // Turn off biasing
244
245             system_state = HARVESTING;
246             break;
247
248         case HARVESTING:
249             // HAL_ADC_Start_DMA(&hadc1, (uint32_t*)adc_buf,
250             ADC_BUF_LEN);
251             HAL_GPIO_WritePin(GPIOA, GPIO_PIN_9,
252                 GPIO_PIN_SET); // Enable measurement
253             HAL_GPIO_WritePin(GPIOA, GPIO_PIN_6,
254                 GPIO_PIN_RESET); //Keep ADC from damage
255             HAL_Delay(1000); //Wait for a while to harvest
256             system_state = REIMBURSEMENT;
257             break;

```



```

242
243         case REIMBURSEMENT:
244             HAL_GPIO_WritePin(GPIOB, GPIO_PIN_5,
                GPIO_PIN_RESET); // Discharge into storage
                capacitor
245             HAL_Delay(100); // Ensure discharge
246             HAL_GPIO_WritePin(GPIOB, GPIO_PIN_5,
                GPIO_PIN_RESET); // Turn off discharge
247             system_state = RECOVERY;
248             HAL_Delay(1000);
249             HAL_GPIO_WritePin(GPIOA, GPIO_PIN_9,
                GPIO_PIN_RESET); //Measurement is disabled
250             break;
251     }
252
253     // General GPIO or control updates
254     Update_GPIO_States(system_state);
255
256     /* USER CODE END WHILE */
257
258     /* USER CODE BEGIN 3 */
259     }
260     /* USER CODE END 3 */
261 }
262
263 /**
264  * @brief System Clock Configuration
265  * @retval None
266  */
267 void SystemClock_Config(void)
268 {
269     RCC_OscInitTypeDef RCC_OscInitStruct = {0};
270     RCC_ClkInitTypeDef RCC_ClkInitStruct = {0};
271
272     /** Configure the main internal regulator output voltage
273     */
274     if
275         (HAL_PWREx_ControlVoltageScaling(PWR_REGULATOR_VOLTAGE_SCALE1)
276          != HAL_OK)
277     {
278         Error_Handler();
279     }
280
281     /** Configure LSE Drive Capability
282     */
283     HAL_PWR_EnableBkUpAccess();
284     __HAL_RCC_LSEDRIVE_CONFIG(RCC_LSEDRIVE_LOW);

```

```

    parameters
285  * in the RCC_OscInitTypeDef structure.
286  */
287  RCC_OscInitStruct.OscillatorType =
    RCC_OSCILLATORTYPE_LSE|RCC_OSCILLATORTYPE_MSI;
288  RCC_OscInitStruct.LSEState = RCC_LSE_ON;
289  RCC_OscInitStruct.MSIState = RCC_MSI_ON;
290  RCC_OscInitStruct.MSICalibrationValue = 0;
291  RCC_OscInitStruct.MSIClockRange = RCC_MSIRANGE_10;
292  RCC_OscInitStruct.PLL.PLLState = RCC_PLL_NONE;
293  if (HAL_RCC_OscConfig(&RCC_OscInitStruct) != HAL_OK)
294  {
295      Error_Handler();
296  }
297
298  /** Initializes the CPU, AHB and APB buses clocks
299  */
300  RCC_ClkInitStruct.ClockType =
    RCC_CLOCKTYPE_HCLK|RCC_CLOCKTYPE_SYSCLK
301      |RCC_CLOCKTYPE_PCLK1|RCC_CLOCKTYPE_PCLK2;
302  RCC_ClkInitStruct.SYSCLKSource = RCC_SYSCLKSOURCE_MSI;
303  RCC_ClkInitStruct.AHBCLKDivider = RCC_SYSCLK_DIV1;
304  RCC_ClkInitStruct.APB1CLKDivider = RCC_HCLK_DIV1;
305  RCC_ClkInitStruct.APB2CLKDivider = RCC_HCLK_DIV1;
306
307  if (HAL_RCC_ClockConfig(&RCC_ClkInitStruct, FLASH_LATENCY_1) !=
    HAL_OK)
308  {
309      Error_Handler();
310  }
311
312  /** Enable MSI Auto calibration
313  */
314  HAL_RCCEx_EnableMSIPLLMode();
315  }
316
317  /**
318   * @brief ADC1 Initialization Function
319   * @param None
320   * @retval None
321   */
322  static void MX_ADC1_Init(void)
323  {
324
325      /* USER CODE BEGIN ADC1_Init 0 */
326
327      /* USER CODE END ADC1_Init 0 */
328
329      ADC_MultiModeTypeDef multimode = {0};

```

