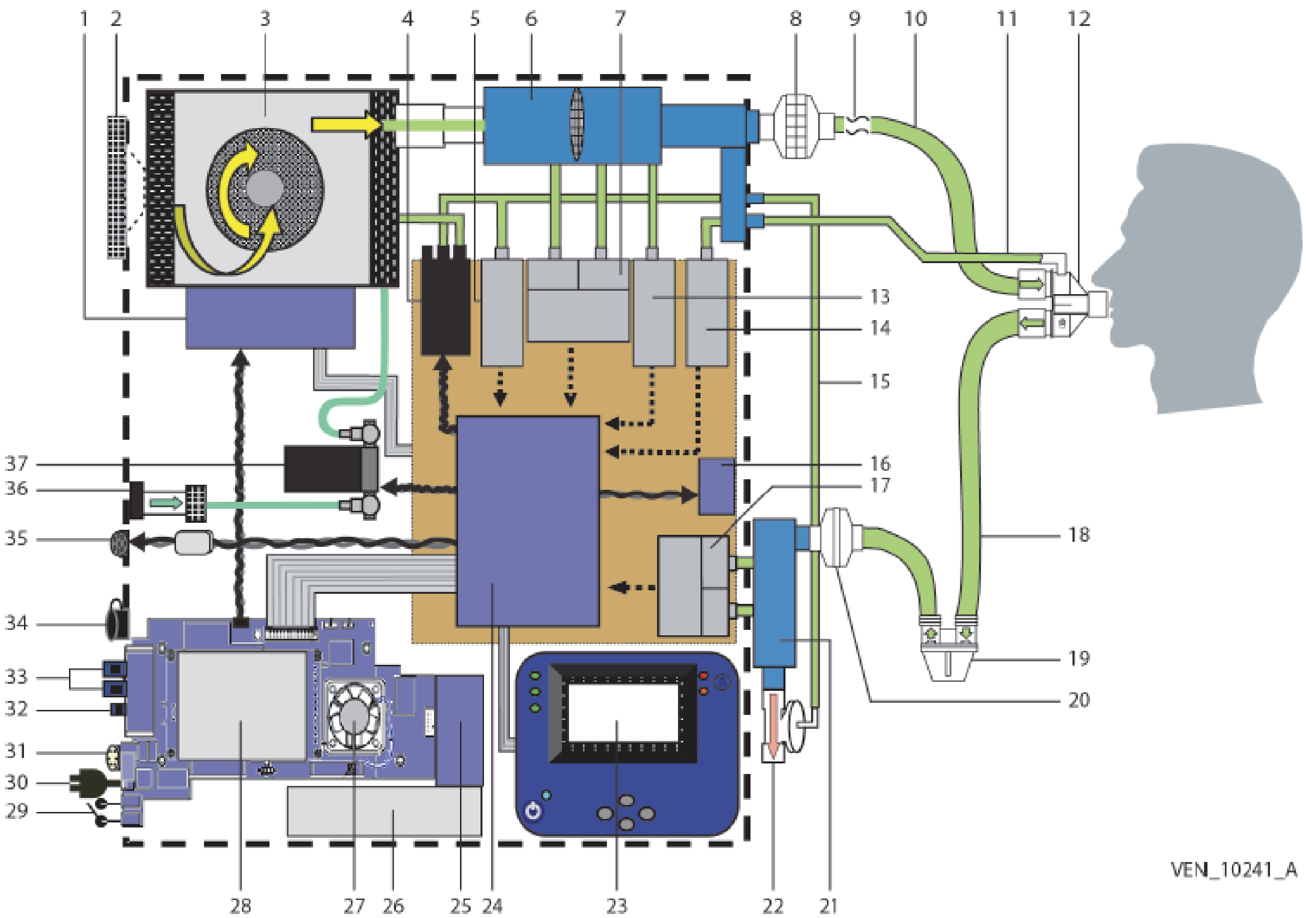
Potential Uses for MRAM in Medical Applications Medical Ventilator Use Case

Section 1
Introduction

There is urgency in increasing the supply of medical ventilators due to the current Covid-19 pandemic. Several companies have issued reference designs for the production of ventilators. Everspin Technologies offers a unique MRAM memory technology that will offer benefits to the electronic system design of this type of equipment. In this application note we will provide some references to ventilator design that is currently available and show which of our MRAM products can enhance the performance and reliability of these designs.

