## Contacting Tecmag

Tecmag, Inc.
10161 Harwin Dr., Suite 150
Houston, TX 77036

Phone: 713-667-8747
Fax: 713-667-3180

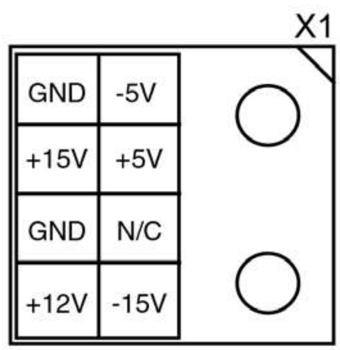
www.tecmag.com
Sales inquires: info@tecmag.com
Support inquires: support@tecmag.com

Revised 10/02/2012

## *Power Supply*

Specifications apply to 2U LapNMR with Sunpower SPS-100PQ2 switching power supply.

| Specification | Value | Notes |
|---|---|---|
| Auxiliary +15V | 2.0 A | Available amperage for auxiliary devices (e.g. preamps) |
| Required currents (if Sunpower supply not used): | | |
| +15 V | 2.0 A | Includes +12 V requirement (R5 or an external jumper must be installed) |
| +5 V | 1.5 A | |
| -5 V | 0.2 A | |
| -15 V | 0.0 A | Provided for daughter boards only |




8 pin Molex power connector

### *Digital Receiver*

All measurements at 12.5 MHz in Normal Mode unless otherwise noted.

| **Specification** | **Value** | **Notes** |
|---|---|---|
| Input impedance (nominal) | 50 ohms | |
| Full-scale input signal range | 1 Vpp FS (+/-500mV) | |
| ADC sample rate | 50 MHz | |
| Input frequency range | DC – 180 MHz (+/- 3dB) | |
| "DC offset" (IF carrier leakage) | < 0.25 bit per scan<br>< 4 µV<br>< -100dBfs | At SW +/- = 50000 Hz and 12.5 MHz IF. |
| Quadrature ghost | < -70dB | At SW +/- = 50000 Hz and full-scale signal |
| Phase transient | < 0.02 deg over 100 µsec | |
| Passband variation | +/- 1% over 70% of SW | Dwell time > 2 µsec, Standard filter |
| | +/- 1% over 50% of SW | Dwell time > 2.5 µsec, Minimum delay filter |
| Minimum dwell time | 60 ns | |
| Maximum dwell time | 21 ms | |
| Minimum Recycle Delay | ≤ 30 µsec + 16 dwell + 1 µsec/pt | Fast mode |
| | ≤ 31 µsec + 1 dwell | Normal mode |
| | ~ 1 dwell | Serial mode |
| | ~ 1 dwell | Serial mode w/ DSP option |

### *RF Receiver*

| **Specification** | **Value** |
|---|---|
| Input impedance (nominal) | 50 ohms |
| Return Loss | < -30 dB (at 62.5 MHz)<br>< -20 dB 200 kHz – 100 MHz |
| Max input signal | ~ 100mVpp (-15 dBm) |
| Input frequency range | < 100 kHz – > 120 MHz |
| Gain control range | > 70 dB |
| Max gain | ~ 80 dB |

## *Transmitter (Analog)*

Typical measurements with 6dB attenuation at 42.57 MHz (1 Tesla).

| Specification | Value | Notes |
|---|---|---|
| Output power | 1 Vpp (+4 dBm +/– 3 dB) | Attenuator = 6 dB |
| Output impedance | 50 ohms | |
| RF Bandwidth | | |
| (– 3 dB) | 40 kHz – 120 MHz | |
| (– 6 dB) | 25 kHz – 125 MHz | |
| Rise time (10-90%) | < 20 ns | |

## *Transmitter (Digital)*

| Specification | Value | Notes |
|---|---|---|
| Phase control (real-time) | 0°, 90°, 180°, 270° | From pulse sequence |
| Phase change latency (delay) | 84 ns | pipeline delay = 28*2.5ns = 70 ns, worst-case $t_{pd}$ = 19.8 ns (U604) |
| Amplitude control | 0.0 – 60.0 dB attenuation | Preset in Apollo.INI file |
| Amplitude control (real-time) | Select either of two preset values | From pulse sequence (preset in Apollo.INI file) |
| Amplitude change latency (delay) | 1.39 μs | Serial transmission delays |
| Attenuator phase shift | < 0.2° | 30 dB step |
| | < 2.0° | 40 dB step |
| Frequency control | To ~0.1 Hz | From dashboard |
| Frequency control (real-time) | Select either of two preset values | From pulse sequence (preset in Apollo.INI file) |
| Frequency change latency (delay) | 2.36 μs | Serial transmission delays |
| Phase reset latency (delay) | 4.66 μs | Serial transmission delays. No RF output for ~2.3 μs during this time |

**NOTES:**

Phase reset, frequency and amplitude changes cannot occur at the same time. All of these actions begin at the rising edge of the relevant LP line pulse and continue for some time. Frequency and amplitude changes also occur on the falling edge of the LP pulse. A delay at least equal to the latency shown above should be included before commencing the next action. Serial transmission times (see above) must be observed in programming these events.

# Specifications

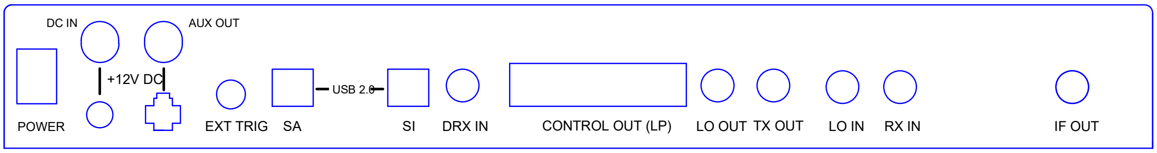
## *Pulse Programmer*

| Specification | Value |
|---|---|
| Time resolution (minimum increment) | 20 ns |
| Minimum event duration | 160 ns |
| Maximum event duration | 85.8993459 s |
| | |
| Maximum events in sequence | 1024 |
| Max depth of nested loops | 5 |
| Maximum loop counter | 16383 |
| | |
| External trigger signal | TTL, any width |

