RAVEN RESEARCH LIMITED

Application Note

The Design and Performance of Systems incorporating

The RR1001 HF Receive Switching Matrix

Contents

1. INTRODUCTION

Raven Research is proud of the performance achieved in HF receive switching systems by the RR1001 16 x 16 HF Signal Exchange Unit. This remarkable design is now offered to system engineers to use as a basic building block in RF switching systems. The unit gives the systems designer an off-the-shelf design with the following benefits:

- **Frequency coverage** 1 - 40MHz in the basic unit with options to extend the frequency coverage to 10kHz.
- **Sixteen input x sixteen output** full fan-out (non blocking) matrix switch in one compact 19 inch rack mounting unit only 4U high.
- **High 2nd order and 3rd order output intercept points** for maximum spurious free dynamic range, typically 100dB.
- **Low noise figure** for a high sensitivity receiver system.
- **Optimum feeder gain** for maximum dynamic range and optimum noise override.
- **High level RF input protection** against both accidental transmissions and static discharge.
- **Modular 19-inch rack mounting unit** for easy design installation and maintenance.
- **Modular construction** for easy maintenance and reduced spares holding.
- **High reliability** for minimum downtime.
- **BITE** for an early warning if something should go wrong and easy maintenance by operations staff.
- **Remote control** for configuration within larger systems and reduced manpower requirements.
- **Extensive line of compatible system controllers** to reduce design time and project completion costs.
- **Fully NATO Codified**

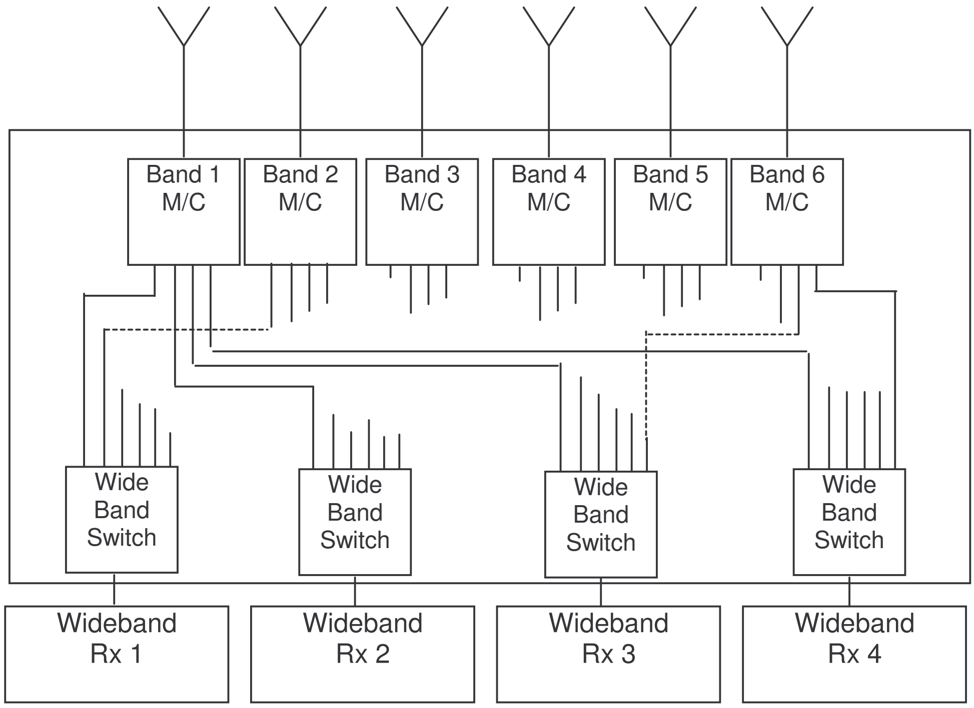

Figure 2.1 – Concept of 6 inputs x 4 outputs Signal Exchange System
(based on separate multicoupler and switch modules)

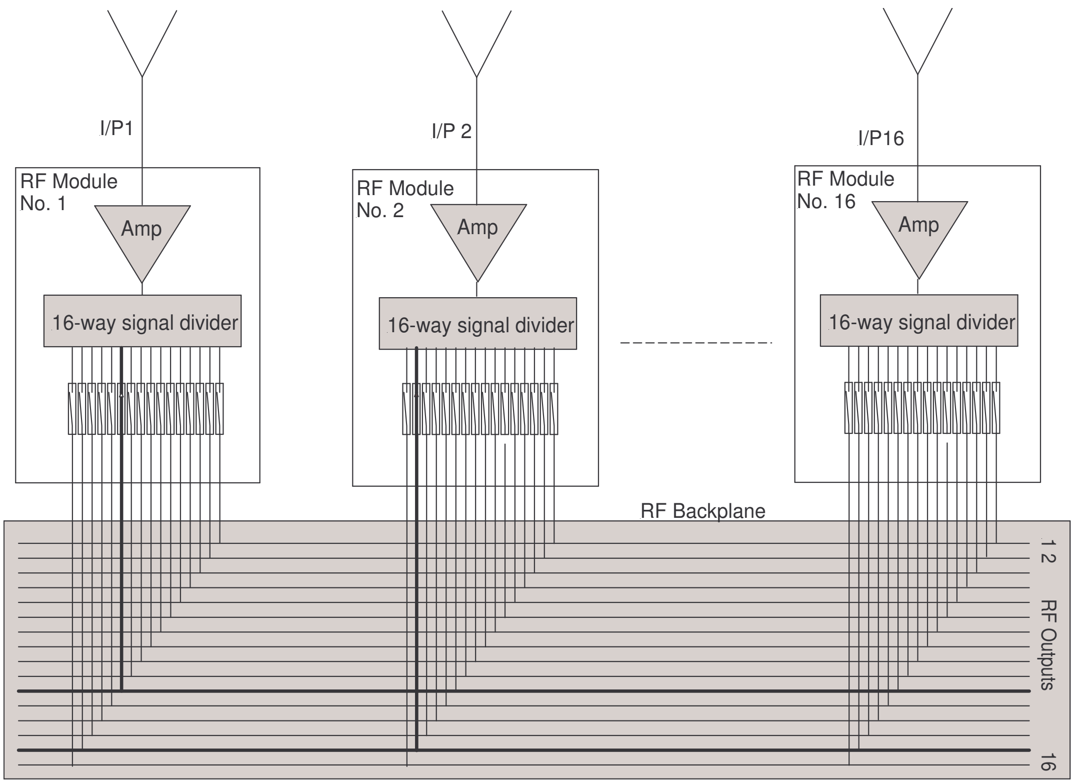

Fig.2.2 – Integrated Concept for RR1001 Signal Exchange Unit.

