REMOTE CONTROLLED TELEMETRY RECEIVER CONSIDERATIONS

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Summary. As the complexity of telemetry systems increases, the desirability of using remote controlled receivers in these systems to reduce human error, setup time, and premission calibration time increases. The specification of such receivers needs to be done carefully to stay within economic and space limitations. A general discussion of possible system objectives is given in which basic decision questions are raised on the degree of remote control required. A tabulation of receiver functions and controls is given followed by detailed discussion of these various parameters in terms of feasibility, problem areas, space requirements and cost where it represents a major impact. The computer-receiver interface is discussed in terms of how this choice will affect cost and system compatibility with other types of equipment. These discussions should provide some insight in the tradeoffs required in specifying a remotely controlled telemetry receiver.

Introduction. Telemetry receivers have steadily evolved in both complexity and cost from the simple fixed bandwidth, fixed tuning range receivers produced by companies such as NEMS-CLARKE in the 1950s to the complex telemetry receivers of today which are characterized by almost complete modularity. During the last few years, attempts have been made to remotely control some functions of the telemetry receiver. The use of remotely controlled telemetry receivers in automatic systems represents the next step in the evolutionary process.

The discussions that follow will attempt to: 1) discuss various problems associated with remotely controlled telemetry receivers; 2) define the functions and parameters required for remote control; and 3) discuss currently available hardware implementation methods and specifications with, in some cases, a relative indication of cost or difficulty. These discussions are given from the point of view of a telemetry receiver manufacturer.

General Discussion. The following objectives have been identified:

1. Reduce setup time for a mission (includes receiver configuration and premission calibration).
2. Reduce operator error.
3. Allow sufficient flexibility to support future missions.

Presently available aircraft and ground receivers require manual change of demodulators, i-f bandwidths, video bandwidths and all operating controls. They also require time-consuming premission calibration procedures to check mission availability. It seems desirable to automate or remote control a large number of these items to reduce setup time and checkout time.

One of the first decisions that must be made is whether to have remote control only, or selectable local-remote control. Remote control only implies no controls on the front panel except possibly an on-off switch. Control of the receivers could be accomplished from either a computer or a central control console which could be designed to several levels of sophistication, which might include:

1. Simple rotary or pushbutton switches to program functions for each receiver.

2. Punched tape reader with teletype keyboard to allow quick receiver setup with the punched tape and modification of instructions with keyboard. Status readouts of i-f bandwidths, modes, etc. would be required to inform the operator of the operational setup and status of each receiver. This function could be supplied by either indicator lamps or (more expensively) a digitally refreshed CRT display.

The use of item 2 would require some form of computer to address and remember commands to the various receivers and to drive the CRT display. The other option is to have both remote and local control, selectable at either the console or at the receiver. This would require a complete set of operating controls on the front panel of the receiver. In addition, remote-local selection circuitry would be needed in the receiver. The additional complexity of the receiver base chassis and front panel would increase cost and possibly chassis size.

Another basic decision that must be made is how the receivers will interface with the control console or computer. This is usually determined by the number of receivers, the number of controlled items and any other equipment which has to interface. These aspects will be discussed later.

Remotely Controlled Functions. A compilation of functions and parameters normally available on current telemetry receivers is presented below. The list is divided into two categories: 1) those associated with receiver configuration for a mission; and 2) those which might be utilized during calibration and the mission. This division may change depending on requirements of a particular mission.

Receiver Configuration Items

(Common for both channels if dual channel receiver)

1. IF Bandwidth
2. Video Bandwidth
3. Independent/Slave 2nd LO
4. Pre-D Record Frequencies
5. Pre-D Playback Frequency
6. Receive/Playback Mode
7. Demod Selection (PM-FM-AM)
8. 2ndLO Mode (XTAL,VFO,APC/AFC)
9. PM/SYN AM Video (PM demod)

Mission and Calibration

(Common for both channels if dual channel receiver)

1. RF Tuned Frequency
2. AGC Time Constant
3. Manual Gain
4. Man Gain/AGC Select
5. Video Gain
6. 2ndLO Tune (Up or Down Slew)
7. Break Lock (PM demod)
8. Loop BW (PM demod)
9: Auto/Man Acquisition (PM demod)

In addition, while not remote controllable items, the following remote indicators, and non-remote calibration adjustments are normally found on receivers.