1.1 Definition/Introduction of Ventilator

(Source https://en.wikipedia.org/wiki/Ventilator, other sources listed at end of material Section 5.2). A **ventilator** is a machine that provides mechanical ventilation by moving breathable air into and out of the lungs, to deliver breaths to a patient who is physically unable to breathe or breathing insufficiently. Modern ventilators are computerized microprocessor-controlled machines, but patients can also be ventilated with a simple, hand-operated bag valve mask. Ventilators are chiefly used in intensive-care medicine, home care, and emergency medicine (as standalone units) and in anesthesiology (as a component of an anesthesia machine).



1 Turbine control PCBA
2 Inlet air filter
3 Turbine
4 Exhalation solenoid valve
5 Exhalation valve pressure sensor
6 Inspiratory block
7 Inspiratory flow sensor
8 Inspiratory bacteria filter
9 Not shown with humidifier, nebulizer, or additional water traps
10 Inspiratory tubing
11 Proximal pressure tube
12 Patient wye
13 Inspiratory pressure sensor
14 Proximal pressure sensor
15 Exhalation valve pilot tube
16 Buzzer PCBA
17 Exhalation flow sensor
18 Exhalation tubing

20 Exhalation bacteria filter
21 Exhalation block
22 Exhalation valve
23 Display
24 CPU PCBA
25 Battery connection PCBA
26 Internal battery
27 Cooling fan
28 Power supply (located above power mgt PCBA)

29 Power switch
30 AC input
31 DC input
32 PC port
33 Type A USB ports (2)
34 SpO2 port (not used)
35 Nurse call port
36 Low pressure O2 inlet
37 O2 solenoid valve

In its simplest form, a modern positive pressure ventilator consists of a compressible air reservoir or turbine, air and oxygen supplies, a set of valves and tubes, and a disposable or reusable "patient circuit". The air reservoir is pneumatically compressed several times a minute to deliver room-air, or in most cases, an air/oxygen mixture to the patient. If a turbine is used, the turbine pushes air through the ventilator, with a flow valve adjusting pressure to meet patient-specific parameters. When over pressure is released, the patient will exhale passively due to the lungs' elasticity, the exhaled air being released usually through a one-way valve within the patient circuit called the patient manifold. Ventilators may also be equipped with monitoring and alarm systems for patient-related parameters (e.g. pressure, volume, and flow) and ventilator function (e.g. air leakage, power failure, mechanical failure), backup batteries, oxygen tanks, and remote control. The pneumatic system is nowadays often replaced by a computer-controlled turbopump. Modern ventilators are electronically controlled by a small embedded system to allow exact adaptation of pressure and flow characteristics to an individual patient's needs. Fine-tuned ventilator settings also serve to make ventilation more tolerable and comfortable for the patient. Because failure may result in death, mechanical ventilation systems are classified as life-critical systems, and precautions must be taken to ensure that they are highly reliable, including their power supply. Mechanical ventilators are therefore carefully designed so that no single point of failure can endanger the patient. They may have manual backup mechanisms to enable hand-driven respiration in the absence of power (such as the mechanical ventilator integrated into an anaesthetic machine). They may also have safety valves, which open to atmosphere in the absence of power to act as an anti-suffocation valve for spontaneous breathing of the patient. Some systems are also equipped with compressed-gas tanks, air compressors or backup batteries to provide ventilation in case of power failure or defective gas supplies, and methods to operate or call for help if their mechanisms or software fail.

1.2 Open-source ventilators

An open-source ventilator is a disaster-situation ventilator made using a freely licensed design, and ideally, freely-available components and parts. Designs, components, and parts may be anywhere from completely reverse-engineered to completely new creations, components may be adaptations of various inexpensive existing products, and special hard-to-find and/or expensive parts may be 3D printed instead of sourced. This reference design uses a permissive license for Open Ventilator Files, issued by Medtronic, which can be downloaded at https://www.medtronic.com/us-en/e/open-files.html.

Section 2
Hardware Design

2.1 System definition

An electronics system for a medical respirator can be complex because of the variety of components and functions that must be accurate.
It must have the following modules:
Power supply—This PCB must power the microcontroller, sensors, display and switch a certain number of valves, typically driven at 200mA and a 12 A air compressor at different voltages. The requirements of the power supply are 12 A to 12 V (air compressor), 2 A to 5 V (four valves, bright LED, display and differential pressure sensors), and 500 mA to 3.3 V (MCU, buzzer, pressure, and temperature sensors). These modes are on the same PCB. A multi-layer PCB will be a requirement.
Communications (USB)—System requires a channel for connectivity with other controlling or monitoring devices to exchange data and provide complete control, for example, anesthetic controllers. USB is a communication channel commonly used for medical devices. The system should support the Medical USB stack with a personal healthcare device class (PHDC) that currently supports human interface device (HID), mass storage device (MSD), communications device class (CDC), audio class and PHDC USB.org standard classes. The PHDC enables the software to allow USB connectivity within medical devices by complying with medical industry standards, such as the Continua Health Alliance. Medical ventilators are not supported by PHDC. CDC is a good option for sharing data from these devices.
Signals treatment and measuring from sensors—Reliable measurement is a critical factor for this application. Signal treatment and decoupling are important factors to consider. The system must avoid electrical noise using capacitors and inductors for decoupling.