## *Data Acquisition*

| Specification | Value | Notes |
|---|---|---|
| No. Points 1D | 1 | Single-Point Acquisition |
| | even, ≥ 8, and:<br>≤ host memory | Host memory |
| | ≥ 48 (fast mode)<br>≤ 4096 (fast mode) | DSP buffer memory on DRX board |
| No. Points 2D, 3D, 4D | ≤ 64k-1 | |
| | | |
| Max total points per expt. | Depends on host physical memory (max is < 50% of physical memory). | Specify in INI file: example: 192 Mbytes = 24M complex pts for 512M host memory (192Mbyte = 512x512x96) |
| | | |
| No. Scans 1D | < 64k | |
| Continuous scan | No | |
| Dummy Scans | Yes | Always use ≥ 2 dummy scans |
| Real-time display | Yes | |
| Soft “Yellow” stop/restart | No | |
| | | |
| Minimum dwell time | 60 ns | |
| Maximum dwell time | 21 ms | |
| Minimum Recycle Delay | See digital receiver section | |
| | | |
| Single-point acq | ≥ 1 µs / point | |

## Back Panel Layout—Portable



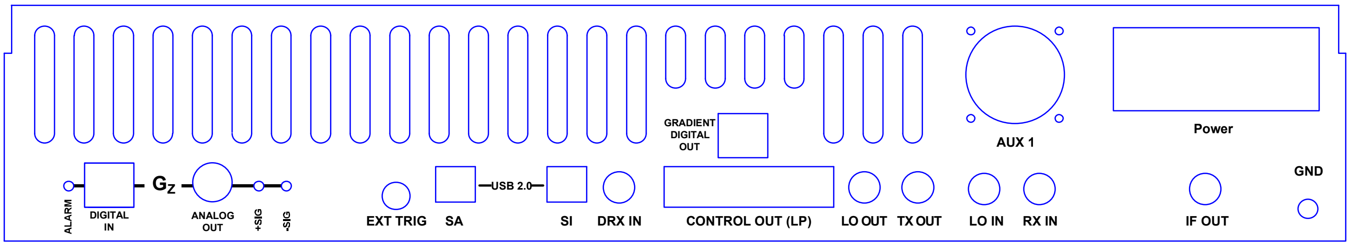

| | |
|---|---|
| RX IN: | Receiver input |
| TX OUT: | Transmitter output |
| CONTROL OUT (LP): | Pulse programmer-controlled TTL outputs for amplifier blanking and scope triggering; additional lines may be added as required |
| SA and SI | USB 2.0 connections to computer |
| EXT TRIG: | External Trigger input; TTL; for external triggering of the LapNMR pulse programmer |
| DC IN | +12$V_{DC}$ input |
| AUX OUT: | +12 $V_{DC}$ output for auxiliary devices including preamplifier |

## Interconnections

*LO OUT* to *LO IN*

*IF OUT* to *DRX IN*

## Back Panel Layout—2U Chassis




| | |
|---|---|
| RX IN: | Receiver input |
| TX OUT: | Transmitter output |
| CONTROL OUT (LP): | Pulse programmer-controlled TTL outputs for amplifier blanking and scope triggering; additional lines may be added as required |
| SA and SI | USB 2.0 connections to computer |
| EXT TRIG: | External Trigger input; TTL; for external triggering of the LapNMR pulse programmer |
| $G_Z$ ANALOG OUT: | Analog (Twin-axial BNC) gradient signal output<br>(for systems equipped with single channel gradient) |
| AUX 1: | +15 $V_{DC}$ output for auxiliary devices including preamplifier |

## Interconnections

*LO OUT* to *LO IN*

*IF OUT* to *DRX IN*

*GRADIENT DIGITAL OUT* to *DIGITAL IN*
(for systems equipped with single channel gradient)

# LapNMR

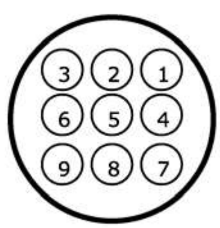
## Voltages

### *Input Power Requirements*

| | | |
|---|---|---|
| Input Voltage: | Portable Chassis AC-DC Adapter: | 100 – 240$V_{AC}$, 50-60 Hz, auto-switching |
| | 2U Chassis w/o Gradient: | 100 – 240$V_{AC}$, 50-60 Hz, auto-switching |
| | 2U Chassis with Gradient: | 100 – 120VAC, 200 – 240 VAC, selectable‡ |
| Power: | Portable Chassis: | 66 Watts |
| | 2U Chassis w/o Gradient: | 125 Watts |
| | 2U Chassis with Gradient: | 150 Watts |

### *2U Chassis Auxiliary Voltage Output*

AUX 1

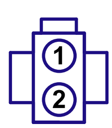



1. +5V
2. 5V GND
3. -5V
4. +15V
5. 15V GND
6. -15V
7-9. N\C

Current: 0.5 Ampere maximum per voltage output

### *Portable Chassis Auxiliary Voltage Output*

**AUX OUT**




**1. +12 $V_{DC}$**
**2. 12$V_{DC}$ GND**

Current: 0.5 Ampere maximum fused output

‡ Removing the 2U chassis top cover reveals the AC voltage selection switch.

