Here is the **README** file for your **STM32F401RE Sawtooth Waveform Generation using PWM (TIM1 CH1 on PA8)** project.

You can save this as **README.md** (for GitHub) or **README.docx** (for a Word document).

**STM32F401RE: Generating a Sawtooth Waveform using PWM (TIM1 CH1 on PA8)**

Since **STM32F401RE does not have a DAC**, this project uses **TIM1 PWM (Pulse Width Modulation) on PA8** to generate a **sawtooth waveform** by **linearly increasing the duty cycle** from **0% to 100%** and then resetting.

✅ **Generates a sawtooth waveform using PWM (TIM1 CH1 on PA8)**  
✅ **Uses 12-bit resolution (0 to 4095) for smooth analog approximation**  
✅ **Configurable waveform frequency by adjusting the timer prescaler**

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**1. Overview**

* **MCU**: STM32F401RE (Nucleo-F401RE)
* **PWM Timer**: **TIM1 CH1 (PA8)**
* **PWM Resolution**: **12-bit (0 to 4095)**
* **Waveform Type**: **Sawtooth (0% to 100% Duty Cycle)**
* **Output Frequency**: Configurable

**📏 How PWM Creates an Analog Effect**

* **PWM Output (PA8) rapidly toggles between HIGH and LOW**.
* By **varying the duty cycle (0% to 100%)**, the **average voltage increases**, creating an **analog-like waveform**.
* The **oscilloscope sees a sawtooth-shaped voltage increase** over time.

**2. Hardware Setup**

| **Peripheral** | **STM32F401RE Pin** | **Description** |
| --- | --- | --- |
| **PWM Output** | **PA8 (TIM1 CH1)** | Generates sawtooth waveform |

**🛠 Connecting an Oscilloscope**

1. Connect **PA8** to the **oscilloscope probe**.
2. Connect **GND** to the oscilloscope **ground**.
3. Observe the **rising sawtooth waveform**.

**3. Software Explanation**

**🟢 TIM1 PWM (Sawtooth Generation)**

* **PWM Frequency = 1 kHz** (adjustable).
* **Resolution = 12-bit (0 to 4095)**.
* **Linearly increases duty cycle** every loop iteration.
* **Resets at 100% duty cycle (4095 counts) for sawtooth effect**.

**🟢 Data Flow**

TIM1 CH1 (PA8) → PWM Duty Cycle Increases (Sawtooth) → Oscilloscope

**4. Project Structure**

.

├── Inc/

│ └── stm32f4xx.h // CMSIS/Device headers

├── Src/

│ └── main.c // Contains TIM1 PWM sawtooth generation logic

└── README.md // This file

**5. Building and Uploading**

**Using Keil uVision / STM32CubeIDE**

1. **Open Keil uVision or STM32CubeIDE**.
2. **Create a new project** for STM32F401RE.
3. **Copy main.c into the Src/ directory**.
4. **Compile and Flash the project** to **Nucleo-F401RE**.

**6. Usage**

**1️⃣ Flash the code to the STM32F401RE**

* Use **Keil uVision** or **STM32CubeIDE**.

**2️⃣ Connect an Oscilloscope**

* **Probe PA8** (TIM1 CH1 output).
* Observe a **rising sawtooth waveform**.

**3️⃣ Adjust Waveform Frequency**

* Increase/decrease delayMs(n); to change waveform frequency.

**7. Troubleshooting**

**🔴 No Output on PA8?**

✅ **Ensure PA8 is properly set to Alternate Function AF1 (GPIOA->AFR[1] |= (1U << 0);).**  
✅ **Confirm TIM1 clock is enabled (RCC->APB2ENR |= (1U << 0);).**  
✅ **Check that TIM1 is enabled (TIM1->CR1 |= (1U << 0);).**

**⚠️ Output Looks Distorted?**

✅ Reduce the delay (delayMs(1);) to **smooth the waveform**.  
✅ Ensure **proper ground connections** in your oscilloscope.

**8. License**

This project is licensed under the **MIT License**.  
You are free to **modify, distribute, and use** the code.

**9. References**

📄 [STM32F401RE Datasheet](https://www.st.com/en/microcontrollers-microprocessors/stm32f401re.html)  
📄 [STM32 Reference Manual (RM0368)](https://www.st.com/resource/en/reference_manual/dm00096844.pdf)  
📄 [PWM Configuration Guide](https://www.st.com/resource/en/programming_manual/dm00245755.pdf)

**🚀 Summary**

✅ **Generates sawtooth waveform using PWM (TIM1 CH1 on PA8)**  
✅ **Outputs a 12-bit increasing signal (0-4095) using duty cycle**  
✅ **Works on STM32F401RE with no external DAC**

📡 **Enjoy waveform generation with STM32F401RE PWM! 🎯**