Human Interface—This system is able to support some operational modes with different parameter values. It is important to have a user interface for a personalized display or even to explore therapies, events, or for teaching sessions. An LCD / TFT panel displays the main parameters and buttons to explore the multiple option menu. As part of the user interface, the system has LED’s for alarming, debugging, and a buzzer for alarm events, and therefore the system provides enough information to the user.
Actuators controlling—System requires controlling several electromechanical actuators that demand high current consumption and generates electrical noise to the system by EMI.

Main CPU PCB — It performs the following functions:
• Controls breath delivery functions of the ventilator
• Displays information to the user through the LCD/TFT panel
• Communicates with the Power Management PCB
• Provides continuous status and monitoring for errors
• **Stores ventilator settings, patient data, and events in memory**
• Interfaces with external devices (USB)

Ventilator and alarm settings are retained in **non-volatile memor**y during periods when the ventilator is turned off.
The Alarm, Technical Fault, and Event logs are also stored in **non-volatile memory** on the CPU PCB, ensuring that the information is retained when the ventilator is powered off and during power loss conditions.
An event log, capable of storing up to multiple entries, is maintained in the ventilator's **non-volatile memory**. After all the entries are stored in the event log, the ventilator overwrites the data using a first-in-first-out (FIFO) strategy.

The event log stores the following information:
• Ventilation starts and stops
• Confirmed ventilator parameter settings
• Confirmed alarm settings
• Alarm and technical fault occurrences with associated actions such as audio paused, alarm reset, and alarm paused actions, and acknowledgment key presses

The event log records any changes to the system's real-time clock by logging the current date/time followed by the new date/time and a unique event code indicating the change
There are four types of non-volatile memories on the CPU PCB:

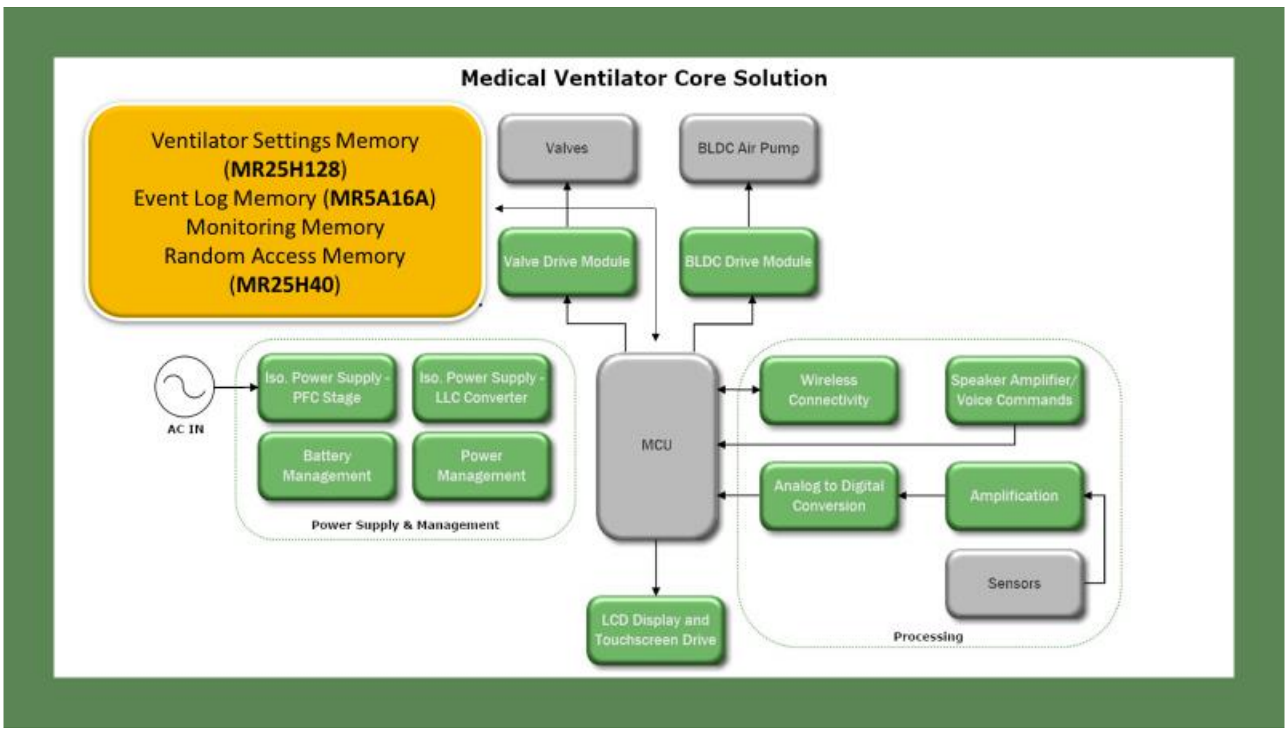
- Ventilator Settings Memory (good fit for MRAM)
- Event Log Memory (good fit for MRAM)
- Monitoring Memory
- Random Access Memory (good fit for MRAM)

