**Final Project Theremin – ECE 5780**

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**Objective**

The purpose of this lab is to implement a program using FreeRTOS to create a digital theremin instrument that can play 25 discrete notes from C3 to C5 and adjust between 8 discrete volumes. Then to use this digital theremin to play a simple song like “Mary had a Little Lamb.”

**Procedure**

For this lab we started by testing the previous code that we had used in Lab 4. This included code that would run the distance sensor and code that would be able to drive the speaker. Once we were able to confirm that we had things set up correctly for that lab to run we began working on the features we would need to add to the new lab.

The first feature that we added was the additional notes that are needed to fulfil the lab requirements. This included two additional octaves. Once we were able to confirm that these notes functioned correctly, we removed the control of the pitch from the keyboard/UART connection and moved it into the distance sensor control. We would poll the distance sensor for a reading every 100ms then use that reading to determine the pitch to be played through the speaker.

Once we had confirmed that each note was playable by controlling the temperature sensor, we moved on to the volume control with the second distance sensor. This included adding an additional UART connection. The UART that we chose to use was UART 4. We connected the second distance sensor and once we had the UART set up we were able to get readings from that sensor as well.

With the second UART connection setup we next had to find a way to control the volume. We decided to control the amplitude of the sine wave that we send to the DAC. This was done by simply multiplying the outputs to the DAC by a scalar. The scalar that we used was based on the 8 volume levels that were required by the lab. With a scalar of 1 being the highest volume and a scalar of 0 being the lowest volume.

The final step that we had to take was making sure that everything got reported to the serial monitor correctly. We made sure that each volume and note change was displayed on the serial monitor. This required use of a mutex to control access to UART 2, which the serial monitor used, because the volume and note changing functions were contained in different tasks.

Once all of this was finished the lab was basically done. The only thing that we had to do was practice and perform a song. The song that we chose to perform was “Mary had a Little Lamb”. We chose this song for its simplicity and beauty.

**Results**

For our lab to produce the desired results we had to modify our existing code to incorporate the new feature of a second proximity sensor and to use the proximity sensors to adjust the volume and frequency of the sound produced from the audio amplifier circuit. In order to do this we had to implement a third UART connection that wrote to and read from the volume controling proximity sensor. While initializing the third UART we had an issue that our UART would not produce any data from the proximity sensor even though we had initialized it the exact same as the previous UARTs. We then found that because we used UART4 that it used a different alternative fuction mode AF8 instead of AF7 which we had previously used on our other two USARTs. After changing this setting the proximity sensor worked great.

**A group of electrical components

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**Figure 1. Proximity Sensors and Audio Amplifier Circuit connected to STM32 Nucleo Board**

After getting both proximity sensors working, we then modified the number of frequencies we could produce to include all the half step notes from C3 to C5, 25 frequencies in total. We implemented a system to make the distance range for each note to be 1 inch tall. We then implemented a scaling variable inside of our timer Interrupt handler that would scale the output of the interrupt based on the sensor data we got to raise or lower the volume of the audio circuit. This allowed us to produce 8 different volume levels from off at 0 to 7 as full volume. We set the volume to change each two inches for each volume except for the first volume level 0 which was 6 inches because it was the most important to use with the instrument and made it easier to play. We then modified our UART2 output to the serial terminal to send updates with the current volume and note being played if there was a change from the previous note or volume.

After testing the playablity of the theremin it was determined that it was very difficult to play with the circuit capable of changing a note 100 times a second. We therefore slowed down the rate of the proximity sensors to run at a 100 ms rate so we could get 10 different notes per second. This made it easier to play and allowed the player to skip in between notes that they did not want to play. After getting the theremin working we then practiced playing the song “Mary had a little lamb” to pass of the final project lab. We then passed it off (With a few mistasks but it least it was kind of recognizable).

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**Figure 2. Pitch and Volume Proximity Sensors Outputs on Serial Terminal**

**Conclusion**

In conclusion, we were able to get our final project theremin instrument working. The theremin is able to play 25 distinct notes from C3 to C5 using the measurements from the first proximity sensor. We are also able to change the volume level of the audio circuit using the second proximity sensor to eight distinct volumes from off to fully on. Our theremin also outputs any changes in the current note or volume to a serial terminal through UART2. In the end our theremin was playable, could produce a recognizable song and met all of the final project requirements. However, it was a bit difficult to play even with practice but this came down to user error instead of a design problem.

**Appendix**

***Main.c code***

1. #include "FreeRTOS.h"

2. #include "stm32l476xx.h"

3. #include "system\_stm32l4xx.h"

4. #include "task.h"

5. #include "timers.h"

6. #include "stdint.h"

7. #include "queue.h"

8. #include "stdio.h"

9. #include "semphr.h"

10.

11. #include "init.h"

12.