2. BASIC THEORY OF OPERATION

2.1 Development of RF Matrices

The RR1001 series SEUs will be of supreme interest to a designer or systems engineer who is faced with the task of switching HF/VHF signals from different antennas to more than one receiver. In HF receiving stations, it is usual to install several antennas covering different parts of the frequency band and different azimuthal sectors. Because of the size and expense of these antennas, the operators need to make as much use as possible of these valuable assets, as well as the corresponding receivers. It has therefore been common practice for the system designer to provision for the interchange of receivers between antennas, depending on the tasking of the station and the time of day, etc. In the past, manual patch panels have achieved this. The antenna-switching matrix was developed to allow this facility to be carried out more quickly and by remote control.

At first, switching matrices were literally built from sets of multicouplers and RF switches, cabled to provide a fully non-blocking antenna switching facility within the station. These assemblies have proved successful in operation. However, the construction and maintenance of such systems is expensive and difficult. When constructed from SP16T switches and multicouplers, a 16 x 16 RF matrix requires at least 256 RF cable assemblies and the corresponding space to house the individual units. *Figure 2.* 1 illustrates the cabling for a notional 6 x 4 switching matrix.

2.2 RR1 001 Series SEU Concept

The logical next step was to integrate the multicoupler with the switches in one compact unit. This step has been taken with the introduction of the RR1001 series, which is a line of HF Switching Matrices providing 16 antenna inputs x 16 receiver outputs, with simultaneously free access for each and every receiver to each and every antenna input. (This is a switching matrix that is non-blocking in the forward direction). Signal paths through the unit are illustrated in *Figure 2.2.*

The RR1001 is a subsystem comprising a set of front-loading input modules mounted in a 19" rack-mounting unit. Each input module comprises a 16~way multicoupler and a set of RF SPDT relays, one on each of the outputs of the multicoupler. Each RR1001 Switching Assembly can accommodate up to 16 of these input cards. The input modules plug into an RF motherboard at the back of the unit, which effectively commonly connects the corresponding outputs from each of the modules onto a single output line. There are 16 such output lines. By switching the inputs to an output line, one at a time, we effectively form a 16 input x 16 output switching matrix, non-blocking in the forward direction.

The unit has a control module also installed as a front-loading removable module. The function of this is to receive an RS232C formatted input command, through a connector on the back of the unit, and decode the command to activate the appropriate switches in the unit.

The RR1001 series product gives the system designer an inherently lower cost more compact and higher performance HF switching matrix than could be designed and manufactured from discrete proprietary equipment, with all the additional features required of system engineering (modularity, BITE, health and safety considerations, detailed documentation, etc.) already built in and available off-the-shelf. The product is fully NATO codified to a modular maintenance level.

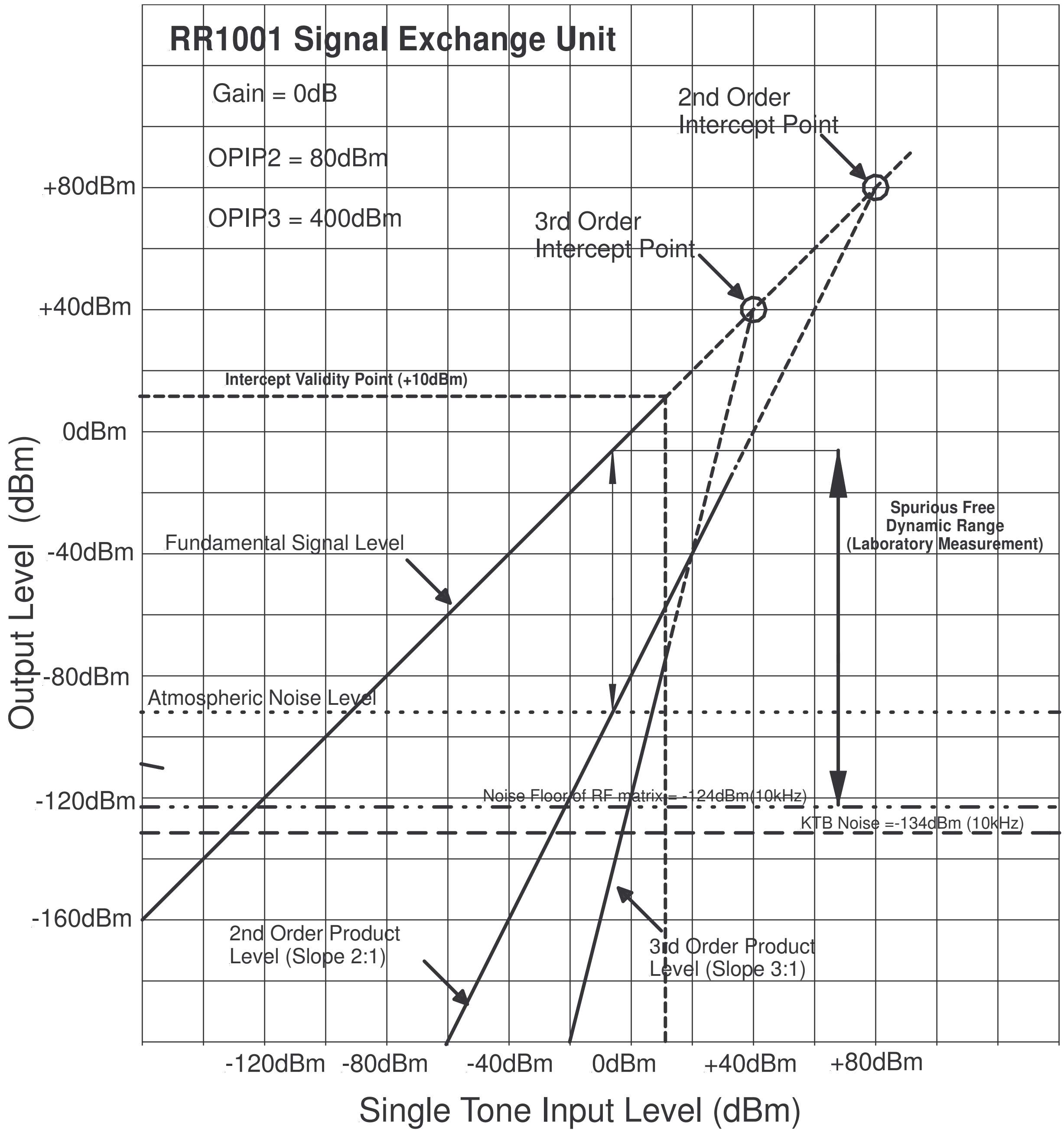

Fig. 3.1 – Signal, Noise and Intermodulation in the RR1001

3. RF PERFORMANCE OF SWITCHING MATRICES

The key parameters for the RF performance of a switching matrix are noise figure, linearity and isolation. The goal of the designer is to be able to switch receivers from antenna to antenna in such a manner that the RF performance of individual channels is no lesser quality than would be the performance of a dedicated single feeder line, if it were there.