Ventilator parameter and alarm settings are stored in a minimum of 128kb (Everspin part number **MR25H128A**) of non-volatile memory to ensure settings are retained when the ventilator's power is turned off or during a loss-of-power condition.

A minimum of 32Mb (**MR5A16A**) of non-volatile event memory stores the event log. This log records information such as ventilator stops and starts, confirmed ventilator and alarm settings, and alarm and technical fault history including any associated audio

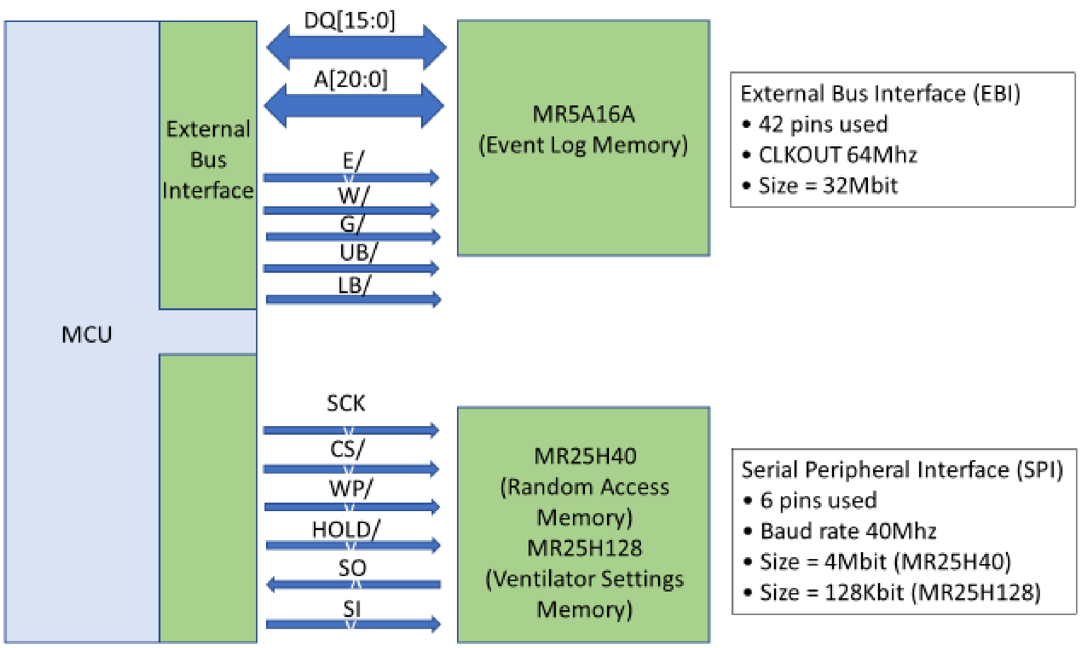
paused or alarm paused key presses, alarm resets, and acknowledgment key presses. This information is also retained when the ventilator is turned off and during power losses.
A minimum of 4Mb (**MR25H40**) of MRAM is available for storage of operating software program variables. The data stored in MRAM are saved during periods when the ventilator is turned off.
The simple asynchronous SRAM standard JEDEC interface of Everspin's parallel I/O MRAM products and the QSPI/SPI interface make the design easy to implement without additional components nor ecosystem support. The robust reliability of Everspin MRAM technology allows engineers to satisfy the demanding requirements of the patient critical medical equipment market with Everspin's standard commercial/industrial grade products.

