AREG Repeater & Linking System Design Philosophies Version 1.0

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1 Introduction

The function of voice and data repeaters assists to extend the communications range of handheld, mobile and base stations utilising the VHF and UHF Bands. Individuals & groups experimenting with repeaters also provide a service to the Amateur Radio Community.

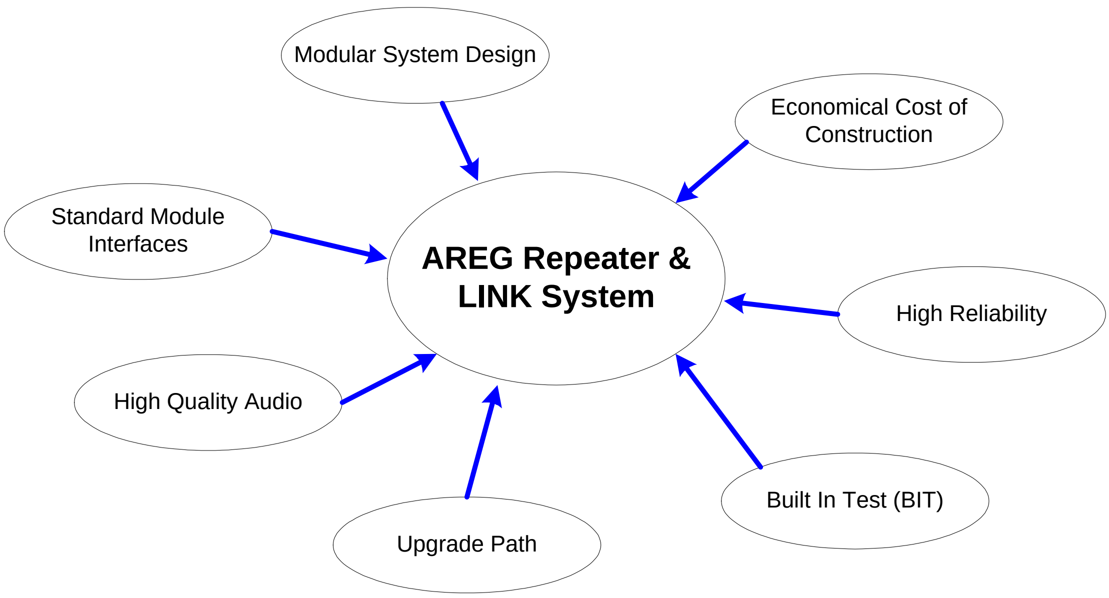
The understanding of the relationships between the various functional aspects behind the design and construction of a repeater system are an important part to a successful repeater project. The choices that were made by the experiments in following a particular implementation of a voice repeater system may not be suitable in all situations.

The following pages discuss some of the aspects important to have a good balance between experimentation and service providing with respect to Amateur Radio Voice and Data Repeaters.

We hope you gain some useful information from the following pages and the type of things that AREG did during our experimentation with repeater systems.

2 Design Philosophies

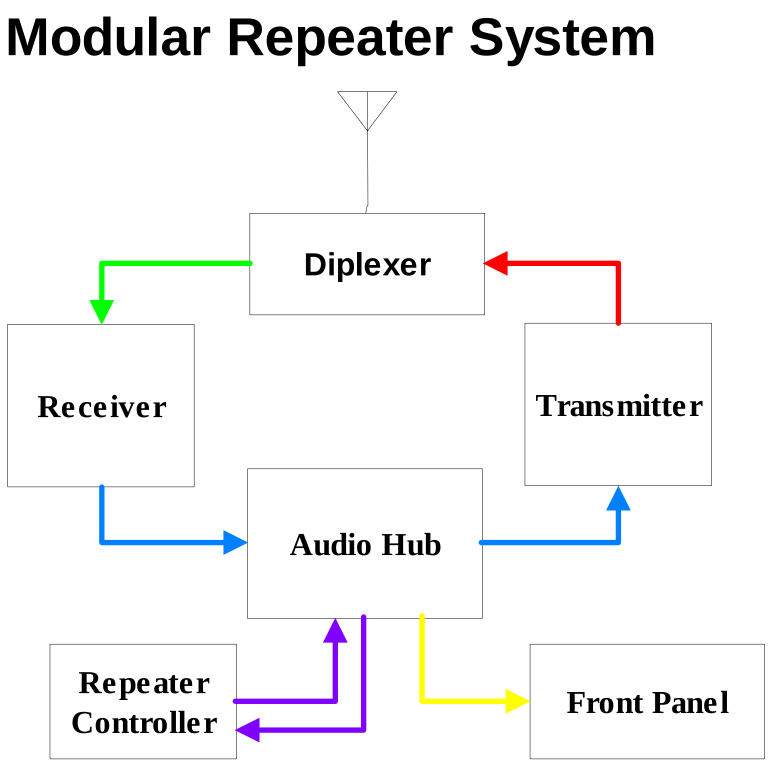
The AREG designers of the repeater system as part of their experiment wanted to include many concepts that are commonplace in the commercial and scientific worlds. The major design philosophies that have been incorporated in the repeater system are listed below.