Nevertheless, the parameter that is probably most discussed is switching speed and in particular the debate concerning the relative merits of solid state and mechanical relays. The following paragraphs describe the performance of the RR1001 in these aspects.

3.1 Noise Figure

In the HF band, the first requirement of the system is to have a relatively low noise but very linear preamplifier in the front end. The RR1001 has a push-pull FET amplifier at the input of each module which features an inherent noise figure of about 4dB and second and third order intercept points of +100dBm and +50dBm respectively.

The specification for system noise figure is usually set at 10dB, which is a reasonable figure, easily achieved by the matrix equipment (unit specification of $\leq$ 7dB). However, in Europe, the effect of local man-made noise and the intermodulation problem described below will usually swamp the effect of noise figure in modern equipment. There is therefore little benefit to be gained by specifying noise figure, as measured in the laboratory, much below the usual 10dB limit. Elsewhere in the world, a lower noise figure might be useful and the radio environment should always be considered before deciding on a system specification.

3.2 Intermodulation

The level of intermodulation distortion allowed in the specification is a source of concern for the performance of the system as a whole. Due to atmospheric and man-made noise, the noise floor for the system would often be expected to be about 20dB or more above KTB noise in the 10-15MHz regions, or approximately -114dBm in the usual 10kHz bandwidth of a communications receiver. To prevent spurious signals generated in the distribution system from rising above this level, the intermodulation suppression of a typical signal at -20dBm needs to be 94dB, the spurious-free dynamic range. This translates to second and third order output intercept points of +74dBm and +27dBm respectively.

In a modern HF receive station, the level of received signals often rises above -20dBm, typically above 0dBm and sometimes above +10dBm. Therefore intermodulation levels should really be specified as valid up to these input receive levels for them to be meaningful. Raven Research specify and test the intercept points of the RR1001 at a level of +10dBm and the figures given in the specification translate to a spurious free dynamic range (SFDR) of approximately 100dB. A graphical representation of the relative levels of noise, intermodulation products and SFDR is given in *Figure 3.1* (opposite).

3.3 Switching Isolation

Isolation is a very important parameter in the switching system but once again, the levels of isolation need to be considered carefully. For the sake of definition, when an output port is

directly connected to an input port, it is referred to as a switched port. When an output port is not switched directly to an input port, it is referred to as an unswitched port.
Isolation is usually quoted as follows

3.4 Input to Output

This is the ratio between,-

the through path attenuation for a desired path, but with selection disabled
the through path attenuation/gain for the desired path selected

This is sometimes termed OFF isolation. The parameter is important in that this is the way in which a high level and (currently) unwanted signal from an antenna of reasonable directivity/gain is isolated from a receiver which is dedicated to another antenna, serving a different frequency range or azimuthal sector.

3.5 Input to Input

This is the ratio between:

the level of signal present at any other input
the level of signal present at any input

This is inherently high in this system but, again, the same arguments about the level of signals on antennas apply as above. The parameter is therefore well inside the limits of practical requirement.

3.6 Output to Input

This is the ratio between --

the level of signal leaking back to the switched input
the level of signal present at an output port

It can be important from the standpoint of re-radiation and was particularly important when receivers were prone to high levels of LO radiation from the RF receive input port. Happily most modern receivers suppress this spurious radiation. The current level of 30dB is adequate in most applications, and (of course) if the path is unswitched, then the isolation is improved correspondingly.

3.7 Output to Output

This is the ratio between:-

the level of signal coupled to an adjacent output port
the level of signal injected at the selected output port

In this case both outputs will have the same selected input. The importance of this parameter is less significant than in the past, when receiver interference in the form of Local Oscillator interference might lead one operator to interfere with another. Modern receiver design has reduced the need for this figure to be greater than 30dB, but 40dB is typically available.

3.8 Frequency Range

It is often a requirement to extend the frequency range beyond the standard commercial HF range of 1.6-32MHz. The RR1001 series, as it stands, has usable performance down to around 250kHz, below which the noise figure, and isolation drop off. For this reason, the matrices are usually protected from interference from the LF/MF band by special filtering and the band is handled in a separate subsystem. However, if the requirement calls for only a small number of LF/MF inputs, then it is possible to fit a modified input module to the standard matrix to handle that band with RF performance equivalent to that of a dedicated VLF multicoupler, down to 10kHz.

The upper specified frequency limit of the RR1001 series is 40MHz, but usable performance extends to above 50MHz where the output match and isolation start to degrade.

3.9 Gain

The gain of the equipment is set at a nominal 1dB. It is a design goal that the operator should not perceive any difference between the performance of his feeder system with the matrix inserted and a direct connection. If the matrix introduces loss, the noise figure of the system is compromised; if the matrix introduces gain then the dynamic range of the system is compromised. Thus the equipment is designed for minimum effect in this area, with sufficient gain to just override subsequent cable losses.

3.10 Input Protection

The input modules to the matrix system may often be subjected to high-level input, either by accident (in the case of a close proximity transmitter) or perhaps due to the effect of a high gain antenna, used at night when signal strengths are very high. The first active stage of the input module is an amplifier that is inherently capable of delivering some 30W of RF power and has a gain of 13dB. It is therefore necessary to protect the following circuitry in the feeder system from such high power levels. This protection is achieved by means of a "gain fold back" circuit within the amplifier, which begins to operate when the signal levels raise above+15dBm. This circuit limits the amplifier output power to about 20dBm.

The system is protected from electrostatic discharge (such as nearby lightning strike) by means of a spark arrester and diode chain. It is important to note that this protection circuit is fitted to every input module as standard, and is guaranteed for 2kV peak voltage with 1.6us rise time and 50us duration to half peak voltage.