2.2 Ventilator High-level System Architecture

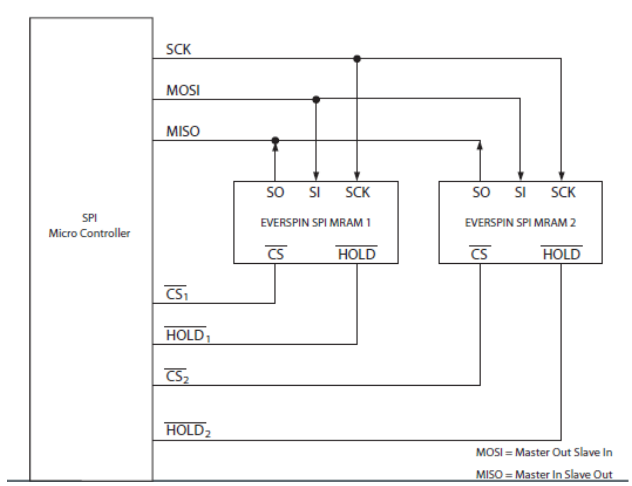


2.3 Hardware Implementation

In this demonstration, the microcontroller utilizes both serial and parallel MRAM interfaces.

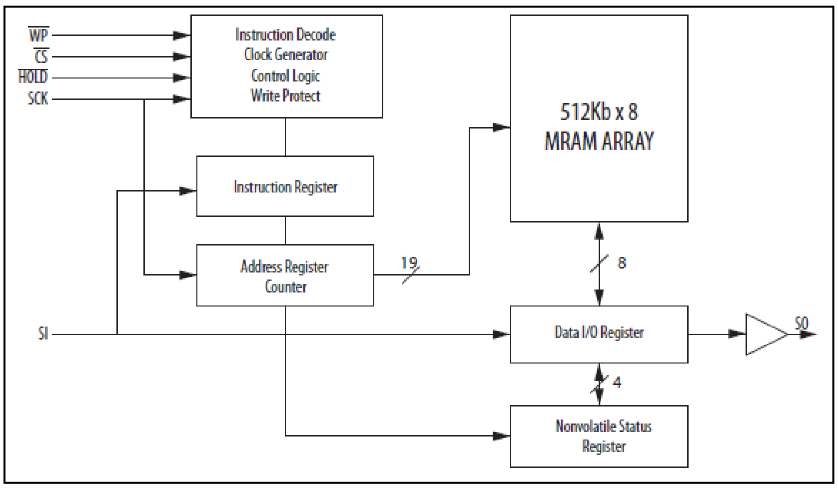


Single or multiple devices can be connected to the SPI bus as shown below. Pins SCK, SO and SI are common among devices. Each device requires CS and HOLD pins to be driven separately.