13. int main(void) {

14. //Initialize System

15. SystemInit();

16. clock\_Config();

17. but\_led\_queue = xQueueCreate(2,sizeof(uint8\_t));

18. but\_tim\_queue = xQueueCreate(2,sizeof(uint8\_t));

19. uart2\_to\_uart3\_queue = xQueueCreate(4,sizeof(uint8\_t));

20. vol\_queue = xQueueCreate(2,sizeof(float));

21.

22. gpio\_Config();

23. USART2\_config();

24. USART3\_config();

25. UART4\_config();

26. timer\_Config();

27. DAC\_Config();

28.

29. //Set the priority for the interrupts

30. //NVIC\_SetPriority(USART2\_IRQn,0x07);

31. NVIC\_SetPriority(TIM4\_IRQn,0x07);

32.

33. //Mutex for writing to serial terminal

34. uart\_mutex = xSemaphoreCreateMutex();

35.

36. //Task for LED

37. if(xTaskCreate(LED\_task, "LED", 32, NULL, 2, NULL) != pdPASS){

38. while(1);

39. }

40. //Task for Button

41. if(xTaskCreate(Button\_task, "Button", 32, NULL, 2, NULL) != pdPASS){

42. while(1);

43. }

44.

45. if(xTaskCreate(note\_task, "note\_task", 256, NULL, 2, ¬e\_handle) != pdPASS){

46. while(1);

47. }

48.

49. if(xTaskCreate(volume\_task, "volume\_task", 256, NULL, 2, &vol\_handle) != pdPASS){

50. while(1);

51. }

52.

53. //Start Task Scheduler

54. vTaskStartScheduler();

55. while(1);

56. }

57.

58. //Function to toggle led\_state

59. void LED\_task(void \*pvParameters){

60. static uint8\_t buffer[1];

61. buffer[0] = 0;

62. while(1){

63. if(uxQueueMessagesWaiting(but\_led\_queue) > 0){

64. if(xQueueReceive(but\_led\_queue,buffer,50)== pdTRUE){}

65. }

66. //If the LED is off turn it on

67. if(buffer[0] == 1){

68. GPIOA->BSRR |= GPIO\_BSRR\_BS5;

69. }

70. //If the LED is on turn it off

71. else if(buffer[0] == 0){

72. GPIOA->BSRR |= GPIO\_BSRR\_BR5;

73. }

74. }

75. }

76.

77. //Function to read in button state and led\_state

78. void Button\_task(void \*pvParameters){

79. static uint8\_t buffer[1];

80. buffer[0] = 0;

81. uint32\_t button\_in;

82. while(1){

83. //Read in the value of the button

84. button\_in = GPIOC->IDR;

85. button\_in &= GPIO\_IDR\_ID13\_Msk;

86.

87. //If the button is pressed toggle the LED

88. if(button\_in == 0){

89. while(button\_in == 0){

90. button\_in = GPIOC->IDR;

91. button\_in &= GPIO\_IDR\_ID13\_Msk;

92. }

93. if(buffer[0] == 0){

94. buffer[0] = 1;

95. //Send led\_state to queue for LED Task

96. xQueueSendToBack(but\_led\_queue,buffer,50);

97. //Send led\_state to queue for TIM4\_IRQHandler

98. xQueueSendToBack(but\_tim\_queue,buffer,50);

99. }

100. else {

101. buffer[0] = 0;

102. //Send led\_state to queue for LED Task

103. xQueueSendToBack(but\_led\_queue,buffer,50);

104. //Send led\_state to queue for TIM4\_IRQHandler

105. xQueueSendToBack(but\_tim\_queue,buffer,50);

106. }

107. }

108. }

109. }

110.

111. void TIM4\_IRQHandler(void){

112. static uint32\_t sine\_count = 0;

113. static uint8\_t buffer[1];

114. //Valid Volumes: 0 0.1428 0.2856 0.4284 0.5712 0.714 0.8568 1

115. static float volume[1] = {1.0};

116.

117. const uint16\_t sineLookupTable[] = {

118. 305, 335, 365, 394, 422, 449, 474, 498, 521, 541, 559, 574, 587, 597, 604,

119. 609, 610, 609, 604, 597, 587, 574, 559, 541, 521, 498, 474, 449, 422, 394,

120. 365, 335, 305, 275, 245, 216, 188, 161, 136, 112, 89, 69, 51, 36, 23,

121. 13, 6, 1, 0, 1, 6, 13, 23, 36, 51, 69, 89, 112, 136, 161,

122. 188, 216, 245, 275};

123.

124. //if there is a message waiting in the queue from ISR

125. if(uxQueueMessagesWaitingFromISR(but\_tim\_queue) > 0){

126. xQueueReceiveFromISR(but\_tim\_queue,buffer,NULL);

127. }

128. //if the LED is on

129. if (buffer[0] == 1){

130. sine\_count++; //Increment to the next value in the table

131. if (sine\_count == 64){

132. sine\_count = 0;

133. }

134. }

135. //if there is a message waiting in the queue from ISR

136. if(uxQueueMessagesWaitingFromISR(vol\_queue) > 0){

137. xQueueReceiveFromISR(vol\_queue,volume,NULL);

138. }

139.

