

by

Rank Magnuski, KA6M
311 Stanford Avenue, Menlo Park, CA 94025
(415) 854-1927

This paper will describe the construction and functioning of the KA6M packet repeater, and will report on the operational results during the first 10 months of service. Since its initial turn-on in December of 1980, the repeater has been transformed from an experiment to a major Bay Area repeater serving a user group now approaching 30 stations. The repeater has been extremely important in testing new hardware and software, and in provoking interest in the area's amateur community.

I. The KA6M packet repeater

From its initial turn-on in December, 1980, and through most of the Spring of 1981 the packet repeater was operating out of my residence in western Menlo Park, California, a location which is in the foothills which border the western shore of the San Francisco Bay. It was an experimental machine then, but could be heard well through most of the northern end of Silicon Valley, even though the power level was modest. The only station equipped to use it then was located in the same house, so there was never any real problem with signal path. Since then we have installed a couple of upgrades to the control software, we have used a better CPU card, increased the power level, moved the repeater up to a 700 ft. elevation, and integrated its operation to be 100% compatible with the protocol used by the Vancouver Digital Communications Group's terminal node controller. The repeater has changed from being a laboratory curiosity to a major Bay Area repeater heard from Marin/Berkeley to south San Jose, and the user community has grown from a couple of stations to a network approaching 30 users. (See the April, 1981, QST for the initial announcement on-the machine.)

The KA6M/R repeater is currently operating on a simplex channel assigned (in the San Francisco Bay area) for non-voice use, 146.580 MHz., and transmits data at a speed of 1200 Baud. The machine consists of a Z-80 microprocessor, a Bell 202 compatible modem, and a solid-state transceiver with power amplifier.

The repeater hardware is based on STD bus cards. The STD bus uses 56-pin 4 1/2" x 6 1/2" cards and is very popular for industrial process control applications. There are now many manufacturers supplying cards for this bus, and the repeater uses the Z-80/CPU-2 card from Mostek, which costs about \$195. The STD card is very compact, and does not have unneeded extra circuitry which is typically found on more versatile personal system CPU cards. A WD1933 chip was breadboarded onto a Vector STD board, and one additional card to control the transmitter is all that was required.

A Bell 202 modem uses a mark tone of 1200 Hz., and a space tone of 2200 Hz. The modulation is AFSK-FM using unmodified voice-frequency radio equipment. The signal is NRZI encoded, which means that each zero data bit causes a mark-space or space-mark transition in the carrier. It is difficult to explain to old-time RTTYers that "mark" and "space" lose their meaning in an NRZI

system. The HDLC frame guarantees that there will be a sufficient number of zeroes sent so that bit timing and clocking can be recovered from the incoming signal. No start/stop bits are ever sent.

The radio is an PT202 handheld transceiver with a 20 Watt power amplifier. Since this repeater runs simplex, problems associated with full-duplex repeaters (desense, etc.) are not encountered, and exotic remedies, such as duplexers, dual antennas, and so forth, are not required.

The control software for the repeater is written in PASCAL/Z, a PASCAL which generates native Z-80 code instructions. Assembly language interface routines have been written to control a Western Digital 1933 HDLC chip. The software fits into two 2716 EPROMS, and 2K bytes of RAM memory are available for use. The repeater can store up to eight 128-byte packets.

Before giving any more details about the repeater, it would be worthwhile reviewing some concepts concerning packet repeaters.

XI. Packet repeaters in Amateur Radio Service

Virtually all repeaters in Amateur Radio Service can be classified into three major categories: Frequency-diversity, Time-diversity, or Space-diversity.

A frequency-diversity repeater is a conventional repeater which uses two or more frequencies for input and output.

A time-diversity repeater may use a single frequency for both input and output, but the signals are separated in time.

A space-diversity repeater or on-channel booster relies on the spatial separation of its input and output channels.

For digital data-communications work in Amateur Radio many variations on the above three approaches are possible. In the frequency-diversity case, for example, we have

Linear translators - Devices which take incoming RF within a specified band and retransmit that RF on a new set of frequencies. There is a one-for-one mapping of each input frequency to each output frequency. Data communications through the soon-to-be-launched AMSAT spacecraft will use linear translators.

Audio transponders - The incoming RF is demodulated, and the recovered audio signal is used to modulate the outgoing carrier. Most 2-meter FM repeaters are of this type.

Digital transponders - The incoming RF is demodulated, and the resultant audio tones are converted to their logic '1' and logic '0' values. The digital signal is then used to modulate the outgoing carrier with the correct AFSK tones. Many RTTY repeaters use this technique; it discourages voice communications. Digital signal regeneration may also be done at the character level, where a complete incoming character is received and then retransmitted with new tones and bit timing.