Remote Indicators

(Two sets for dual channel receiver)

1. AGC or Signal Strength Indicator
2. Tuning/Loop Stress Indicator
3. Audio Monitor
4. Carrier Present Indicator
5. Video Level Indicator
6. 2nd LO Frequency Indicator
7. AFC/APC Search Indicator

Additional Non-Remote Receiver Adjustments

1. Video Level Indicator Calibration
2. Carrier Operated Relay Threshold
3. Tuning/Loop Stress Indicator Zero
4. Record AGC Output Zero and Scale
5. FM Discriminator DC Zero

Discussion of Receiver-Control Parameters

RF Tuning. The preferred method for rf tuning is through use of a remotely programmable synthesizer. This has the advantage of providing total flexibility in tuning of the receiver.

A small synthesizer capable of being included inside the receiver is currently being developed which will operate in the 112.5 MHz to 117.5 MHz range for S Band and will tune in 5 kHz increments. This signal will be multiplied by 20 to produce the proper mixer injection frequency in 100 kHz tuning increments at S Band.

Since the accuracy of the synthesized local oscillator signal depends only on an oven stabilized 5 MHz reference oscillator, which has an aging adjustment, a tuned frequency accuracy of $\pm 5 \times 10^{-8}$ may be achieved. This is approximately two orders of magnitude better than the cutting accuracy of MIL crystals currently used.

At first glance, the inclusion of an individual synthesizer in a receiver seems like it would be too costly. Consider, though, that its use will eliminate a bank of 99 crystals and probably also crystal ovens for each receiver. There would also be no storage area required for the now absent banks of crystals and ovens.

There are potential problems associated with this approach. One drawback of multiplication by 20 is that synthesizer phase noise and spurious outputs are increased in level relative to the carrier by 20 log 20 or 26 dB. Even so, performance comparable to presently multiplied crystal oscillators is achievable as far as phase jitter is concerned when a commercially available state of the art synthesizer is utilized. A second drawback is that synthesizer spurious levels are also increased by 26 dB. These spurious signals on the local oscillator signal are transferred to the desired signal at the same relative level in the first mixer of the receiver. Thus, an 86 dB spurious free synthesizer would be degraded to a 60 dB spurious synthesizer when multiplied to S Band. The maximum desired signal to spurious sideband ratio would be 60 dB which should be acceptable for most applications.

Whether or not these performance levels are achievable in a small synthesizer remains to be seen. They are achievable in full sized units (seven-inch rack mounted types). If they are not, then an improvement in performance could be obtained by translating the synthesizer frequency instead of multiplying it. This entails a much greater complexity and cost so that a cost and size tradeoff would have to be made between the small translated synthesizer and the larger rack-mounted type.

An analysis of allowable frequency uncertainties from IRIG-106-73 shows ±30 ppm for transmitters and ±10 ppm for receivers which translates to ±92 kHz at 2300 MHz. Satellites traveling at 1800 mph would contribute ±61 kHz of one-way doppler. Thus, total receiver and received signal variation would be ±153 kHz at 2300 MHz which could be handled by 2nd local oscillator (2nd LO) fine tuning (see discussion on 2nd LO tuning).

Second Local Oscillator Tuning. As presently envisioned, the 2nd local oscillator will need to function as the fine tuning mechanism of the receiver to allow correction of up to ±153 kHz of frequency uncertainty and doppler frequency shift. In addition, it must have a controlled slew rate when its frequency is charged to prevent loss of lock when the phase locked pm demodulator is tracking a signal. Present receivers utilize a 10 turn manually-operated potentiometer to accomplish this function. It is impractical to remote this potentiometer due to hum pickup problems. Thus, some other means of accomplishing this function is necessary.