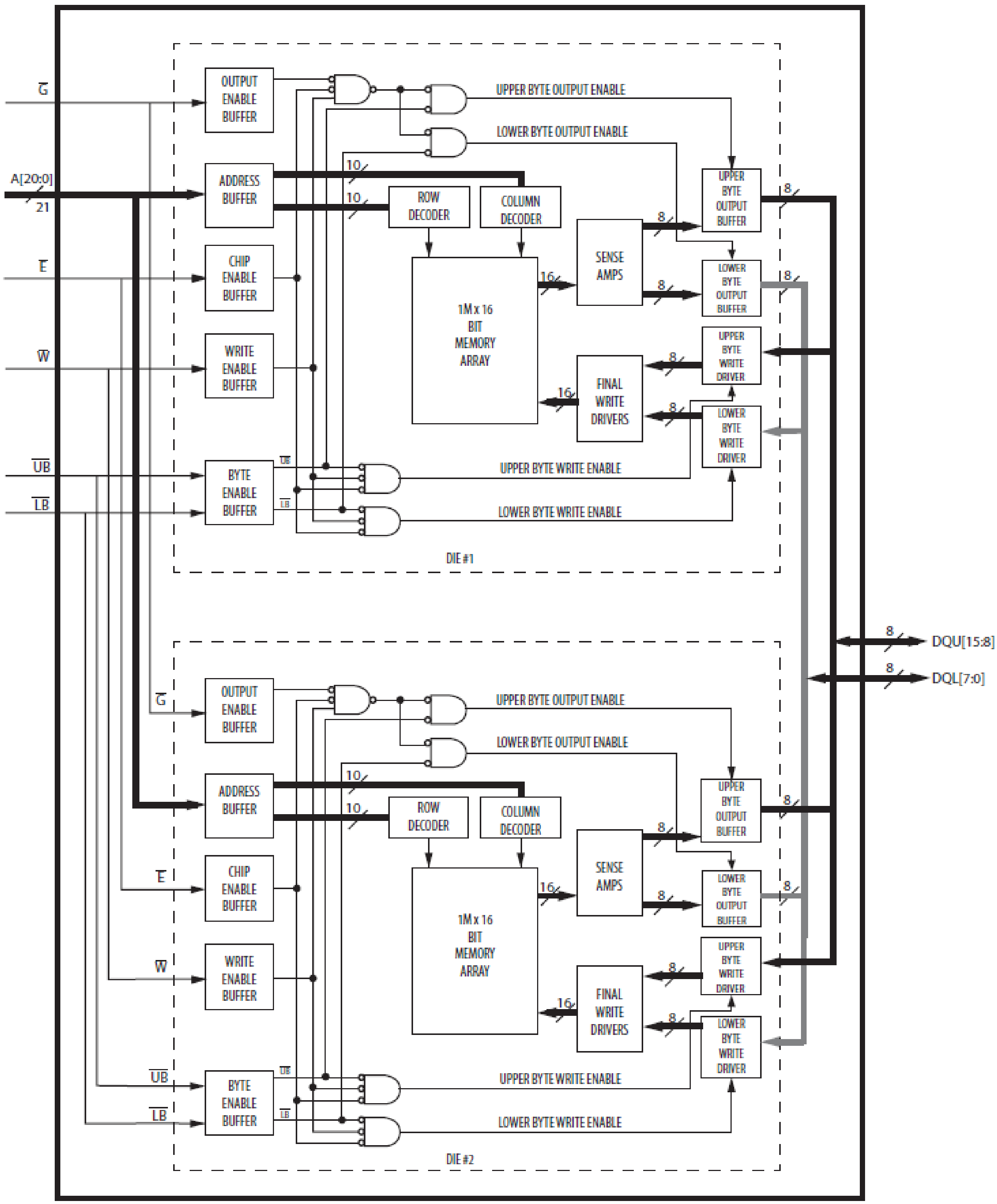
MR25H40 Toggle MRAM with Block Diagram

The MR2xH40 family is an SPI interface MRAM family with a memory array logically organized as 512Kx8 using the four pin interface of chip select (CS), serial input (SI), serial output (SO) and serial clock (SCK) of the serial peripheral interface (SPI) bus. The MRAM implements a subset of commands common to SPI EEPROM and SPI Flash components. This allows the SPI MRAM to replace these components in the same socket and interoperate on a shared SPI bus. The SPI MRAM offers superior write speed, unlimited endurance, low standby & operating power, and simple, reliable data retention compared to other serial memory alternatives.