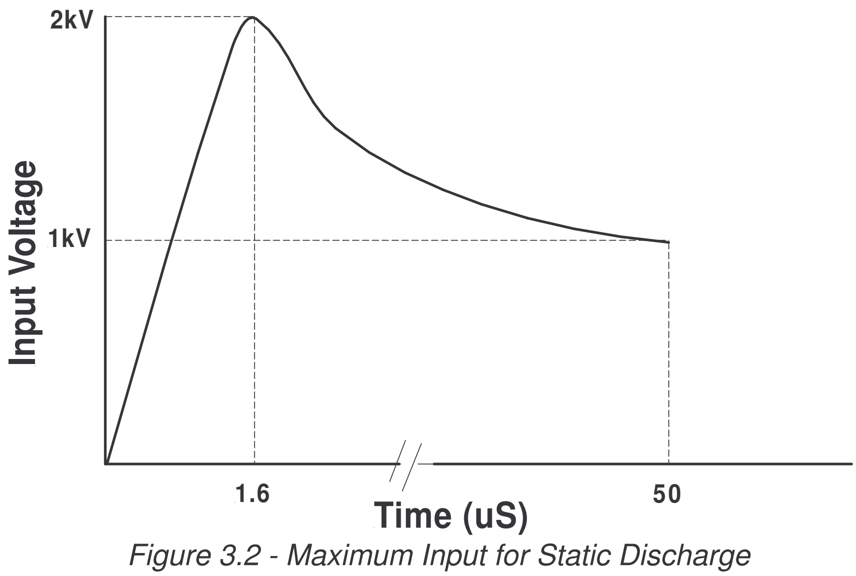

Figure 3.2 - Maximum Input for Static Discharge

4. RF SWITCHING SPEED

Usually, the first design parameter to be considered in the design of an HF matrix feeder system is RF switching speed. There are very few situations where high speed switching is required in the HF frequency band (1.6-32MHz), because the information bandwidths and data rates are relatively low. As a result, switching in less than 5ms versus 10-20ms will not generate any noticeable increase in information received. Another factor related to switching speed is the rate at which selections are made. In most communications applications, changes to distribution selections are not rapid, with a selected path being retained for often minutes and sometimes hours. In such a case, an electromechanical switch is the best solution. In the rare cases of frequent selection changing, such as for a commutating antenna switching system, a solid-state solution would have longer lifetime. However, the electromechanical switch approach is still viable as shown in the following example:-

Example: In a typical size of matrix switching system with 32 inputs and 32 outputs (1024 cross points) fitted with high reliability relay switches (mechanical lifetime of >10 million operations) an average system rate of change at 10 per second will result in a typical life of 32.5yr per relay. Software facilities are available to be able to log switch operations, so that automatic maintenance can be performed at required intervals.

An additional point to consider is the overall switching time of the system being designed. The RF envelope switching may well be achieved in less than 1ms for a solid-state solution, but the associated control system response time may be much longer as shown in the following example:-

Example: If RS232C serial data is used to control the switching system and a data rate of 4800Bd is used then each 8-bit character takes more than 2ms. For revertive data systems with tell back using 2 character commands, the control system response time will be well in excess of 5ms. To fully utilise the speed of solid-state switching, high-speed serial data (RS422) or parallel switching is needed. Very few systems can justify the control complexity and cost required.

If high speed is not an **ESSENTIAL** factor, the electromechanical switch is the preferred solution, offering the best performance for all other operational parameters.

The most recent advance in the RF switching relay is the Ultra Miniature PC mounted relay, designed to support the 900MHz mobile radio market as a transmit/receive changeover switch. Raven Research uses this type of relay, which is specified for HOT switching at 10W (+40dBm) CW, with a lifetime in excess of 10 million switching operations for +10dBm signal levels. The relay features a Bifurcated Contact, resulting in a wiping action with a minimum of contact bounce. Typically, RF switching is achieved in 2-3ms.

This new form of relay provides very high OFF isolation at HF (typically in excess of 100dB), combined with almost zero (<0.ldB) insertion loss, resulting in an almost ideal switch. In addition the common usage, and multi-sourced supply of this device ensures a long-term supply of low cost devices.

As a statement of confidence Raven Research undertakes production testing of Intermodulation Performance at test tone levels of +10dBm at the switch interface. Very few solid-state switching HF distribution systems would maintain performance beyond -10dBm levels.

Since 1987 Raven Research has delivered these RF relays into HF Switching Distribution systems throughout the world. [1] In most HF switching/distribution systems power handling, intermodulation performance and isolation are the prime considerations in choosing the switch technology. Our conclusion is that the high performance bifurcated contact RF relay is best suited for the task. Where fast switching speed is essential care should be exercised to ensure that the associated control system matches the RF switching time.

Based on experience in RF switching techniques, Raven Research chose the new RF bifurcated contact switching relay to form the basis of its design in the RR1001 series HF switch matrices and RR1400 series of switching units. Using this device ensures that the best overall performance can be delivered to its customers at the lowest possible price.

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[1] In 2004, customers are finally reporting failed relay switching boards. These boards have been monitored for relay operation. Some relays on them have completed over 30million operations. Some have completed only >200,000 operations but have nevertheless failed, but only after some 5-8 years in service. Obviously the failure mode is still a matter for research and analysis.

5. CONTROL ASPECTS

Control of the RR1001 series of switching matrices is exercised by a 3-wire full duplex serial data link, conforming to the EIA-RS232C standard, to a remote controller. The preferred interface should employ a command echo technique to ensure correct operation. Consequently hand shaking between RTS/CTS lines and DTR/DSR is not required. Any command processor that generates the correct commands as described below can control the unit, but Raven Research has designed a variety of controllers to suit different situations. Please contact your local distributor for more details of these.

5.1 Interface Connector

The remote interface connector is a 25-way female D-type mounted on the rear panel of the SEU. The connector pin out is as follows:

Pin 1	not connected
Pin 2	Rx Data
Pin 3	Tx Data
Pins 4 & 5	Linked
Pins 6 & 8 & 20	Linked
Pin 7	Signal Ground
Pins 9-19	not connected
Pins 21-25	not connected

The screen of the data cable connected to this interface is connected to the shell of the mating connector, in accordance with standard EMC practice.

5.2 Communications Protocol

The serial communications protocol used on the interface is usually set as follows:

Character Length	6 bits
Parity	Even
Start Bits	1
Stop Bits	1
Baud Rate	9600

However, different protocols can be selected by means of DIL switches in the control module, with baud rate selectable in the range 50-19200 baud.

5.3 Command Format

Matrix switching commands are formed from two six-bit command characters as follows:-

Character Type	MSB		Bit Number			(LSB)
	6	5	4	3	2	1
Type A	0	Status	Switch Select			
Type B	1	0	Module Select			

Character Type A:- determines the matrix output to be switched; the 'status" bit determines whether it should be switched ‘on’ or ‘off’. The "switch select" value is determined by the expression “RF output No.-1”. For example 1001 is the RF output number 10 is required.

Character Type B:- determines the (Antenna) matrix input, which is to be switched to the designated (Receiver) matrix output; the "Module Select" value is determined by the expression "RF input No. minus 1". For example, if the designated antenna is connected to SEU input 3, the module select value 0010 is used.

Response data will normally be issued from the matrix by echoing the command character back to the remote controller to signify correct operation. If parity, framing or overrun error occurs, then no revertive data will be issued and the matrix ignores the command. The remote controller should utilise a time out routine to detect such faults; a value of 25ms should be adequate. Under normal conditions of operation, where an existing antenna selection is to be changed to a new one, the remote controller must issue command characters to turn off the existing setting before attempting to effect the new selection (i.e. break-before-make). A total of four command characters are therefore required in the order Character A (OFF), Character B, Character A (ON), Character B.