In all of the above examples, input and output activity occurs simultaneously, with practically no time lag in retransmission of the signal. Such repeaters are termed "duplex" machines, because the information is going in two ways at the same time.

In the time-diversity case there is local storage for packets or frames at the repeater site, and we can run the repeater in a "simplex" mode, i.e., transmitting and receiving the frame on the same frequency. The outgoing signal is completely regenerated at the frame level, and all receiving stations are presented with a uniform signal, independent of the condition of the original input.

The primary function of a packet repeater, as with a more conventional repeater, is to extend the geographic range and coverage of fixed or mobile stations. A packet repeater, however, can be programmed to selectively repeat only those packets addressed to it, thus allowing the possibility of multiple repeaters on the same frequency, an advantage instead of a curse! In fact, there is a wide range of functions which can be programmed into a packet repeater, and we will discuss some of these options later in this article.

The FCC currently considers a packet repeater to be in the same category as an ordinary voice repeater) and so it must abide by the rules governing voice machines. Thus, it must be in the repeater subbands, must ID with a /R, cannot be used on a simplex HF frequency, etc.

Of the three or four packet repeaters currently in use in amateur radio service there are no two alike, and each of the different approaches has its own merits:

Contention Protocol Repeaters - Each station transmits on the channel without regard to the activity of other stations. If a packet collision occurs, the station will not receive an acknowledgement for the packet, will delay for a random period of time, and then transmit again.

Carrier Sense Multiple Access - Each station is able to sense the carrier of other users and waits until the channel is clear. Collisions will occur in this form of contention protocol, but less frequently than above.

Time Division Multiple Access - Each station is assigned a time slot for its transmission. Not used by amateurs yet.

Polling Protocol Repeaters - The repeater cycles through a list of active stations requesting

traffic from each one. No collisions occur, but stations must respond to the polls in milliseconds and the poll list must be kept short for good throughput.

The trade-off in these different approaches is channel utilization vs. centralized control and coordination. The tighter controls lead to better throughput, but the penalty is dependence on the functioning of a central station or on increased complexity of station equipment. Since the Amateur Radio service is a voluntary, non-professional operation, any scheme which depends on the 24-hour functioning of a single, central control station for all network users should be looked at very carefully. A philosophy which adopts looser controls and multiple or redundant repeat points will probably prove more workable in the long term.

The design of the local area network and repeater for each amateur community will probably be different and tailored to the needs of that community and subject to the technical preferences and biases of its designers. As long as the local net designers provide for future compatibility with whatever national networking scheme is adopted there should be no problem with variations of a protocol for a given region.

Here in the Bay Area we are considering the possibilities of a two-repeater system, one serving the north Bay, and one for the south. The alternative is a single high-level repeater. We need further study of our expected traffic patterns and of the interconnects required to nearby cities. The higher the repeater the greater the range and coverage, and consequently the increased traffic and throughput delays. Lower level repeaters can handle smaller groups of users with better throughput, but connects to distant locations may require double and triple packet hops.

Our design so far has stressed the ability of users to be able to do direct point-to-point connects to target stations if they are within radio range. This can offload some of the traffic from the repeater and allows stations to communicate with each other should the repeater go down. Note also that the 1200 Baud throughput is cut in half when packets have to be repeated, and is down to a third or less when two hops are involved. Some of our next experiments will be with two repeaters in tandem so that we can gain some experience in coupling two machines.

While we're on the subject it would be worthwhile mentioning some devices which are very similar to packet repeaters but which have different names:

Gateways - It is frequently necessary to convert a packet from one media to another or to transport a packet from one local net to another. A "local network" usually implies geographic proximity, a common medium, and addressing which is unambiguous and at the lowest level of the protocol hierarchy. Each of the stations using a particular satellite channel might be a member of a different local net, and the satellite channel would be used to connect different local nets around the globe. A gateway would be used to convert a satellite packet to the format of another local net, say, the net consisting of all the stations using the KA6M repeater.

Station Nodes - If a repeater participates in creating or dissolving a connection between two or more users, or if it has extensive information about the state of the network and provides routing directives to other repeaters, that device is normally called a "station node". The exact functions of a station node depend on the design of the network, but in general we think of it as a repeater which has been promoted into the first level of network management.

Host Node - There are many different types of services which might be offered on a packet network, the most frequently mentioned one being electronic mail. Services such as that should be done by host machines on the network and probably should not be incorporated into a repeater. The hardware of a repeater should be simple and reliable, and should not depend on disk storage or other failure prone equipment.

In summary, it becomes clear that with a programmable device we can implement many different levels of complexity and service in a repeater.