140. //Assign DAC to Sine\_Wave Table Current Value

141. DAC->DHR12R1 = (uint16\_t)(sineLookupTable[sine\_count]\* volume[0]) + 45;

142. TIM4->SR &= ~TIM\_SR\_UIF; //Clears Interrupt Flag

143. }

144.

145. /\*void USART2\_IRQHandler(void){

146. uint8\_t uart\_buffer[1];

147. uart\_buffer[0] = (uint8\_t)(USART2->RDR); //Get serial data

148. change\_note(uart\_buffer[0]);

149. //If uart\_buffer = t or p send into the queue

150. if (uart\_buffer[0] == 't' || uart\_buffer[0] == 'p'){

151. xQueueSendToBackFromISR(uart2\_to\_uart3\_queue,uart\_buffer,NULL);

152. }

153. }\*/

154.

155. void change\_note(uint8\_t note){

156. if (note == 'a'){

157. TIM4->ARR = 0xFFFF00EF; //239; 130.813 Hz C3

158. }

159. else if (note == 'b'){

160. TIM4->ARR = 0xFFFF00E1; //225; 138.591 Hz C#3

161. }

162. else if (note == 'c'){

163. TIM4->ARR = 0xFFFF00D5; //213; 146.832 Hz D3

164. }

165. else if (note == 'd'){

166. TIM4->ARR = 0xFFFF00C9; //201; 155.563 Hz D#3

167. }

168. else if (note == 'e'){

169. TIM4->ARR = 0xFFFF00BE; //190; 164.814 Hz E3

170. }

171. else if (note == 'f'){

172. TIM4->ARR = 0xFFFF00B3; //179; 174.614 Hz F3

173. }

174. else if (note == 'g'){

175. TIM4->ARR = 0xFFFF00A9; //169; 184.997 Hz F#3

176. }

177. else if (note == 'h'){

178. TIM4->ARR = 0xFFFF009F; //159; 195.998 Hz G3

179. }

180. else if (note == 'i'){

181. TIM4->ARR = 0xFFFF0096; //150; 207.652 Hz G#3

182. }

183. else if (note == 'j'){

184. TIM4->ARR = 0xFFFF008E; //2 MHz/(142) = 14.080 kHz interrupt rate; 220 Hz sine wave A3

185. }

186. else if (note == 'k'){

187. TIM4->ARR = 0xFFFF0086; //134; 233.082 Hz sine wave A#3

188. }

189. else if (note == 'l'){

190. TIM4->ARR = 0xFFFF007E; //126; 246.94 Hz B3

191. }

192. else if (note == 'm'){

193. TIM4->ARR = 0xFFFF0077; //119; 261.626 Hz C4

194. }

195. else if (note == 'n'){

196. TIM4->ARR = 0xFFFF0071; //113; 277.183 Hz C#4

197. }

198. else if (note == 'o'){

199. TIM4->ARR = 0xFFFF006A; //106; 293.66 Hz D4

200. }

201. else if (note == 'p'){

202. TIM4->ARR = 0xFFFF0064; //100; 311.127 Hz D#4

203. }

204. else if (note == 'q'){

205. TIM4->ARR = 0xFFFF005E; //94; 329.63 Hz E4

206. }

207. else if (note == 'r'){

208. TIM4->ARR = 0xFFFF0059; //89; 349.23 Hz F4

209. }

210. else if (note == 's'){

211. TIM4->ARR = 0xFFFF0054; //84; 369.994 Hz F#4

212. }

213. else if (note == 't'){

214. TIM4->ARR = 0xFFFF004F; //80; 392.00 Hz G4

215. }

216. else if (note == 'u'){

217. TIM4->ARR = 0xFFFF004B; //75; 415.305 Hz G#4

218. }

219. else if (note == 'v'){

220. TIM4->ARR = 0xFFFF0046; //71; 440 Hz A4

221. }

222. else if (note == 'w'){

223. TIM4->ARR = 0xFFFF0043; //67; 466.164 Hz A#4

224. }

225. else if (note == 'x'){

226. TIM4->ARR = 0xFFFF003F; //63; 493.883 Hz B4

227. }

228. else if (note == 'y'){

229. TIM4->ARR = 0xFFFF003C; //60; 523.251 Hz C5

230. }

231. }

232.

233. void note\_task(void \*pvParameters){

234. uint16\_t measurement;

235. float inches = 0;

236. uint32\_t change = 0;

237.

238. //Track what is the previous and current note being played

239. uint8\_t note = 'a';

240. uint8\_t prev\_note = 'a';

241. float volume[1] = {1};

242. //float prev\_volume[1] = {1};

243.

244. while(1){

245. vTaskPrioritySet(note\_handle,3);

246. USART3\_write(0x55);

247. while (!(USART3->ISR & USART\_ISR\_RXNE)); //Wait until hardware sets RXNE

248. measurement = USART3->RDR;

249. measurement \*= 256;

250. while (!(USART3->ISR & USART\_ISR\_RXNE)); //Wait until hardware sets RXNE

251. measurement += USART3->RDR;

252. inches = (float)(measurement / 25.4);

253.