Satisfactory operation must be confirmed by waiting for an echo response between each command character; command characters must not be sent "back-to-back" because this may produce erroneous switching within the matrix. The remote controller should utilise a time-out routine to detect the lack of such a response. If, after repeating the command character, there is still no echo response, then an appropriate error message should be generated by the remote controller to indicate an interface failure.

The following example illustrates a typical switching sequence for the RR1001-1616 matrix.

Example:

Consider the situation where an RR1001-1616 matrix is set with output 10 connected to input 6, and it is desired to switch output 10 to input 3. The controller will issue the following commands to effect the new selection:

OFF Command	{Character A: 001001}	Turn OFF existing selection
	{Character B: 100101}	
ON Command	{Character A: 011001}	Turn ON new selection
	{Character B: 100010}	

The matrix incorporates hardware status monitoring circuits, which generate a single failure character when a fault is detected within an RF module.

Character Type	MSB		Bit Number			(LSB)
	6	5	4	3	2	1
Fault	1	1	X	X	X	X

Where "X" is a ‘don't care’ state.

The matrix sends this fault response asynchronously when the fault condition is first detected and subsequently whenever a command is received from the remote controller (until the fault is cleared). The remote controller must be capable of detecting the fault character, if it is to fully utilise the fault detection facilities of the matrix.

In summary the control philosophy is based on simplicity of operation combined with robust handshaking ensure a fail-safe mode of operation.

6. CONSTRUCTION AND MAINTENANCE PHILOSOPHY

The RR1001 series has been designed in a highly modular way to enable ease of initial configuration straightforward expansion and ease of maintenance.

The units contain a very large number of components to achieve the desired function. However, the level integration is very high resulting in only two types of replaceable modular assemblies, the RF module and the Control module.

Up to 16 RF modules are fitted to achieve the full 16 Input by 16 Output systems. All modules are front panel loaded and each RF module features a status indicator on the front that glows green for correct operation and flashes red in the case of faulty operation.

Maintenance of the matrix unit is a matter of observing the front panel, identifying the faulty modules and replacing them. It is not necessary to power-down the unit during maintenance. The Control module features a similar status indicator.

A modular maintenance policy is all that is required to support this product.

Figure 6. 1 - RR1001 HF Receive Switching Matrix Unit

7. EXPANSION OF SWITCHING SYSTEMS

The basic RR1001 series of RF Matrix switch is capable of providing up to 16 inputs and 16 outputs (see figure 7.1) with completely non-blocking access for all outputs to any of the inputs. However, in some cases, larger capacity is required. The largest system that Raven Research has completed so far encompasses over 250 outputs with non-blocking access to 48 inputs. Such systems are built up using the RR1001 as a basic building block.

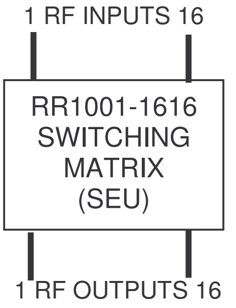

Fig 7.1 - Basic

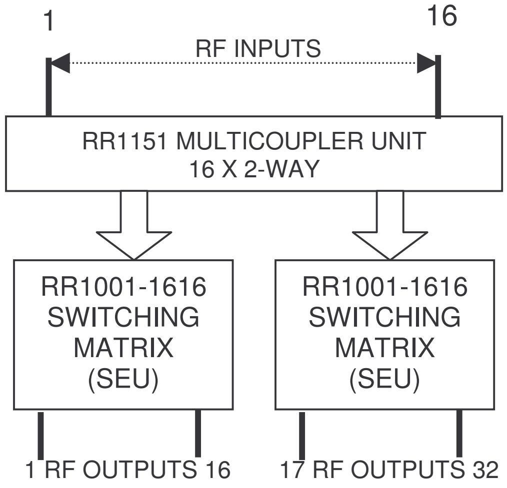

Fig 7.2 – Output Expansion
(16 Input x 32 Output)

a) Output Expansion

Multicouplers are installed on the RF antenna feeder outputs to increase the number of outputs (see Figure 7.2). These are fed in turn to the switching matrices.

b) Input Expansion

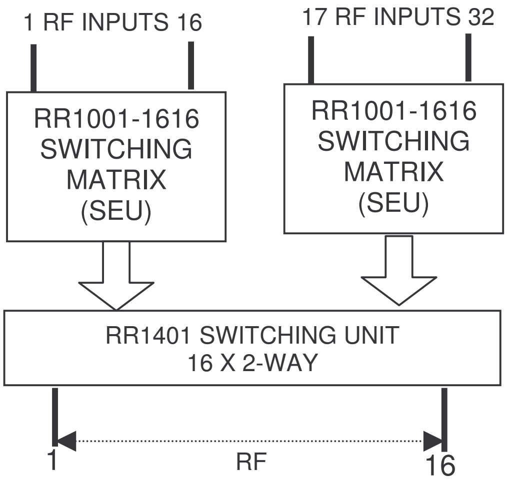

Fig 7.3 –Input Expansion
(32 Input x 16 Output)