## *Utility*

**Overview:**
The 2012 Utility module replaces the previous External Trigger / Rotor Synchronization Module (RSM). It incorporates all of the features of the Ext. Trig / RSM module and is drop-in compatible with it, however, it also adds a number of features including

- Two six-channel analog-to-digital converters (ADCs)
- An on-board temperature sensor
- Conditional branching inputs
- A tachometer

**ADCs:**
Some of the ADC channels are used for monitoring internal Redstone voltages including ± 5V and ±15V. The analog-to-digital values can be retrieved using the Application-level OLE command *GetAuxDataChannelFormatted(n)* where n is the channel number. For example, the on-board temperature may be monitored by retrieving channel n=2. Two analog signal inputs are provided on the EXT IN DB25 rear-panel connector.

| Aux Channel | Signal |
|---|---|
| 0 | ADC 0 |
| 1 | ADC 1 |
| 2 | Temperature |
| 8 | +15V |
| 9 | +5V |
| 10 | -5V |
| 11 | -15V |

| "EXT IN" DB25 pin | Signal |
|---|---|
| 1 - 8 | Conditional Branch bit 0-7 |
| 9 | ADC 0 input |
| 10 | ADC 1 input |
| 11 | External trigger TTL |
| 12 | Tachometer TTL (RSM) |
| 13 | +5V |
| 14 - 25 | GND |

**Triggering and Tachometer:**
The external trigger / RSM and tachometer are configurable allowing the user to trigger the Ext Trig pulse-sequence line using either the external trigger TTL input or the Tachometer TTL (RSM) input. Furthermore, the on-board tachometer can monitor either TTL input. For rotors / spinners with multiple tach markings, a Tach divider can also be configured for proper spin rate determination.
The tachometer signal can be retrieved using the Application-level *GetSpinRate()* command.

| Tach Mode* | Ext Trig Source | Tachometer Source |
|---|---|---|
| 0x00n0 | ext trig TTL | ext trig TTL |
| 0x00n1 | RSM TTL | ext trig TTL |
| 0x00n2 | ext trig TTL | RSM TTL |
| 0x00n3 | RSM TTL | RSM TTL |
| **n = Tach divider (hex: 1-F)* | | |

**Apollo.ini Tachometer Configuration**

```
[Tach]
ModuleType = Tachometer
; Mode - bits 6..4 - Tach divider (does not apply to ext trig input)
;        bit     1 - Tachometer readout source (1 = tach, 0 = ext trig)
;        bit     0 - Trigger source (1 = tach, 0 = ext trig)
Mode      = 0x0013   ;divider = 1, RSM TTL for tach and trigger
CountInterval = 1.0    ; seconds
LogLevel   = 1
```

# Modules

## *Digital Attenuator*

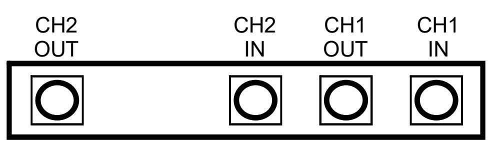
**Overview:**
The digital attenuator incorporates a two-channel digital attenuator module with two Hittite Microwave Corp. HMC470LP3 digital attenuators. Five-bit control is provided via the cluster backplane. The software interface is accomplished using the Ext_Gain line of the TNMR pulse sequence editor.

The attenuator allows 1.0 dB incremental attenuation from 0 dB to 31 dB (5-bits). However, due to the logic of the device, software control is presented as a "Gain" since a value of 31 (all 5 bits high logic) delivered to the device corresponds to 0 dB attenuation while a value of 0 (all 5 bits low) results in maximum attenuation. NOTE: The two channels are controlled together using the same sequence editor control.

The attenuator hardware is factory installed as an internal component of the Redstone. It may be installed in the System or LO Synthesizer Cluster; it is inserted in the cable path between the RX input on the Redstone back panel and the RX analog receiver input. All cabling has been installed in the factory; no additional installation is required. The SMA Port Assignments are illustrated below.

The /tnmr/config/config.con file should be modified to include a 5-bit control line (e.g. Ext_Gain) for pulse sequence control.

**Operating Instructions:**
1. Add a "Gain" value or variable on the Ext_Gain line during every acquisition event in the TNMR pulse sequences.
2. For maximum signal, enter a value of 31. For minimum signal, use a variable set to zero. For 10 dB attenuation, enter 31 – 10 = 21.

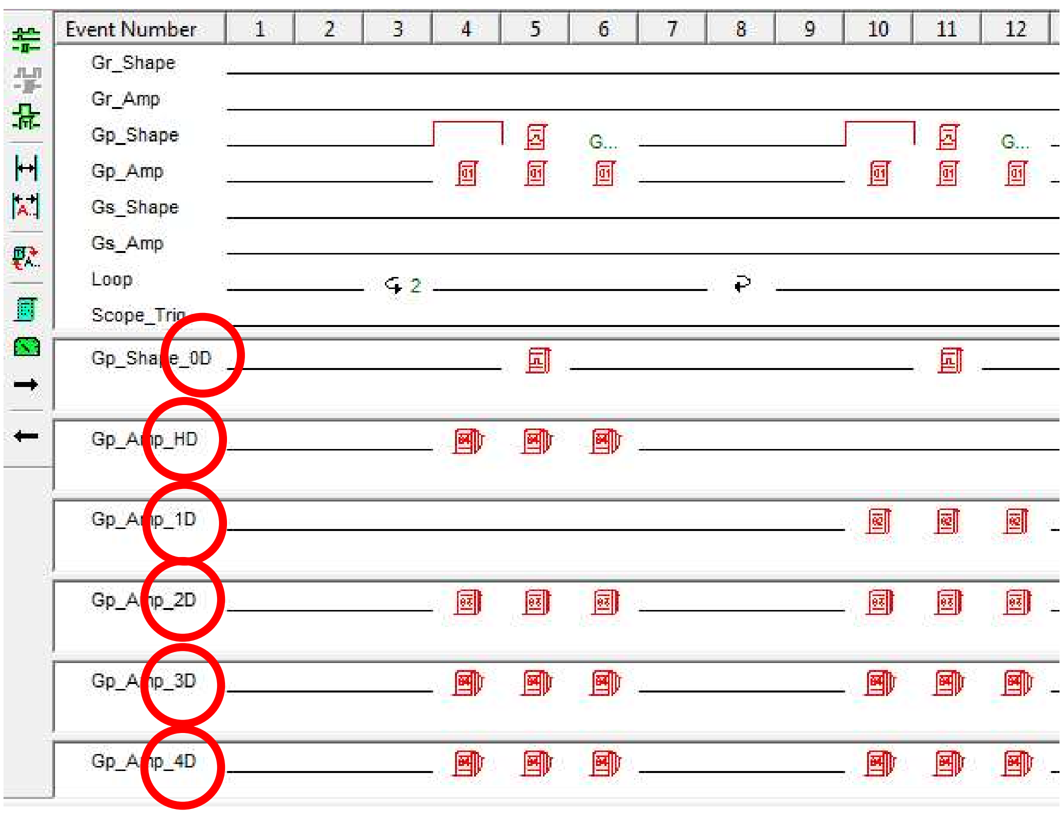



***Two Channel Digital Attenuator***
*SMA Port Assignments*

### *Simultaneous Tables*

New functionality has been included in the Redstone architecture that allows for simultaneous waveform (i.e. 0D or shape tables) and multi-dimensional (i.e. 1D, 2D, 3D, 4D, etc) tables. This now allows for example 0, 90, 180, and 270 phase manipulation of a phase-modulated shaped RF pulse by creating phase cycling tables and waveform tables.