```

330     ADC_ChannelConfTypeDef sConfig = {0};
331
332     /* USER CODE BEGIN ADC1_Init 1 */
333
334     /* USER CODE END ADC1_Init 1 */
335
336     /** Common config
337     */
338     hadc1.Instance = ADC1;
339     hadc1.Init.ClockPrescaler = ADC_CLOCK_ASYNC_DIV1;
340     hadc1.Init.Resolution = ADC_RESOLUTION_12B;
341     hadc1.Init.DataAlign = ADC_DATAALIGN_RIGHT;
342     hadc1.Init.ScanConvMode = ADC_SCAN_DISABLE;
343     hadc1.Init.EOCSelection = ADC_EOC_SINGLE_CONV;
344     hadc1.Init.LowPowerAutoWait = DISABLE;
345     hadc1.Init.ContinuousConvMode = ENABLE;
346     hadc1.Init.NbrOfConversion = 1;
347     hadc1.Init.DiscontinuousConvMode = DISABLE;
348     hadc1.Init.ExternalTrigConv = ADC_SOFTWARE_START;
349     hadc1.Init.ExternalTrigConvEdge = ADC_EXTERNALTRIGCONVEDGE_NONE;
350     hadc1.Init.DMAContinuousRequests = ENABLE;
351     hadc1.Init.Overrun = ADC_OVR_DATA_PRESERVED;
352     hadc1.Init.OversamplingMode = DISABLE;
353     if (HAL_ADC_Init(&hadc1) != HAL_OK)
354     {
355         Error_Handler();
356     }
357
358     /** Configure the ADC multi-mode
359     */
360     multimode.Mode = ADC_MODE_INDEPENDENT;
361     if (HAL_ADCEx_MultiModeConfigChannel(&hadc1, &multimode) !=
362         HAL_OK)
363     {
364         Error_Handler();
365     }
366
367     /** Configure Regular Channel
368     */
369     sConfig.Channel = ADC_CHANNEL_8;
370     sConfig.Rank = ADC_REGULAR_RANK_1;
371     sConfig.SamplingTime = ADC_SAMPLETIME_2CYCLES_5;
372     sConfig.SingleDiff = ADC_SINGLE_ENDED;
373     sConfig.OffsetNumber = ADC_OFFSET_NONE;
374     sConfig.Offset = 0;
375     if (HAL_ADC_ConfigChannel(&hadc1, &sConfig) != HAL_OK)
376     {
377         Error_Handler();
378     }

```

```

378     /* USER CODE BEGIN ADC1_Init 2 */
379
380     /* USER CODE END ADC1_Init 2 */
381
382 }
383
384 /**
385  * @brief TIM2 Initialization Function
386  * @param None
387  * @retval None
388  */
389 static void MX_TIM2_Init(void)
390 {
391
392     /* USER CODE BEGIN TIM2_Init 0 */
393     /* USER CODE END TIM2_Init 0 */
394
395     TIM_ClockConfigTypeDef sClockSourceConfig = {0};
396     TIM_MasterConfigTypeDef sMasterConfig = {0};
397     TIM_IC_InitTypeDef sConfigIC = {0};
398
399     /* USER CODE BEGIN TIM2_Init 1 */
400     /* USER CODE END TIM2_Init 1 */
401     htim2.Instance = TIM2;
402     htim2.Init.Prescaler = 0;
403     htim2.Init.CounterMode = TIM_COUNTERMODE_UP;
404     htim2.Init.Period = 4294967295;
405     htim2.Init.ClockDivision = TIM_CLOCKDIVISION_DIV1;
406     htim2.Init.AutoReloadPreload = TIM_AUTORELOAD_PRELOAD_DISABLE;
407     if (HAL_TIM_Base_Init(&htim2) != HAL_OK)
408     {
409         Error_Handler();
410     }
411     sClockSourceConfig.ClockSource = TIM_CLOCKSOURCE_INTERNAL;
412     if (HAL_TIM_ConfigClockSource(&htim2, &sClockSourceConfig) !=
413         HAL_OK)
414     {
415         Error_Handler();
416     }
417     if (HAL_TIM_IC_Init(&htim2) != HAL_OK)
418     {
419         Error_Handler();
420     }
421     sMasterConfig.MasterOutputTrigger = TIM_TRGO_RESET;
422     sMasterConfig.MasterSlaveMode = TIM_MASTERSLAVEMODE_DISABLE;
423     if (HAL_TIMEx_MasterConfigSynchronization(&htim2,
424         &sMasterConfig) != HAL_OK)

```