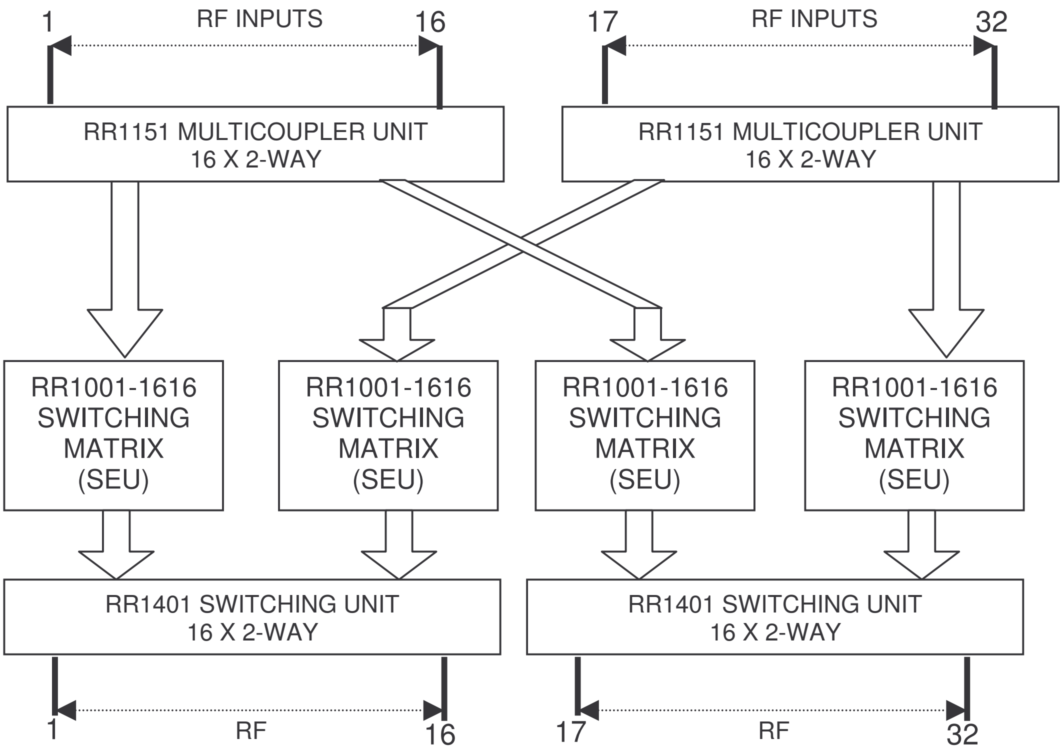

Fig 7.4 –Input AND Output Expansion (32 Input x 32 Output)

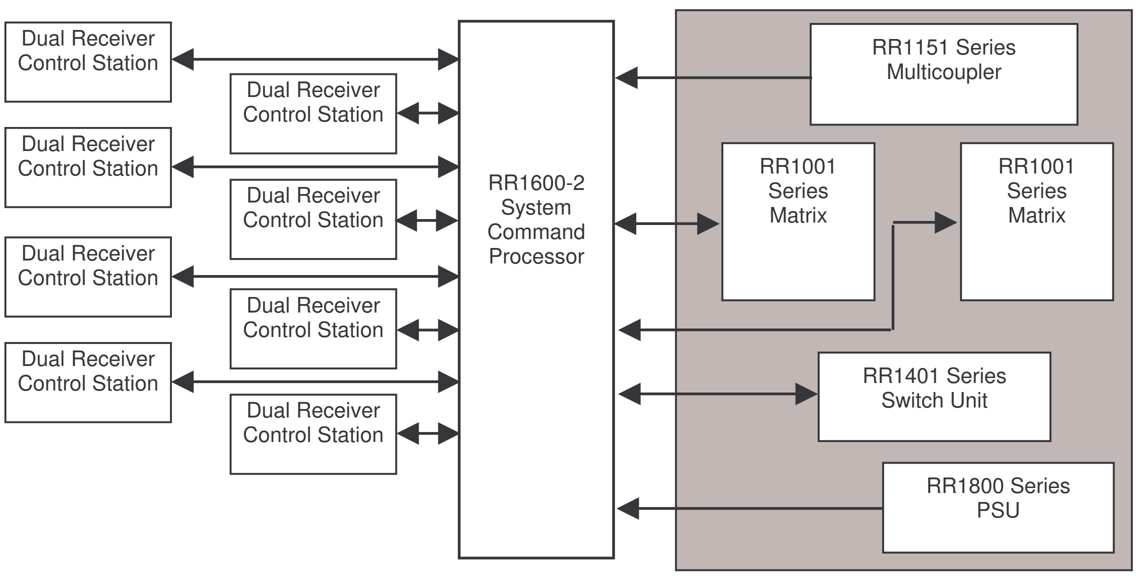

Figure 7.5 - Block Schematic of Distributed Control Arrangement
(Showing 8 dual-receiver control operator positions)

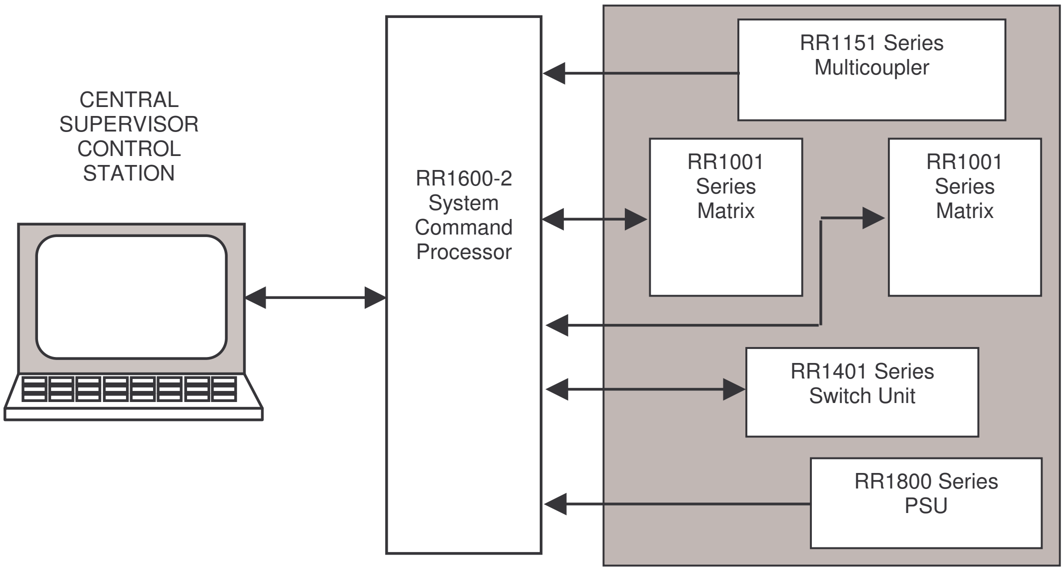

Figure 7.6 - Block Schematic of Central Control Arrangement
(Showing central supervisor control by computer)

The number of inputs is expanded by installing RF switches on the RR1001 RF outputs (see Figure 7.3), which allows the outputs of the system access to more than one basic matrix unit.

There are a number of such rack mounting equipments in the inventory of Raven Research, both multicouplers and switches, which we designed for the convenience of the customer. However, the use of Raven Research units is not essential. Other proprietary units, perhaps already in service in the customer's installation can also be used.

When designing these larger systems the key issues are the control of the system, the installation and the use of BITE.

c) Control Aspects of Larger Systems

A small system comprising only one RR1001 matrix is usually best controlled using a commonly available PC or a simple controller with a set of front panel controls. A typical example of the latter is the RR1550 (see separate data sheet).

A larger system *(see Figure* 7.4) usually implies that a larger number of users will want to access the system and it must be firmly established at the outset, whether each user will have independent access (distributed control) to the system or whether the access will be centrally supervised (central control). Either way, a system command processor is needed to interface between the control input and the various switches and matrices that make up the system. A block diagram for a typical distributed control system is shown in *Figure* 7.5. A block diagram for a typical central control system is shown in *Figure 7.6.*

The control of larger systems is a matter for individual system requirements and is best supervised by the systems design authority for each individual project. Raven Research is able to undertake design consultancy or project management of turnkey systems if necessary.