In order to support the changes, the graphical pulse sequence editor in TNMR has been modified. All tables including waveform tables (0D), half-D loop tables (HD), and multi-dimensional tables (1D – 4D) are now displayed separately in panes toward the bottom of the sequence editor window. A place-holder icon is still displayed in the main pane.



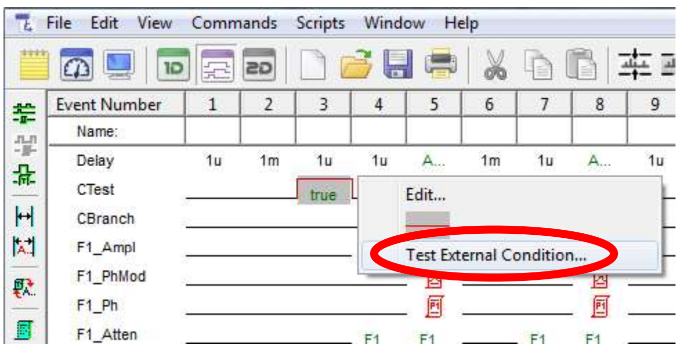
Hardware Interface for Conditional Branching:

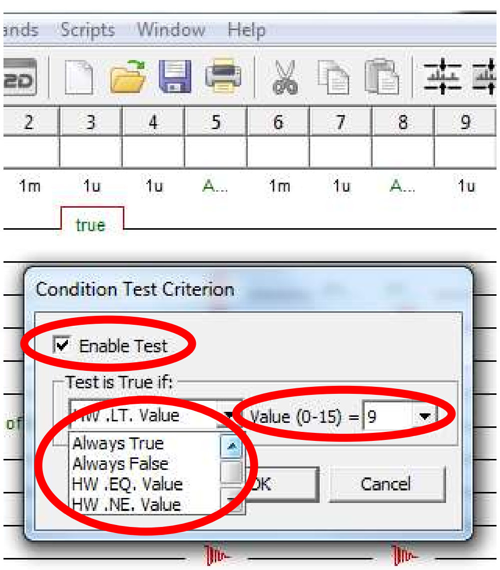
A DB-25 connector labeled “EXT IN” is provided on the Redstone back panel to interface external hardware signals for conditional branch control. Currently four bits are tested allowing 16 values (“conditions”).

| EXT IN | |
|---|---|
| **Bit** | **Pin** |
| 0 | 1 |
| 1 | 2 |
| 2 | 3 |
| 3 | 4 |
| GND | 25 |

CTest Logic Conditions:

The TNMR Sequence Editor provides a number of logic options for conditional branch testing.




| “Test is True if:” | Expression |
|---|---|
| Always True | True for all Values |
| Always False | False for all Values |
| HW .EQ. Value | = |
| HW .NE. Value | ≠ |
| HW .GT. Value | > |
| HW .LT. Value | < |
| HW .GE. Value | ≥ |
| HW .LE. Value | ≤ |

Example 2: Conditional (“Gated”) Acquisition

The following example shows how to maintain a steady-state magnetization while acquiring signals only when an external hardware condition is satisfied. This is useful, for example, in respiratory gating, where data are only acquired during a restricted phase of the subject’s breathing cycle.

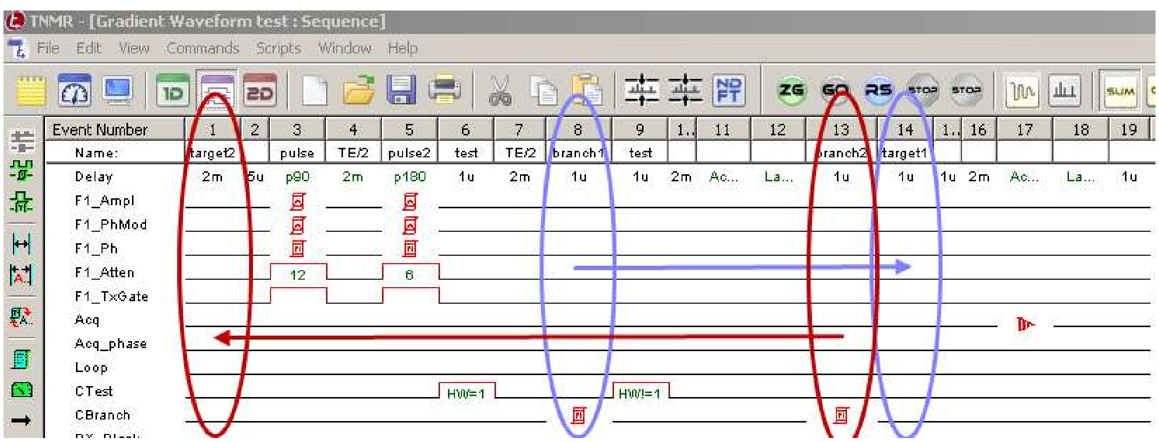
In the example, events 8-13 and 14-19 have exactly the same time duration. Depending upon the state of the external hardware, the sequence will either:

- execute events 8-13, then branch to event 1 (branch2 – target2, in red), without incrementing the counters, and then repeat the same scan, or
- branch from 8 to 14 (branch1 – target1, in blue), then execute events 14-19, then increment the 1D/nD counters and advance to the next scan.