The ability to link repeaters together at some time in the future was also considered as one of the design philosophies. As there is a number of different methods to link repeaters together, each method has is advantages / dis-advantages. The possibility of using different methods of linking was considered and has been incorporated into the repeater design.

2.1 Modular Design

The concept behind the modular system design is to split a large system up into small manageable parts. In large commercial systems a small number of spares is usually required to maintain a large system. As each module can be changed out in the event of a failure and replaced with a spare module.



The spare module performs the same function and requires no realignment at installation for the system to work correctly. As each module is tested and aligned in the workshop prior to installation.

The AREG repeater system was designed with the modular approach in mind. As each modular part of the repeater can be changed with re-alignment of the various modules.

A modular approach has many advantages when applied to amateur radio repeater and linking systems, such as:

- Fast restorations times
- Minimal spares requirements
- Project development

2.1.1 Fast restorations times

The traditional amateur repeater systems construction method involved building a project from scratch or modifying commercial equipment to do the job. This approach does not facilitate repairs without requiring the system to be taken off line and returned to the workshop while the repair is done.

The modular approach allows various system components to be interchanged onsite without realignment. As each module is setup and tested in the workshop prior to the modules being installed at a remote site. As the requirement for specialised test equipment has been removed, the fragile test equipment doesn't have to be placed in the back of the four-wheel drive and bounced up the side of the local mountain. Each time a linking system fault occurs.

The modular system facilitates people other than the system builder/s to be able to fault find and repair the system when required. Any faulty modules being changed over for working ones and then returned to the workshop for repair.

AREG determined the modular approach will usually mean the system is back and operating in days not months.

2.1.2 Minimal Spares Requirements

The modular system design approach allows for a small number of spares are required to maintain the repeater & link system. As common building blocks have been used to build the repeater & link system. A small number of spare circuit cards, receivers and transmitters can be kept on the shelf ready to be used for fault restoration.

2.1.3 Project development

The construction of the repeater & link system using the modular system allows for parts of the project to be shared between several people and or groups. The advantage is the length of time required to build your project is greatly reduced. The disadvantage is the construction quality and testing may vary from one person or group to the next. This can be over come with good project management, setting of expectations of construction standards, testing of built components, time line requirements and documentation.

AREG found because the repeater & link system was broken down into smaller components, as these small parts were completed, all involved will gained a good sense of achievement and positive feedback. This built enthusiasm and momentum in completing the project.

2.2 Modules Interfaces

A predefined interface between each module is essential to allow the modular system to work. The modular system will fail if interconnection signal amplitudes, impedances, polarity and connector type are not compatible. The standard interface is the basic building block to the repeater and link system. The interface is part of the modular approach that has been applied to the various systems. The standard interface is comprised of several components:

- Defined connector types and polarities
- Standardized functions assigned to each pin
- Audio level standards
- Control line levels & polarity

The Repeater & Link Standard Interface document details all the connections between each PCB and module in the voice repeater and link system.

Instead of defining a new interface each time a new function is required, a few well define interfaces are better than many poorly defined interfaces. Allowing for expansion as experiments progress is an important part of interface design. This does not mean the interface can't be redefined. Rather, when the time comes to redefine the interface, consider the future and leave room for expansion.