254. //Based on the distance from the sensor change the note being played

255. if (inches <= 2){ //C3

256. note = 'a';

257. }

258. else if (inches > 2 && inches <= 3){ //C#3

259. note = 'b';

260. }

261. else if (inches > 3 && inches <= 4){ //D3

262. note = 'c';

263. }

264. else if (inches > 4 && inches <= 5){ //D#3

265. note = 'd';

266. }

267. else if (inches > 5 && inches <= 6){ //E3

268. note = 'e';

269. }

270. else if (inches > 6 && inches <= 7){ //F3

271. note = 'f';

272. }

273. else if (inches > 7 && inches <= 8){ //F#3

274. note = 'g';

275. }

276. else if (inches > 8 && inches <= 9){ //G3

277. note = 'h';

278. }

279. else if (inches > 9 && inches <= 10){ //G#3

280. note = 'i';

281. }

282. else if (inches > 10 && inches <= 11){ //A3

283. note = 'j';

284. }

285. else if (inches > 11 && inches <= 12){ //A#3

286. note = 'k';

287. }

288. else if (inches > 12 && inches <= 13){ //B3

289. note = 'l';

290. }

291. else if (inches > 13 && inches <= 16){ //C4 --Mary 13 - 16

292. note = 'm';

293. }

294. else if (inches > 16 && inches <= 17){ //C#4

295. note = 'n';

296. }

297. else if (inches > 17 && inches <= 20){ //D4 --Mary 17 - 20

298. note = 'o';

299. }

300. else if (inches > 20 && inches <= 21){ //D#4

301. note = 'p';

302. }

303. else if (inches > 21 && inches <= 24){ //E4 --Mary 21 - 24

304. note = 'q';

305. }

306. else if (inches > 24 && inches <= 25){ //F4

307. note = 'r';

308. }

309. else if (inches > 25 && inches <= 26){ //F#4

310. note = 's';

311. }

312. else if (inches > 26 && inches <= 29){ //G4 --Mary 26 - 29

313. note = 't';

314. }

315. else if (inches > 29 && inches <= 30){ //G#4

316. note = 'u';

317. }

318. else if (inches > 30 && inches <= 31){ //A4

319. note = 'v';

320. }

321. else if (inches > 31 && inches <= 32){ //A#4

322. note = 'w';

323. }

324. else if (inches > 32 && inches <= 33){ //B4

325. note = 'x';

326. }

327. else if (inches > 34){ //C5

328. note = 'y';

329. }

330.

331. //Change the note frequency based on distance from sensor

332. change\_note(note);

333. //Only update output on serial terminal if the note changed

334. if (note != prev\_note ){

335. change = 0;

336. xSemaphoreTake(uart\_mutex,(TickType\_t)50);

337. USART2\_write(note,volume,change);

338. xSemaphoreGive(uart\_mutex);

339. }

340. prev\_note = note;

341. vTaskPrioritySet(note\_handle,2);

342. vTaskDelay(100 / portTICK\_PERIOD\_MS);

343. }

344. }

345.

346. void volume\_task(void \*pvParameters){

347. uint16\_t measurement;

348. float inches = 0;

349. uint32\_t change = 0;

350.

351. uint8\_t note = 'a';

352. //uint8\_t prev\_note = 'a';

353. float volume[1] = {1};

354. float prev\_volume[1] = {1};

355.

356. while(1){

357. vTaskPrioritySet(vol\_handle,3);

358. //Pull distance value from 2nd proximity sensor for volume

359. UART4\_write(0x55);

360. while (!(UART4->ISR & USART\_ISR\_RXNE)); //Wait until hardware sets RXNE

361. measurement = UART4->RDR;

362. measurement \*= 256;

363. while (!(UART4->ISR & USART\_ISR\_RXNE)); //Wait until hardware sets RXNE

364. measurement += UART4->RDR;

365. inches = (float)(measurement / 25.4);

366.

367. //Determine what the volume scaler should be based on 2nd proximity sensor

368. if (inches <= 6){ //volume off

369. volume[0] = 0;

370. }

371. else if (inches > 6 && inches <= 7){

372. volume[0] = 0.1428;

373. }

374. else if (inches > 7 && inches <= 8){

375. volume[0] = 0.2856;

376. }

377. else if (inches > 8 && inches <= 9){

378. volume[0] = 0.4284;

379. }

380. else if (inches > 9 && inches <= 10){

381. volume[0] = 0.5712;

382. }

383. else if (inches > 10 && inches <= 11){

384. volume[0] = 0.714;

385. }

386. else if (inches > 11 && inches <= 12){

387. volume[0] = 0.8568;

388. }

389. else if (inches > 12){ //Volume on fully

390. volume[0] = 1;

391. }

392.

393. //Send volume multiplier to Timer Interrupt handler

394. xQueueSendToBack(vol\_queue,volume,50);

395.