Pulse Programming notes:

> There are two condition tests, in events 6, and 9, with opposite logic. The test in event 6 is true if hardware bit 0 is high (logic “1”), while the test in event 9 is false.
> The CBranch table in event 8 has one entry, “14”. The table in event 13, likewise has one entry, “1”.
> Be sure to count the events executed along each path and set the durations equal in order to maintain constant timing of the sequence.

(Note that this example assumes that the external condition bit is constant for the duration of the scan. This can be achieved, for example, by using an LP output in event 18 to latch in a new value).

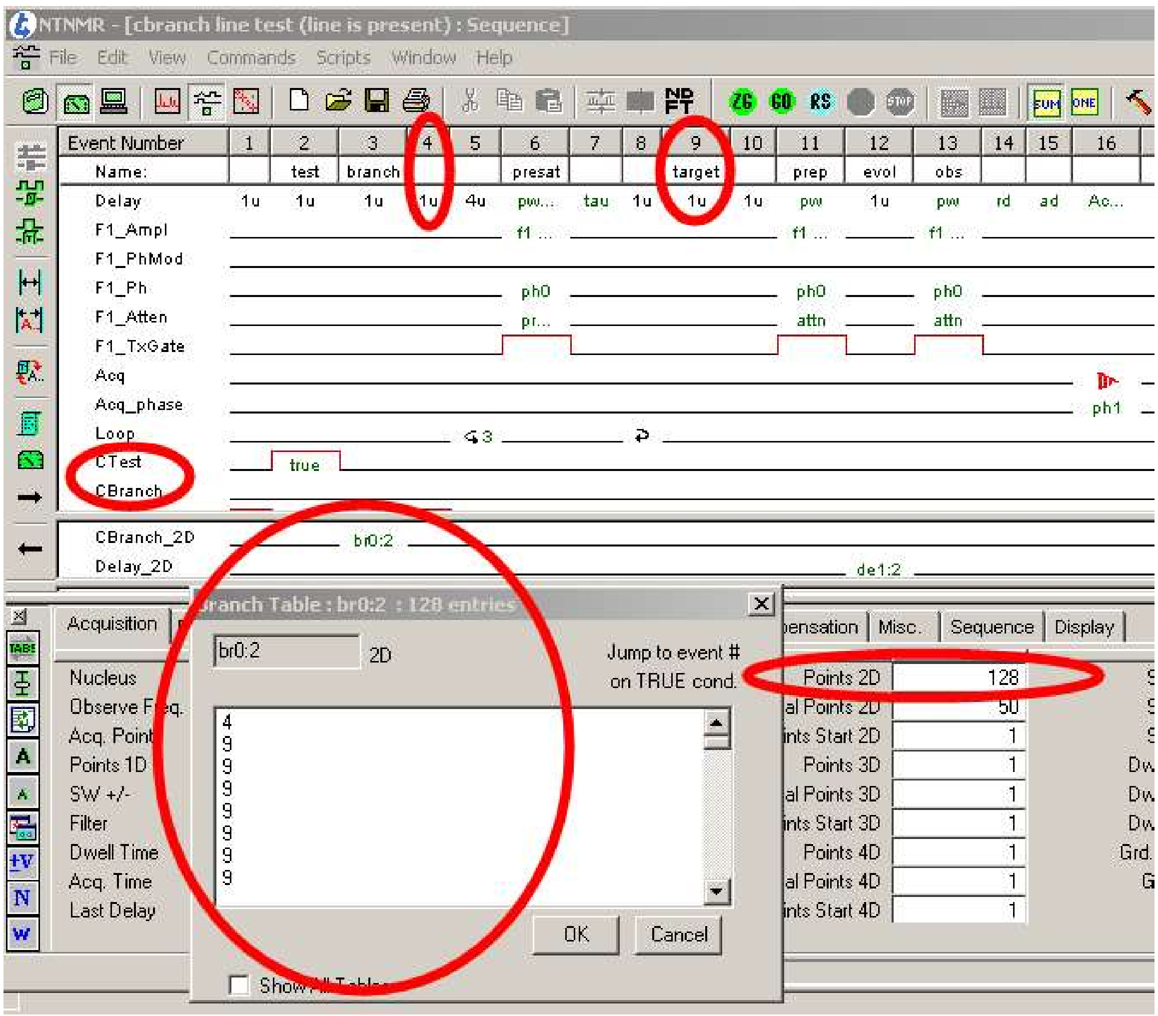


Example 1: <u>2D Preparation Sequence</u>

The following example performs the presaturation loop (events 5-7) only once for each 2D plane. On the first scan, events 4-8 are executed (the branch is from event 3 to 4). On all subsequent scans, a branch from event 3 to 9 causes events 4-8 to be skipped. Note the extra event (#4) inserted before the loop start to provide a target for the first jump.

Pulse Programming procedure:

In event 2, place "Always True" on the CTest line.
In event 3, place a 2D table on the CBranch line.
Put the following entries in the table: 4, 9, 9, 9…. (the target event numbers, total 128 entries)



### Conditional Branching

Conditional branching allows the execution of events in a pulse sequence in a different order, depending upon some **condition**. Such conditions might include:

- Scan count values
- Presence or absence of an external (hardware) signal (future)

The changed order of events results from a **branch**, from a branch event to a target event (The target is normally some event other than the next one in the sequence).

To allow the increased flexibility in pulse programming that results from conditional branches, some hardware and software features have been added to the Redstone system:

- A hardware state or condition input distributed to every EM-III (implemented with PCB rev C)
- A **CTest** sequence line to specify when the condition input is to be tested or detected, and what sort of test to perform. A CT event specified on this line will set an internal flag bit = 1 if the condition is true. The flag state is stored and persists until the next CT event occurs.
- A **CBranch** sequence line to specify the branch destinations. Tables on this line indicate the target event(s) for a branch. A branch occurs if the flag (from CTest) is true when the branch event is executed.