2.2.1 Defined connector types and polarities

The defining of connector types and polarities allows the various system modules to be connected. The standard details what connector is used in each application. The choice of each connector type is very important to ensure the connector is intended for the correct use. As well as the cost of the various connectors, as most Amateur Radio projects are built with low budgets, the use of expensive components is very prohibitive. Low cost but functional connector choices are an important part of the standard interface.

2.2.2 Standardized functions assigned to each pin

The standardizing of function assignments to each pin of the connector will assist with the interconnection of the various modules. The assignments are made so in general straight through cables can be used to connect different modules together. Avoiding completed connector wiring that would otherwise be necessary.

2.2.3 Audio level standards

The amplitude range and impedance of audio signals has to be matched between the various interconnecting system modules. This is an essential part of the modular system to ensure minimal distortion and impedance mismatch problems.

The range of audio signal levels is proportional to the deviation of the FM radio signal. The audio level standard at the module interface has to be referenced to a FM Deviation.

It is common in most amateur repeater systems the normal deviation will be 3.5KHz, this will vary depending on the particular equipment used.
A maximum deviation for the radio system is required, this is set to 5KHz, as the FM signal deviation is proportional to the audio level, a maximum audio level of 2.19Volts peek to peek will be generated.

The repeater & link system module interface impedance is set to 600ohms, as this is common impedance used in the broadcast and telecommunications industries. The maximum audio level on the linked repeater system module interface is 0dBm, which is 1mW of power dissipation into a 600ohm load. The 0dBm also equates to a maximum FM signal deviation of 5KHz

The linked repeater module interface can have either balanced and unbalanced audio lines. The balanced audio terminating in the balanced line receiver will be terminated into a 600ohm resistor with a maximum audio level of 0dBm. The unbalanced audio terminating in an unbalanced line receiver will also terminate into a 600ohm resistor with a maximum audio level of 0dBm.

2.2.3.1 Transmitter

The transmitter for either a voice repeater or a link radio should be aligned such that when supplied with a standard level of 0dBm. A constant deviation of 5KHz +/- 100Hz deviation should result, across the desired audio frequency range.

2.2.3.2 Receiver

The receiver for either a voice repeater or a link radio should be aligned such that when an RF signal achieves 20dB quieting and have a deviation of 5KHz is being feed into the receiver RF input. A constant audio level of 0dBm +/- 0.1dB should result, across the desired audio frequency range.

2.2.4 Control line levels & polarity

The modular system incorporates not only audio signals between the different system modules but a wide range of axially signals that include PTT, Squelch, Monitoring Signals, built in test (BIT) and etc.
These signals can be split into two different types:

- Logic signals
- Analogue signals

2.2.4.1 Logic Signals

The logic signals as the name suggests have one of two states, a logic high or a logic low.
The voltage levels are two categories:

- TTL 0-5volt level range, 0Volts equates to a logic ‘0’ and 5volts equates to a logic ‘1’.

- OC output current sink / High Z inputs. An Active LOW output, logic ‘1’ equates to current being sunk by the OC output, a logic ‘0’ equates to no current being sunk by the OC output.

In a modular system it is important that when a module loses power, it should not adversely affect the operation of other system modules. The use of open collector drivers on the output of a module and high Z inputs for the module logic line input.

With some types of integrated transistor array OC drivers, a protection diode may be incorporated to protect against the output being greater than the VCC of the IC. This type of IC should be avoided as it causes problems when the module loses power, the protection diode that is connected to VCC rail is then grounded by the power loss. Thus the OC output is activated by the protection diode now being forward biased. When selection transistor array OC drivers, be careful to ensure the protection of the chip will not affect the operation of other modules if the driving module loses power.

The specifications for each of the signals and there functions for all module connectors in the repeater / link system are given in the Repeater & Link Standard Interface.

2.2.4.2 Analogue Signals

The voltage range of the analogue signals is between 0 to 10Volts unless otherwise specified. These signals are used for various things like transmitter power measurement and receiver signal strength as examples.

The modules of the repeater & link system use analogue signals for various tasks. The specifications for each of the signals are given in Repeater & Link Standard Interface document.

The interconnections between modules / PCB’s is usually limited to one interface. Thus signals from one module may be routed through other modules but not used on those modules. This is done to simplify the wiring between modules and or PCB’s. Upon closer examination of the connector interfaces and module wiring / PCB circuits, you will notice that the BIT signals are a good example of this practice.