8. INTEGRATION INTO DISTRIBUTION SYSTEM

8.1 Mechanical

The RR1001 series of RF switching matrices are contained in 19 " rack mountable equipment frames, conforming to IEC297. An installation drawing for the equipment is given at *Figure 8.* 1. Raven Research would normally fit these units to rails or bracket fixings within the cabinet, which support the equipment frame. When fully equipped, the frame weighs 15.5kg. The use of slides, allowing the equipment frame to be removed and maintained in-situ, is not recommended as there is no need for on site maintenance or adjustment of the frame itself.

The input modules (up to 16) and the control module are loaded into the front of the frame and these can be inserted and withdrawn without disturbing the frame or even turning off the power. When an RF module is withdrawn, the other modules in the frame continue to function normally.

On the front of each module is positioned an LED, which normally glows green. If the BITE circuit detects any abnormal running in the circuit, this LED will change from green to flashing red. It is important therefore that the maintenance engineer does have sight of and easy access to the front panel of the equipment.

All RF and control connections are made to the rear panel of the equipment. RF connectors are 5O Q BNC socket types. The control connector is a 25-way D-type and the power connector is an AXR type plug. Raven Research Ltd will always supply mating connectors and standard back shells for the control and the power input circuits. Mating connectors are not supplied for RF connections.

8.2 Power Supply

The RR1001 series of RF matrix switches are powered by a 24Vdc supply, which must be provided to the equipment frame from the host cabinet. The supply is required to drive the control module and the RF Input modules. A fully populated equipment frame will draw up to 8.5A of dc current at 24Vdc. This design approach has been taken so that customers may use a variety of mains supplies in various localities and because of the increasing need to eliminate high voltages from equipment and comply with national health and safety standards for professional electronic equipment. We recommend the use of linear power supplies as the best means of avoiding the noise associated with switched mode supplies. Raven Research has both a 20 Amp single linear supply and a dual redundant linear supply, off-the-shelf, but the use of these proprietary supplies, especially in small systems, is by no means essential to the proper operation of the switching matrix. A typical example is the RR1802 dual redundant 20A supply (see separate data sheet).

8.3 Heat Dissipation and Thermal Management

In order to achieve the level of performance which is required in a modern communications system, the receive amplifiers have to be rated for high power handling capability as well as low noise figure. In the RR1001 series the pre-amplifiers are inherently capable of linear performance up to 10W output, though this power output is deliberately limited as described earlier.