Some rules:

- Conditional branches apply only to Redstone/EM-III systems.
- Minimum time for CB/CT events is 1μs
- The condition must be tested BEFORE the branch event.
- The branch event and its target are always executed.
- Branches are always specified in tables. All branches are specified by the target event number as shown in the sequence editor. (If the number of events in the sequence is changed, the sequence editor will attempt to update the target event numbers, and warn the user if this is not possible).
- No branching INTO or OUT OF a loop (an entire loop may be skipped, however).
- No branching into another scan: i.e. beyond the START or END-OF-SCAN events for the current scan.
- No branch can skip any slow-io event (frequency hop, gradient rotation, or acquisition).
- nD tables: the highest dimension overrides any lower dimension branches (tables replace rather than add).
- A branch may not have a waveform table on the same event. However, the branch's target may have a waveform.
- A branch may not occur in the same event as an external trigger event.
- There is no protection against infinite loops

Limitations:

There are presently no software protections against illegal branches, infinite loops, or other problems that might cause the pulse programmer to lock up. Users must test their sequence under safe conditions (e.g. with the power amplifiers disabled).


To specify extended table behavior, check the box in the table editor, as shown above. This feature is available for “Icon types” A3, E3, G3, P3, R3, and W3.

Other notes:

- All tables in the same dimension, on the same event, and on the same module (e.g. amplitude and phase), must have the same setting of the “extended” flag. The compiler creates a composite table for this event, and uses the flag value from the last table it processes.
- The number of table entries should be different from the corresponding Scans nD or Points nD, in order to be useful.

# New Features with EM-III

The Tecmag Redstone system is based on the latest Event Module—the EM-III. Below are detailed a few of the new features made possible with the EM-III including *Extended Tables, Conditional Branching,* and *Simultaneous Tables.*

## *Extended Tables*

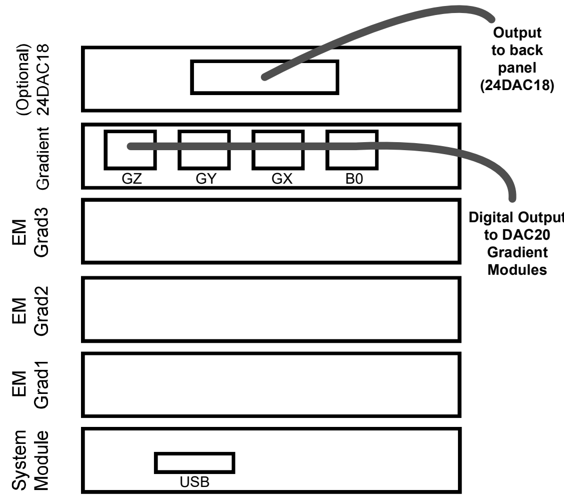
Certain table types may now be "extended". This means that the table pointer is no longer reset along with the associated scan counter. Thus, (depending upon the number of entries) the table entries can become "asynchronous" from the scan counter. For example, suppose it is desired to apply a pseudo-random phase to the transmitter and receiver on each excitation, to accomplish so-called "rf-spoiling" of the transverse magnetization. In such a case, it would be undesirable for this phase pattern to repeat itself synchronously with the phase encoding in a 2D experiment (e.g., every 4$^{th}$ record). If we use an extended table, we can accomplish this, as illustrated in the chart below, which compares the phase from the following tables:

- Standard 1D table (0º, 180º)
- Standard 2D table (0º, 90º, 180º, 270º)
  vs.
- Extended 1D table (117º, 234º, 351º, 108º, 225º, 342º, 99º, 216º, 333º, 90º, 207º, 324º, 81º)

| 1D scan # | 2D scan # | Phase from standard 1D table | Phase from standard 2D table | Net phase from standard tables | Phase from 1D extended table |
|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | **0** | **117** |
| 2 | 1 | 180 | 0 | **180** | **234** |
| 1 | 2 | 0 | 90 | **90** | **351** |
| 2 | 2 | 180 | 90 | **270** | **108** |
| 1 | 3 | 0 | 180 | **180** | **225** |
| 2 | 3 | 180 | 180 | **0** | **342** |
| 1 | 4 | 0 | 270 | **270** | **99** |
| 2 | 4 | 180 | 270 | **90** | **216** |
| 1 | 5 | 0 | 0 | **0** | **333** |
| 2 | 5 | 180 | 0 | **180** | **90** |
| 1 | 6 | 0 | 90 | **90** | **207** |
| 2 | 6 | 180 | 90 | **270** | **324** |
| 1 | 7 | 0 | 180 | **180** | **81** |
| 2 | 7 | 180 | 180 | **0** | **117** |
| 1 | 8 | 0 | 270 | **270** | **234** |
| 2 | 8 | 180 | 270 | **90** | **351** |

In this example, 2D records 1, 5, and so on have the same phase with the standard tables. The 1D extended table repeats on the second scan of the 7$^{th}$ record, resulting in far less correlation with record number. Note that because this table is a **1D extended table**, the pointer increments with the **1D scan counter**.

## *Gradient Cluster*

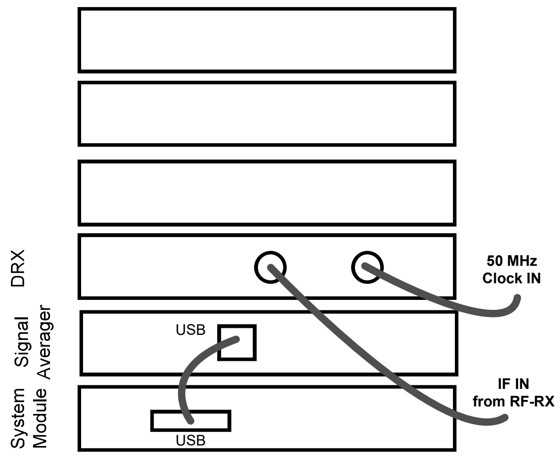



The digital output of the Gradient cluster is delivered to DAC20 modules (not shown) using RJ-45 cable that has been modified at the factory to inhibit ground loops. Depending on the configuration the DAC20 modules may be located in a separate 2U rack-mountable DAC chassis, mounted within the Redstone chassis, or installed within certain gradient amplifier models.