2.3 High Quality Audio Systems

The repeater & link system should maintain the audio quality from one end of the system to the other. A number of factors have to be considered to facilitate high quality audio system through the linked repeater network.

- Signal to Noise
- Frequency response
- Pre-emphasis / De-emphasis vs Flat Audio
- Audio Signal level measurement

The four factors listed above, have been considered during the design of the various module interfaces. The philosophies associated with each point are explained below.

2.3.1 Signal to Noise

The signal to noise of the system is very important, if this is not maintained, you end up with unintelligible audio emerging from the far end of the linked repeater system even with good signals going it.

- Site Environmental factors
- Link paths and distances

The site environmental factors have to been taken into account, as a large number of amateur repeaters share commercial sites. As most radio / repeater systems have high levels of RF noise at or near the equipment, maintaining a good signal to noise ratio on the interconnection cables in the modular system is very important.

2.3.1.1 Site Environmental Factors

The maximum audio signal level of 0dBm (2.19Volts peek to peek) provides a good signal to noise ratio between the audio signal and any stray RF on the audio cables. It is not uncommon the stray noise will be around the 1mV to 10mV in level, with a maximum audio level of 0dBm, greater than 30dB signal to noise ration can be maintained. The use of good quality shielded cable will also help ensure the stray noise on the audio lines is kept to a minimum.
The use of balanced audio systems between linked repeater system modules provides excellent capabilities to improve the signal to noise ration. As the balanced audio system removes any common noise, the stray noise generated by stray RF signals or other environmental factors can be further reduced.

A number of readily available balanced line drivers and receivers eg Burr Brown DRV134PA and INA137UA can be operated on a single supply rail. The maximum audio level of 0dBm (2.19Vp-p) is within their operating parameters. The balanced line driver / receiver provide an audio frequency response range from 50Hz to 20KHz using a regulated supply of 11 Volts and common mode rejection ration (CMMR) greater than 80dB. These devices are ideal for use in the repeater & link system running from nominal 12Volt battery / mains power systems.

2.3.1.2 Link paths and distances

The radio path design between the various repeater sites should not be underestimated. The requirement for highly reliable links is essential in the linked repeater system design. The various links should be designed with the following factors in mind.

- 100% reliable path is desirable
- Link needed to maintain good signal to noise.

The link path between the two repeater sites should be designed for 100% reliability. Users of the linked repeater system will be easily annoyed with links that are no available 100% of the time. The section on types of linking will discuss this further.

There is not point having a good repeater system that is linked together using a link that has poor signal to noise for the audio. In general this will quickly annoy users, and a poor quality link defeats the purpose of linking repeaters together in the first place.

2.3.2 Frequency response

The ideal repeater & link system does not alter the audio quality / frequency response as audio transverses the linked repeater system. The frequency response of the link repeater system is dependant on a number of factors.

- Link system modules frequency response
- Phase response of system modules
- Receiver / Transmitter audio frequency response

The minimum specification for the repeater & link system frequency response should exceed that of the general radio communications transceiver is from 300Hz to 3.5KHz voice band. Considering that CTCSS (PL tone) may also be used.
The repeater & link system frequency response was chosen to be 50Hz to 5KHz, this frequency response would allow CTCSS tones to be used as well as high end signal tones near 5KHz. As compared to a the general communications transceiver, the linked repeater system would have a HIGH-FI feel about it.

The approach of using a frequency response from 50Hz to 5KHz encourages operators to ensure their audio from their transceiver sounds good, as the linked repeater system does not alter their audio quality.

The repeater & link system should also be designed to preserve the phase response of the original audio signal. This will also assist with the HIGH-FI sound of the system.