```

425     }
426     sConfigIC.ICPolarity = TIM_INPUTCHANNELPOLARITY_RISING;
427     sConfigIC.ICSelection = TIM_ICSELECTION_DIRECTTI;
428     sConfigIC.ICPrescaler = TIM_ICPSC_DIV1;
429     sConfigIC.ICFilter = 0;
430     if (HAL_TIM_IC_ConfigChannel(&htim2, &sConfigIC, TIM_CHANNEL_1)
        != HAL_OK)
431     {
432         Error_Handler();
433     }
434     /* USER CODE BEGIN TIM2_Init 2 */
435     /* USER CODE END TIM2_Init 2 */
436
437 }
438
439 /**
440  * @brief TIM16 Initialization Function
441  * @param None
442  * @retval None
443  */
444 static void MX_TIM16_Init(void)
445 {
446
447     /* USER CODE BEGIN TIM16_Init 0 */
448     /* USER CODE END TIM16_Init 0 */
449
450     /* USER CODE BEGIN TIM16_Init 1 */
451     /* USER CODE END TIM16_Init 1 */
452     htim16.Instance = TIM16;
453     htim16.Init.Prescaler = 7;
454     htim16.Init.CounterMode = TIM_COUNTERMODE_UP;
455     htim16.Init.Period = 65535;
456     htim16.Init.ClockDivision = TIM_CLOCKDIVISION_DIV1;
457     htim16.Init.RepetitionCounter = 0;
458     htim16.Init.AutoReloadPreload = TIM_AUTORELOAD_PRELOAD_DISABLE;
459     if (HAL_TIM_Base_Init(&htim16) != HAL_OK)
460     {
461         Error_Handler();
462     }
463     /* USER CODE BEGIN TIM16_Init 2 */
464     /* USER CODE END TIM16_Init 2 */
465
466 }
467
468 /**
469  * @brief USART2 Initialization Function
470  * @param None
471  * @retval None
472  */

```

```

473 static void MX_USART2_UART_Init(void)
474 {
475
476     /* USER CODE BEGIN USART2_Init 0 */
477     /* USER CODE END USART2_Init 0 */
478
479     /* USER CODE BEGIN USART2_Init 1 */
480     /* USER CODE END USART2_Init 1 */
481     huart2.Instance = USART2;
482     huart2.Init.BaudRate = 115200;
483     huart2.Init.WordLength = UART_WORDLENGTH_8B;
484     huart2.Init.StopBits = UART_STOPBITS_1;
485     huart2.Init.Parity = UART_PARITY_NONE;
486     huart2.Init.Mode = UART_MODE_TX_RX;
487     huart2.Init.HwFlowCtl = UART_HWCONTROL_NONE;
488     huart2.Init.OverSampling = UART_OVERSAMPLING_16;
489     huart2.Init.OneBitSampling = UART_ONE_BIT_SAMPLE_DISABLE;
490     huart2.AdvancedInit.AdvFeatureInit = UART_ADVFEATURE_NO_INIT;
491     if (HAL_UART_Init(&huart2) != HAL_OK)
492     {
493         Error_Handler();
494     }
495     /* USER CODE BEGIN USART2_Init 2 */
496     /* USER CODE END USART2_Init 2 */
497
498 }
499
500 /**
501  * Enable DMA controller clock
502  */
503 static void MX_DMA_Init(void)
504 {
505
506     /* DMA controller clock enable */
507     __HAL_RCC_DMA1_CLK_ENABLE();
508
509     /* DMA interrupt init */
510     /* DMA1_Channel1_IRQn interrupt configuration */
511     HAL_NVIC_SetPriority(DMA1_Channel1_IRQn, 0, 0);
512     HAL_NVIC_EnableIRQ(DMA1_Channel1_IRQn);
513
514 }
515
516 /**
517  * @brief GPIO Initialization Function
518  * @param None
519  * @retval None
520  */
521 static void MX_GPIO_Init(void)

```