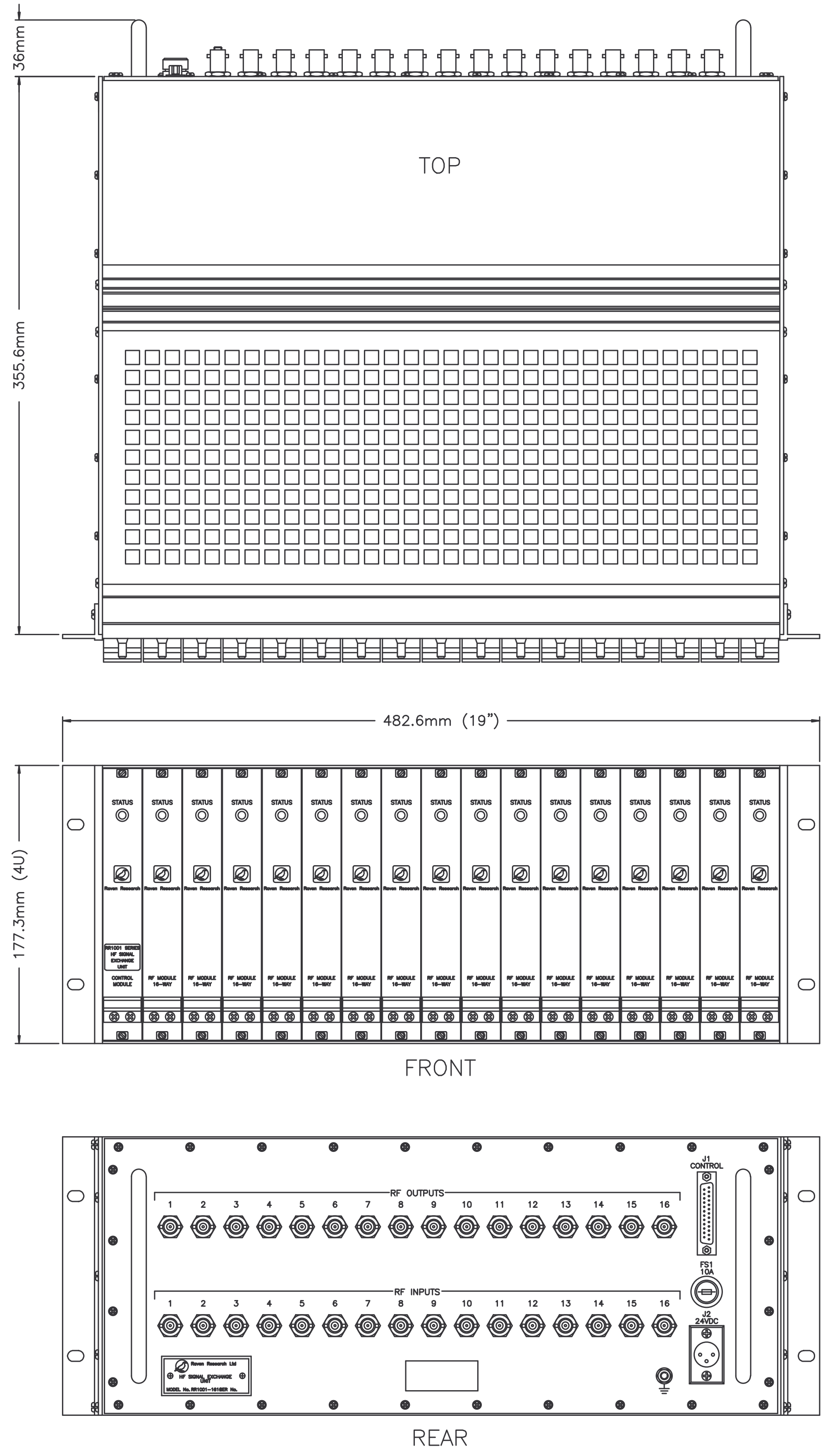

Fig 8.1 – RR1001 Installation Details

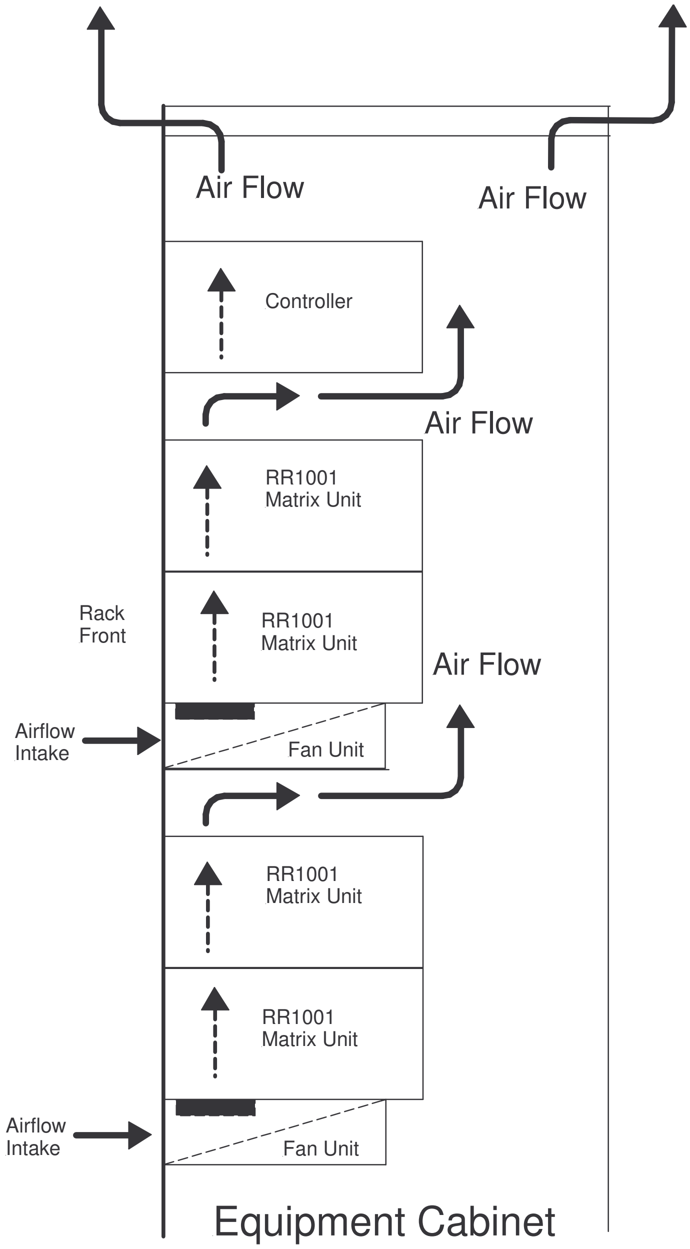

Fig.8.2 – Airflow through RR1001 SEU Matrix Units mounted in a 19" equipment rack (side cut-away view)

The consequence of this is that the amplifiers generate considerable wild heat, which has been taken into consideration in the thermal design of the RF input modules. Typically we expect that the front panel will be at a temperature of about 15^{o}C to 20^{o}C above ambient and may even be somewhat uncomfortable to the touch. The heat is dissipated through heat sinks which are built into every RF input module and which are in turn air cooled, the air flowing through the equipment frame, in through the bottom surface and out at the top.

A fully equipped matrix frame, standing in an uninhibited air space at temperatures up to 50^{o}C is capable of sufficient cooling to allow safe continuous operation. A fully equipped frame will dissipate up to 20OW. When installed into equipment racks, the installation should allow such a flow of free air and, preferably, the air should be forced through the equipment by means of fans, designed to draw the cooling air in through the front of the cabinet, through the equipment frame and to the rear of the cabinet. The air then needs to be directed away, preferably to the top of the cabinet, where it is exhausted *(see Figure 8.2).* A typical installation is shown at *Figure 8.3.*

Raven Research recommends the use of a fan tray assembly (Schroff D-7541), which will move 84m^3/hr of air at ambient temperature. This is sufficient to cool two RR1001 assemblies fully equipped and stacked, one on top of the other, with **NO** space between them. The thermal design of such a cabinet is not difficult but, where required, Raven Research will be pleased to provide consultancy services in this respect.

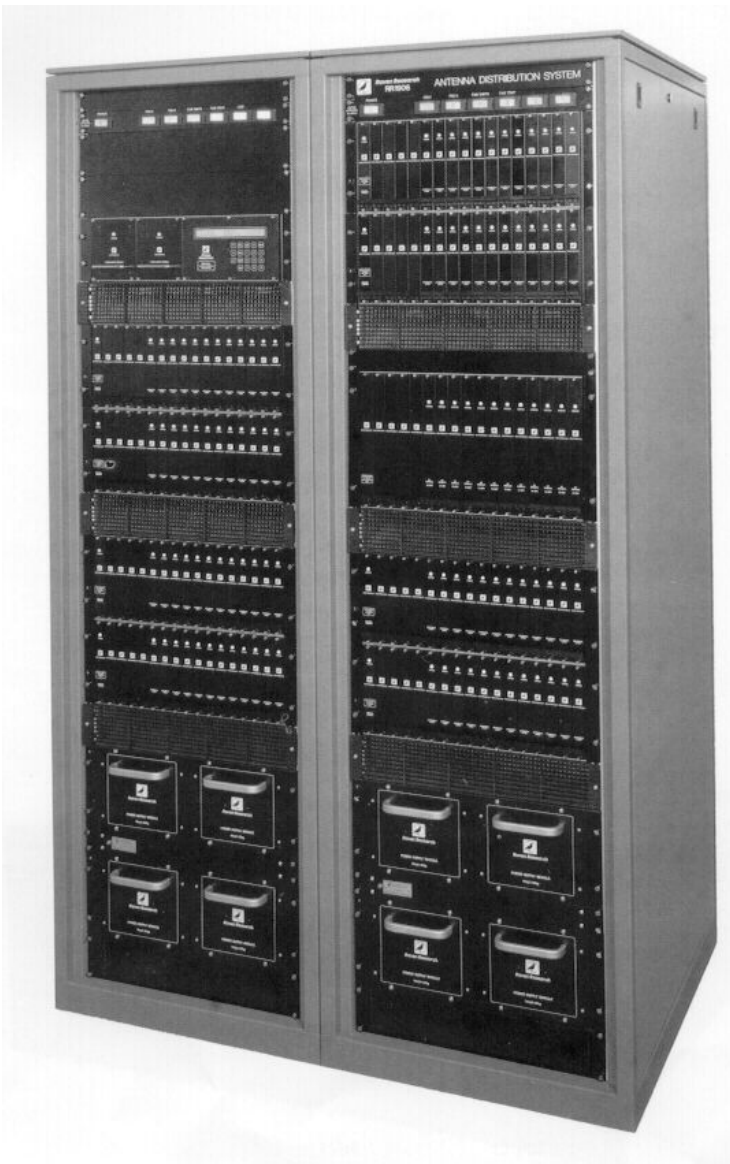

Fig.8.34 – Typical Rack Installation