The linearity of the tuning curve of the present 60 MHz vco used for the 2nd local oscillator is fairly good - about ±10 kHz from best, straight line over a 550 kHz tuning range. The frequency drift with temperature is 10 ppm per degree C which results in a 30 kHz drift for 0° to +50°C temperature change. Thus, an absolute maximum 40 kHz uncertainty would exist if the tuning voltage were programmed. This could be acceptable for many applications. A three-decade BCD D/A converter would allow 999 steps of approximately 0.6 kHz. One problem that must be overcome is possible break lock when the Ø-lock pm demodulator is utilized. The maximum time rate of change of oscillator frequency is determined by the Ø-lock loop bandwidth, being on the order of 7 Hz/second for a 10 Hz loop bandwidth and 70 kHz/second for a 1000 Hz loop bandwidth. Any step change in frequency will cause the loop to break lock. A way to overcome this is to apply the output of the D/A converter to an RC lowpass filter which could limit the maximum rate of change of its output voltage to the required value. The initial rate of output voltage change for a voltage step input of magnitude E is E/RC volts/second. If larger steps were taken, the slew rate would increase. This might occur if the operator had thumbwheel switches to program the 2nd LO tuning (i.e. units switch, tens switch and hundreds switch). If the digital commands were generated by a three decade up-down counter whose input was a clock rate, then the magnitude of the steps could be insured (i.e. single steps). In operation, the unit would have an up-slew or a down-slew mode and a digital readout of the up-down counter output would tell the operator where on the control voltage curve he was. The slew rate could be varied by changing the clock rate and/or the RC time constant of the RC filter.

A more accurate (but more expensive) version of this scheme would utilize a counter to actually count the 2nd LO frequency. Independent control of 2nd LO tuning for each channel of a dual channel receiver is required to allow use of the afc and apc loops.

An alternative to actually tuning the 2nd LO is to utilize the pm and fm demodulators in the apc (automatic phase control) and afc (automatic frequency control) modes with automatic search and acquisition. This may be the only practical way to operate the pm demodulator. Remote 2nd LO tuning using these schemes has not been implemented in a receiver to the author’s knowledge.

2nd LO Mode Switching. Selection of 2nd LO mode should be done on a common basis for dual channel receivers. It involves several areas of the receiver other than the 2nd LO. The normal modes are: XTAL, External (OFF), VFO, AFC and APC. The basic modes are: XTAL, OFF and VFO, whose selection involves supplying switched voltages to either the crystal oscillator or vfo oscillator. The afc and apc modes are utilized with the fm and pm demodulators respectively and involve switching of certain feedback paths and inputs on the afc/apc amplifier card.

Remote selection of 2nd LO modes has not been implemented in hardware as of yet, but should present no problems other than minor redesign of two modules to allow logic control of the necessary witching functions.

IF Bandwidth. One present implementation consists of switching six i-f bandwidths per channel in a dual channel receiver. Solid-state switching is utilized to energize the proper i-f filter/amplifier and to switch the rf inputs and outputs. The technique could be extended to seven bandwidths and possibly eight bandwidths. Since whole i-f filter/ amplifier strips are utilized, the bandwidth tolerances, shape factor and phase linearity achievable are the same as presently realizable in the manually changeable 2nd i-f filter/ amplifiers. Typical specifications are:

Selectivity (60/6 dB ratio)	3.0:1 maximum
Bandwidth (3 dB)	±10%
Phase Response	linear within 8°, over 80% of 3 dB bandwidth
Peak-to-Valley Ratio	0.5 dB maximum.

There is also an "available space" tradeoff which must be made since all bandwidths desired must be included inside the receiver. The more bandwidths desired, the less space there would be for other functions.

Video Bandwidth. A present capability exists for switching 10 video bandwidths remotely in each channel of a dual channel receiver. This is accomplished by utilizing a video filter switch assembly at the input and output of each filter. The video filter switch assembly utilizes SPST NO reed relays energized by appropriate logic signals. The technique could be extended to include more filters at the expense of requiring more space in the receiver and additional cost.

Standard filters are linear phase with asymptotic slope of 24 dB per octave with low overshoot of 3% maximum (1% typical). Bandwidths (-3 dB) available are: 6.25, 12.5, 25, 60, 100, 250, 500, 750, 1000, 1500 kHz and Bypass. Other bandwidths are available as are Butterworth-type filters for sharper stop band attenuation. The tolerance for the 3 dB cutoff frequency is ±10%.