396. //Only update output on serial terminal if the volume changed

397. if (volume[0] != prev\_volume[0]){

398. change = 1;

399. xSemaphoreTake(uart\_mutex,(TickType\_t)50);

400. USART2\_write(note,volume,change);

401. xSemaphoreGive(uart\_mutex);

402. }

403. prev\_volume[0] = volume[0];

404. vTaskPrioritySet(vol\_handle,2);

405. vTaskDelay(100 / portTICK\_PERIOD\_MS);

406. }

407. }

408.

409. void USART3\_write(uint8\_t measure\_type){

410. //Send command to measure the temperature or proximity distance

411. while(!(USART3->ISR & USART\_ISR\_TXE)); //Wait until hardware sets TXE

412. USART3->TDR = measure\_type & 0xFF; //Writing to TDR clears TXE Flag

413.

414. //Wait until TC bit is set. TC is set by hardware and cleared by software

415. while (!(USART3->ISR & USART\_ISR\_TC)); //TC: Transmission complete flag

416.

417. //Writing 1 to the TCCF bit in ICR clears the TC bit in ICR

418. USART3->ICR |= USART\_ICR\_TCCF; //TCCF: Transmission complete clear flag

419. }

420.

421. void UART4\_write(uint8\_t measure\_type){

422. //Send command to measure the temperature or proximity distance

423. while(!(UART4->ISR & USART\_ISR\_TXE)); //Wait until hardware sets TXE

424. UART4->TDR = measure\_type & 0xFF; //Writing to TDR clears TXE Flag

425.

426. //Wait until TC bit is set. TC is set by hardware and cleared by software

427. while (!(UART4->ISR & USART\_ISR\_TC)); //TC: Transmission complete flag

428.

429. //Writing 1 to the TCCF bit in ICR clears the TC bit in ICR

430. UART4->ICR |= USART\_ICR\_TCCF; //TCCF: Transmission complete clear flag

431. }

432.

433. void USART2\_write(uint8\_t note,float volume[1],uint32\_t change){

434. int nBytes = 30;

435. char serial\_message[30] = {0};

436.

437. //Send update to serial terminal if the note changed

438. if (change == 0){

439. switch(note){

440. case 'a':

441. sprintf(serial\_message, "C3\n\r");

442. break;

443. case 'b':

444. sprintf(serial\_message, "C#3\n\r");

445. break;

446. case 'c':

447. sprintf(serial\_message, "D3\n\r");

448. break;

449. case 'd':

450. sprintf(serial\_message, "D#3\n\r");

451. break;

452. case 'e':

453. sprintf(serial\_message, "E3\n\r");

454. break;

455. case 'f':

456. sprintf(serial\_message, "F3\n\r");

457. break;

458. case 'g':

459. sprintf(serial\_message, "F#3\n\r");

460. break;

461. case 'h':

462. sprintf(serial\_message, "G3\n\r");

463. break;

464. case 'i':

465. sprintf(serial\_message, "G#3\n\r");

466. break;

467. case 'j':

468. sprintf(serial\_message, "A3\n\r");

469. break;

470. case 'k':

471. sprintf(serial\_message, "A#3\n\r");

472. break;

473. case 'l':

474. sprintf(serial\_message, "B3\n\r");

475. break;

476. case 'm':

477. sprintf(serial\_message, "C4\n\r");

478. break;

479. case 'n':

480. sprintf(serial\_message, "C#4\n\r");

481. break;

482. case 'o':

483. sprintf(serial\_message, "D4\n\r");

484. break;

485. case 'p':

486. sprintf(serial\_message, "D#4\n\r");

487. break;

488. case 'q':

489. sprintf(serial\_message, "E4\n\r");

490. break;

491. case 'r':

492. sprintf(serial\_message, "F4\n\r");

493. break;

494. case 's':

495. sprintf(serial\_message, "F#4\n\r");

496. break;

497. case 't':

498. sprintf(serial\_message, "G4\n\r");

499. break;

500. case 'u':

501. sprintf(serial\_message, "G#4\n\r");

502. break;

503. case 'v':

504. sprintf(serial\_message, "A4\n\r");

505. break;

506. case 'w':

507. sprintf(serial\_message, "A#4\n\r");

508. break;

509. case 'x':

510. sprintf(serial\_message, "B4\n\r");

511. break;

512. case 'y':

513. sprintf(serial\_message, "C5\n\r");

514. break;

515. }

516. }

517. //Send update to serial terminal if the volume changed

518. else if (change == 1){

519. //Print out current volume

520. if((double)volume[0] < 0.1){

521. sprintf(serial\_message, "Vol 0\n\r");

522. }

523. else if((double)volume[0] > 0.1 && (double)volume[0] < .25){

524. sprintf(serial\_message, "Vol 1\n\r");

525. }

526. else if((double)volume[0] > 0.25 && (double)volume[0] < .4){

527. sprintf(serial\_message, "Vol 2\n\r");

528. }

529. else if((double)volume[0] > 0.4 && (double)volume[0] < .55){

530. sprintf(serial\_message, "Vol 3\n\r");

531. }

532. else if((double)volume[0] > 0.55 && (double)volume[0] < .7){

533. sprintf(serial\_message, "Vol 4\n\r");

534. }

535. else if((double)volume[0] > 0.7 && (double)volume[0] < .85){

536. sprintf(serial\_message, "Vol 5\n\r");

537. }

538. else if((double)volume[0] > 0.85 && (double)volume[0] < 1.0){

539. sprintf(serial\_message, "Vol 6\n\r");

540. }

541. else if((double)volume[0] >= 1.0){

542. sprintf(serial\_message, "Vol 7\n\r");

543. }

544. }

545.