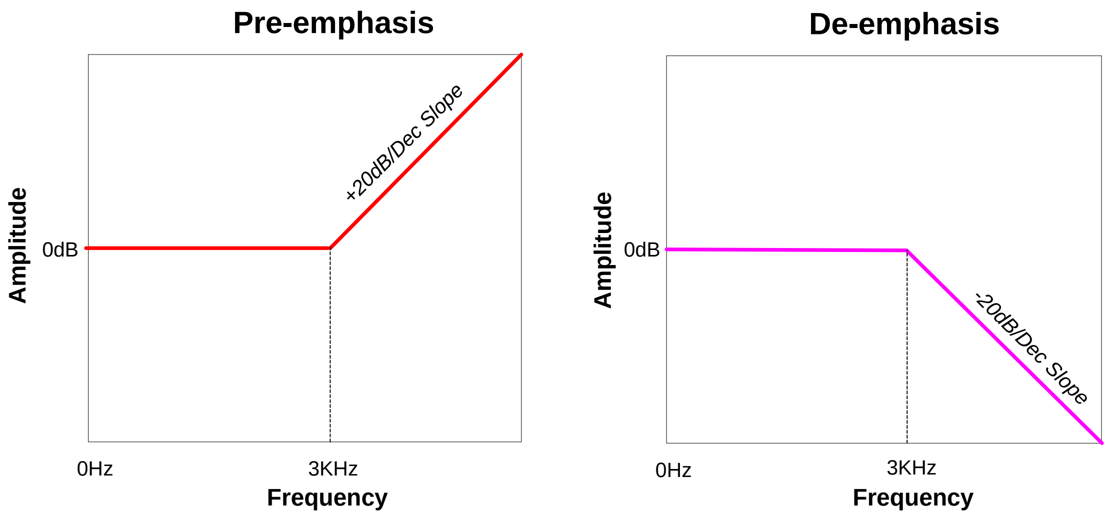
The frequency response of the receiver / transmitter will have the greatest affect on the repeater & link system. In general an unmodified transceiver frequency response is not suitable.

The AREG designers have found through experimentation the receivers is usually the easier to modify and obtain the desired frequency response. The transmitter depending on its type, problems with the phase lock loop and splatter filters may affect the audio response.

The repeater & link system designers have created some specially designed interface boards will allow the general transceiver to meet the desired frequency response of 50Hz to 5KHz. As there are so many different types or transceivers that can be used, from commercial to custom built, some will be easier to modify than others. Modification and alignment of the receiver / transmitter will be covered in more detail later in the document.

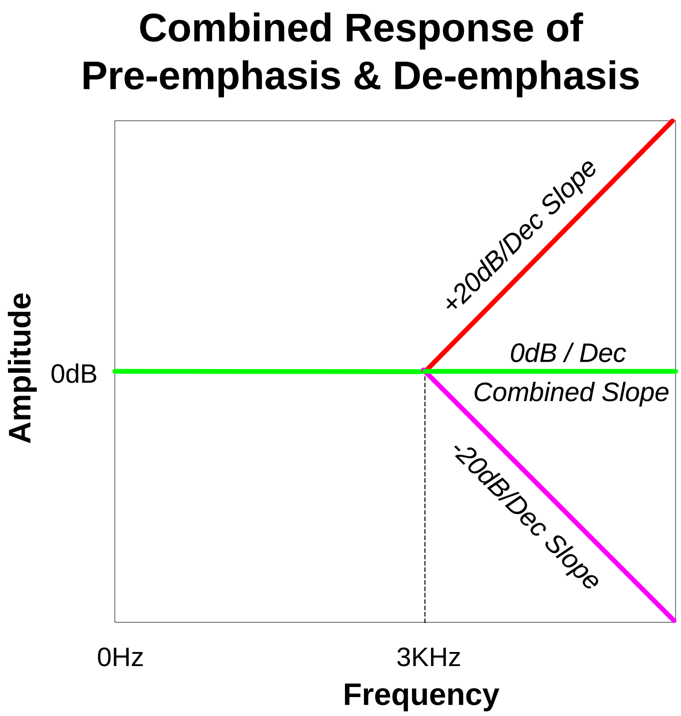
2.3.3 Pre-emphasis - De-emphasis VS Flat Audio

In frequency modulation (FM) radio communications systems intended for voice applications, pre-emphasis / de-emphasis is incorporated. The incorporation of pre-emphasis / de-emphasis is used to improve the signal to noise ratio of audio frequencies above 3KHz. The following diagram shows a theoretical response for Pre-emphasis and De-emphasis.



Pre-emphasis works by increasing the amplitude of audio frequencies above 3KHz by passing the audio through an appropriately shaped filter network before the modulator in the transmitter.

De-emphasis is required in the receiver to reverse the effect of pre-emphasis, thus audio is passed through an appropriately shaped filter just after the discriminator. The pre-emphasis / de-emphasis must be matched to each other to ensure no audio frequency response changes occur. The diagram below shows the theoretical response of the audio after Pre-emphasis and De-emphasis have been applied.