Video Gain. Presently available receivers do not have remotely programmable video gain. Video levels are in general, higher than rf/i-f levels and thus present special problems. At first glance, one might think that a good approach would be to put voltage variable resistance feedback around an amplifier whose resistance could be controlled by an analog voltage. Such voltage or current controllable resistors tend to be non-linear and cause the distortion of the amplifier to rise significantly.

A better approach is to program the video gain in discrete 1 dB steps. This approach can utilize a programmable attenuator to provide 0 to 20 dB of gain control in 1 dB steps. An additional 20 dB step can be provided thus providing 40 dB of attenuation in 1 dB steps. Since the purpose of the video gain control is mainly to keep the video level within the limits of recording and processing equipment, a tolerance of ±1 dB would seem to be appropriate. This would allow the use of inexpensive attenuator pads fabricated from stock resistors and switched with reed relays.

AGC Time Constants. Remote selection of agc (automatic gain control) time constants is desirable so that real time changes of agc time constant may be made when signal characteristics so warrant. This might occur for a change in a-m tracking signal scan rate or severe multipath conditions.

A selection of five time constants is presently available covering decade steps from 0.1 millisecond to 1000 milliseconds. The effort to remote control them is minimal, and has been successfully implemented using solid-state switching elements. Dual channel receivers should utilize common control of agc time constants for each channel (i.e. one command controls both channels identically).

AGC time constants will vary with variation in the slope of the gain-controlled amplifier gain control curve. In addition, for an agc system exhibiting an essentially linear dB vs voltage agc curve, the time constant must be defined in terms of magnitude of input rf level step and in which direction (up or down) since the agc loop is exponential (non-linear). A common definition is to specify the "incremental" or small signal time constant, γ . This may be measured by utilizing a small percentage (10-20%) a-m modulated signal and noting the lower -3 dB frequency at the a-m detector as the modulation frequency is lowered. γ is then:

$$\gamma = \frac{1}{2\pi f_m} \quad \text{where } f_m = \text{lower -3 dB modulation frequency.}$$

A tolerance of ±50% is typical and should not be specified any closer since the time constant depends on the gain control curve of the receiver which will vary over the dynamic range of the receiver.

Manual Gain. Remote control of manual gain may be highly desirable for premission checkout of receiver sensitivity using solar calibration techniques.

When desired, a simple approach is to provide 60 to 100 steps using digital commands to a D/A converter. The output of the D/A is scaled and applied to the receiver agc amplifier in the same manner that the present manual gain voltage is applied. The step size is approximate and depends on the linearity of the gain control curve of the receiver. The normal use of the manual gain control is to adjust the receiver gain for some specified output from the receiver and thus the absolute value of steps is not usually important.

A second and more desirable approach is to utilize circuitry which samples the agc upon command and then freezes the agc voltage at that point. This approach has been successfully implemented in a dual channel receiver and may be a very desirable alternative to the standard manual gain concept. Any desired receiver gain may be achieved by first allowing the receiver gain to stabilize in the agc mode and commanding the receiver to “freeze” the agc voltage.

Manual Gain/AGC Select. If a remote manual gain feature is included in the receiver, then it will be necessary to have remote selection of agc mode or manual gain mode. This will present no special problems and has been implemented using solid state switches.

Pre-D Record and Playback Frequencies. A remote selection of four Pre-D record or playback frequencies is currently available. Since the receiver is not used simultaneously for record and playback, there is no need to have independent selection. Dual channel receivers should have common selection of record frequencies for both channels. Standard IRIG record frequencies of 112.5, 225, 450, and 900 kHz should be utilized.

Receive/Playback Mode Select. If so desired, a remote Receive/ Playback mode select may be included. Since playback may not be a mission requirement, there may not be a need for remote selection.

The playback mode involves deactivating the rf tuner power so that noise from the rf tuner does not degrade the playback signal-to-noise ratio. A playback scheme which up-converts the record carrier to the first i-f frequency should be utilized. This allows the signal to be fine tuned to the center of the i-f passband, if necessary, or to utilize the afc loop or pm demodulator.

Demodulator Selection. Typical manual receivers utilize front panel plug-in demodulators for fm or pm. The pm demodulator is suitable for use with all presently available i-f bandwidths. The fm demodulator, however, must be switched in three ranges to accommodate all the i-f bandwidths. In terms of a remotely controlled receiver, a decision must be made as to whether the fm and pm capability must be instantly selectable (i.e., both located within the receiver) or whether it is permissible to reconfigure the receiver between missions by either a front panel plug-in or by changing internal modules.