546. //Send Serial message to USART2 to send to serial terminal

547. for (int i=0; i < nBytes; i++){

548. while(!(USART2->ISR & USART\_ISR\_TXE)); //Wait until hardware sets TXE

549. USART2->TDR = serial\_message[i] & 0xFF; //Writing to TDR clears TXE Flag

550. }

551. //Wait until TC bit is set. TC is set by hardware and cleared by software

552. while (!(USART2->ISR & USART\_ISR\_TC)); //TC: Transmission complete flag

553.

554. //Writing 1 to the TCCF bit in ICR clears the TC bit in ICR

555. USART2->ICR |= USART\_ICR\_TCCF; //TCCF: Transmission complete clear flag

556. }

557.

**Init.c**

1. #include "FreeRTOS.h"

2. #include "stm32l476xx.h"

3. #include "system\_stm32l4xx.h"

4. #include "task.h"

5. #include "timers.h"

6. #include "stdint.h"

7. #include "queue.h"

8. #include "semphr.h"

9.

10. #include "init.h"

11.

12. void clock\_Config(void){

13. //Change System Clock from MSI to HSI

14. RCC->CR |= RCC\_CR\_HSION; // enable HSI (internal 16 MHz clock)

15. while ((RCC->CR & RCC\_CR\_HSIRDY) == 0);

16. RCC->CFGR |= RCC\_CFGR\_SW\_HSI; // make HSI the system clock

17. SystemCoreClockUpdate();

18.

19. //Turn Clock on for GPIOs

20. RCC -> AHB2ENR |= RCC\_AHB2ENR\_GPIOAEN;

21. //RCC -> AHB2ENR |= RCC\_AHB2ENR\_GPIOBEN;

22. RCC -> AHB2ENR |= RCC\_AHB2ENR\_GPIOCEN;

23. }

24.

25. void gpio\_Config(void){

26. //Set PA5 to output mode for LED

27. GPIOA->MODER &= ~GPIO\_MODER\_MODE5\_1;

28. GPIOA->MODER |= GPIO\_MODER\_MODE5\_0;

29. //Turn LED on

30. GPIOA->BSRR |= GPIO\_BSRR\_BS5;

31. //Set PC13 to input mode for Button

32. GPIOC->MODER &= ~GPIO\_MODER\_MODE13; //0xf3ffffff

33. }

34.

35. void timer\_Config(void){

36. //Turn on Clock for TIM4

37. RCC -> APB1ENR1 |= RCC\_APB1ENR1\_TIM4EN;

38.

39. //Enable interrupts for TIM4

40. NVIC->ISER[0] |= 1 << 30;

41. NVIC\_EnableIRQ(TIM4\_IRQn);

42.

43. TIM4->CR1 &= ~TIM\_CR1\_CMS; // Edge-aligned mode

44. TIM4->CR1 &= ~TIM\_CR1\_DIR; // Up-counting

45.

46. TIM4->CR2 &= ~TIM\_CR2\_MMS; // Select master mode

47. TIM4->CR2 |= TIM\_CR2\_MMS\_2; // 100 = OC1REF as TRGO

48.

49. TIM4->DIER |= TIM\_DIER\_TIE; // Trigger interrupt enable

50. TIM4->DIER |= TIM\_DIER\_UIE; // Update interrupt enable

51.

52. TIM4->CCMR1 &= ~TIM\_CCMR1\_OC1M;

53. TIM4->CCMR1 |= (TIM\_CCMR1\_OC1M\_1 | TIM\_CCMR1\_OC1M\_2); // 0110 = PWM mode 1

54.

55. TIM4->PSC = 0x7; // 16 MHz / (7+1) = 2 MHz timer ticks

56. TIM4->ARR = 0xFFFF008E; // 2 MHz / (141+1) = 14.080 kHz interrupt rate; 64 entry look-up table = 220 Hz sine wave

57. TIM4->CCR1 = 0x23; // 50% duty cycle (35)

58. TIM4->CCER |= TIM\_CCER\_CC1E;

59.

60. //Enable Control Register 1 for Counting

61. TIM4->CR1 |= TIM\_CR1\_CEN;

62. }

63.