The incorporating pre-emphasis / de-emphasis over a repeater & link system can be very difficult to align and maintain. As each time the audio transitions between audio to modulated RF signal (pre-emphasis is applied) and from modulated RF signal back to audio (de-emphasis is applied). The frequency response of pre-emphasis and de-emphasis networks will not be completely composite. Audio tailoring will result from the transitions between audio and RF and back again. In a linked repeater system this transition will occur many times, with each time the frequency response of the audio is changed.

The tailoring of the audio is a huge problem and only gets worse when radio equipment from different manufactures is used in the link system. As each manufacture designs the pre-emphasis circuit and de-emphasis circuits differently.

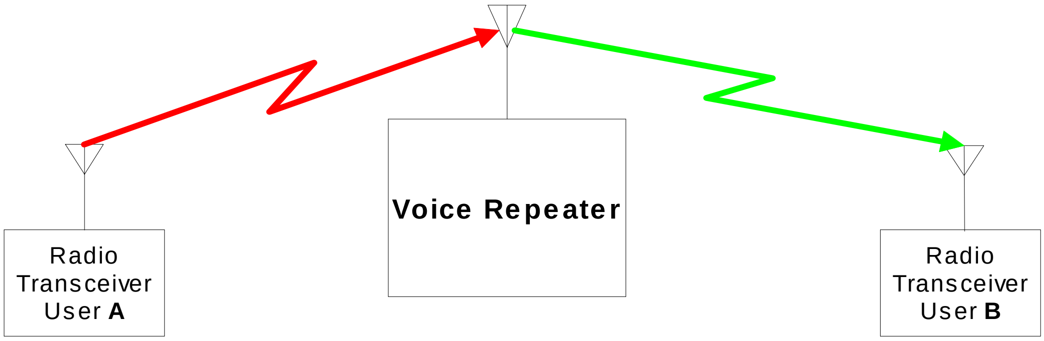
If the linked system incorporated transceivers from the same manufacture. The tolerances in the components will cause a difference in the pre-emphasis / de-emphasis filter curves resulting in audio tailoring.

The solution to this problem is to remove the requirement for pre-emphasis / de-emphasis network in the repeater & link system altogether by using flat audio approach.

2.3.3.1 Flat Audio

The flat audio systems does not incorporate any pre-emphasis / de-emphasis audio filters through the repeater & link system. A uniform frequency response is easier to achieve using a flat audio approach to align the receiver / transmitter, than to try to correct a poorly shaped pre-emphasis or de-emphasis frequency response.

Simple Repeater Use Diagram



The transceiver equipment used to access the repeater & link system employs pre-emphasis in the transmitter and de-emphasis in the receiver.
As ***User A*** of the repeater system transmits a signal to the repeater, the audio has pre-emphasis applied by their transceiver. The repeater & link system receives and then re-transmits the signal with out applying pre-emphasis or de-emphasis. A second person ***User B*** listening to the repeated signal using their transceiver equipment, the transceiver applies de-emphasis to the audio.

The flat audio system allows audio to transverses the repeater & link system from the user transceiver and back again with only one pre-emphasis and one de-emphasis filters being applied to the audio. The application of the flat audio system is well suited to the modular approach of the repeater & link system.

2.3.4 Audio Signal level measurement

The technique used to measure the audio signal levels at the module interfaces will vary depending on the type of test equipment available. What ever the equipment used, the audio interface must be terminated into the correct load impedance, otherwise misleading results may be yielded. The linked repeater system the correct impedance for balanced / unbalanced line is 600ohms.

The telecommunications industry uses a wide variety of equipment capable of measure the balanced / un-balanced audio lines, and example of this is a TIMS unit. The TIMS unit will provide a measurement in dB, which makes life very easy to measure 0dBm when setting up receiver / transmitter interface boards.

Other similar units are available, however for the average amateur, the availability of this type of test equipment is prohibitive. A dual channel oscilloscope in differential mode is a good substitute and can be used to easily measure the amplitude of balanced audio lines.