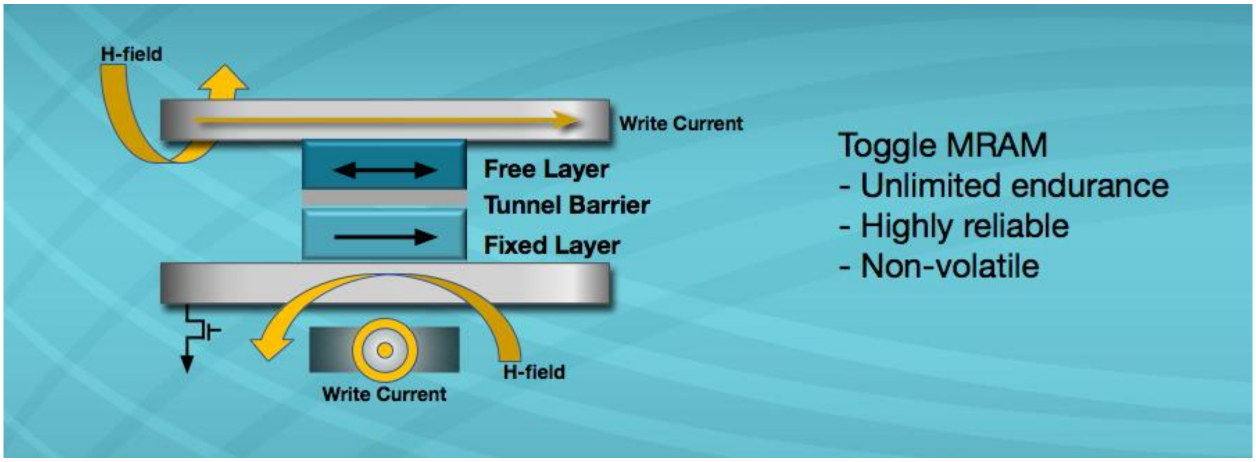


MR5A16A Toggle MRAM with Block Diagram

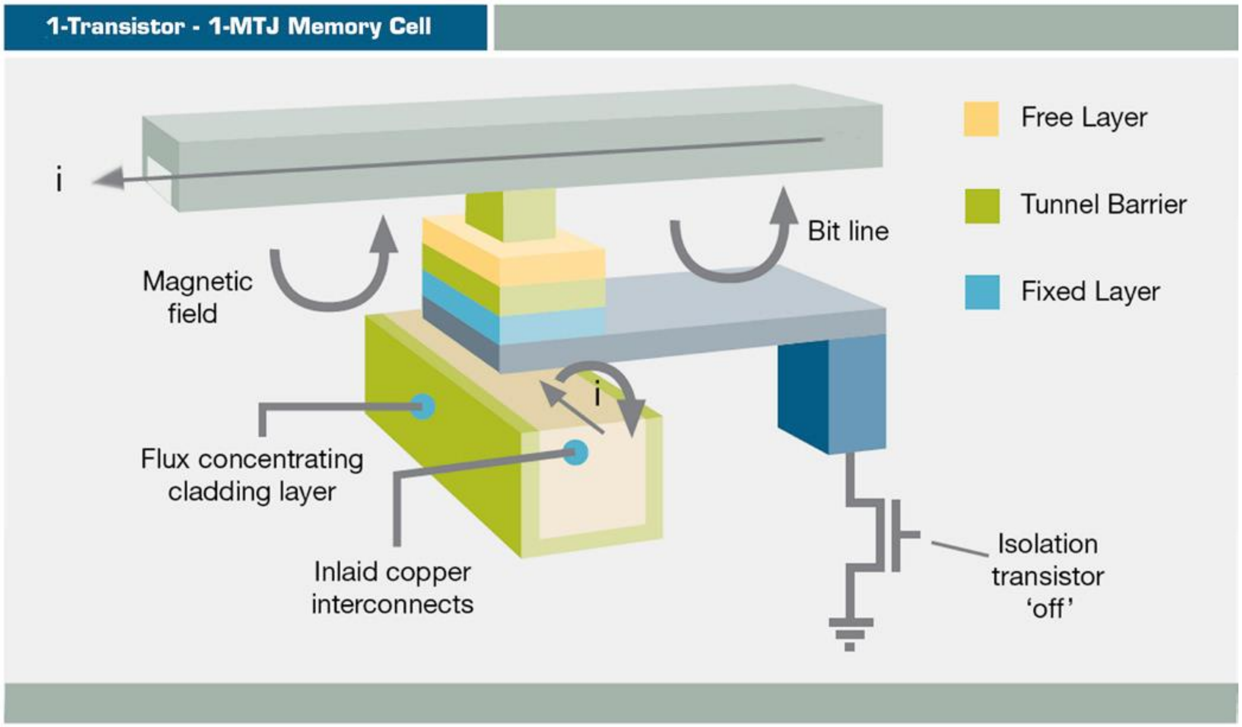
The MR5A16A is a 33,554,432-bit magnetoresistive random access memory (MRAM) device organized as 2,097,152 words of 16 bits. The MR5A16A offers SRAM compatible 35 ns read/write timing (45ns for automotive temperature option) with unlimited endurance. Data is always non-volatile for greater than 20 years. Data is automatically protected on power loss by low-voltage inhibit circuitry to prevent writes with voltage out of specification. To simplify fault tolerant design, the MR5A16A includes internal single bit error correction code with 7 ECC parity bits for every 64 data bits. The MR5A16A is the ideal memory solution for applications that must permanently store and retrieve critical data and programs quickly.


G
A[20:0]
21
E
W
UB
LB
OUTPUT ENABLE BUFFER
ADDRESS BUFFER
CHIP ENABLE BUFFER
WRITE ENABLE BUFFER
BYTE ENABLE BUFFER
UPPER BYTE OUTPUT ENABLE
LOWER BYTE OUTPUT ENABLE
ROW DECODER
COLUMN DECODER
SENSE AMPS
1M x 16 BIT MEMORY ARRAY
FINAL WRITE DRIVERS
UPPER BYTE OUTPUT BUFFER
LOWER BYTE OUTPUT BUFFER
UPPER BYTE WRITE DRIVER
LOWER BYTE WRITE DRIVER
UPPER BYTE WRITE ENABLE
LOWER BYTE WRITE ENABLE
DIE #1
DIE #2
DQU[15:8]
DQL[7:0]