The primary problem of demodulator selection is available space. The present size of a receiver will grow if both fm and pm demodulators must be placed inside of the receiver. A logical choice would be to split the receiver into an rf drawer and an i-f/demodulator drawer.

FM Demodulator. Present manual-controlled receivers utilize plug-in fm demodulators having up to three bandwidths. Manual selection of demodulator bandwidth has to be made, however. A successful implementation of remote selection of the two widest fm demodulators has been made for a dual channel receiver. There was not sufficient room to include the narrow bandwidth in a standard housing.

Future units could incorporate all three bandwidths if more space were made available. The basic demodulator consists of a common input amplifier; two fm limiter/discriminator circuits (intermediate and wide); a common interface amplifier; and common afc time constant circuitry. The basic functions which must be switched internally, when a bandwidth is remotely selected, are as follows:

1. IF Input to Limiter
2. FM Video Output to Receiver Base Unit
3. Deviation Meter Amplifier Input
4. Deviation Meter Range
5. ±15 Volt Power Supply to Each Limiter/Discriminator
6. AFC Detector Output to AFC Time Constant Switch.

The deviation meter range should probably be switched to its highest range when remote control is used. This is to keep the deviation meter on the receiver front panel (if present) reading less than full scale.

A manually controllable afc time constant selection was provided; however, it could just as easily be included in the remote control functions of the fm demodulator. This again is a system decision as to whether it is required. Three different time constants in the range of 0.01, 0.1 and 1.0 second are manually available. These correspond to approximate afc lower loop video responses of.16 Hz, 1.6 Hz and 0.06 Hz, respectively.

Remote selection of fm demodulator bandwidth may be accomplished in one of two ways: either direct command or keyed to i-f bandwidth selection, thus eliminating another command decision. If keyed to i-f bandwidth, it should be possible to pre-program which demodulator bandwidth is called up for each i-f bandwidth position. This is desirable to take care of future changes of i-f bandwidth.

PM Demodulator. The pm demodulator typically used in telemetry receivers is of the long loop type with automatic-phase control of the 2nd local oscillator. The 10 MHz i-f signal is compared to a 10 MHz crystal reference oscillator. The following controls are typically provided:

1. Phase Lock Loop Bandwidth (10, 30, 100, 300, 1000 Hz)
2. Manual-Automatic Acquisition Select
3. Break Lock Switch
4. Fine Tune (2nd LO tuning)
5. PM/Syn AM Video Select
6. Env/Syn, AM and AGC Select
7. Noise Balance and Lock Threshold Adjustments

It appears likely that the only feasible remote operation mode of the pm demodulator would be the automatic acquisition mode. The remote control of these controls is discussed in the following:

1. Phase Lock Loop Bandwidth (PUL bandwidth) - Acquisition time, signal threshold, low frequency video response and search range are all affected by the PLL bandwidth. It is also sometimes desirable to change loop bandwidths after the signal has been acquired. The maximum automatic search rate (Hz/second) that will allow 90% probability of acquisition is proportional to the square of the loop bandwidth. Thus, at wide loop bandwidths ($2B_L$ = 1000 Hz), sweep rates on the order of 70 kHz/sec are usable while at narrow loop bandwidths ($2B_L$ = 10 Hz), a sweep rate of only 7 HZ/sec is allowable. The minimum sweep rate achievable due to capacitor, leakage and phase detector offset voltages is on the order of 1 kHz/sec with the present phase demodulator designs. Thus, automatic acquisition is not feasible at the lower loop bandwidths and manual acquisition must be utilized, which would require some operator assistance and an aural monitor.

   The automatic search range is usually selected in conjunction with the loop bandwidth such that the total sweep time does not become excessive. Typical values for sweep rate, sweep range and sweep time are shown below:

2BL, Hz	Rate	Range	SweepTime
1000	69.2 kHz/sec	±150 kHz	4.3 sec
300	2.8 kHz/sec	± 30 kHz	21.5 sec
100,30,10	1 kHz/sec	± 5 kHz	10 sec

These represent practical values and are representative of existing equipment. Computer control of the PLL bandwidth should probably also control sweep rate and sweep range to avoid controlling too many functions.