Using a dual channel oscilloscope in differential mode connect channel one to the +VE audio wire and channel two, to the –VE audio wire. A peek - peek voltage of 2.19Volts across a 600ohm resistor is desired, this equates to 0dBm. Thus, the maximum audio level in the modular system can be easily adjusted. As a 600ohm resistor is not available in the standard E12 or E24 range, two 1.2Kohm 1% resistors in parallel can be used.

2.4 Upgrade path

The upgrade path for the linked repeater system once it has been constructed is a very important aspect. With all things electronic, parts sooner or later become obsolete, and are no longer available.

When things fail due to long service life, or natural events like lightning strikes, the system will have to be repaired using new parts. The modular system provides an excellent vehicle for upgrades to occur in a seamless manner. As each module has predefined inputs and outputs, a module can be changed over for a new version as long as the interfaces on the new module comply to the standard. A classic example of this is the humble repeater controller, as the microprocessor are usually only around for 2 to 3 years before they are obsolete with the new part replacing the old one. Sometimes you can take the new part and it will plug into the old board and work fine, otherwise it's a re-design of the repeater controller board. It could be as simple as a new repeater controller has more functions than the old one, and you just want to upgrade the controller.

It does not matter the reason for the upgrade, the combination of the modular system and the standard interface between modules makes it an easy task to upgrade the linked repeater system.

2.5 High Reliability

The requirement for high reliability is a very necessary part of a system that will span many repeater sites. The problems associated with visiting a repeater site to do repairs can be as simple as going for a short drive up the hill and have a look. On the other hand it could be quite hard to obtain access to the repeater site, as it may be remote on top of some mountain that only has 4WD access during the dry part of the year. The repeater or link equipment could be on top of a building in the middle of the CBD, to gain access you have to make several phone calls and request a time to access the site in advance.

The reliability of a site is very important, whether it is the in convince of going to the site, or the access requirements, having highly reliable equipment will make a large difference in it's operation and maintainability.

The requirements for high reliability increase as the size of the linked repeater system increases. As fault finding large systems can be a large problem if they are spread over hundreds of kilometers. It can be very difficult to determine the fault location in such a system. When fault finding large linked repeater systems, assistance from many people will be required, the necessity for good documentation becomes mandatory.

The design of large linked repeater systems requires construction philosophies that are normally reserved for commercial or military type projects. The budget requirements will be higher than just building a single repeater system or a couple of repeaters. The amateur radio community can usually find ways to help produce a high quality product at a much low cost.

2.6 Built In Test (BIT)

The BIT (Built In Test) functions are common place in commercial & military equipment. As short restoration times are required in critical systems in the event of a fault. The BIT test information proves invaluable to quickly fault find the problem in a completed system.

The BIT system will vary greatly from one piece of equipment to an other, however they are all designed to provide the maintainer of the equipment with faulting finding information. Some BIT system are as simple as a few lights or LED’s, where as others have computer interfaces and terminals to assist with the fault finding of the system.

AREG wanted to include the ability to incorporate BIT functions in the designs. The Audio Hub is one example where a vast array of information about the state of the repeater can be gained from the front panel connector.

In the case of the repeater the BIT can be as simple as a few LEDs showing the power is various parts of the repeater along with current operation status. A more completed type of BIT with displays of TX power level, RX signal level and battery volts being displayed at the push of a button.

The BIT function of the repeater system can be as completed as the constructor wants it to be, the facility to add more functionality down the track has been provided by the repeater & link system designers.

2.7 Economical cost of construction

The cost of construction of Amateur Radio Repeater & Linking systems is always a concern. As many projects are funded by individuals or from small budges in the case of a club-sponsored project. The money is just not there to do the type of things that the commercial & military organisations would do.

The designers of the repeater & link system that is described in these pages have made a reasonable trade off between cost of construction and other requirements such as system reliability, site access, site requirements and labour available for the construction and ongoing maintenance. The various modules of the repeater can be upgraded as required in the future without the necessarily replacing the entire repeater.

3 Standard Repeater Modules

The AREG standard repeater modules are not covered by this document. For full details on the various modules and PCB used by AREG to construct the linking system, please refer to the AREG Standard Modular Repeater & Link System documents / web pages.

4 Summary

AREG hopes you have enjoyed what you have read so far in regards to the design philosophies that AREG has used when designing our repeater and linking systems.

Additional information is available from the AREG web site, http://www.areg.org.au