III. Operational Aspects and Details of KA6M/R

The Z-80 was an obvious choice for the basis of constructing a microprocessor based repeater system. It is a very popular chip, and some interesting high-level language support is available for it. The STD cards are small and compact, and it is extremely easy to wire a new board for testing ideas,

The choice of the Western Digital 1933 chip needs more explanation. Quite a few manufacturers are now making HDLC/SDLC VLSI chips. Of the half-dozen or so available, only two have all the hardware required for easy use in an amateur radio environment. The special features required are NRZI encoding and an on-board digital phase-locked loop for timing recovery. The two chips which have this circuitry are the Intel 8273 and the Western Digital 1933. The Intel chip has a more elegant programming interface, but is slower and more expensive than the Western Digital unit. In quantity purchase the Intel part is about \$35, and the Western Digital part is \$25.

The Bell 202 modem operates at the maximum Baud rate permitted on VHF, and works very well with voice frequency equipment. Also, 202's are available from many different sources and can be found at surplus electronics houses.

The 2-meter band was selected because it permits 1200 Baud transmission and radio equipment for it is widely available. Keeping the entry threshold low for packet users was an important part in introducing the service here. It's quite enough to ask someone to buy a new controller board and a modem. Requiring special radio equipment on top of that would be a burden.

The repeater design assumed that the machine eventually would be on a mountain top, and that limited access to it would be the rule. Thus the design was kept simple, and minimum functionality was planned for the first installation. Virtually no manipulation is done on an incoming packet. The repeater allows arbitrary binary information to be present in the information field, and the only field which is manipulated is the address field.

The repeater does not participate in the link-level protocol, and any acknowledgements or requests for retransmission must be done by the end-user stations. Initially the repeater was set up to repeat a single packet with up to 256 bytes in the information field. That was changed, however, and it will now repeat up to eight 128 byte packets. Storing and repeating multiple packets in a single transmission is important for compatibility with the current VADCG software, and is required when packets are hopping down a chain of repeaters. If two packets are coming from opposite directions, one of the repeaters at crossover point must be able to store more than one packet.

The address byte modifications which were adopted work as follows: the repeater will repeat packets which have an address byte of hex 80 to 9F. In repeating the packet, the outgoing address will be the incoming address plus hex 20. Thus, repeated packets will have an address in the range A0 to BF. This is the only alteration to the packet, and is otherwise an exact duplicate of the incoming packet. The address change is required so that receiving stations are not confused by a packet coming both from the sending station and the repeater. Stations wishing to direct connect may use addresses in the range 01 through 7F. The VADCG TNC software has been modified so that a station receiving a connect message adjusts its outgoing address to match the repeater/non-repeater range of the incoming connect message. So, a station wishing to log into the mailbox can do so directly or be repeated, and the mailbox will automatically adjust itself to the selection made by the operator.

This addressing scheme has two major problems. First, it requires an individual to coordinate address assignments within a user community. Second, if the user population grows beyond the 32 slots currently assigned to the KA6M repeater, something has to give. Several suggestions have been made to let the repeater dynamically assign addresses, but what we're really facing here is the tip of the iceberg with respect to some real serious issues concerning local area and nationwide network addresses and how to handle them. Some bandaids could be applied to the addressing strategy described above, but I think it would be better to face the more global issues right away.

As soon as a packet is received the frame check sequence (FCS) field is checked, and if not correct, the packet is discarded. Next, the incoming address byte is checked for the right range, and if approved, the address field is modified and the packet is put on the outgoing list. When one or more packets are ready for retransmission and when the modem carrier detect signal has dropped to the channel clear state, the repeater turns on its transmitter and transmits all packets on the outbound list.

The repeater has circuitry to sample both RF Carrier Sense and Modem Carrier Detect. Originally packet retransmission waited for a clear RF channel, but this proved unworkable in an RF jungle such as Silicon Valley. Now, the beacon will hold back if RF Carrier Sense is on, but packet retransmission will only be delayed by other packet activity on channel, or by tones which can fool the modem, such as RTTY AFSK.

If at least 5 minutes have elapsed, and the

channel has been RF free for the last 30 seconds, then the repeater executes a beacon subroutine which transmits three 70 character packets. The beacon messages are very useful for testing the receive path of new packet stations, and for verifying that everything is in order both at a working station and at the repeater. They also have attracted lots of attention from hams in the community who have never before listened to packet transmissions. One uninformed gentleman described the beacon packets as "The longest squelch tail I ever heard".

Entering the beacon subroutine also triggers the CW identification. The hardware has separate control leads for request-to-send and transmitter on. The software currently turns the transmitter on and then toggles R-T-S on and off to produce the code required to ID. This procedure is not as good as the VADCG CWID routine, for packet stations can fire off a packet in the dead air time between the dits and dahs. The repeater, of course, is not listening. The VADCG TNC keeps R-T-S on continuously and uses Mark (1200 Hz.) for the dits and dahs, and Space (2200 Hz.) for the inactive time.