2. Manual-Automatic Acquisition Select - This control selects either the automatic sweep discussed above or manual search which requires an operator to tune the 2nd LO of the receiver. Even though methods exist for tuning the 2nd LO remotely, it seems likely that the only feasible way for a computer to utilize the pm demodulator is in the automatic acquisition mode. Even with automatic acquisition, the possibility exists of locking onto a sideband instead of the carrier. Anti-sideband reject circuits are available and should be included in the pm demodulator.

3. Break Lock - As its name implies, this control opens the PLL and is utilized to open the loop when improper lock (i.e. sideband lock) has occurred. It could be useful under both manual and automatic acquisition and should be computer controlled.

4. Fine Tuning (2nd LO tuning) - This was discussed previously. Some form of computer control is desirable to remove loop stress after the loop locks.

5. PM/Syn AM Video Select - Provides selection of either pm video or synchronous a-m video and is not present on all demodulators. If present, remote control may be necessary for mission requirements.

6. ENV/Syn AM and AGC -This switch selects envelope a-m and agc or synchronous a-m and agc. It is not present on all pm demodulators but when present may need to be remote controlled for mission requirements.

Cost tradeoffs exist in that the minimum number of computer-controlled functions necessary should be specified. Consideration should also be given to space availability as to whether both the fm demodulator and pm demodulator must be located inside the receiver chassis at the same time.

Remote Indicators. Remote indicators may or may not be needed in the system concept. If they are, then the form in which they are supplied must be considered. For example, the tuning/loop stress indicator would normally be supplied as an analog dc voltage. It may be more useful to a computer to have the information in digitized form which, of course, will require additional circuitry, cost and space. Some of the indicators which could be supplied are: a-m detector dc level, remote signal level meter, remote tuning/loop stress meter, carrier operated relay remote indication, afc search remote indication, remote video level meter, and remote audio line.

Computer/Receiver Interface. Many types of interfaces exist. They may be of serial data format or parallel data format. The computer may send serial data with addresses to a receiver control unit (RCU) which then sends either serial or parallel data to individual receivers. If a large number of receivers is to be controlled, then some form of serial format should be considered to reduce the number of control lines. It should be pointed out that serial data interfaces are more expensive and use up more space in the receiver than parallel data interfaces. The choice of interface needs to be made carefully in that a computer-controlled system must also interface with a variety of other equipment. Remember that the purpose of automating is to reduce the number of operators (and operator errors), to reduce system configuration setup time and therefore, to increase the probability of mission success. Inherent to this philosophy is the requirement that the signal generator be automated and, depending on system complexity, that other test equipment such as bit-error-rate-testers, counters and power meters be automated.

There are two basic standard interfaces in use. The most popular at present seems to be the one described by Electronic Industries Association Specification RS-232 which is widely used by computers, teletype machines, and other communications-type equipment. It consists basically of seven or eight bit characters transmitted serially over a pair of balanced lines asychronously.

The characters are converted to parallel form in the receiver and then must be addressed to various holding registers. The cost of addressing the characters to the various registers depends critically on whether all characters of a receiver command are sent in a prearranged order or whether only update characters are sent on a random basis which increases the complexity and cost considerably.

The other interface is the bit parallel/byte serial type developed by Hewlett-Packard and adopted by the IEEE as Standard No. 488-1975. It may be more suitable if the receivers have to interface with test equipment located fairly close together. This interface is commonly referred to as the HP Interface Bus. If long distances are involved, the RS-232 interface may be a better choice.

Conclusions. The remote controlled telemetry receiver must be examined very carefully with respect to the desired remote controlled functions and parameters. Of prime importance is a good system concept within which the receiver must operate. Based on this, an intelligent choice may be made as to the minimum number of remote controlled parameters and the best interface between the system and receivers. The inclusion of all possible controlled functions and remote indicators in a single receiver will likely be too costly and also result in a receiver which is too large for practical use. Remember that a new era is beginning. After several more years of experience with remote controlled telemetry receivers, perhaps standard off-the-shelf receivers will be available.

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