64. void DAC\_Config(void){

65. //Turn on Clock for DAC1

66. RCC -> APB1ENR1 |= RCC\_APB1ENR1\_DAC1EN;

67. //Configure DAC1 GPIO in Analog Mode 0x3

68. GPIOA->MODER |= GPIO\_MODER\_MODE4;

69. //Enable DAC1 Channel 1

70. DAC->CR |= DAC\_CR\_EN1;

71. }

72.

73. void USART2\_config(void){

74. //Enable PA2 (TX) and PA3 (RX) to alternate function mode

75. GPIOA->MODER &= ~(0xF << (2\*2));

76. GPIOA->MODER |= (0xA << (2\*2));

77. //Enable alternate function for USART2 for the GPIO pins

78. GPIOA->AFR[0] |= 0x77 << (4\*2); //set pin 2 and 3 to AF7

79. //High Speed mode

80. GPIOA->OSPEEDR |= 0xF<<(2\*2);

81. //Pull up mode for PA3 RX

82. GPIOA->PUPDR &= ~(0xF<<(2\*2));

83. GPIOA->PUPDR |= 0x5<<(2\*2); //Select pull-up

84. //GPIO Output type: 0 = push-pull

85. GPIOA->OTYPER &= ~(0x3<<2);

86.

87. //Enable clk for USART2

88. RCC->APB1ENR1 |= RCC\_APB1ENR1\_USART2EN;

89. //Select system clock for USART2

90. RCC->CCIPR &= ~RCC\_CCIPR\_USART2SEL\_0;

91. RCC->CCIPR |= RCC\_CCIPR\_USART2SEL\_1;

92.

93. //Disable USART2

94. USART2->CR1 &= ~USART\_CR1\_UE;

95. //set data length to 8 bits

96. USART2->CR1 &= ~USART\_CR1\_M;

97. //select 1 stop bit

98. USART2->CR2 &= ~USART\_CR2\_STOP;

99. //Set parity control as no parity

100. USART2->CR1 &= ~USART\_CR1\_PCE;

101. //Oversampling to 16

102. USART2->CR1 &= ~USART\_CR1\_OVER8;

103. //Set up Baud rate for USART to 9600 Baud

104. USART2->BRR = 0x683; //1D4C

105. //USART2 Enable Receiver and transmitter

106. USART2->CR1 |= (USART\_CR1\_TE | USART\_CR1\_RE);

107.

108. //Enable interrupt for USART2

109. NVIC\_EnableIRQ(USART2\_IRQn);

110. //Enables interrupts for USART RX

111. USART2->CR1 |= USART\_CR1\_RXNEIE;

112.

113. //Enable USART2

114. USART2->CR1 |= USART\_CR1\_UE;

115.

116. //Verify that USART2 is ready for transmission

117. while ((USART2->ISR & USART\_ISR\_TEACK) == 0);

118. //Verify that USART2 is ready for reception

119. while ((USART2->ISR & USART\_ISR\_REACK) == 0);

120. }

121.

122. void USART3\_config(void){

123. //Enable PC4 (TX) and PC5 (RX) to alternate function mode

124. GPIOC->MODER &= ~GPIO\_MODER\_MODE4\_0;

125. GPIOC->MODER |= GPIO\_MODER\_MODE4\_1;

126. GPIOC->MODER &= ~GPIO\_MODER\_MODE5\_0;

127. GPIOC->MODER |= GPIO\_MODER\_MODE5\_1;

128. //Enable alternate function for USART3 for the GPIO pins

129. GPIOC->AFR[0] |= GPIO\_AFRL\_AFSEL4; //set pin 4 to AF7

130. GPIOC->AFR[0] &= ~GPIO\_AFRL\_AFSEL4\_3;

131. GPIOC->AFR[0] |= GPIO\_AFRL\_AFSEL5; //set pin 5 to AF7

132. GPIOC->AFR[0] &= ~GPIO\_AFRL\_AFSEL5\_3;

133. //High Speed mode

134. GPIOC->OSPEEDR |= 0xF << (2\*4);

135. //Pull up mode for PC5 RX

136. GPIOC->PUPDR &= ~(0xF<<(2\*4));

137. GPIOC->PUPDR |= 0x5<<(2\*4); //Select pull-up

138.

139. //Enable clk for USART3

140. RCC->APB1ENR1 |= RCC\_APB1ENR1\_USART3EN;

141. //Select system clock for USART3

142. RCC->CCIPR &= ~RCC\_CCIPR\_USART3SEL\_0;

143. RCC->CCIPR |= RCC\_CCIPR\_USART3SEL\_1;

144.

145. //Disable USART3

146. USART3->CR1 &= ~USART\_CR1\_UE;

147. //set data length to 8 bits

148. USART3->CR1 &= ~USART\_CR1\_M;

149. //select 1 stop bit

150. USART3->CR2 &= ~USART\_CR2\_STOP;

151. //Set parity control as no parity

152. USART3->CR1 &= ~USART\_CR1\_PCE;

153. //Oversampling to 16

154. USART3->CR1 &= ~USART\_CR1\_OVER8;

155. //Set up Baud rate for USART3 to 9600 Baud

156. USART3->BRR = 0x683;

157. //USART3 Enable Receiver and transmitter

158. USART3->CR1 |= (USART\_CR1\_TE | USART\_CR1\_RE);

159.