Section 3
Everspin Technologies Toggle MRAM Technology



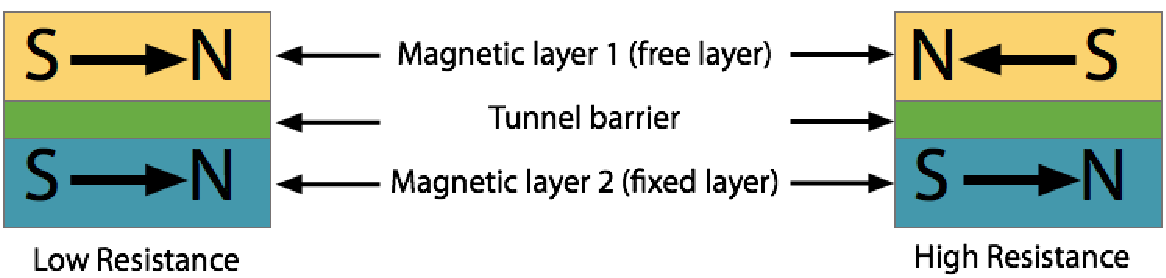
Everspin MRAM is Integrated with Standard CMOS Processing
Everspin MRAM is based on magnetic storage elements integrated with CMOS processing. Each storage element uses a magnetic tunnel junction (MTJ) device for a memory cell.



The Magnetic Tunnel Junction Storage Element

The magnetic tunnel junction (MTJ) storage element is composed of a fixed magnetic layer, a thin dielectric tunnel barrier and a free magnetic layer. When a bias is applied to the MTJ, electrons that are spin polarized by the magnetic layers traverse the dielectric barrier through a process known as tunneling.

MTJ Storage Element



The MTJ device has a low resistance when the magnetic moment of the free layer is parallel to the fixed layer and a high resistance when the free layer moment is oriented anti-parallel to the fixed layer moment. This change in resistance with the magnetic state of the device is an effect known as magnetoresistance, hence the name “magnetoresistive” RAM.

Toggle MRAM Characteristics

NON-VOLATILE	Data retention > 20 years
FAST	Symmetrical read/write - 35ns
UNLIMITED ENDURANCE	No wear-out mechanism
MODULAR INTEGRATION	Easily integrated with CMOS
EXTENDED TEMPERATURES	-40c < T < 150C operation demonstrated
HIGHLY RELIABLE	Intrinsic reliability exceed 20 year lifetime at 125C

Everspin MRAM Technology is Reliable

Unlike most other semiconductor memory technologies, the data is stored as a magnetic state rather than a charge and sensed by measuring the resistance without disturbing the magnetic state. Using a magnetic state for storage has two main benefits. First, the magnetic polarization does not leak away over time like charge does, so the information is stored even when the power is turned off. Second, switching the magnetic polarization between the two states does not involve actual movement of electrons or atoms, and thus no known wear-out mechanism exists.

Everspin MRAM devices are designed to combine the best features of non-volatile memory and RAM to enable "instant-on" capability and power loss protection for an increasing number of electronic systems.

Everspin Toggle MRAM Technology Portfolio


Industrial & IOT Products – Available Now

Technology	Capacity	Interface	Package	2018	2019	2020
Toggle	128kb	SPI	DFN	MP		
	256kb	Parallel, SPI	DFN, BGA, TSOP2	MP		
	1Mb	Parallel, SPI, QSPI	DFN, BGA, TSOP2, SOIC	MP		
	2Mb	Parallel	BGA, TSOP2			ES CS MP
	4Mb	Parallel & SPI	DFN, BGA, TSOP2	MP		
	8Mb	Parallel	BGA, TSOP2			ES CS MP
	16Mb	Parallel	BGA, TSOP2	MP		
	32Mb	Parallel	BGA, TSOP2			ES CS MP

MRAM products address a wide array of applications with long design life

Section 4
MRAM Demonstration Software
4.1 Software Example
The software in the link shows some examples of Everspin Technologies MRAM use, specifically for MR25H40 SPI 4Mb memory. It is available at the following link:
https://os.mbed.com/teams/Everspin-Technologies-Inc/code/MRAM_MR25H00-EVAL/file/d840fdc82450/main.cpp/
MR25H00-EVAL Shield Demo Program for Everspin SPI MRAMs

Section 5
Conclusion and References
5.1 Conclusion
This complex and critical medical system for patients can benefit from the unique attributes of MRAM from Everspin Technologies.
Engineers can choose from a range of MRAM memory options because of the inherent non-volatility of MRAM, requiring no battery or capacitors, the unlimited non-volatile write endurance and high speed in both non-volatile write cycles and read cycles. These unique MRAM attributes increase the reliability of the system which is of the utmost importance in high reliability medical equipment market.

5.2 Sources
1.Medtronic Open Ventilator Files: https://www.medtronic.com/us-en/e/open-files.html
2.Medical Ventilator: https://en.wikipedia.org/wiki/Ventilator
3.NXP Semiconductors: Ventilator/Respirator Hardware and Software Design Specification, Rev. 0, 11/2011 (DRM127)
4. Everspin Toggle MRAM supporting material, other use cases: www.everspin.com

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