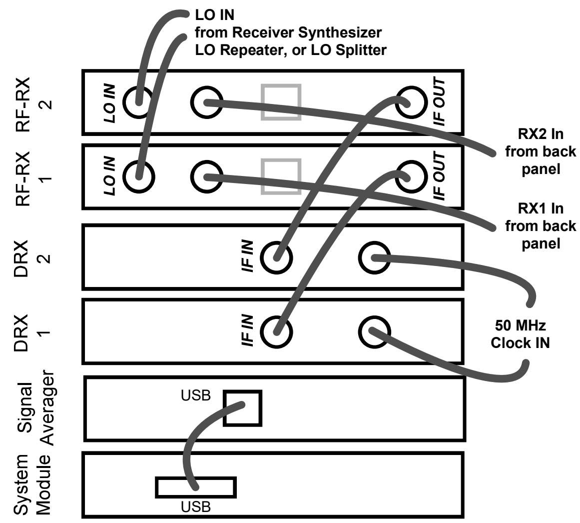

A Gradient Cluster with optional 24DAC18

### *Acquisition Cluster*

## Single Receiver



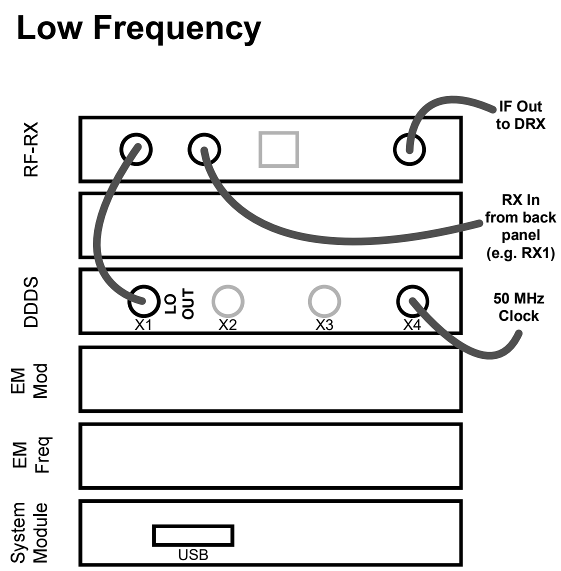

## Dual Receiver

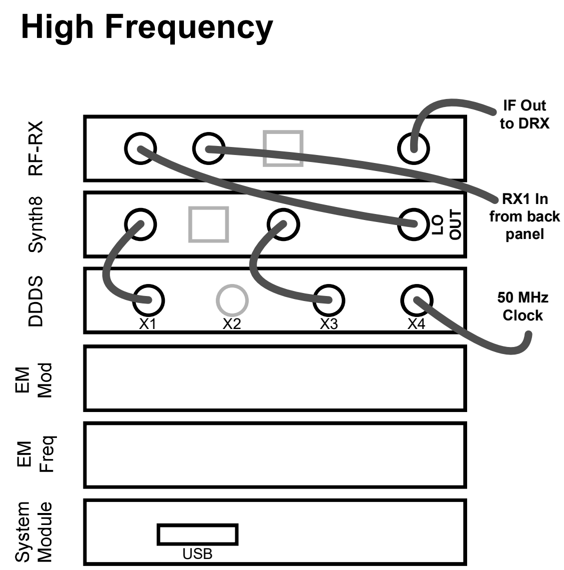




An Acquisition Cluster for a single receiver Redstone

### *Receiver Cluster*



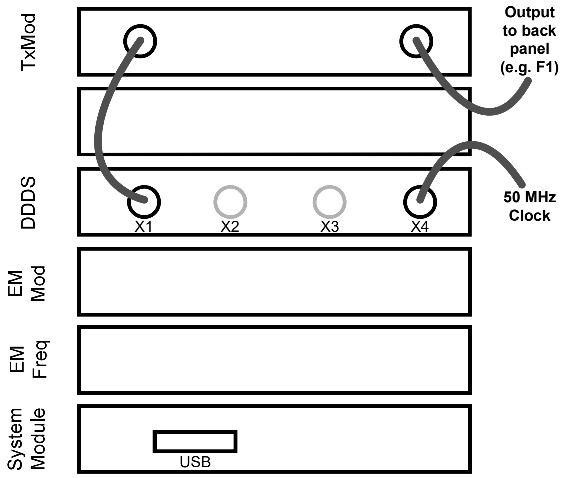




Single receiver configurations are shown here. When configured for multiple receivers the RF-RX analog receivers are located in the Acquisition cluster rather than the Receiver synthesizer cluster (See Acquisition Cluster—Dual Receivers below).

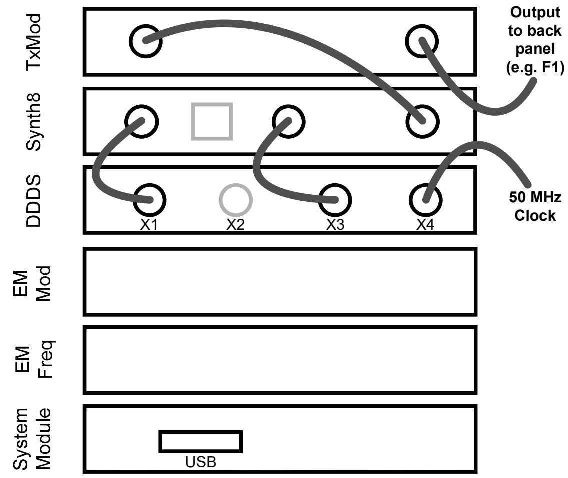
A high frequency Receiver Cluster for a single receiver Redstone