160. //Enable USART3

161. USART3->CR1 |= USART\_CR1\_UE;

162.

163. //Verify that USART3 is ready for transmission

164. while ((USART3->ISR & USART\_ISR\_TEACK) == 0);

165. //Verify that USART3 is ready for reception

166. while ((USART3->ISR & USART\_ISR\_REACK) == 0);

167. }

168.

169. void UART4\_config(void){

170. //Enable PA0 (TX) and PA1 (RX) to alternate function mode

171. GPIOA->MODER &= ~GPIO\_MODER\_MODE0\_0;

172. GPIOA->MODER |= GPIO\_MODER\_MODE0\_1;

173. GPIOA->MODER &= ~GPIO\_MODER\_MODE1\_0;

174. GPIOA->MODER |= GPIO\_MODER\_MODE1\_1;

175. //Enable alternate function for UART4 for the GPIO pins

176. GPIOA->AFR[0] &= ~GPIO\_AFRL\_AFSEL0; //set pin 0 to AF8

177. GPIOA->AFR[0] |= GPIO\_AFRL\_AFSEL0\_3;

178. GPIOA->AFR[0] &= ~GPIO\_AFRL\_AFSEL1; //set pin 1 to AF8

179. GPIOA->AFR[0] |= GPIO\_AFRL\_AFSEL1\_3;

180. //High Speed mode

181. GPIOA->OSPEEDR |= 0xF;//<<(2\*0);

182. //Pull up mode for PA1 RX

183. GPIOA->PUPDR &= ~(0xF);//<<(2\*0));

184. GPIOA->PUPDR |= 0x5;//<<(2\*0); //Select pull-up

186. //Enable clk for UART4

187. RCC->APB1ENR1 |= RCC\_APB1ENR1\_UART4EN;

188. //Select system clock for UART4

189. RCC->CCIPR &= ~RCC\_CCIPR\_UART4SEL\_0;

190. RCC->CCIPR |= RCC\_CCIPR\_UART4SEL\_1;

191.

192. //Disable UART4 ---------------------------------------

193. UART4->CR1 &= ~USART\_CR1\_UE;

194. //set data length to 8 bits

195. UART4->CR1 &= ~USART\_CR1\_M;

196. //select 1 stop bit

197. UART4->CR2 &= ~USART\_CR2\_STOP;

198. //Set parity control as no parity

199. UART4->CR1 &= ~USART\_CR1\_PCE;

200. //Oversampling to 16

201. UART4->CR1 &= ~USART\_CR1\_OVER8;

202. //Set up Baud rate for UART4 to 9600 Baud

203. UART4->BRR = 0x683;

204. //USART3 Enable Receiver and transmitter

205. UART4->CR1 |= (USART\_CR1\_TE | USART\_CR1\_RE);

206.

207. //Enable USART4

208. UART4->CR1 |= USART\_CR1\_UE;

209.

210. //Verify that UART4 is ready for transmission

211. while ((UART4->ISR & USART\_ISR\_TEACK) == 0);

212. //Verify that UART4 is ready for reception

213. while ((UART4->ISR & USART\_ISR\_REACK) == 0);

214. }

**Init.h**

1. #ifndef INIT\_H

2. #define INIT\_H

3.

4. #include "FreeRTOS.h"

5. #include "stm32l476xx.h"

6. #include "system\_stm32l4xx.h"

7. #include "task.h"

8. #include "timers.h"

9. #include "stdint.h"

10. #include "queue.h"

11.

12. #define BufferSize 8

13.

14. static QueueHandle\_t but\_led\_queue;

15. static QueueHandle\_t but\_tim\_queue;

16. static QueueHandle\_t uart2\_to\_uart3\_queue;

17. static QueueHandle\_t vol\_queue;

18. static TaskHandle\_t note\_handle;

19. static TaskHandle\_t vol\_handle;

20. static SemaphoreHandle\_t uart\_mutex;

21.

22. void LED\_task(void \*pvParameters);

23. void Button\_task(void \*pvParameters);

24. void note\_task(void \*pvParameters);

25. void volume\_task(void \*pvParameters);

26.

27. void clock\_Config(void);

28. void gpio\_Config(void);

29.

30. void timer\_Config(void);

31. void DAC\_Config(void);

32. void TIM4\_IRQHandler(void);

33.

34. void USART2\_config(void);

35. //void USART2\_IRQHandler(void);

36. void USART2\_write(uint8\_t note,float volume[1],uint32\_t change);

37. void change\_note(uint8\_t uart\_buffer);

38.

39. void USART3\_config(void);

40. void USART3\_write(uint8\_t measure\_type);

41.

42. void UART4\_config(void);

43. void UART4\_write(uint8\_t measure\_type);

44.

45. #endif