The transmitter control card has some simple push-to-talk control circuitry on it and a 30 second watchdog timer. An absolutely foolproof watchdog timer is difficult to construct because it would have a hard time discriminating between normal program operation and a loop which periodically turned RTS and the PTT circuit on and off. Now it only catches a continuous RTS on state. One really needs two or three independent checks on the program to insure proper functioning. Failure of any one of those checks should reset the repeater.

The FT202 radio has worked rather well considering its initial cost, and any similar unit would be suitable for small to medium size metropolitan areas. Crystal controlled radios, in general, are ideal for packet service. They tend to have faster switching times than the new synthesized units. We are going to have to upgrade the unit here, however, because of the dense RF in this area.

One of our more interesting findings is that the repeater has proven to be tremendously useful as a test tool for bringing up and checking out stations. The machine is there 24 hours a day, and by bouncing a packet off it you can quickly verify if your station is in order. The beacon messages provide a readily available signal source. The eight packets which can be stored represent nearly a third of a page of text, enough to trigger failures in T/O interfaces which might be prone to dropping characters.

We also discovered, and this sounds really incestuous, that you can self-connect through the repeater. Due to the way the VADCG and repeater software and addressing is structured a station can make a complete round-trip connection loop to its own equipment. A line of text typed in at a terminal will come back to the screen via the repeater, and all error checking, retransmit and flow control logic is active during such a test. This is an excellent way for a personal computer system to exercise its software and test to see if there are any conditions under which bits and

pieces might be dropped.

The repeater users have found that packet radio service is more demanding of their stations than originally expected. Modem programs that used to work fine at 45 or 300 Baud may not be able to keep up at the 1200-9600 Baud rate coming from the TNC. File transfers are expected to be 100% reliable, so the flow control mechanisms have to function perfectly in order to not lose data. Radios, modems and antennas have to be adjusted for optimum settings if the 1200 Baud 202 modem rate is going to be meaningful. We have reached the point where most of the pieces of our network are working, but a lot of fine tuning remains to be done.

IV. Advanced Functions for Repeaters

The following are some of the ideas which have accumulated but which are not currently implemented in our repeater:

Program bootstrap - A ground station is used to load the bulk of the repeater program. New features and functions, program corrections, routing tables, etc. could be maintained at a convenient host station away from the repeater site.

Changeable beacon messages - Special packets could be sent to load new messages of importance to the repeater users.

Time of Day - A realtime clock. could transmit current time and date or GMT.

Statistics - The repeater could keep track of the number of packets sent, packets in the last hour, number of users, total traffic, and so on.

Diagnostics - The repeater could be put into a mode where it would send nearly continuous packets of some interesting pattern for a period of time. This would be useful for checking modems and levels and continuous reception of data at a station.

Log list - Users like to know what stations might be monitoring and what stations were active in the recent past. The callsigns of the last ten connecting stations could be kept in a first-in first-out list,

Multi-party conferences - The current point-to-point connections provided by the HDLC link level protocol do not allow real-time conferences or round tables. The issue, of course, is data integrity. Error checking, and retransmission must be done for each user plugged into the discussion. A smart repeater or station node might be able to arrange such a multi-way conference.

Terminal-node repeaters - Any user who desired or was in a strategic location could program his TNC to act as a repeater in addition to the usual TNC functions,

Role in larger network - The real mission of a repeater is to be a member of a larger national or international network. What functions have to be added to the program logic of a repeater to accomplish this is a subject for debate, and will hopefully be outlined in the near future.

V. Future Directions

There are many possibilities for future development of repeaters in the amateur service:

Hardware - High speed, 48 Kilobaud UHF repeaters using direct digital modulation of the RF, with no audio modems used at all. Decoding will be done directly from the IF strip. Repeaters with dual RF modules and selective control of frequencies and antennas. Spread spectrum transmission, with selective targeting of a repeater by changing the transmit hop codes.

Software - Development of higher level networking protocols in higher level languages such as PASCAL, C, ADA, FORTH, and others. Interconnects with other networks and CBBS's. Development of

broadcast protocols which handle real-time conferencing and networking games.

It seems to me that we are only beginning, and that there is still plenty of room for future experimentation.

VI. Acknowledgement

I wish to thank the amateur radio operators of the Northern California area for their contributions to this report, and thanks also to Woody Teague, WA6TAT, for the current repeater site.

The software and schematics will be available from me for a modest charge. Contact me if you are seriously interested in duplicating this equipment.