### *Transmitter Cluster*

**Low Frequency**




**High Frequency**



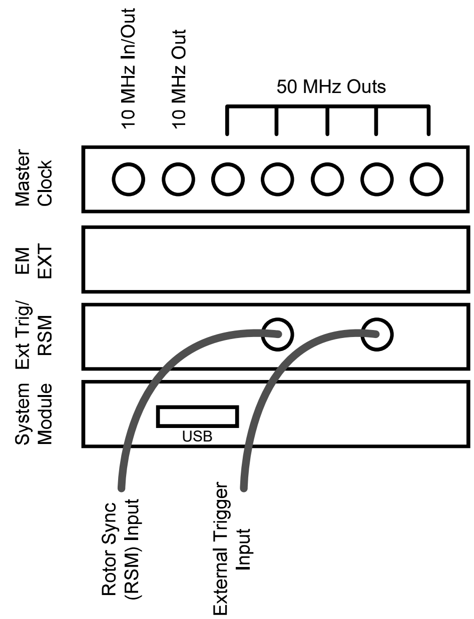

| | |
|---|---|
| Low Frequency: | 0.1 to 125 MHz[†] |
| High Frequency: | 5 to 500 MHz[*] |
| Max Output: | At least 0-4 dBm across frequency range |
| Max Rise Time: | <30 ns @ 100 MHz |


A high frequency Transmitter cluster

[†] Extended frequency ranges available upon request

# Cluster Cabling

## *System Cluster*

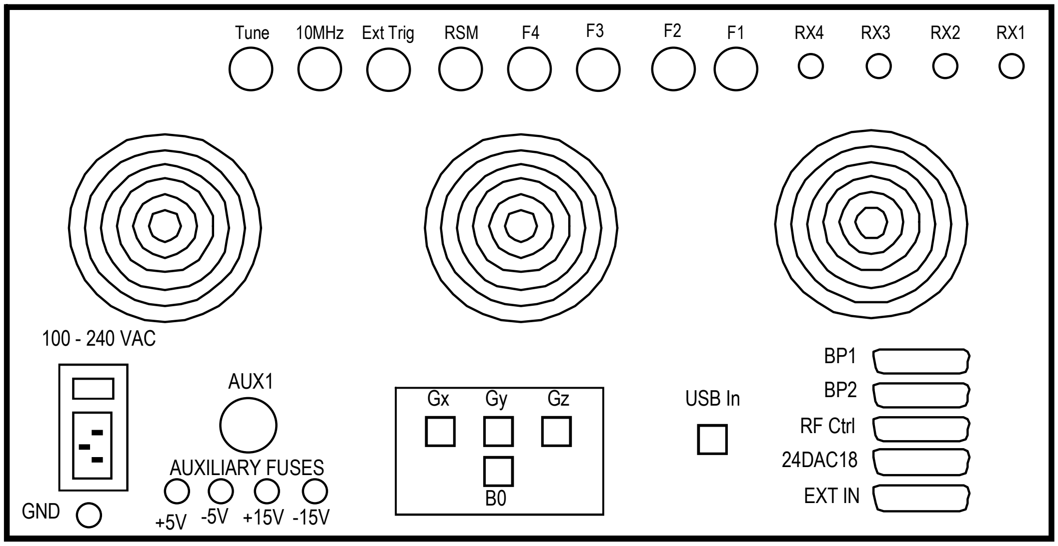



(Optional) **EM EXT** provides latched voltage output lines for Tecmag Probe Interface, RF relay control, etc.

**Master clock**: Default configuration is internal clock with the first 10 MHz port defined as an output. It is possible to switch to external clock mode (contact technical support) in which case the first port becomes a 10 MHz input for synchronizing the Redstone to another device.

**Ext Trig/RSM (shown here) or Utility**: In 2012, the Ext Trig / RSM module was replaced with a Utility module. A ribbon cable header is used for inputs rather than SMB connectors

## Back Panel Layout*




| | |
|---|---|
| RX1 – RX4: | Receiver inputs |
| F1 – F4: | Transmitter outputs |
| RSM: | Rotor Synchronization Module input from probe tachometer circuitry or Tecmag Air Control |
| Ext. Trig: | External Trigger input; TTL; for external triggering of the Redstone pulse programmer |
| 10 MHz: | 10 MHz clock output (internal clock configuration--default)<br>10 MHz clock input (external clock configuration) |
| Tune: | Optional RF output to Tecmag Probe Interface or directional coupler for RF tuning |
| BP1 and BP2: | Pulse programmer-controlled TTL outputs for amplifier blanking and scope triggering; additional lines may be added as required |
| RF Ctrl: | Optional latched voltage output for Tecmag Probe Interface |
| 24DAC18: | Optional 24 channel DAC output for Tecmag SU-24 room temperature shim controller |
| EXT IN: | The EXT IN 25-pin connector provides inputs for conditional branching hardware tests. Pins 1-4 are bits 0-3, respectively; pin 25 is a ground (GND). |
| $G_X$, $G_Y$, $G_Z$, $B_0$: | Digital (RJ-45) or Analog (Twin-axial BNC) gradient signal outputs |
| AUX1 and fuses: | 0.5 amp +5, -5, +15, and -15$V_{DC}$ outputs for auxiliary devices including preamplifiers, Tecmag Probe Interface, and Tecmag Air Control |

* Exact connector location & labeling subject to change. Consult installation documentation.

# Redstone

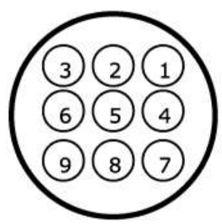
## Voltages

### *Input Power Requirements*

| | |
|---|---|
| Voltage: | 100 – 240 $V_{AC}$ auto-switching |
| Frequency: | 50 – 60 Hz |
| Power: | Nominally 600 W depending on configuration |

### *Auxiliary Voltage Output*

AUX 1&2



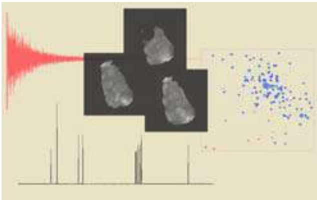

1. +5V
2. 5V GND
3. -5V
4. +15V
5. 15V GND
6. -15V
7-9. N\C

Auxiliary Current:

| Voltage | Max. Current (A) |
|---|---|
| +5V | 3 |
| -5V | 0.5 |
| +15V | 0.5 |
| -15V | 0.5 |


Rear panel Redstone Auxiliary DC Amphenol power connector & fuses

# LapNMR



# Hardware Reference Manual

## Redstone