```

522 {
523     GPIO_InitTypeDef GPIO_InitStruct = {0};
524     /* USER CODE BEGIN MX_GPIO_Init_1 */
525     /* USER CODE END MX_GPIO_Init_1 */
526
527     /* GPIO Ports Clock Enable */
528     __HAL_RCC_GPIOC_CLK_ENABLE();
529     __HAL_RCC_GPIOA_CLK_ENABLE();
530     __HAL_RCC_GPIOB_CLK_ENABLE();
531
532     /*Configure GPIO pin Output Level */
533     HAL_GPIO_WritePin(GPIOA,
534         SW4_Pin|Pulse_Out_Pin|GPIO_PIN_8|Outswitch2_Pin
535         |GPIO_PIN_10|OutSwitch1_Pin,
536         GPIO_PIN_RESET);
537
538     /*Configure GPIO pin Output Level */
539     HAL_GPIO_WritePin(GPIOB, SW1_Pin|LD3_Pin|SW3_Pin|CHRG_EN_Pin
540         |SW2_Pin, GPIO_PIN_RESET);
541
542     /*Configure GPIO pins : SW4_Pin Pulse_Out_Pin PA8 Outswitch2_Pin
543         PA10 OutSwitch1_Pin */
544     GPIO_InitStruct.Pin =
545         SW4_Pin|Pulse_Out_Pin|GPIO_PIN_8|Outswitch2_Pin
546         |GPIO_PIN_10|OutSwitch1_Pin;
547     GPIO_InitStruct.Mode = GPIO_MODE_OUTPUT_PP;
548     GPIO_InitStruct.Pull = GPIO_NOPULL;
549     GPIO_InitStruct.Speed = GPIO_SPEED_FREQ_LOW;
550     HAL_GPIO_Init(GPIOA, &GPIO_InitStruct);
551
552     /*Configure GPIO pins : SW1_Pin LD3_Pin SW3_Pin CHRG_EN_Pin
553         SW2_Pin */
554     GPIO_InitStruct.Pin = SW1_Pin|LD3_Pin|SW3_Pin|CHRG_EN_Pin
555         |SW2_Pin;
556     GPIO_InitStruct.Mode = GPIO_MODE_OUTPUT_PP;
557     GPIO_InitStruct.Pull = GPIO_NOPULL;
558     GPIO_InitStruct.Speed = GPIO_SPEED_FREQ_LOW;
559     HAL_GPIO_Init(GPIOB, &GPIO_InitStruct);
560
561     /*Configure GPIO pin : PA11 */
562     GPIO_InitStruct.Pin = GPIO_PIN_11;
563     GPIO_InitStruct.Mode = GPIO_MODE_AF_PP;
564     GPIO_InitStruct.Pull = GPIO_NOPULL;
565     GPIO_InitStruct.Speed = GPIO_SPEED_FREQ_LOW;
566     GPIO_InitStruct.Alternate = GPIO_AF12_COMP1;
567     HAL_GPIO_Init(GPIOA, &GPIO_InitStruct);
568
569     /* USER CODE BEGIN MX_GPIO_Init_2 */
570     /* USER CODE END MX_GPIO_Init_2 */

```

```

568 }
569
570 /* USER CODE BEGIN 4 */
571 //Called when first half of buffer is filled
572 void HAL_ADC_ConvHalfCpltCallback(ADC_HandleTypeDef* hadc){
573     if (hadc->Instance == ADC1) {
574         HAL_GPIO_TogglePin(GPIOA, GPIO_PIN_10);
575     }
576 }
577
578
579
580 //Called when buffer is completely filled
581 void HAL_ADC_ConvCpltCallback(ADC_HandleTypeDef* hadc) {
582     if (hadc->Instance == ADC1) {
583         HAL_GPIO_TogglePin(GPIOA, GPIO_PIN_10);
584     }
585 }
586
587 void HAL_ADC_LevelOutOfWindowCallback(ADC_HandleTypeDef* hadc)
588 {
589     /* Set variable to report analog watchdog out of window
590        status to main          */
591     /* program.
592
593        */
594     //HarvestVoltage = HAL_ADC_GetValue(&hadc2);
595     ubAnalogWatchdogStatus = SET;
596 }
597
598 /* USER CODE END 4 */
599
600 /**
601  * @brief This function is executed in case of error occurrence.
602  * @retval None
603  */
604 void Error_Handler(void)
605 {
606     /* USER CODE BEGIN Error_Handler_Debug */
607     /* USER CODE END Error_Handler_Debug */
608 }
609
610 #ifdef USE_FULL_ASSERT
611 /**
612  * @brief Reports the name of the source file and the source
613         line number
614  *
615  * where the assert_param error has occurred.
616  * @param file: pointer to the source file name
617  * @param line: assert_param error line source number

```



```
613     * @retval None
614     */
615 void assert_failed(uint8_t *file, uint32_t line)
616 {
617     /* USER CODE BEGIN 6 */
618     /* USER CODE END 6 */
619 }
620 #endif /* USE_FULL_ASSERT */
```

Listing A.1: HAL C code written for STM32L412KB NucleoBoard for ElectroStatic Energy Harvesting